BMBF research programme BioTip: "Tipping Points, Dynamics and Interdependencies of Social-ecological Systems"

Collaborative Project BioTip: Understanding and Managing Desertification Tipping Points in Dryland Social-Ecological Systems – A Namibian Perspective (NamTip Phase I)

INTERIM PROJECT RESULTS FROM NAMTIP PHASE I

(MARCH 2019 – JULY 2023)

Participant organizations	Country

German partner organizations

University of Bonn (SP 1)	Germany
University of Tübingen (SP 2)	Germany
University of Cologne (SP 3)	Germany
Helmholtz Centre for Environmental Research – UFZ (SP 4)	Germany
Institute for Social-Ecological Research – ISOE (SP 5)	Germany

Namibian partner organizations

University of Namibia (UNAM)	Namibia
Namibian University of Science and Technology (NUST)	Namibia
EduVentures Trust	Namibia
Agri-Ecological Services (AES)	Namibia

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Summary

Aim and content of the project

The NamTip project aimed to comprehensively understand both ecological and social drivers of desertification tipping points (DTPs) and to investigate and communicate effective management interventions. Drylands, prone to tipping point phenomena, can experience sudden ecological shifts due to changing environmental conditions, such as droughts, combined with increased land use pressure. The project focused specifically on DTPs in Namibia's Waterberg region, known for diverse land use types and steep degradation gradients. The project employed an integrated, interdisciplinary approach, combining natural and social sciences within a research design comprising three modules, namely retrospective analysis, comparative approach, and prospective approach. Each module consisted of two work packages (WPs) dedicated to collecting specific data in the ecological (E) and social (S) subsystems, respectively. Results of these work packages were incorporated into three overarching, interdisciplinary work packages, aiming at integrating empirical results into a data-based investigation of early warning indicators and management options (WP 4), modeling social-ecological systems in an agent-based simulation (WP 5), and disseminating knowledge through capacity building and transdisciplinary collaboration (WP 6). Finally, WP 0 ensured project coordination and facilitated internal and external communication.
The project was structured in ten WPs as follows:

- WP 0: Project coordination;
- WP E1: Early warning indicators for DTPs based on time series analyses of primary production;
- WP E2: Comparative studies on DTPs;
- WP E3: Experimental studies on DTPs;
- WP S1: Retrospective analysis of the social causes and consequences of DTPs
- WP S2: Comparative study of socio-ecological processes
- WP S3: Scenario development and decision-making practices
- WP 4: Data-based search for management options;
- WP 5: Model-based exploration of management options;
- WP 6: Capacity development.

Main results

Early warning indicators for DTPs were identified in WP E1, using aboveground net primary production (ANPP) as a metric and revealing correlations with the Enhanced Vegetation Index (EVI) and rainfall. Land degradation risk assessments indicated a cartographic risk level for future land degradation. WP E2's comparative studies on DTPs could not capture tipping point behaviors but showed differences between communal and freehold areas, highlighting higher degradation threats in communal rangelands. WP E3's experimental “TipEx” study indicated varied responses to overgrazing and drought. WP S1's retrospective analysis of social causes and consequences of DTPs identified historical, structural, and managerial factors influencing communal areas, while poor grass availability and income deficits contributed to desertification on freehold farms. WP S2's comparative study of socio-ecological processes in communal and freehold farming areas revealed the crucial role of local institutions in communal areas in managing DTPs. Changes in land cover between communal and freehold areas were observed, influenced by historical and socio-economic factors. WP S3 investigated decision-making processes in communal and freehold farms facing DTPs, with farmers proposing alternative strategies to prevent them. In WP 4, early warning indicators and proactive management strategies were identified, and initial experiments on reseeding perennial grasses showed promising signs of restoration in communal camps. WP 5 utilized ecohydrological and agent-based modeling to study the dynamics of pastoral socio-ecological systems, emphasizing the impact of grazing on vegetation and the need to adjust stocking rates. Finally, WP 6 centered on capacity development, integrating young researchers and providing academic training. Project results were presented by NamTip researchers at various national and international conferences, as well as at stakeholder events.

NamTip places a significant emphasis on stakeholder involvement to disseminate project results. Stakeholder workshops were organized annually both in Namibia and in virtual form to promote exchange on desertification causes and effects, farmers' coping mechanisms, and proactive management strategies. A special emphasis was placed on bush encroachment's role in DTPs and the need for sustainable bush use. This interaction allowed to sharpen the project objectives with regard to the specific situation in the region and the local stakeholders' needs, as well as to evaluate the applicability and relevance of the project's results, which were shared with the stakeholders also in form of training materials for school learners and farmers. The organization of the Namibian Rangeland Forum presented further opportunities for interaction with consultants, farmers, and government officials. Farmers' days and training sessions with farmers further disseminated knowledge on avoiding DTPs and restoring degraded rangelands.

Usefulness and possible applications of the project results

The work done in the NamTip project can be considered as important, necessary and adequate in terms of research approaches and tools, as it has contributed to generating crucial insights into the mechanisms that lead to the occurrence of DTPs, and to identifying management strategies to avoid them.

Linking vegetation and soil data aided in exploring DTPs, which is key for assessing desertification. Notably, habitat-specific sampling enhanced the precision of carbon stock calculations with global implications for climate science. Remote sensing methods and drone technology deepened the understanding of DTPs' causes, allowing for larger-scale monitoring. Novel approaches like Serious Gaming and dynamic simulation modeling demonstrated their potential applicability beyond the project. The anthropological approach of the social subsystem shed light on the causes and effects of socio-political factors and complemented the findings of the natural sciences, thus enabling a more comprehensive understanding of the socio-ecological processes surrounding DTPs.

Scientific visibility was ensured through publications and conference contributions, while capacity building measures fostered collaboration and strengthened networks between German and Namibian partners. This is especially important in view of future opportunities for further scientific knowledge transfer and cooperation, including during a second project's phase.

1. Aim of the project

The central objectives of the NamTip project were to understand both ecological and social drivers for desertification tipping points (DTPs), including their social-ecological effects (objective I) and to research and communicate management interventions (objective II). Drylands are known for so-called tipping point phenomena, where changing environmental conditions, e.g. droughts, in combination with increasing land use pressure can cause ecosystems to suddenly "tip over". This can have serious ecological and socio-economic consequences. An important type of land degradation in drylands is known as desertification. Accordingly, the NamTip project focused on desertification tipping points (DTPs). Namibia's Waterberg region was chosen as the study area because a variety of landuse types are found within close proximity (communal and freehold grazing lands, communal conservation areas as well as a national park). Furthermore, the region is characterized by steep degradation gradients.

2. Content of the project

Understanding and solving complex and urgent environmental problems requires a highly integrated, interdisciplinary approach. NamTip followed this approach and integrated natural and social sciences in an overarching research design (**Fig. 1**). The collection of empirical data was divided into three modules, which aimed to understand DTP behavior using three complementary methods, namely retrospective, comparative and prospective analysis. Each module consisted of two work packages (WPs) that collected specific data on the ecological subsystem (work package "E") and on the social subsystem (work package "S"). The work in these three modules led to the achievement of the project objective 1.

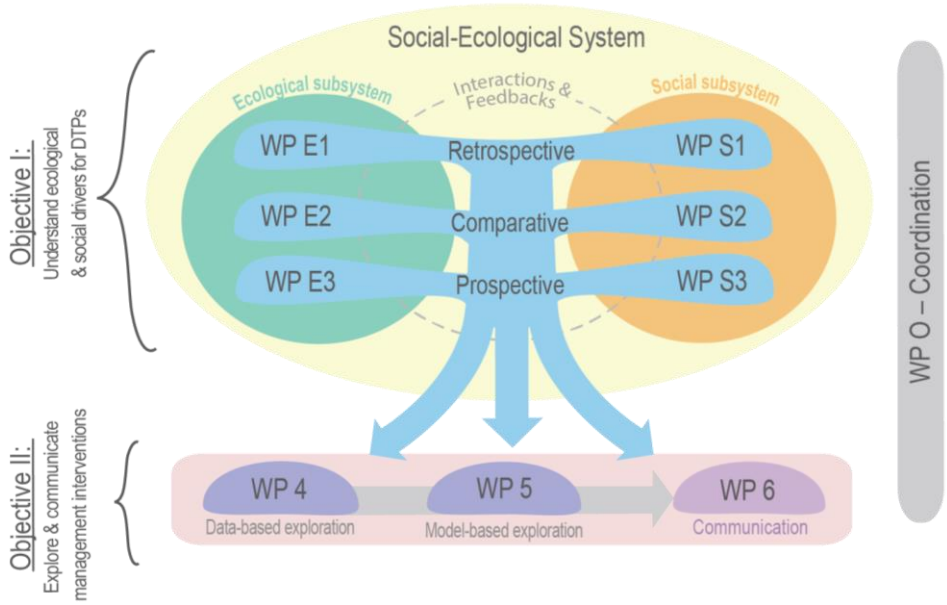


Fig. 1: *NamTip Phase I project structure and inter-/ transdisciplinary research*

The first module comprised the retrospective analysis of tipping points from time series (WP E1) in combination with archive research and interviews with experienced farmers and experts (WP S1). By integrating the results of both work packages, we were able to understand human and environmental factors contributing to DTPs, and consequently to identify early warning indicators and socio-economic impacts of DTPs on land management systems from a historical perspective.

The second module used a comparative approach along spatial gradients of land use pressures. Hence, a so-called space-for-time substitution was used to compare non-desertified ecosystems (WP E2) with

desertified ones, and to characterize farms and community villages with different degrees of degradation and livestock densities (WP S2). Ecological and anthropological fieldwork took place at the same locations, allowing for a deep understanding of social-ecological interactions and feedback.

The third module followed a prospective (i.e. experimental) approach to investigate socio-ecological aspects that were not accessible from observational studies. These included the field experiment TipEx (WP E3) and the implementation of the scientific game "NamSed" (WP S3).

Results of these work packages were incorporated into three overarching, interdisciplinary work packages, which were intended to achieve the project objective 2. By integrating empirical results of the previous WPs into WP 4, a data-based investigation of early warning indicators and management options was conducted first. WP 5 combined the knowledge gained from all previous WPs to investigate the coupled social-ecological systems in an agent-based simulation model. Finally, WP 6 promoted academic and non-academic capacity building and disseminated the new knowledge on DTPs through transdisciplinary collaboration.

WP 0 ensured the project coordination, as well as internal and external communication. These include the organization of regular online meetings and annual project meetings (**Fig. 2**), and the development of the NamTip project website (which is currently in the process of being transferred to a web domain of the University of Potsdam for the project's second funding phase).

***Fig. 2**: The NamTip annual meeting in September 2022 was held in hybrid format. Nevertheless, this allowed to have exciting and fruitful discussions.*

3. Main scientific and technical results of NamTip Phase I

All work packages (WPs) dealing with this objective used a common study design and a harmonized methodology for their activities (see **Fig. 1**).

The following is a list of the main results from each WP:

WP E1: Early warning indicators for DTPs based on time series analyses of primary production

This WP aimed to identify early warning indicators for DTPs based on time series analyses of large-scale remote sensing data on primary production and rainfall in dry pasture areas. This WP built upon novel insights in tipping point research using an aboveground net primary production (ANPP)-based approach. This is a promising approach as (i) ANPP is a well-documented ecosystem metric, (ii) ANPP

is an aggregated measure of ecosystem performance and highly responsive to system behavior on the brink of a DTP; and (iii) ANPP-based early warning indicators may easily be implemented in existing monitoring practices.

Based on a literature review on time series analyses on ANPP, the concept of "Ecological Functional Syndromes" was identified as suitable to characterize the changes in vegetation. Data on ANPP and precipitation amounts was extracted from satellite images. From these datasets models based on EVI (Enhanced Vegetation Index) and rainfall were developed, and the first results obtained. These showed that EVI as a proxy for productivity in dryland systems was positively related to rainfall. The Ecological Functional Syndrome analysis revealed that vegetation changes over the past two decades (between 2001-2020) for the Greater Waterberg Region were such that most of the communal areas did not experience any significant changes, while vegetation loss was the main change in the freehold farms (**Fig. 3**). Further analysis using the so-called "RESTREND" method to discriminate the effect of climatic and non-climatic drivers on the above observed vegetation changes, showed that climatic drivers (precipitation and temperature) are the main driving forces of vegetation changes across most of the study area. The land degradation risk in the landscape of Greater Waterberg was studied based on a multi-criteria approach. This revealed a cartographic risk level in the region for future land degradation.

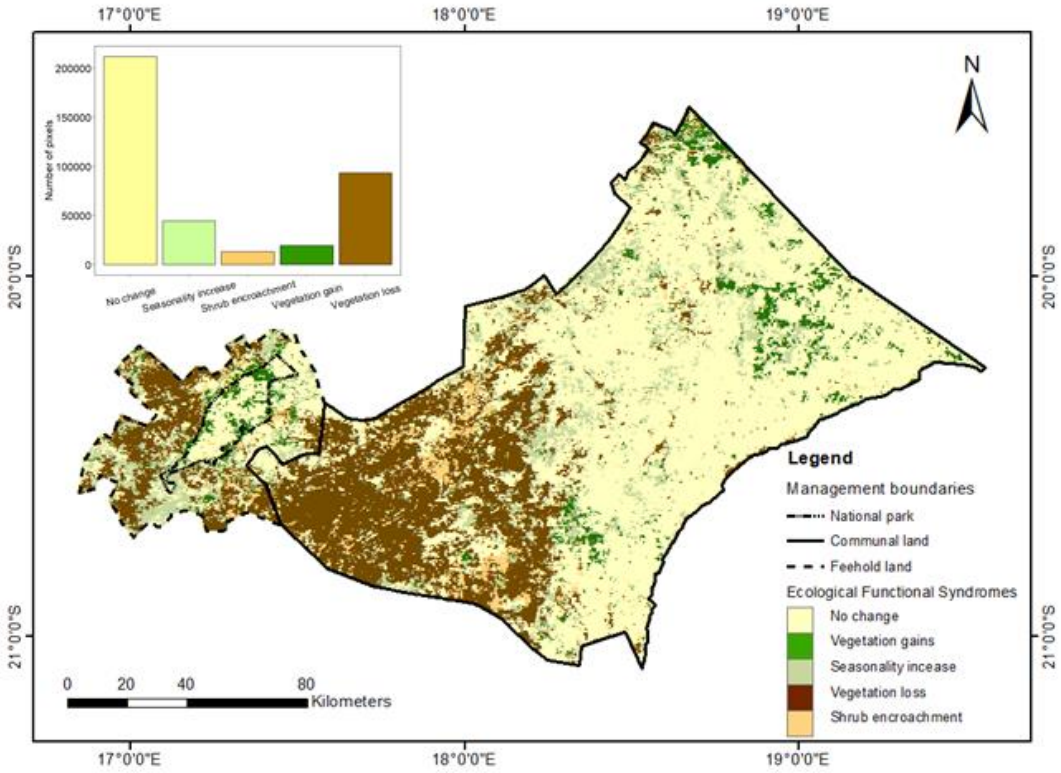


***Fig. 3**: Distribution of functional syndromes in the greater Waterberg region. The different colours show the vegetation change in the recent period compared to the previous period. Light yellow indicates no changes in vegetation condition, light green represents an increase in seasonality, dark green shows vegetation gain, orange shows shrub encroachment, and brown indicates land degradation.*

WP E2: Comparative studies on DTPs

This WP examined the structure and functioning of rangeland ecosystems along grazing gradients, thus using a space-for-time substitution for tipping point processes. We assumed that along gradients, both tipped and non-tipped states would be found, and that cascading tipping point processes can be identified along these gradients. To this end, different ecological compartments of the ecosystem

along 16 local grazing gradients were investigated, with emphasis on vegetation-ecological and pedological studies.

Based on the studied parameters, our results did not show the expected tipping point behavior, but variations along the gradients. However, there were clear differences between the two management systems with generally less favorable conditions (increased presence of stress-tolerant plant species and communities, lower density and species richness of the soil seedbank, lower above-ground net primary productivity, lower soil clay content, and lower soil organic carbon stocks) in communal areas, suggesting that the two management systems are in different ecological states (**Fig. 4 and 5**). Under current land management, communal rangelands faced higher degradation threats than freehold farms.

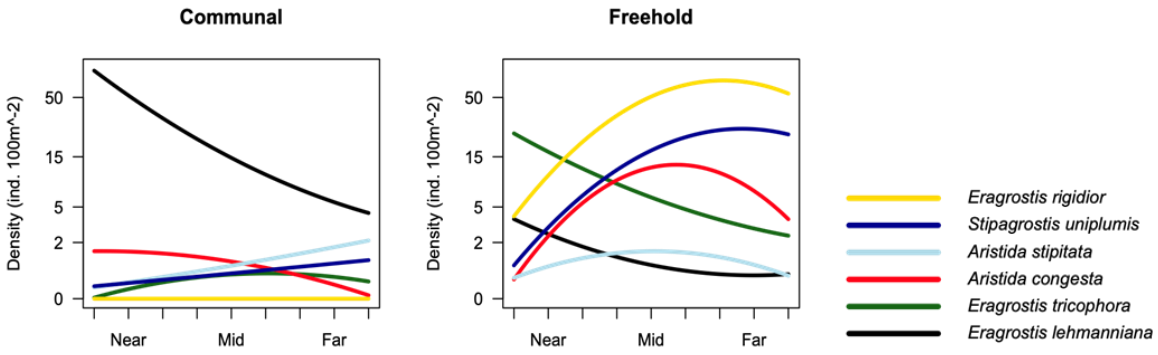


Fig. 4: *Mean densities of six perennial grass species in 10 m x 10 m plots, in two land management types (communal or freehold farms) across assumed grazing gradients (plots "Near" or "Far" from waterpoints).*

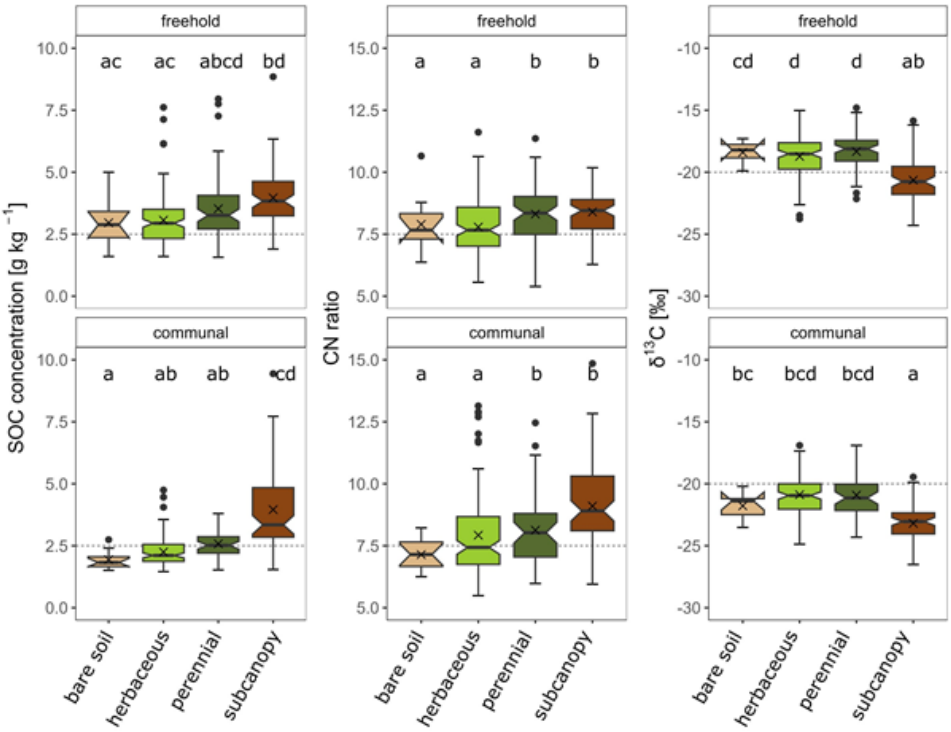


Fig. 5: *SOC concentrations, CN ratios and $\delta^{13}C$ isotopes in topsoil (0-10 cm) in respect to tenure system and vegetation patch type distinguishing bare soil (n=23), herbaceous vegetation (n=243), perennial grass (n=113), and subcanopy (n=143). The median is shown as a bold line, the mean as a cross, and the 95% confidence interval as a notch. Different letters indicate significant differences for each parameter at p<0.05 (HSD) between different vegetation units, and tenure systems.*

A further objective of this WP was to estimate primary production from multispectral imagery and use ground-truthing information to validate and develop predictive regression models for primary production. To this end, multispectral imagery and ground-truthing data was collected from all sites. The multispectral data was preprocessed to generate data products from which proxies of primary production (biomass and vegetation cover) were analyzed and reflectance maps were produced. Overall, unmanned aerial systems proved accurate in mapping primary production proxies in a dryland savannah (**Fig 6**).

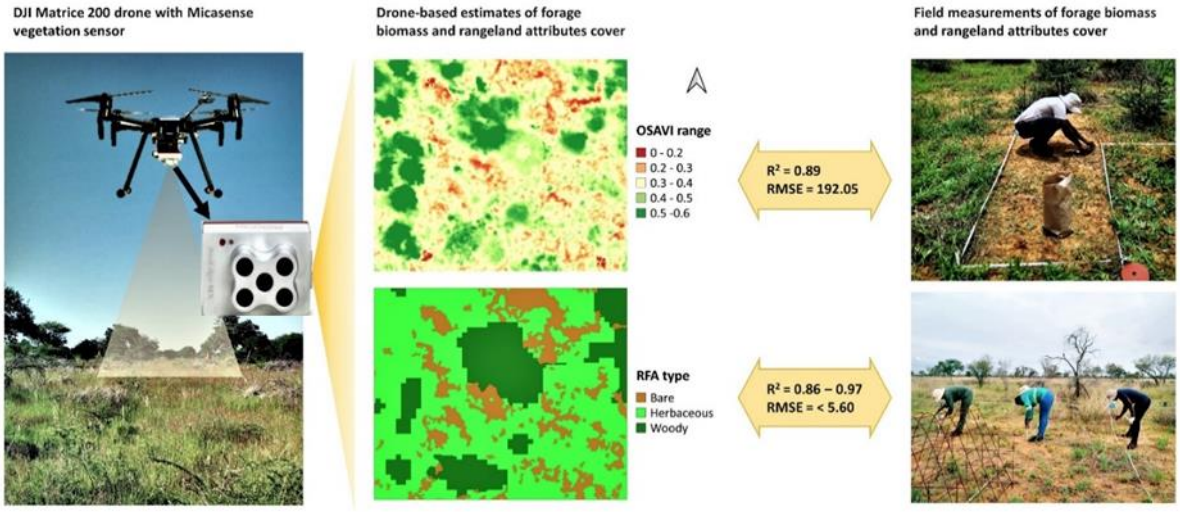


Fig. 6: *Graphical abstract of the published manuscript by Amputu et al. 2023 showing how drone technology validated using field measurements accurately maps primary production proxies in a dryland savannah.*

WP E3: Experimental studies on DTPs

This WP aimed to experimentally push two savanna rangeland sites beyond a DTP by combining treatments of overgrazing and severe drought through the "TipEx" experiment. Here, one of the two sites (Site A) was further away from a DTP than the other (Site B). Analogous to WP E2, it was assumed that cascading effects through different compartments of the ecosystem can be observed when experimentally crossing a DTP. As in WP E2, data on vegetation, soil and seed bank development were collected for this purpose after the experiment's installation (fencing, trench construction, rain protection). In particular, the response of key perennial grass species to varying levels of biomass clipping and precipitation was analyzed (**Fig. 7**). Plant inventories and cover assessments were conducted to explore shifts in plant communities. Seedbank sampling and germination assessments provided insights into changes in seed composition and density. Analyses of forage quantity and quality were conducted, including on the effect of rain use efficiency on net primary productivity. Soil moisture and temperature were measured on both sites, and soil samples were collected from each plot and analyzed.

Baseline data indicated lower grass densities and seedling recruitment in proximity to tipping points, with varied responses to grazing and precipitation treatments. Some insights of shifts in plant communities were observed, although more data is needed. A larger seedbank dominated by perennial grasses was found in the site further away from a DTP. Analysis of forage quantity showed influences of grazing and drought treatments on net primary productivity, while hyperspectral measurements for forage quality revealed variations in metabolizable energy yield per plot. The analysis of the continuously measured soil moisture data showed a decrease of approximately 25% in soil water content under the rain shelters during the growing season. No significant differences in carbon and nitrogen concentrations were observed between the treatments. The first season with full treatments

in 2022 allowed a complete dataset to be collected and used for synthetic analysis, indicating differences in perennial grass populations. The cascading trend of responses across different ecosystem components is evident, with variations in plant populations observed sooner than changes in soil chemistry.

Finally, multispectral imagery was collected from the TipEx sites before the simulated grazing events in 2021 and 2022. The imagery was preprocessed to produce reflectance maps allowing to estimate how simulated grazing and drought affected forage quantity in a dryland system (see WP E2).

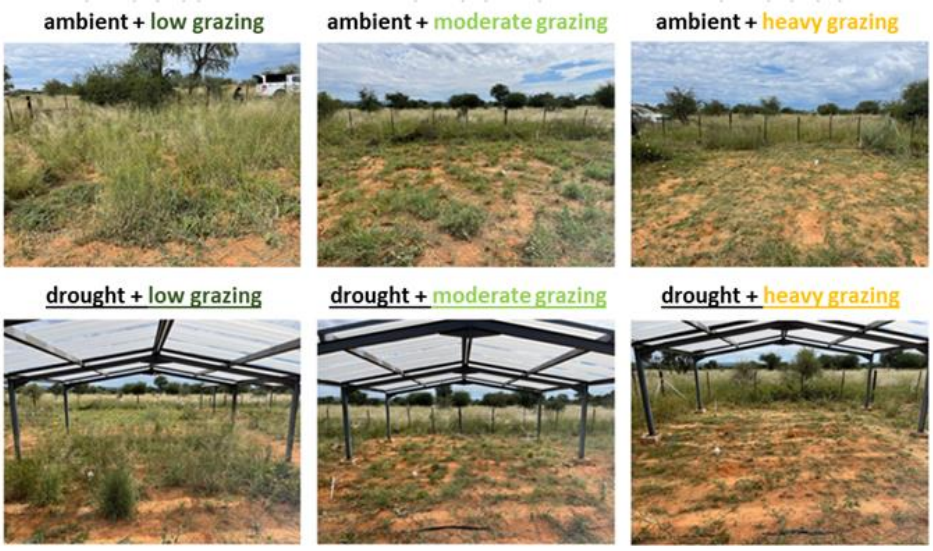


Fig. 7: *An exemplary treatment block showing the general vegetation response under ambient and drought treatments, and different clipping treatments imitating grazing intensities (low, moderate and high grazing).*

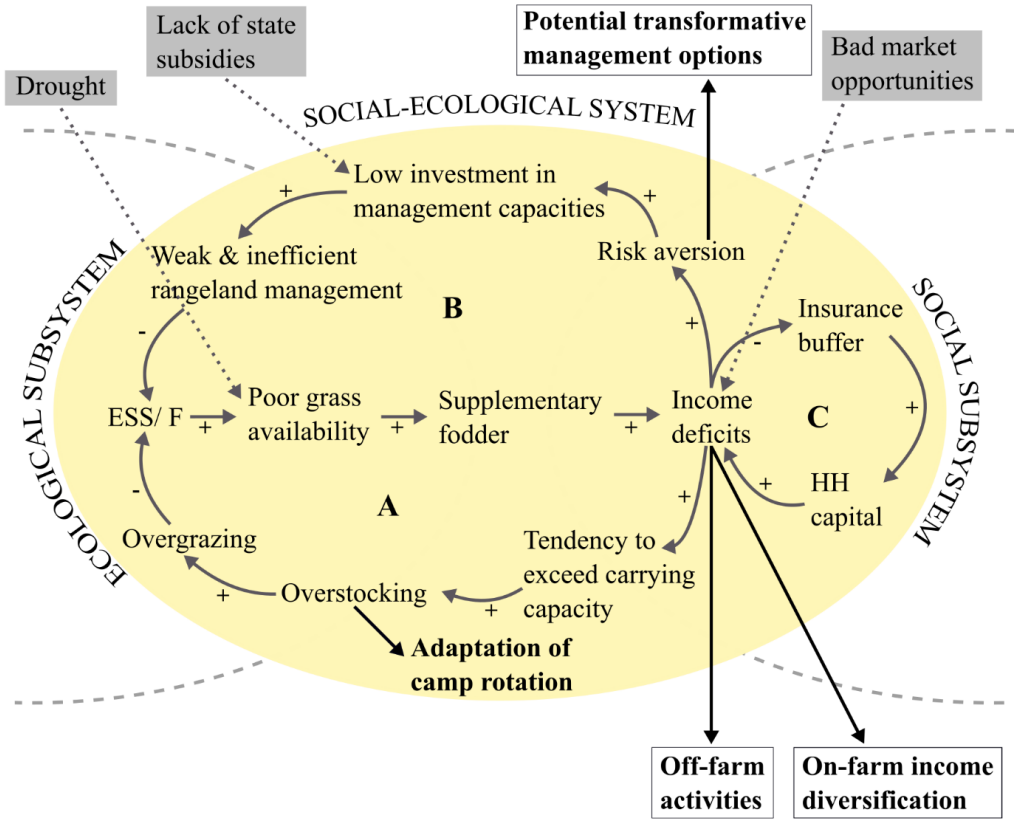
WP S1: Retrospective analysis of the social causes and consequences of DTPs

WP S1 took a retrospective approach to identify social drivers of DTPs as well as DTP effects on social subsystems. As required for an SES framework, the study of feedback between human factors and desertification is based on understanding local socio-ecological dynamics and perceptions (internal factors) in the context of political, socio-economic, and historical development (external factors). The retrospective analysis was based on archival and literature research, interviews with communal farmers, freehold farmers and decision makers, the recording of oral histories, online surveys, participatory mapping, GIS analyses and stakeholder workshops. It assessed the historical drivers of DTP in the region, local perceptions and coping strategies related to DTP, and the ongoing socio-economic impacts of DTP.

Multiple socio-historical, structural, and managerial factors have recently influenced DTPs in communal areas. These factors include colonial resettlement policies, poor infrastructural development (e.g., boreholes), territorial encapsulation, livestock mobility restrictions, and uncontrolled fencing. Ovaherero pastoralists know DTPs very well from experience. They have extensive knowledge that enables them to identify and predict DTPs in various complementary ways. These methods include identifying symptoms directly in the pasture (e.g., low grass density or predominantly annual grasses), indicators in livestock (e.g., condition, meat quality), wildlife (e.g., behavior), and indicators of good/bad rainfall (e.g., wind directions). Ovaherero pastoralists face multiple challenges in maintaining and rebuilding their livestock herds in tipping-point situations, such as extreme droughts. Essential coping strategies such as livestock mobility, reservation of emergency pastures, and social institutions of cooperation are minimal. Key limiting factors include colonial

legacies such as unequal land distribution, overpopulation, lack of capital (poverty), and the individualization of livestock ownership.

Furthermore, the retrospective analysis of the social causes and consequences of DTPs (WP S1) showed that the poor availability of grass in combination with income deficits plays a key role in the desertification of rangeland on freehold farms. This process is characterized by self-reinforcing feedback loops that cause a Social Ecological Trap (SET) of desertification. Only a sustainable change in the prevailing positive feedback loops through transformative management options and diversification of on-farm and off-farm income can avoid or mitigate the effects of ecological regime shifts and help farmers break out of the SET cycle of desertification. The farmers surveyed were reluctant to use bush fodder as a long-term coping strategy and would predominantly only use it in times of drought.



A compensatory/ practice loop **B** rangeland management loop **C** capital management loop

Fig. 8: *Causal loop diagram within a social-ecological system (SES) showing the nested feedback loops and external factors (grey boxes) that form the social-ecological trap (SET) of desertification and farmers' strategies (white boxes) to respond to it. The arrows indicate the interrelationship between the factors within the feedback loop (+ = the values of both factors change in the same direction; - = a change in one factor leads to a change in the other factor in the opposite direction).*

The analysis of the perspective of decision-makers and planners showed, on the one hand, that in the very dynamic field of de-bushing and bush use, which is structured differently on freehold land and communal land, specific legal regulations for both systems were lacking and that this gap was only closed in 2022. Secondly, it became clear that in communal areas, development projects to combat desertification have been key links between the international, national and local levels since independence. However, the measures implemented by the development projects were hardly successful in the long term and across the board.

WP S2: Comparative study of socio-ecological processes

WP S2 consisted in a comparative analysis of different social-ecological processes based on case studies selected from the two land management systems characteristic of the research region, namely communal and freehold farming. The comparative study of different social-ecological processes was built on the retrospective analysis. It focused on one hand on in-depth ethnographic research among pastoralists in four communal villages, allowing for a comparative study of farmers' institutions, technologies, knowledge, and practices to prevent, negotiate, and manage DTPs. On this basis, best practices were identified from the farmers' perspective and experience, and social-ecological processes were characterized. The results were compared with the social-ecological dynamics in neighboring freehold farming areas. These were investigated through qualitative interviews and participatory mapping, which were later supplemented by an online survey and further interviews on site. Such a comparison between social-ecological dynamics in communal and freehold farming systems allowed us to make statements about the causes and consequences of DTPs in both land use systems.

DTPs in communal areas are managed locally through the negotiation and implementation of community-level social institutions that perform the following three functions: (i) regulating group and resource boundaries, (ii) maintaining and prioritizing land use for grazing, and (iii) protecting grazing areas around settlements. The management and treatment of DTPs at the individual level is not possible. Therefore, the practical implementation of these institutions is challenging due to collective action problems, such as rule compliance. Although desertification is a common problem in communal areas, we found significant differences between settlements. Communities that have created and effectively regulated critical environmental and physical infrastructures, such as extensive grazing areas and cattle posts, have better rangeland conditions. However, whether these principles can be adopted and applied by other communities in the region remains a challenge due to the lack of space and the social costs involved.

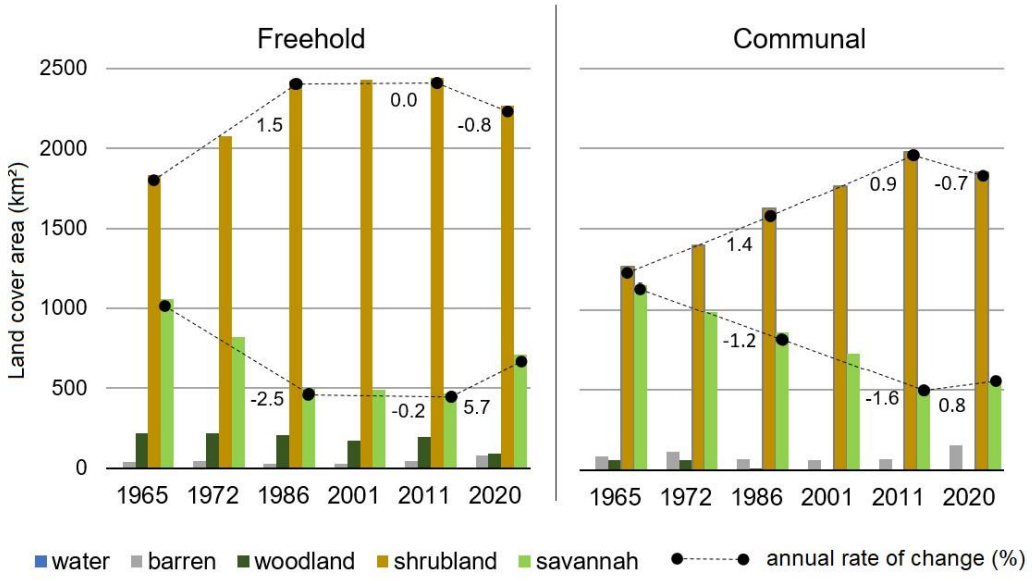


Fig. 9: *Area (km²) of land cover classes from 1965 to 2020 on freehold land and communal land. The numbers within the bars indicate the annual rate of change (%) for shrubland and grass-dominated savannah, which was calculated for the observation periods 1965 to 1986, 1986 to 2011 and 2011 to 2020.*

The comparison of social-ecological processes and outcomes between communal and freehold areas based on land cover classification shows different trends between 1965 and 2020 (**Fig. 9**). Both were affected by deforestation and bush encroachment. At the beginning of our observation period, the

proportion of grass-dominated savannah was higher on communal land than on freehold land. While a linear increase in scrub encroachment was observed on communal land after 1965, the trend of scrub encroachment on freehold land reversed from 2011 onwards, which can be attributed primarily to the implementation of de-bushing measures. The main drivers of rangeland change and associated desertification processes were, in particular, land management and the historical and socio-economic context associated with colonialism.

WP S3: Scenario development and decision-making practices

WP S3 investigated decision-making processes in communal areas and freehold farms in the face of DTPs and farmers' perceptions of potential futures of local social-ecological systems (SES). Methods from social sciences (vignettes) and environmental sciences (scenario development) were combined with a novel approach of "serious gaming" (**Fig. 10**). In this way, qualitative scenarios were developed on how farmers imagine future land use options under different social and ecological conditions. The approach was intended to help identify viable decision-making strategies that farmers can use to proactively manage their rangelands in the face of DTPs.

Fig. 10: *NamSed serious game.* ***A)*** *Initial game state before the start of the game that depicts a stylized village with three homesteads (yellow, blue, and purple), a water bore hole, shop, school, and the village grazing land.* ***B)*** *Final game state at the end of a game session. Through the game course, additional elements have been added to the game via game events which the players are confronted with and must react, e.g., various climatic and land conditions such as droughts, bare soil, or bush encroachment.* ***C)*** *NamSed game session at Okahitwa communal village* ***D)*** *Interview and NamSed game session on freehold farm La Paloma.*

Two field trips to the Okakarara case study region were conducted in 2020 & 2021, investigating the perceptions of communal farmers on the future of livestock farming, expected challenges as well as planned strategies to overcome them. The development and implementation of the NamSed serious game was completed in 2022 and game sessions were conducted in five communal villages as well as with four freehold farmers.

Farmers in the case study area foresee various social-ecological challenges—like more frequent droughts, population increase, and bush encroachment—affecting livestock farming. They aim to tackle these by adopting alternative farming practices, like crop farming, creating bush feed, and shifting towards smaller livestock and poultry. However, to succeed, they need support like training, government-endorsed de-bushing plans, and affordable irrigation systems. A set of land-use strategies and factors influencing farmer decision-making, particularly their values, motives, and norms, was derived from the NamSed serious gaming sessions that will contribute to a typology of farmer decision-making strategies.

WP 4: Data-based search for management options

This WP aimed to identify early warning indicators and proactive management options in the face of impending DTPs, based on qualitative and quantitative results of retrospective, comparative and prospective studies (WPs E1-3 and S1-3). To this end, an interdisciplinary synthesis of local knowledge and scientific findings of the ecosystems studied was carried out. In particular, a literature review and interviews with communal farmers and experts were conducted to reveal practices and barriers to such management strategies. An experiment resting and reseeding perennial grasses in communal camps was initiated in 2022 (**Fig. 11**). A study examining pre-treatments' impact on seed emergence rates was started during NamTip Phase 1 and will be continues during the project's second funding phase. A further study linked to this WP assessed land degradation using indigenous indicators and ecological approaches.

Fig. 11: *An example of a resting cage for perennial grasses in communal camps. Note that the surroundings are bare.*

Potential indicators of tipping points were identified, such as breakpoints in the densities of certain perennial grass species, especially *Stipagrostis uniplumis*, as well as soil organic carbon, due to its role in maintaining soil health and supporting ecological functions. Experiments reseeding perennial grasses in communal camps (including after pre-treatments) showed promising signs of recuperation

in resting spaces. Expert interviews and communal farmers' suggestions aligned, emphasizing effective preventative measures and collective planned grazing.

The expertise on social-ecological systems and the results of the empirical analyses from WP S1 and S2 were incorporated into the overarching synthesis work of the project and specifically in a joint manuscript outlining the project's research design.

WP 5: Model-based exploration of management options

WP 5 used a combination of ecohydrological and agent-based modeling to study the dynamics of pastoral socio-ecological systems. The aim of the work package was to understand drivers and mechanisms of DTPs and to identify early warning indicators and appropriate management interventions. For this purpose, qualitative and quantitative results of the empirical work (WPs E1-3 & S1-3) and the interdisciplinary synthesis of WP 4 were integrated into simulation models designed to capture feedback processes between ecosystem dynamics and farmers' management strategies. In particular, two modeling approaches have been developed and used in WP 5, namely an ecohydrological model (EcoHyD) and an agent-based model.

The eco-hydrological simulation model EcoHyD was adapted for the case study and used to analyze rangeland management strategies, particularly intensive grazing periods, and their impacts on long-term vegetation dynamics. Model results indicate that already short periods of intensive grazing may shift grass-dominated rangelands towards an undesired state. Furthermore, if perennial grass cover falls below a minimum level during heavy grazing (~10%), perennial grasses may be threatened by delayed extinction which can be triggered by a sequence of dry years. Adjusting stocking rates during heavy grazing and providing sufficient resting afterwards may reduce the risk of perennial grass extinction.

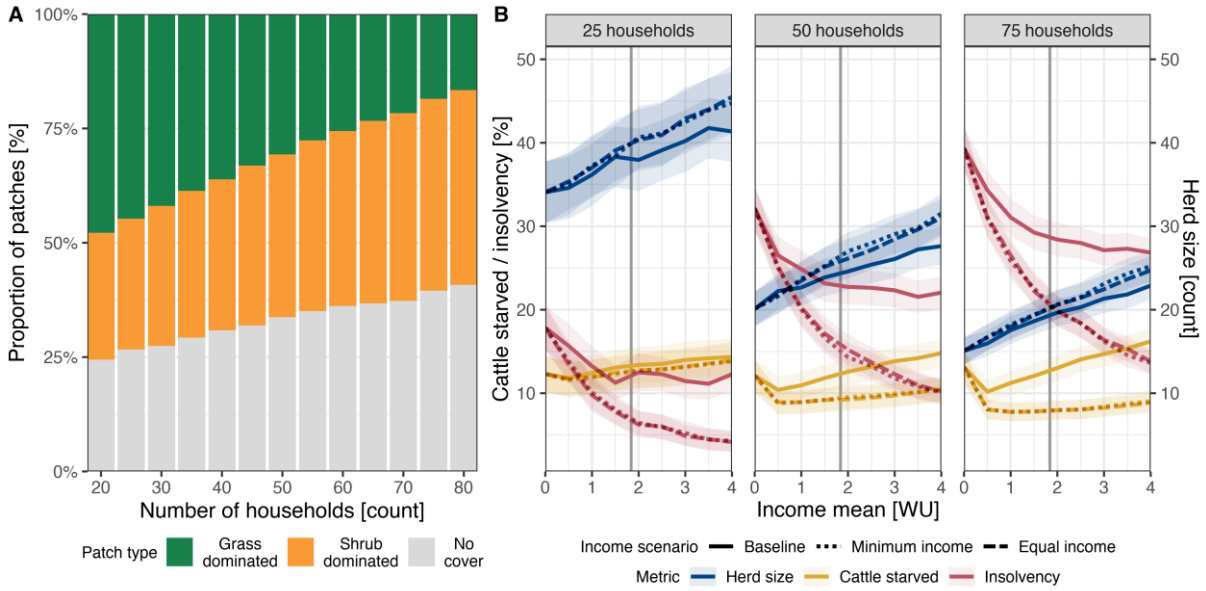


Fig. 12: *Results of the agent-based model.* ***A)*** *Influence of increasing population density on the ecological state of the system: higher household numbers lead to a decrease of the proportion of grass dominated patches and an increase in the proportion of both shrub dominated patches as well as patches without vegetation cover.* ***B)*** *Influence of mean income on the socio-economic state of the system for three household income scenarios and three household density levels: higher mean income leads to higher average herd sizes and less households becoming insolvent but may have an opposite effect on the proportion of cattle starving, especially for higher household numbers. Compared to the baseline scenario (solid lines) where three income groups exist (no income, medium income and high*

income), providing at least a minimum income (dotted line) to all households significantly reduces the proportion of insolvent households and starved cattle. Equal income (dashed line) does not provide additional improvements compared to minimum income scenario. Vertical grey line represents the standard value of income mean. Lines represent mean of 50 simulation runs, shaded area represents the 95% confidence interval.

An agent-based simulation model was developed to investigate the livelihood security of communal farmers in the face of desertification (**Fig. 12**). Model results indicate that mitigation strategies, such as a diversification of income sources, or proactive management of herd sizes, can improve socio-economic conditions of households but may further deteriorate vegetation conditions, thus requiring additional management strategies (e.g., restoration of degraded pastures or bush control measures).

Finally, conceptual advancements have been made regarding the upscaling of models in socio-environmental systems and how to make socio-environmental modeling more useful to support policy and management.

WP 6: Capacity development

The objective of this WP was to share new knowledge on DTPs as a contribution to societal and scientific progress. The WP mainly aimed at providing learning and training opportunities, but also at supporting policy developments to enable sustainable environmental management. A special focus was given on providing tools to facilitate response to impending DTPs. The capacity development offers were tailored to the different needs of Namibian stakeholders and institutions.

In terms of academic capacity development, a total of 34 young researchers have been integrated into the NamTip project since its inception: eight postdoctoral researchers (five in Germany, three in Namibia), eight PhD students (four in Germany, four in Namibia), ten Master's students (eight in Germany, two in Namibia), five Honour's students (all in Namibia), and six Bachelor's students (one in Germany, five in Namibia). Despite the constraints from the Covid-19 pandemic, substantial scientific output was generated and further manuscripts and PhD thesis are still in progress, with confidence in completing them in the second funding phase. The pandemic also affected the planned guest lectures for Namibian students. Nevertheless, these were offered virtual participation in lecture series and ecological statistics courses. Further trainings for the early career researchers were offered also in conducting qualitative interviews and writing policy briefs. In addition, the results of the NamTip project were presented to the scientific community on several occasions in the form of peer-reviewed scientific papers, as well as presentations at national and international conferences (see section 7).

Dissemination of project results was a major objective of NamTip and WP 6 in particular, which aimed at continuously involving Namibian stakeholders to discuss the research questions and results. At the first stakeholder workshop in Windhoek (September 17th, 2019), discussions focused on the causes and effects of desertification and the coping strategies of farmers with regard to desertification processes. The second stakeholder workshop (November 17th, 2020), which was held online, focused on discussions on policies and their implementation. In 2021, the first day of the online project meeting (September 27th, 2021), where the status of the individual work packages was presented, was open to stakeholders. The project results were also presented and discussed at a third stakeholder workshop as part of the Namibian Rangeland Forum in Windhoek (September 28th - 29th, 2022), whereby the target groups were primarily technical advisors, farmers and government officials. On the first day, NamTip scientists gave ten presentations on the project results. On the second day, eleven presentations were given by farmers, technical advisors and NGO representatives. In this way, the project scientists engaged with the stakeholder groups. The written evaluation of the event by the participants was very positive and the discussions during the events were extensive. The Farmer Day in Okakarara (October 1st, 2022) and the field trip to the TipEx sites (October 2nd, 2022) were aimed at community farmers in the study area. Both events were well attended and the project results were

also discussed in detail. For further details on capacity development outside of academia, please refer to the paragraph below.

4. Stakeholder involvement during NamTip Phase I

One of the main goals of NamTip is to disseminate the project results by involving Namibian stakeholders through the development of target group specific formats for decision makers and practitioners. The two Namibian implementation partners EduVentures and Agri-Ecological Services (AES) played a pivotal role in the stakeholder involvement throughout the project's duration. Representatives of both implementing partners presented themselves at the kick-off workshop and the subsequent stakeholder day, which was organized by SP 1 and SP 5 in Windhoek in September 2019 with a total of 38 participants. The main objective of the workshop was to present the NamTip research concept, discuss research approaches and results, and identify further activities for collaboration. Discussions were held in two focus groups (FG) to exchange and discuss preliminary results. FG 1 discussed possible causes and effects of desertification based on the preliminary results. The aim was to compare the different views (NamTip scientists, stakeholders and farmers) and to discuss possible early warning signals of desertification processes. FG 2 worked on farmers' coping mechanisms with regard to desertification processes. Ideas for promising (proactive) management strategies were collected and possible challenges for their implementation were discussed. The results of the stakeholder workshop were compiled in a report and made available to all participants.

The stakeholder workshop was followed by a joint field research trip, which also involved the participation of the Namibian implementing partner. On this occasion, the development of a training module on desertification tipping points for the Ombombo mobile classroom was discussed. As a result, in 2020 EduVentures designed an integrated approach consisting of the development of didactic modules for the school curriculum, school visits with the EduVentures mobile classroom (Ombombo) and learning expeditions with scientists, and ultimately participation in science fairs and NamTip workshops. Similarly, training concepts for knowledge transfer to farmers were developed also by AES. In particular, they designed training materials including sections on understanding the problems of DTP, early warning indicators and possible proactive management interventions. Both partners collaborated on the refinement and preparation of these training concepts for knowledge dissemination to school learners and farmers. A feedback loop with colleagues was implemented to ensure quality assurance.

A second stakeholder workshop was organized in virtual form on November 17th, 2020 with a total of 32 participants (stakeholders and NamTip scientists). Due to the online format and the farmers' limited access to the internet, the focus was placed on representatives of NGOs and development cooperation organizations. Participation was lower than at the first stakeholder workshop, partly due to the challenges of the Covid-19 pandemic situation. In the first part of the stakeholder workshop, the research concept of NamTip was presented and the first research results were communicated and discussed. In the second part, the relevant policies and their implementation were discussed with the stakeholders. Due to the composition of the stakeholders, the topic of bush encroachment and sustainable bush use was at the center of the discussion. In the third part, the ideas for the application of the 2nd project phase of NamTip were discussed with the stakeholders. In the discussion, the stakeholders mentioned the following research gaps and interests:

- Rangeland management
- Relationship between number of animals, grazing period and resting period
- Indicators of land degradation
- Restoration of tipped areas
- Management recommendations
- Bush encroachment and sustainable bush use
- Effects of bush thinning and de-bushing on soil quality, biodiversity and ecosystem

- Ideal bush density
- Competing effects of larger trees
- Stable state of the ecosystem
- Bush fodder

A stakeholder workshop was held virtually also in September 2021 as part of the Annual NamTip Meeting. The first part of the workshop involved the presentation and discussion of research findings. In the second part, potential topics and requests for the second phase proposal were discussed. During the discussion, stakeholders highlighted the role of bush encroachment in DTP, emphasizing its connection to the reduction of groundwater recharge. Additionally, stakeholders brought up the notion that higher temperatures and increased CO_2 concentrations due to climate change would promote bush growth, considering deforestation as a climate adaptation measure. The sustainable utilization of bush was described as a necessity. Furthermore, a stronger focus on restoration, in addition to early detection of degradation, was identified as an important complement to the project approach. These findings served as a crucial starting point for the development of the proposal for a second project funding phase.

In 2022 EduVentures finalized the development of four teaching modules using Smart Notebook software. These smart modules covered several topics related to DTPs, including “Introduction to Climate Change and DTPs in Namibia”, “Understanding ecological and social drivers of DTPs”, “Impacts of DTPs”, and “Managing DTPs”. Five schools (Okakarara Senior Secondary School, Waterberg Junior Secondary School, Coblenz Combined School, Okamatapati Combined School, and Okondjatu Combined School) were visited to introduce the project. The preliminary visit had the objectives of introducing the EduMobile classroom to students and teachers, as well as to present the proposal and selection criteria to the learners, and to make contact with the teachers. A total of 700 learners took part in the preliminary visits. Once the learners had been selected, EduVentures visited the five schools again to carry out the teaching units. This school visit included a five-day visit to the schools where the learners participated in the program. A total of 20 students per school participated in the program, for a total of 100 students at the five schools mentioned.

AES organized the Namibian Rangeland Forum on September 28th – 29th, 2022 (**Fig. 13**). The target groups of the Namibian Rangeland Forum were consultants, freehold and communal farmers and government officials. Research results were presented and discussed. The participation was lower compared to previous Namibian Rangeland Forums, because several other events for the targeted stakeholder groups were held in spring 2022 after Covid-19 restrictions were lifted. On the first day, NamTip scientists gave the following presentations on the project results:

- Amputu V., Heshmati S., Männer F., Knox N., Tielbörger K., Linstädter A. (2022). Using remote sensing at different scales to detect DTPs.
- Hamunyela N., Zimmer K., Sandhage-Hofmann A., Nesongano C., Linstädter A. (2022). Below-ground responses in soils and soil seed banks for DTP observations.
- Liehr, S., Lüdtke, D., Brinkmann, K., Gurny, M., Rößler, R., Schlecht, E. (2022). Bush fodder as a coping strategy?
- Menestrey Schwieger, D. (2022). Anthropological insights on desertification tipping points: Selection of results from the NamTip project.
- Moyo, N., Heita, H.T.N. (2022). Future and current perspectives on desertification tipping points in Okakarara communal farms.
- Munyebvu-Chambara, F., Bilton, M.C., Nesongano, W.C., Linstädter, A. (2022). Perennial grass populations as desertification tipping points indicators.
- Rauchecker, M., Brinkmann, K., Bickel, L., Menestrey Schwieger, D., Heshmati, S. (2022). Comparison of rangeland changes and its underlying drivers on freehold and communal land.
- Zimmer K., Amputu V., Schwarz L., Sandhage-Hofmann A. (2022). Rangeland soils in Namibian semi-arid savannas (poster).

On the second day, farmers, consultants and NGO representatives gave eleven talks. Thus, project scientists got into exchange with stakeholders. The attendees' written evaluation of the event was very positive and discussions were extensive.

Fig. 13: *Several NamTip scientists enriched the Namibian Rangeland Forum in 2022 with their contributions and discussed with local farmers and stakeholders.*

AES also facilitated a farmer's day in Okakarara (October 1st, 2022) as well as a field trip to the TipEx sites (October 2nd, 2022). These activities addressed communal farmers and had a good turnout and also extensive discussions (**Fig. 14**). At the farmer's day, NamTip scientists gave nine talks about the project results. In addition, AES gathered results from the project scientists to prepare a training manual for farmers on DTPs. This consisted in a 37-page farmers' training manual entitled "Rangeland Management and Monitoring in the Eastern Communal Lands of Namibia", which provides a background to the NamTip project, incorporating data from the project, and practical guidance on how to avoid tipping points and rangeland degradation, and how to restore degraded rangelands. A total of 300 color training manuals (A5 format) were printed and distributed to farmers and other stakeholders. From June 6th to 8th, 2023, three training sessions were held with farmers in the grazing areas of Ovitatu, Okomumbonde and Ozongarangombe villages involved in the NamTip study. Each training session was attended by 10-15 community members. The program during these days included a presentation of the content of the training manual, field sessions to practice some methods, and a final discussion based on the field session and touching on further methods to deal with food shortages. In addition, training manuals were distributed to other stakeholders in Okakarara (representatives of the Namibia National Farmers Union, members of the Communal Conservancy) and surrounding areas, thereby promoting the dissemination of information on rangeland management in the region.

Fig. 14: *As part of the Namibian Rangeland Forum, there was an extra day in the field where local communal farmers were invited. The Tipping Point Experiment in Okakarara was visited and there were exciting presentations by our team members.*

5. Statement on the usefulness and possible applications of the project results

The work done in the NamTip project is considered necessary and appropriate, as it has contributed to gain a profound understanding of the mechanisms that lead to the occurrence of DTPs, to identify management and intervention strategies that may be used to avoid them, and to explore farmer's perceptions about future land-use and their decision-making strategies.

The linkage of the vegetation and soil data within the comparative (WP E2) and experimental approaches (WP E3) builds a valuable foundation to explore tipping points in drylands and overall terrestrial ecosystems. Understanding ecological tipping points is of utmost importance to combat issues like desertification. Our generated knowledge within NamTip can contribute to conservation efforts and policies to preserve these ecosystems and their biodiversity. The habitat specific sampling of soil organic carbon as a suitable indicator for identifying degradation improved the precision of its assessment. These findings have the potential to significantly contribute to improving the precision of carbon stock calculations and enhancing global carbon models, which may have implications for climate science, ecosystem management, and efforts to address climate change on a global scale.

By using remote sensing methods adjusted by ground truthing, NamTip scientists were able to provide a deeper understanding of the proximate causes of desertification tipping points (e.g. overstocking, climate extremes). Primary productivity dynamics (measured by drone technology) were found to be a valuable indicator of land degradation and DTPs in dryland systems. This novel approach has the potential to increase the understanding of ecological shifts in African rangelands and to establish a framework for future studies in arid and semi-arid ecosystems, whereby larger areas could be monitored for the risk of crossing tipping points.

The methodological approaches developed in the project, in particular the novel Serious Gaming approach (to observe decision-making strategies of communal and freehold farmers) and the dynamic simulation modeling approaches (using sensitivity analysis techniques and a pattern-oriented approach to support model parameterization in the absence of field data), have a high potential to be applied in other drylands as well as in other social-ecological land-use contexts.

The NamTip project also significantly contributed to the body of knowledge in the literature on social-ecological processes related to DTPs and pastoralism in drylands. Using ethnographic data collection methods and political ecology as an analytical lens to study DTP, the project addressed two major issues in the literature, namely the little attention given to people's anticipatory knowledge of tipping points, and the role that socioeconomic and political factors play in causing social change processes. The results of the social subsystem, through an anthropological approach, complemented the findings of the natural sciences, thus enabling a more comprehensive understanding of the socio-ecological processes surrounding DTPs.

These results have been helpful at various levels and are expected to continue to benefit multiple stakeholders beyond the funding period. Furthermore, the project has developed a training manual for farmers, teaching units for school classes and a policy brief for decision-makers to raise awareness of desertification tipping points and their risks for rangeland management. These materials were used to train farmers, teach school children and present the results of the NamTip project at the *Namibian Rangeland Forum* and during several stakeholder workshops and farmers' days. A positive economic effect can be assumed from this dissemination of knowledge, for example through the adoption of sustainable forms of rangeland management that minimize the risk of degradation and desertification. In this way, our work can indirectly contribute to securing livelihoods and improving the living conditions of the rural population.

The strong and partly reciprocal connection that emerges between social and ecological changes and factors from the project findings, called for an investigation of socio-ecological tipping points and cascading processes in a second project phase, in which more emphasis should be put on the effects of climate change on land cover change and farmers' strategies. Further key issues to be tackled are bush management (de-bushing and sustainable bush use) and the restoration of degraded areas. These aspects were incorporated into the application for a second project phase, which was approved on 31.07.2023. Phase 2 of NamTip focuses on further developments in four areas: 1) interlinked socio-ecological tipping point dynamics; 2) cascading tipping point dynamics and climate change; 3) ways to reverse degradation processes; and 4) bush use as a way to deal with alternative tipping points.

The visibility of the project findings, both in terms of content and methodology, was ensured by scientific publication in renowned international, interdisciplinary journals. Furthermore, they have been presented at national and international conferences. Further publications in peer-reviewed journals are currently in progress. Capacity building measures, including exchange and joint supervision of German and Namibian students and young researchers, also contributed to increase the scientific competitiveness of all project partners, and to create a network of young scientists for future projects.

Finally, all such results were achieved through the close cooperation between Namibian and German project partners within and across work packages, as well as with other local partners and stakeholders, thus strengthening existing valuable connections and establishing new ones. This is especially important in view of future opportunities to deepen and transfer the scientific knowledge achieved in the framework of NamTip through follow-up projects, mentoring of students and researchers, and further cooperation between German and Namibian partners.

6. Appendix: Results that have been or are planned to be published

All publications in connection with the NamTip project that have been or are planned to be published are listed below. **Authorships of German scientists of the NamTip consortium are highlighted in bold black**, and **authorships of African partners are highlighted in bold red**.

6.1. Completed publications

(i) Publications in peer-reviewed journals:

- **Zimmer, K., Amputu, V., Schwarz, L.-M., Linstädter, A., Sandhage-Hofmann, A.** (2024). Soil characteristics within vegetation patches are sensitive indicators of savanna rangeland degradation in central Namibia. *Geoderma Regional*, e00771. https://doi.org/10.1016/j.geodrs.2024.e00771
- **Amputu, V.,** Braun, A., **Heshmati, S.,** Retzlaff, R., Röder, A., Knox, N., **Tielbörger, K.** (2023). Unmanned Aerial Systems accurately map rangeland condition indicators in a dryland savannah. *Ecological Informatics*, 102007. https://doi.org/10.1016/j.ecoinf.2023.102007
- **Brinkmann, K., Menestrey Schwieger, D.A., Grieger, L., Heshmati, S., Rauchecker, M.** (2023): How and why do rangeland changes and their underlying drivers differ across Namibia's two major land tenure systems? *The Rangeland Journal*, 45(3):123-139. https://doi.org/10.1071/RJ23007
- **Heita, H.T.N., Dressler, G., Menestrey Schweiger, D., Mbidzo, M.** (2023) Pastoralists' perceptions on the future of cattle farming amidst rangeland degradation: A case study from Namibia's semiarid communal areas. *Rangelands*, 10001. https://doi 10.1016/j.rala.2023.10.001
- **Menestrey Schwieger, D.A.** (2023). Overcoming Namibia's worst drought in the last 40 years: Ethnographic insights from Okakarara constituency. *Journal of Namibian Studies*, 33, 31-56. https://doi.org/10.59670/jns.v33i.272
- Anderies, J.M., Cumming, G.S., Clements, H.S., Lade, S.J., Seppelt, R., Chawla, S., **Müller, B.** (2022). A framework for conceptualizing and modeling social-ecological systems for conservation research. *Biological Conservation*, 275, 109769. https://doi.org/10.1016/j.biocon.2022.109769
- **Dressler, G.,** Groeneveld, J., Hetzer, J., Janischewski, A., Nolzen, H., Rodig, E., Schwarz, N., Taubert, F., Thober, J., Will, M., Williams, T., Wirth, S.B., **Müller, B.** (2022). Upscaling in socio-environmental systems modelling: Current challenges, promising strategies and insights from ecology. *Socio-Environmental Systems Modelling*, 4, 18112. https://doi.org/10.18174/sesmo.18112
- Koch, F., Tietjen, B., **Tielbörger, K.,** Allhoff, K. T. (2022). Livestock management promotes bush encroachment in savanna systems by altering plant–herbivore feedback. *Oikos*, e09462. https://doi.org/10.1111/oik.09462
- **Menestrey Schwieger D.A.** (2022). Exploring pastoralists' perceptions of desertification tipping points in Namibia's communal drylands: An ethnographic case study from Okakarara constituency. *Pastoralism*, 12(3). https://doi.org/10.1186/s13570-022-00231-x
- Will, M., **Dressler, G.,** Kreuer, D., Thulke, H.H., Grêt-Regamey, A., **Müller, B.** (2021). How to make socio-environmental modelling more useful to support policy and management? *People and Nature*, 3, 560-572. https://doi.org/10.1002/pan3.10207
- Williams, T.G., **Dressler, G.,** Stratton, A.E., **Müller, B.** (2021). Ecological and financial strategies provide complementary benefits for smallholder climate resilience: Insights from a simulation model. *Ecology and Society*, 26(2):14. https://doi.org/10.5751/ES-12207-260214
- **Menestrey Schwieger, D.A., Mbidzo, M.** (2020). Socio-historical and structural factors linked to land degradation and desertification in Namibia's former Herero 'homelands.' *Journal of Arid Environments*, 178, 104151. https://doi.org/10.1016/j.jaridenv.2020.104151

(ii) Peer reviewed conference papers:

- **Männer, F.A.,** Muro, J.M., Ferner, J. Schmidtlein, S.**, Linstädter, A.** (2023). Predicting forage provision of grasslands across climate zones by hyperspectral measurements. In: National Organizing Committee of 2023 IGC (Ed.), International Grassland Congress Proceedings. Conference May 2023. https://doi.org/10.52202/071171-0399
- **Schwarz, L.-M.,** Carmona, C.P., **Bilton, M.C., Munyebvu-Chambara, F.,** Behn, K., **Linstädter, A.** (2023). Evaluating functional diversity as potential early-warning indicator of rangeland degradation. In: National Organizing Committee of 2023 IGC (Ed.), International Grassland Congress Proceedings. Conference May 2023. https://doi.org/10.52202/071171-0063

- **Amputu, V., Tielbörger, K.,** Knox, N., (2022). Drone-based multispectral imagery is effective for determining forage availability in arid savannahs. In: Grassland Science in Europe, Vol. 27 – Grassland at the heart of circular and sustainable food systems. Proceedings of the 28th European Grassland Federation General Meeting, France, ISBN: 978-2-7380-1445-0, p. 527 – 529
- **Männer, F.A.,** Dubovyk, O., Ferner, J., Freyaldenhoven, A., Muro, J., Schmidtlein, S., **Linstädter, A.,** (2022). Forage quality predicted by hyperspectral reflection readings across climate zones. In: Grassland Science in Europe, Vol. 27 – Grassland at the heart of circular and sustainable food systems. Proceedings of the 28th European Grassland Federation General Meeting, France, ISBN: 978-2-7380-1445-0, p. 656 – 658
- **Amputu, V., Tielbörger, K.,** Knox, N., (2021). Assessment of rangeland condition in a dryland system using UAV-based multispectral imagery. In: Grassland Science in Europe, Vol. 26 – Sensing – New Insights into Grassland Science and Practice. Proceedings of the 21st Symposium of the European Grassland Federation, Germany. https://doi.org/10.13140/RG.2.2.21470.51529
- **Amputu, V., Tielbörger, K.,** Knox, N., (2021). Assessment of rangeland condition in a dryland system using UAV-based multispectral imagery. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/1-2/3/
- **Brinkmann, K., Liehr, S., Bickel, L.** (2021). Rangeland management in Namibia in the face of looming desertification: Insights from the freehold farmers' perspective. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/5/1/
- **Hamunyela, N., Nesongano, W.C., Tielbörger, K.,** (2021) The importance of soil seed bank dynamics as potential indicators of desertification tipping point, in: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/2-3/11/
- Klingenfuss, S., **Heshmati, S., Ruppert, J.C., Tielbörger, K.** (2021). Towards early warning signals for desertification. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/5/4/
- **Männer, F.A., Schwarz, L.-M., Menestrey Schwieger, D., Amputu, V., Bilton, M.C., Brinkmann, K., Dressler, G., Hamunyela, N., Heita, H., Heshmati, S., Liehr, S., Mbidzo, M., Munyebvu-Chambara, F., Nesongano, W.C., Rauchecker, M., Sandhage-Hofmann, A., Tielbörger, K., Zimmer, K., Linstädter, A.** (2021). An integrated framework to study ecological tipping points in social-ecological systems. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/1-2/2/
- **Munyebvu-Chambara, F., Nesongano, W.C., Bilton, M.C., Linstädter, A.** (2021). Utilizing perennial grass species' population patterns to detect looming desertification tipping points in semi-arid regions. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. https://uknowledge.uky.edu/igc/24/5-2/21/

(iii) Other publications and conference contributions:

- **Kruger, B., van der Waal, C.** (2023): Rangeland Management and Monitoring in the Eastern Communal Lands of Namibia (Training Booklet). Windhoek: Agri-Ecological Services.
- **Männer, F.A.**, Muro, J.M., Ferner, J. Schmidtlein, S., **Linstädter, A.** (2023). Predicting forage provision of grasslands across climate zones by hyperspectral measurements. 25th International Grassland Congress, 14 – 19 May 2023, Northern Kentucky Convention Center in Covington, Kentucky, USA. (oral presentation)
- **Munyebvu-Chambara, F., Bilton, M.C., Nesongano, W.C., Linstädter, A.** (2023). Investigating potential indicators of rangeland degradation on perennial grass populations along a semi-arid grazing intensity gradient. 12th Oppenheimer Research Conference, 4 – 6 October 2023, Midrand, South Africa. (oral presentation)
- **Rauchecker, M., Mbidzo, M., Bickel, L. Menestrey Schwieger, D. A. (2023).** (2023). Combating desertification in the context of climate change - Development projects in the communal areas in Namibia's Waterberg area from 1991 to 2018. European Conference on African Studies (ECAS). (oral presentation).
- **Zimmer, K.**, Becker, M., Frindte, K., **Sandhage-Hofmann, A**. (2023). Soil respiration and its temperature sensitivity (Q10) in semi-arid rangelands of Namibia. Tagung der Deutschen Bodenkundlichen Gesellschaft 2023. 2-8 September 2023, Halle/Saale, Germany. (oral presentation)

- **Amputu, V., Männer, F., Linstädter, A., Tielbörger K.,** Knox, N. (2023). Spatio-temporal transferability of UAS-based prediction models for forage supply in a dryland savannah. 35th Conference of the Plant Population Biology (PopBio) Section of the Ecological Society of Germany, Austria and Switzerland (GfÖ), 11 - 13 May 2023, University of Hohenheim, Stuttgart, Germany. (poster presentation)
- **Hamunyela, N., Nesongano, W.C., Tielbörger, K. (2023**). Soil seed bank dynamics as potential indicators of grazing-induced land degradation threshold in a dryland savanna. 35th Conference of the Plant Population Biology (PopBio) Section of the Ecological Society of Germany, Austria and Switzerland (GfÖ), 11 - 13 May 2023, University of Hohenheim, Stuttgart, Germany. (poster presentation)
- **Schwarz, L.-M**., Carmona, C.P., **Bilton, M.C., Munyebvu-Chambara, F.,** Behn, K., **Linstädter, A.** (2023). Evaluating functional diversity as potential early-warning indicator of rangeland degradation. 25th International Grassland Congress, 14 – 19 May 2023, Northern Kentucky Convention Center in Covington, Kentucky, USA. (poster presentation)
- **Amputu V., Tielbörger K,** Knox, N., (2022). Drone-based multispectral imagery is effective for determining forage availability in arid savannahs. In: Grassland Science in Europe, Vol. 27 – Grassland at the heart of circular and sustainable food systems. Proceedings of the 28th European Grassland Federation General Meeting, Caen, France. (oral presentation)
- **Bickel, L., Brinkmann, K., Liehr, S.** (2022). Rangeland desertification and land use changes on commercial land in Namibia's Waterberg region. 4th ESP Europe Conference, 10-14 October 2022. Heraklion, Greece. (oral presentation)
- **Dressler, G.,** Irob, K., **Rauchecker, M., Liehr, S.,** Tietjen, B., **Müller, B.** (2022). Adequate grazing management may be insufficient to prevent irreversible rangeland degradation: a social-ecological analysis of long-term vegetation dynamics. World Conference on Natural Resource Modelling (WCNRM 2022), 14 – 17 June 2022, Leipzig, Germany. (oral presentation)
- **Hamunyela, N., Zimmer, K., Nesongano , C., Sandhage Hofmann, A., Tielbörger, K., Linstädter, A.** (2022). Below-ground responses in soils and soil seed banks for DTP observations. Namibian Rangeland Forum, 28-29 September 2022. Windhoek, Namibia. (oral presentation)
- **Männer, F.A.,** Dubovyk, O., Ferner, J., Freyaldenhoven, A., Muro, J., Schmidtlein, S., **Linstädter, A.** (2022). Forage quality predicted by hyperspectral reflection readings across climate zones. In: Grassland Science in Europe, Vol. 27 – Grassland at the heart of circular and sustainable food systems. Proceedings of the 28th European Grassland Federation General Meeting, Caen, France. (oral presentation)
- **Munyebvu-Chambara, F., Bilton, M.C., Nesongano, W.C., Linstädter, A.** (2022). Perennial grass populations as desertification tipping points indicators. Namibian Rangeland Forum, 28-29 September 2022. Windhoek, Namibia. (oral presentation)
- **Rauchecker, M., Mbidzo, M., Bickel, L., Menestrey Schwieger, D.** (2022). Post-independence development projects to combat desertification in communal areas in Namibia's Waterberg region. 4th ESP Europe Conference, 10-14 October 2022. Heraklion, Greece. (oral presentation)
- **Zimmer, K., Amputu, V., Schwarz, L., Sandhage-Hofmann, A.** (2022). Tipping Points in semi-arid savanna rangelands - A Namibian case study. Tagung der Deutschen Bodenkundlichen Gesellschaft 2022, 5-8 September 2022. Trier, Germany. (oral presentation)
- **Amputu V., Tielbörger K,** Knox, N., (2022). Mapping rangeland condition in arid savannahs using drone technology. 34th Plant Population Biology Conference, 19 -21 May 2022. Bolzano, Italy. (poster presentation)
- **Bickel, L., Brinkmann, K.,** Bubenzer, O. (2022). Rangeland desertification and land use changes on commercial land in Namibia's Waterberg region. Tropentag 2022, 14-16 September 2022. Prague, Czech Republic. (poster presentation)
- **Gurny, M., Lüdtke, D.,** Rössler, R., **Brinkmann, K.** (2022). Bush fodder production on commercial farms in the Waterberg region, Namibia: challenges and potentials. Tropentag 2022, 14-16 September 2022. Prague, Czech Republic. (poster presentation)
- **Hamunyela, N., Tielbörger, K., Nesongano, W.C.** (2022) Soil seed bank composition as an indicator of degradation in arid rangelands Namibian Rangeland Forum, 28-29 September 2022. Windhoek, Namibia. (poster presentation)
- **Männer, F.A., Amputu, V.,** Knox, N., **Tielbörger, K, Linstädter, A.** (2022). Exploring capabilities of modelling forage quality and quantity using field spectroscopy and UAV imagery in a semi-arid rangeland. Living Planet Symposium 2022. 23-27 May 2022. Bonn, Germany. (poster presentation)
- **Schwarz, L.-M., Bilton, M., Munyebvu-Chambara, F.,** Behn, K., **Linstädter, A.** (2022). Functional diversity as an indicator of rangeland degradation - insights from a Namibian grazing gradient study. Tropentag 2022, 14-16 September 2022. Prague, Czech Republic. (poster presentation)

- **Zimmer, K., Amputu, V., Sandhage-Hofmann, A.** (2022). Drivers of rangeland degradation in Namibian semi-arid savannas. 22nd World Congress of Soil Science, 31 July – 5 August 2022. Glasgow, UK. (poster presentation)
- **Brinkmann, K., Liehr, S., Bickel, L.** (2021). Rangeland management in Namibia in the face of looming desertification: Insights from the freehold farmers' perspective. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October. Nairobi, Kenya. (oral presentation)
- **Dressler, G.,** Groeneveld, J., Hetzer, J., Janischewski, A., Nolzen, H., Röding, E., Schwarz, N., Taubert, F., Thober, J., Will, M., Williams, T., Wirth, S., **Müller, B.** (2021). Upscaling in socio-environmental systems modelling: Current challenges, promising strategies and insights from ecology. GfÖ Virtual Annual Meeting 2021, 30 August – 1 September. (oral presentation)
- **Heita, H., Dressler, G., Mbidzo, M., Menestrey Schwieger, D.A.** (2021). The future of cattle farming in the communal areas of the Greater Waterberg. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. (oral presentation)
- Klingenfuss, S., **Heshmati, S., Ruppert, J.C., Tielbörger, K.** (2021). Towards early warning signals for desertification. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. (oral presentation)
- **Männer, F.A.,** Ferner, J., Freyaldenhoven, A., Schmidtlein, S., **Linstädter, A.** (2021). Grassland Forage Provision Predicted by Hyperspectral Reflection Readings Across Climate Zones. GfÖ Virtual Annual Meeting 2021, 30 August – 1 September 2021. (oral presentation)
- **Männer, F.A., Schwarz, L.-M., Menestrey Schwieger, D., Amputu, V., Bilton, M.C., Brinkmann, K., Dressler, G., Hamunyela, N., Heita, H., Heshmati, S., Liehr, S., Mbidzo, M., Munyebvu-Chambara, F., Nesongano, W.C., Rauchecker, M., Sandhage-Hofmann, A., Tielbörger, K., Zimmer, K., Linstädter, A.** (2021). An integrated framework to study ecological tipping points in social-ecological systems. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference Oct 2021. (oral presentation)
- **Menestrey Schwieger, D.A., Munyebvu-Chambara, F., Hamunyela, N., Tielbörger, K., Nesongano, W.C., Bilton, M.C., Bollig, M., Linstädter, A.** (2021). Understanding desertification at the community level in Namibia's eastern communal rangelands: a comparative study integrating social and ecological insights. 3rd ESP Europe Conference, 7-10 June 2021. Tartu, Estonia. (oral presentation)
- **Menestrey Schwieger, D.A.** (2021). Exploring pastoralists' perceptions of desertification tipping points in Namibia's communal drylands: An ethnographic case study from Okakarara constituency. Anthropology Southern Africa/ Ethnological and Anthropological Society of Nigeria International Conference, 2-4 December 2021. Windhoek, Namibia. (oral presentation)
- **Munyebvu-Chambara, F., Linstädter, A., Bilton, M.C., & Nesongano, W.C.** (2021). A comparative analysis of vegetation patterns in the face of possible desertification tipping points. University of Namibia - Annual Research Conference on Agriculture, Engineering and Natural Sciences (ARCAENS - 2021), 17 – 18 November. Windhoek, Namibia. (oral presentation)
- **Rauchecker, M.,** Kasymov, U., Drees, L., Ring, I. (2021): State's Immobility vs. Pastoralist Mobility – A Case Study of Mongolia and Namibia. 3rd ESP Europe Conference, 7-10 June 2021. Online. (oral presentation)
- **Schwarz, L.-M., Männer, F.A., Menestrey-Schwieger, D.A., Amputu, V., Bilton, M.C., Brinkmann, K., Dressler, G., Hamunyela, N., Heita, H., Heshmati, S., Liehr, S., Mbidzo, M., Munyebvu-Chambara, F., Nesongano, W.C., Rauchecker, M., Sandhage-Hofmann, A., Tielbörger, K., Zimmer, K., Linstädter, A.** (2021) Studying transitions in ecological systems by applying an integrated social-ecological framework. GfÖ Virtual Annual Meeting 2021, 30 August – 1 September. (oral presentation)
- **Amputu V., Tielbörger K,** Knox, N., (2021). Assessment of rangeland condition in a dryland system using UAV-based multispectral imagery. In: National Organizing Committee of 2021 IGC/IRC Congress (Ed.), International Grassland Congress Proceedings. Kenya Agricultural and Livestock Research Organization, Online Conference, 25-29 October 2021. Nairobi, Kenya. (poster presentation)
- **Amputu V., Tielbörger K,** Knox, N., (2021). Assessment of rangeland condition in a dryland system using UAV-based multispectral imagery. 21st European Grassland Federation Symposium, 17-19 May 2021. Kassel, Germany. (poster presentation)
- **Hamunyela, N., Tielbörger, K., Nesongano, W.C.** (2021) The importance of soil seed bank dynamics as potential indicators of desertification tipping points. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October 2021. Nairobi, Kenya. (poster presentation)

- **Heita, H., Dressler, G., Mbidzo, M., Menestrey Schwieger, D.A.** (2021). The future of cattle farming in the communal areas of the Greater Waterberg. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October 2021. Nairobi, Kenya. (poster presentation)
- **Männer, F.A.,** Ferner, J., Freyaldenhoven, A., Schmidtlein, S., **Linstädter, A.** (2021). Predicting grassland forage provision from spectral canopy reflection for different climate zones. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October 2021. Nairobi, Kenya. (poster presentation)
- **Munyebvu-Chambara, F., Nesongano, W.C., Bilton, M.C., Linstädter, A.** (2021). Utilizing perennial grass species' population patterns to detect looming desertification tipping points in semi-arid regions. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October 2021. Nairobi, Kenya. (poster presentation)
- **Munyebvu-Chambara, F., Nesongano, W.C., Bilton, M.C., Linstädter, A.** (2021). Grass species dynamics assist to detect rangeland transitions. GfÖ Virtual Annual Meeting 2021, 30 August – 1 September 2021. (poster presentation)
- **Schwarz, L.-M., Männer, F.A., Menestrey Schwieger, D.A., Amputu, V., Bilton, M.C., Brinkmann, K., Dressler, G., Hamunyela, N., Heita, H., Heshmati, S., Liehr, S., Mbidzo, M., Munyebvu-Chambara, F., Nesongano, W.C., Rauchecker, M., Sandhage-Hofmann, A., Tielbörger, K., Zimmer, K., Linstädter, A.** (2021). An integrated framework to study ecological tipping points in social-ecological systems. The Joint International Grassland and International Rangeland Congress 2021, 25-29 October 2021. Nairobi, Kenya. (poster presentation)

(iv) Completed PhD, MSc, Honours and BSc theses:

- **Lotz, Julian Patrick**. Land degradation risk assessment in a dryland savannah. (MSc thesis, 2023, University of Tübingen)
- **Schröter, Helen.** The effects of drought and grazing on ANPP and RUE in a Namibian rangeland with two different land-use histories being further and closer to a DTP. (MSc thesis, 2023, University of Potsdam)
- **Vogel, Hannes.** Property Regimes of Pastoralist Systems. (MSc thesis, 2023, UFZ & Stockholm University)
- **Bickel, Lena**: Rangeland desertification and land use changes on commercial land in Namibia's Waterberg Region over the past 60 years. (MSc thesis, 2022, ISOE & Ruprecht-Karls-Universität Heidelberg)
- **Gurny, Melissa:** Bush Fodder Production on commercial Farms in the Waterberg Region, Namibia: Challenges and Potentials (MSc thesis, 2022, ISOE & Georg-August University of Göttingen)
- **Mustelin, Katinka**. Livelihood security in the face of looming desertification: exploring long-term social-ecological dynamics using an agent-based model. (MSc thesis, 2022, UFZ & Leuphana University Lüneburg)
- **Bekele, Matiwos.** Effects of grazing intensity on semi-arid grassland plant community composition over time. (MSc thesis, 2021, University of Bonn)
- **Hammer, Leonard.** Analyzing mechanisms of poverty trap formation using agent-based modelling. (MSc thesis, 2020, UFZ & Philipps-University Marburg)
- **Ndjimba, J.T.** Assessing Woody Vegetation Dynamics along Degradation Gradients in Communal Areas of the Greater Waterberg Landscape Conservation Area, Central Namibia. (Mini thesis for Honours degree, 2022, Namibia University of Science and Technology)
- **Namupolo, H.N.** Comparison of Woody Vegetation Dynamics in Cleared and Non-cleared Commercial Farms in the Greater Waterberg Landscape, Central Namibia. (Mini thesis for Honours degree, 2022, Namibia University of Science and Technology)
- **Jaoo, Maria D.** Title: Assessing rangeland conditions in the communal area of the Greater Waterberg Landscape conservation area, using forb species dynamics as a possible indicator of degradation. (Mini thesis for Honours degree, 2022, University of Namibia)
- **Barth, Lena**. Land degradation assessment using Residual Trend Analysis (RESTREND) of Enhanced Vegetation Index (EVI), soil moisture and rainfall in Greater Waterberg Landscape, Namibia from 2001 to 2020. (BSc thesis, 2022, University of Tübingen)
- **Ndapulamo, Ndeshihafela W.** Seasonal variation in foraging behaviour of cattle in the communal area of the Greater Waterberg Landscape. (BSc report, 2022, University of Namibia)
- **Nashini, Martha E.** Spatial and temporal variation in rangeland condition in the communal areas of the Greater Waterberg Landscape, central Namibia. (BSc report, 2022, University of Namibia)
- **Nenkete, Simon.** The role of selected woody species on seedling recruitment and survival in the communal area of the Greater Waterberg Landscape. (BSc report, 2022, University of Namibia)

- **Enondubo, Sarafia L.** An analysis of seasonal variations in the nutritional content of selected common palatable grasses in the Greater Waterberg Communal area. (BSc research report, 2021, University of Namibia)
- **Jaoo, Maria D.** Assessing rangeland conditions in the communal area of the Greater Waterberg Landscape, using forb species dynamics as a possible indicator of degradation. (BSc research report, 2021, University of Namibia)

6.2 Planned publications

(i) Publications in peer-reviewed journals:

- **Amputu, V., Männer, F., Linstädter, A., Tielbörger K.,** Knox, N. (in prep.) Spatio-temporal transferability of UAS-based prediction models to predict forage supply in a dryland savannah. *Ecological Applications*
- **Amputu, V.,** Knox, N., **Linstädter, A., Tielbörger K.** (in prep.) Space for time substitution approach to quantify rangeland degradation and identify possible early warning signals of the desertification tipping point from high-resolution drone imagery in a dryland savannah. *International Journal of Ecology*
- **Dressler, G., Jäger, F.,** Irob, K., **Rauchecker, M.**, **Liehr, S.**, Tietjen, B., **Müller, B.** (in prep.). The role of grazing management for savanna rangeland degradation: a social-ecological analysis of long-term vegetation dynamics. *Ecological Complexity*
- **Grieger, L., Brinkmann, K., Liehr, S., Rauchecker, M.** (under review) Desertification as social-ecological trap: How does it come about and what are Namibian freehold farmers doing about it? *Ecology and Society*
- **Hamunyela, N., Nesongano, W.C., Tielbörger, K.** (under revision). Soil seed bank dynamics as potential indicators of grazing-induced land degradation threshold in a dryland savanna. *Journal of Ecology*
- **Hamunyela, N., Tielbörger, K., Nesongano, W.C.** (in prep.). The role of plant-plant interactions for size and composition of seed rain and soil seed banks in grazed semi-arid savanna.
- **Männer, F.A.,** Muro, J., Ferner, J., Schmidtlein, S., **Linstädter, A.** (in prep.). Grassland forage quality and quantity successfully predicted by hyperspectral measurements across climate zones
- **Männer, F.A., Schwarz, L.-M., Amputu, V., Bilton, M.C., Linstädter, A.,** (in prep.). Rangeland Degradation in Namibia: Impacts of Grazing Management and Bush Encroachment on Forage Biomass and Quality
- **Männer, F.A., Schwarz, L.-M., Amputu, V., Bilton, M.C., Hamunyela, N., Munyebvu-Chambara, F., Zimmer, K., Linstädter, A.** (in prep.) Grazing and bush cover effects on Biodiversity and Ecosystem Services relationship in Namibia´s semi-arid savannah
- **Männer, F.A., Schwarz, L.-M., Menestrey Schwieger, D.A., Amputu, V., Bilton, M.C., Brinkmann, K., Dressler, G., Hamunyela, N., Heita, H., Heshmati, S., Liehr, S., Mbidzo, M., Munyebvu-Chambara, F., Nesongano, W.C., Rauchecker, M., Sandhage-Hofmann, A., Tielbörger, K., Zimmer, K., Linstädter, A.** (in prep.). A novel methodological framework to study ecological tipping points in social-ecological systems.
- **Menestrey Schwieger, D. A., Munyebvu-Chambara, F., Hamunyela, N., Tielbörger, K., Nesongano, W.C., Bilton, M. C., Bollig, M., Linstädter, A.** (in prep.). Understanding rangeland desertification at the community level in Namibia: a comparative study integrating social and ecological insights. *Human Ecology*
- **Moyo, S.N., Bilton M.C., Mbidzo, M.** (in prep.). Reseeding and resting as proactive management strategies to restore grass cover in the rangelands of the GWL communal farms.
- **Moyo, S.N., Mbidzo, M.** (in prep.). A comparison of stakeholders' views on proactive management strategies in avoiding desertification: Communal farmers vs Experts.
- **Munyebvu-Chambara, F., Bilton, M.C., Nesongano, W.C., Linstädter, A**. (in prep.). Investigating potential indicators of desertification tipping points on perennial grass populations along semi-arid grazing intensity gradients.
- **Munyebvu-Chambara, F., Bilton, M.C., Schwarz L.-M., Nesongano, W.C., Linstädter, A**. (in prep.). How herbaceous plant population dynamics assist as early warning indicators of possible irreversible rangeland transition in dryland regions.
- **Mustelin, K., Dressler, G., Menestrey-Schwieger, D.A., Müller, B.** (in prep.). Livelihood security in the face of looming desertification: exploring long-term social ecological dynamics using an agent-based model, *PLOS ONE*
- **Rauchecker, M., Mbidzo, M., Bickel, L., Menestrey Schwieger, D.** (in prep.). Combating desertification in the context of climate change – Development projects in the communal areas in Namibia's Waterberg area from 1991 to 2018. *World Development*
- **Schwarz, L.-M., Männer, F.A., Zimmer, K., Sandhage-Hofmann, A., Munyebvu-Chambara, F., Menestrey Schwieger, D.A., Bilton, M.C.,** Behn, K., **Linstädter, A.** (in prep.). Towards a quantitative grazing intensity index for semi-arid rangelands.

- **Schwarz, L.-M.,** Carmona, C.P.**, Bilton, M.C., Munyebvu-Chambara, F.,** Behn, K.**, Linstädter, A.** (in prep.). Plant community patterns and functional diversity as potential early warning indicators of rangeland degradation.
- **Zimmer, K.**, Becker, M., Frindte, K., **Sandhage-Hofmann, A**. (in prep.). Soil respiration and its temperature sensitivity (Q10) in arid rangelands of Namibia.

(ii) Planned PhD, MSc or BSc theses:

- **Amputu, Vistorina.** Leveraging drone technology to map and understand grazing-induced rangeland degradation in a southern African dryland system. (PhD thesis, University of Tübingen)
- **Hamunyela, Ndamonenghenda.** Relative importance of sources of plant recruitment and the role of plant-to-plant interactions as early indicators of a desertification tipping point. (PhD thesis, University of Namibia)
- **Männer, Florian.** Rangeland degradation dynamics analyses in a Namibian savannah ecosystem using remote and proximal sensing of forage supply and vegetation patterns. (PhD thesis, University of Bonn)
- **Moyo, Sihlangene Nali.** Investigating the use of proactive management strategies in the Greater Waterberg Landscape farms (PhD thesis, Namibia University of Science and Technology)
- **Munyebvu-Chambara, Faith.** Utilising herbaceous plant population patterns as indicators of desertification tipping points: An experimental and space-for-time approach. (PhD thesis, University of Namibia)
- **Schwarz, Lisa-Maricia.** Comparative Analysis of Desertification Tipping Points in Namibian Rangelands with Methods of Functional Plant Ecology. (PhD thesis, University of Bonn)
- **Zimmer, Katrin.** Indicators of soil degradation in savanna rangelands, Namibia. (PhD thesis, University of Bonn)
- **Mahulilo, Salvation.** Using infiltration as an early warning indicator for rangeland degradation in the Greater Waterberg Landscape of Namibia. (MSc thesis, University of Namibia)
- **Nambahu, Esther.** Assessing Land Degradation Using Indigenous Knowledge and Ecological Approaches in the Communal Areas of Waterberg Landscape, Omaheke Region. (MSc thesis, Namibia University of Science and Technology)
- **Mburae, Keja.** Germination of selected Namibian grass species for potential rangeland rehabilitation. (Honours thesis, Namibia University of Science and Technology)
- **Nashini, M.E.** Spatial and temporal variation in rangeland condition in the communal areas of the Greater Waterberg Landscape conservation area, central Namibia. (Mini thesis for Honours degree, University of Namibia)