BMBF SPACES Final Report (Public version)

Subproject 1: Coordination and EC flux measurements (WP1), including socioeconomic surveys (WP5)

Joint project: ARS AfricaE - Adaptive Resilience of Southern African Ecosystems

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Brief description

1.1 Aims and tasks

The Adaptive Resilience of Southern African Ecosystems (ARS AfricaE) project established a network of research clusters to study the effect of land disturbance and/or land use change on water and carbon cycling and their interaction along an aridity gradient. The main task of Subproject (SP) 1 was setting up the central infrastructure for the project by establishing Eddy Covariance (EC) flux towers onto the survey sites and equipping them with micrometeorological instruments for trace gas flux measurements between the savanna ecosystems and the atmosphere. Apart from processing, analysing and providing EC data to the other working packages, Johann Heinrich von Thünen Institute for Climate-Smart Agriculture (TI-AK) was responsible for overall project coordination. Furthermore, TI-AK was responsible for the coordinated and issued subcontracts for all South African collaborators; an overview of the SA collaborators' results is included in this report. A more detailed report of WP5 (University of the Witwatersrand (WITS)) about socioeconomic surveys on fuelwood use is also incorporated within this report.

1.2 Preconditions for the project

The working group of PI C. Brümmer at the TI-AK has long-term expertise in the development and use of EC techniques. Setting up the research clusters in South Africa required the ability to design tailored solutions for security issues, electrical power supply and maintenance efforts in remote areas. The project also benefited of the ARS AfricaE consortium members having past experience with using EC techniques at similar sites, including the Kruger National Park (KNP) and Kataba Forest Reserve in Zambia, in the context of several national and international projects.

The TI-AK SP grant allowed the hiring of an engineer/technician, which was essential for the establishment and maintenance of the research infrastructures in South Africa. The successful completion of project coordination tasks was possible due to the recruitment of a postdoctoral project coordinator. With a grant from the German Academic Exchange Service (DAAD), a PhD student was hired to process and analyze the flux data, while the time of PI Brümmer was provided as an in-kind contribution by the TI-AK.

Furthermore, the successful completion of the project relied on good collaboration from the South African counterparts, who had an important role in the planning, set-up and maintenance of the infrastructures. The recruitment of a DAAD-funded PhD student as well as additional funds to conduct field work were essential for the implementation of the socioeconomic surveys and monitoring of fuelwood extraction under WP5 (WITS).

1.3 Project planning and execution

SP1 started its work by identifying the German and Southern African partners already in 2013 when the idea of building a joint multi-disciplinary consortium by initial project coordinator W.L. Kutsch and C. Brümmer was born while participating in the Savanna Science Network Meeting in Skukuza, KNP, South Africa. At the same time, the first Science Partnerships for the Assessment of Complex Earth System Processes (SPACES) call had been launched as a follow-up of the 'German-South African Year of Science' in 2012. The consortium was established in a way that every partner of South Africa with its respective expertise (i.e., large-scale modelling, agent-based modelling, remote sensing, socio-economy, micrometeorology) would have a German counterpart. The pre-proposal and full proposal were submitted with a final approval for the project start in August 2014.

The project coordination tasks of WP1 included project reporting, follow-up on the completion of milestones, organisation of project-related meetings and the presentation of the joint project at international meetings. The implementation of the scientific part of the subproject, including the construction of the EC infrastructure and the provision and analysis of flux data, was completed in three phases:

1. **Preparation phase**, including the selection of field sites, obtaining research authorization, and the preparation and final design of the flux towers. The selection of field sites was made to identify suitable locations along a moisture gradient, with each cluster comprising at least two sites, representing different land-use types ("near-natural" and "human-managed"). The selection of the Karoo cluster sites was made immediately following the ARS AfricaE annual meeting in 2014, on a field visit with the South African partner Grootfontein Agricultural Development Institute resp. The Small Stock Research Trust (GADI). The access permissions and security measures were clarified immediately following the selection. The design and instrumentation of the Karoo sites was initiated in April 2015, and the towers were erected and set up during September/October 2015. Following the initial plan, the Zambian research site of Mongu was visited in November 2014; however, collaboration was stopped due to a change in regulations preventing the participation of the Zambian collaborators. The previously existing flux tower sites at the KNP (Skukuza and Malopeni) were visited during 2015, when also ground-truthing for the Skukuza site was conducted for the calibration of satellite products. The discussions of the potential location of the Agincourt tower, as well as the selection of the site at the premises of the University of Venda were also initiated in 2015. The Agincourt tower was set up in spring 2016. Assistance from project partner W. Twine (WITS) was crucial in the Agincourt case, especially in contacts with traditional village leaders and the local government. The Vuwani tower was erected and set up during June/July 2016. (See Figure 1.1 for research site locations and Appendix A.2 for descriptions of research sites).

   The training of Southern African scientists and technicians was also included as part of the preparation phase (see section "Capacity building" under 2.1).

2. **Installation phase** of the EC towers, including the completion of the flux tower infrastructures with micrometeorological instruments for trace gas flux measurements between the savanna ecosystems and the atmosphere (see Figure 1.2).

3. **Operational phase**, including the processing, analysis and integration of the data, as well as continuous maintenance of the towers. Constant, ongoing maintenance efforts are mainly related with cleaning, repairing and recovering stolen or broken instruments, and developing new,

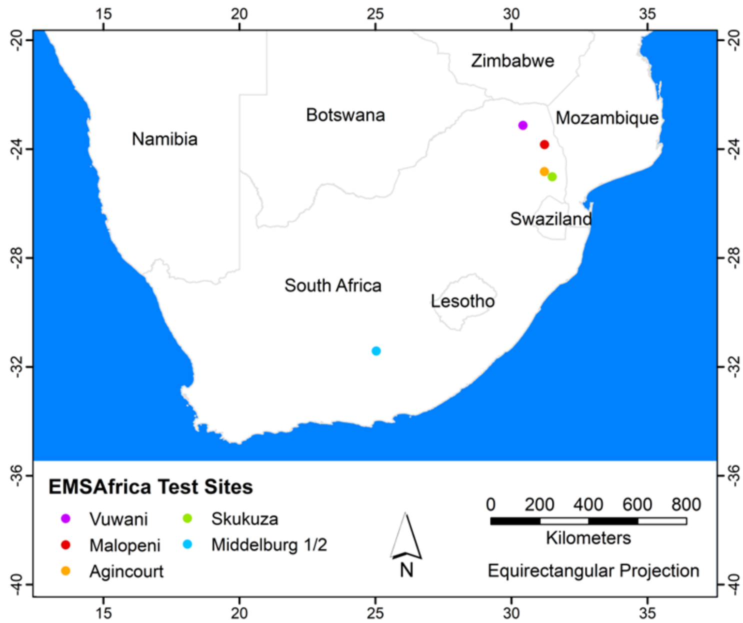

Figure 1.1: The ARS AfricaE observation sites within South Africa.

improved solutions for problem cases. Data analysis, compilation of results and deriving conclusions was largely undertaken by K. Mukwashi, under the supervision of PI Brümmer and Prof. C. Thomas (University of Bayreuth). Mr Mukwashi is about to submit his thesis in the second half of 2018, and some of his main results are presented under Chapter 2.1.

The work done under WP5 is based on quantitative socio-economic surveys conducted by WITS of 580 rural households sampled across nine villages at the Agincourt research site in 2014, co complete earlier datasets collected in the same area. Data was collected to enable the quantification of household use of fuelwood and appropriation of carbon in the study site.

1.4 Scientific and technical state of knowledge at time of project initiation

1.4.1 Eddy Covariance flux measurements (WP1)

Eddy Covariance is a direct and continuous micrometeorological flux measurement technique that allows investigations of diurnal to decadal time scales. A further benefit of the technique is that it depends on a less stringent set of assumptions than other (indirect) methods. Depending on atmospheric conditions, flux measurements are representative of a diameter of up to about a hundred times the sensor height. Beside flat terrain and a homogeneous fetch area, the EC technique requires ultrasonic anemometers and gas-analyzers with fast response times and sampling rates (10 Hz or higher) and aerodynamically small physical dimensions. Following developments in EC sensor techniques, the need of maintenance effort and electricity have been reduced. This has made it easier to run flux towers in remote areas, making the ARS AfricaE setup possible.

Figure 1.2: Introduction of the Karoo tower infrastructure to the ARS AfricaE consortium by TI-AK engineer J.-P. Delorme (top left); installation of soil heat flux plates (bottom left); close-up of Vuwani Biomet system (top right); working up in the Vuwani tower (bottom right).

Although the majority of savanna areas are used for cultivation or grazing, few studies using CO_2 flux data measurements have been conducted in these areas (Räsänen et al., 2017), while most data exists from nature reserves (Archibald et al., 2008). Furthermore, most EC studies are campaign-based and lack a long-term perspective (Ago et al., 2014; Archibald et al., 2008; Brümmer et al., 2008; Quansah et al., 2015; Räsänen et al., 2017; Tagesson et al., 2015; Tagesson et al., 2016; Veenendaal et al., 2004).

1.4.2 Human use of savanna ecosystems (WP5)

Wood biomass remains the dominant energy source for cooking in most communal areas, including the rural districts west of the Kruger National Park (Twine et al., 2003; Madubansi and Shackleton, 2007). Due to poverty, these communities are unable to switch to alternative energy sources, even when the woody resources are getting depleted. Substantial changes to savanna composition and structure as result of fuelwood collection have been recorded in the central Lowveld region of South Africa (Higgins et al., 1999; Giannecchini et al., 2007; Fisher et al., 2012). While the link between human disturbance and ecosystem degradation is relatively well understood, there remains a need for the development of appropriate models for promoting resilience and sustainable resource use within these systems.

1.5 Third-party collaborations

The main South African collaborators of TI-AK were the Council for Scientific and Industrial Research (South Africa) (CSIR) (A. Mudau), GADI (J. du Toit) and The University of Venda (UniVen) (Dr V. Sankaran, Dr E. Maluta). The role of these collaborators in the preparation, installation and operation phase of the EC flux towers was essentially important, as explained under section 1.3.; furthermore, WITS (W. Twine) had a crucial role in the preparation, setup and maintenance of the Agincourt tower.

The researchers and technicians of the working group of PI Brümmer at the TI-AK gave significant support during the design of the EC towers and instrumentation, the maintenance operations, and the processing and analysis of the EC data.

During ARS AfricaE, TI-AK formed an initial agreement for developing and establishing a research infrastructure collaboration with the Department of Science and Technology (DST)-funded and South African Environmental Observation Network (SAEON)-hosted South African Research Infrastructure Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) and its European counterpart Integrated Carbon Observation System (ICOS). Furthermore, the team holds very close links to the Horizon 2020 project Supporting EU-African Cooperation on Research Infrastructures for Food security and Greenhouse gas observations (SEACRIFOG), also coordinated at the group of PI Brümmer.

Prof. Christoph Thomas from the University of Bayreuth (UBT) acted as an academic supervisor of the DAAD-funded PhD project of K. Mukwashi. Mr Mukwashi will receive his PhD degree from the UBT.

Detailed report

2.1 The use of the grant and the achieved results in detail

2.1.1 EC flux measurements and data integration

As shown in section 1.3, the completion of the scientific part of SP1 (i.e. EC flux measurements and data integration) focused on the planning and construction of the central infrastructures of ARS AfricaE and was undertaken in three phases: preparation, installation, and operational phase. The main results of SP1 can be summarized as follows:

- Four EC flux towers (Karoo/Middelburg 1, 2, Agincourt, Vuwani; see Figure 2.1) were set up and instrumented to complement the existing South African infrastructures, and two existing EC towers (Skukuza, Malopeni) were joined to the ARS AfricaE observation sites network.
- EC data was provided to other ARS AfricaE WPs and the SASSCAL database, and used to calibrate and parameterize vegetation models (WP2).
- EC data analyses were coupled with remote sensing data from WP4 to improve our understanding on the climatic factors affecting primary production and carbon uptake potential in natural and grazed savanna ecosystems.

The EC tower infrastructures

Skukuza and Malopeni: The two EC towers that already existed at the KNP formed the main "natural-like", i.e. "reference" sites for the study of land management impacts. The Skukuza and Malopeni towers are maintained by the CSIR, and they represent sites with low human impact, being situated in a protected area. The Skukuza tower has been operational since the year 2000, and the Malopeni tower since 2007. Especially the Skukuza site is well researched in previous studies (e.g. Scholes et al., 2001).

Agincourt/Bushbuckridge: A tower site representing a relatively high human impact (village/settlement) was set up by CSIR at Agincourt/Bushbuckridge, where also long-term socioeconomic studies are conducted by WITS. The good, long-term connections of the South African collaborator W. Twine (WITS) were essential in the initial establishment of the tower, and in the solving of security issues regarding tower technology. This research site is maintained by the CSIR.

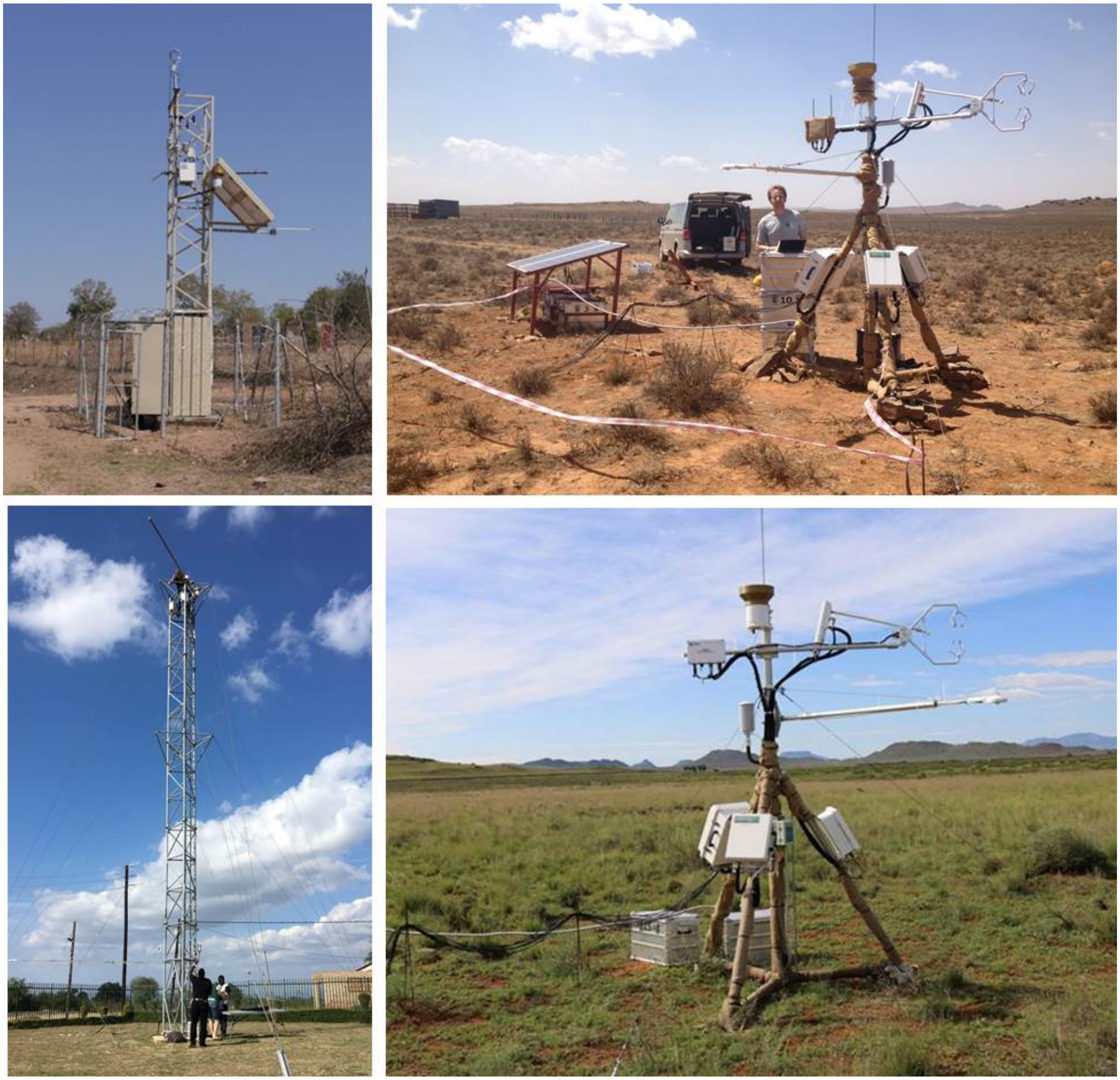

Figure 2.1: The four newly set up Eddy Covariance flux towers: Agincourt (top left), Vuwani (bottom left), Karoo 1 (top right) and Karoo 2 (bottom right).

Vuwani: The northernmost ARS AfricaE site that was put up by the TI-AK and UniVen in a comparatively high rainfall area in the premises of the UniVen at the Vuwani Science Resource Centre. This site is maintained by the UniVen team (Dr E. Maluta, Mr S. Mathebe). It is at a secure, fenced location within the premises of the Vuwani Science Resource Centre, and its data can potentially be used in various student projects at UniVen. The Vuwani site represents a heavily human-modified, peri-urban environment.

Karoo/Middelburg 1 and 2: The two towers that were set up by the TI-AK team and GADI at Middelburg, Karoo, represent the driest observation sites, with annual precipitation averaging 372 mm. The first site represents low-intensity human management, with controlled grazing of livestock. The second research site has been overgrazed in the past, but rested from grazing since approximately eight years (See Fig. 2.1 and Appendix A.1). The past impacts of overgrazing are still visible in vegetation in terms of the low abundance of palatable grasses.

Provision and integration of EC tower data

EC flux data from the ARS AfricaE towers was provided and used for the calibration and validation of the vegetation modelling by WP2. The measured carbon fluxes were compared with modeled values to better understand and interpret the processes represented in the adaptive Dynamic Global Vegetation model (aDGVM). Further plans of model calibration and development with EC data, and joint plans of future work to estimate the carbon budgets of savanna ecosystems under different emission and land management scenarios will be realized under the EMSAfrica follow-up project as collaboration between the Johann Wolfgang Goethe University, Frankfurt (JWGU)/Senckenberg Biodiversity and Climate Research Centre (SBiK-F) and TI-AK. EC flux data is also used in ecophysiology student projects at the Stellenbosch University (SU). In an additional side project, EC flux data and meteorological time series were checked for scale affiliation and periodicities using wavelet analysis with WP3 (Hamburg University of Applied Sciences (HAW)).

The TI-AK team conducts continuous processing, analysis and integration of the flux data. The meteorological data collected at the towers managed by the TI-AK team with South Africa (SA) partners (Karoo1, Karoo2 and Vuwani) was submitted to the Southern African Science Service Centre for Climate Change and Adaptive Land use (SASSCAL) database in summer 2018, along with complete tower metadata. The submission of flux data is planned for the beginning of the year 2019, once the thesis of K. Mukwashi is submitted.

Finally, a joint integrative manuscript of the ARS AfricaE project approach and first results was initiated and coordinated by SP1 and submitted to an interdisciplinary journal in July 2018 (Berger et al., unpubl.).

Analysis and results of EC tower data

The focus on the analyses was on 1) the climatic factors affecting primary production and carbon uptake potential at a natural savanna ecosystem site (Skukuza), and 2) disentangling the impacts of climate and land management (grazing) on carbon exchange (Karoo).

In Skukuza, we compared the optimum gross primary production (i.e. maximum total amount of carbon fixed by plants per unit area and time; GPP_{opt} in Figure 2.2) across six growing seasons (vegetative functional seasons) of varying temperature and soil moisture conditions. Figure 2.3 (top part) depicts the positive and linear correlation between GPP_{opt} and soil moisture. This pattern was observed across all measured vegetative functional seasons, indicating that water availability is one of the main controlling factors of CO_2 exchange and productivity in semi-arid savanna ecosystems, such as Skukuza.

In addition to GPP_{opt} differences across the soil moisture classes (Figure 2.2), the GPP_{opt} also varied between years: for example, the highest GPP_{opt} of 29.47 ± 2.3 μmol CO_2 m^{-2} s^{-1} was observed under wet soil moisture condition in 2010-2011 (a year of higher-than-average precipitation), while a far lower wet-period GPP_{opt} of 13.3 ± 2.1 μmol CO_2 m^{-2} s^{-1} was measured during the “drought year” of 2002-2003 (lowest precipitation out of measured values between 2000-2014). The season 2002-2003 also stands out with relatively low values of the remote-sensed vegetation indices (EVI,

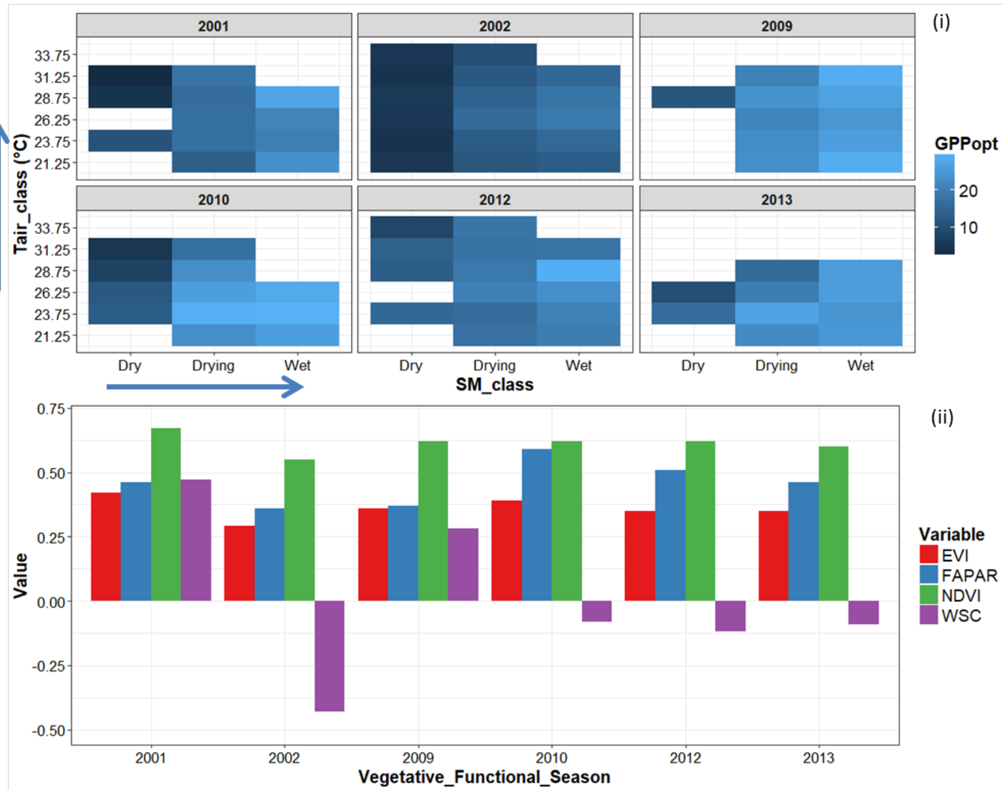

Figure 2.2: Two-dimensional surface plot of inter-annual variability of growing season integrated (i) optimum gross primary production (GPP_{opt}) across soil moisture (SM) classes: dry (SM $<$ 6%); drying (6% $\leq$ SM $\leq$ 9%); wet (SM $>$ 9%), and air temperature (T_{air}) classes, and (ii) bar plot of annual variation of Enhanced Vegetation Index (EVI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Normalized Difference Vegetation Index (NDVI) and Water Storage Change (WSC).

FAPAR and NDVI) as well as WSC compared to other years (see Figure 2.2). As can be expected, the lowest GPP_{opt} values were measured in 2002 under the driest soil water conditions.

The bottom part of Figure 2.3 shows that under wet soil moisture conditions, GPP_{opt} generally increased with increasing air temperature, while the opposite was true for dry soil moisture conditions. During the transition from dry to drying soil moisture conditions, productivity mostly decreased with increasing air temperature. Notably, during the drought period of 2002-2003, temperature appeared to have no impact on productivity that remained steadily very low.

To further investigate the combined impact of moisture and air temperature on ecosystem photosynthesis potential, we focused on the Vapor Pressure Deficit (VPD). VPD is a function of temperature and relative humidity, and has an important regulatory role in leaf gas exchange and diurnal evolution of transpiration in semiarid ecosystems (Jenerette et al., 2009). As seen in Figure 2.4, GPP_{opt} decreased with increasing VPD in a linear fashion under dry soil conditions. Depending on their photosynthetic sensitivity to low humidity conditions, decrease in production is connected to plants closing down their stomata in high VPD conditions. At the transition from dry to drying soil moisture condition, we observed an increase in GPP_{opt} with increasing VPD but then a decrease in GPP_{opt} at VPD larger than 20 hPa on average. The effect of VPD on GPP_{opt} under wet conditions was not clear, although an increase in soil moisture seemed to delay the effects of VPD on GPP_{opt}.

Figure 2.5 shows that the relationship between GPP_{opt} and NEE_{offset} was initially linear in their

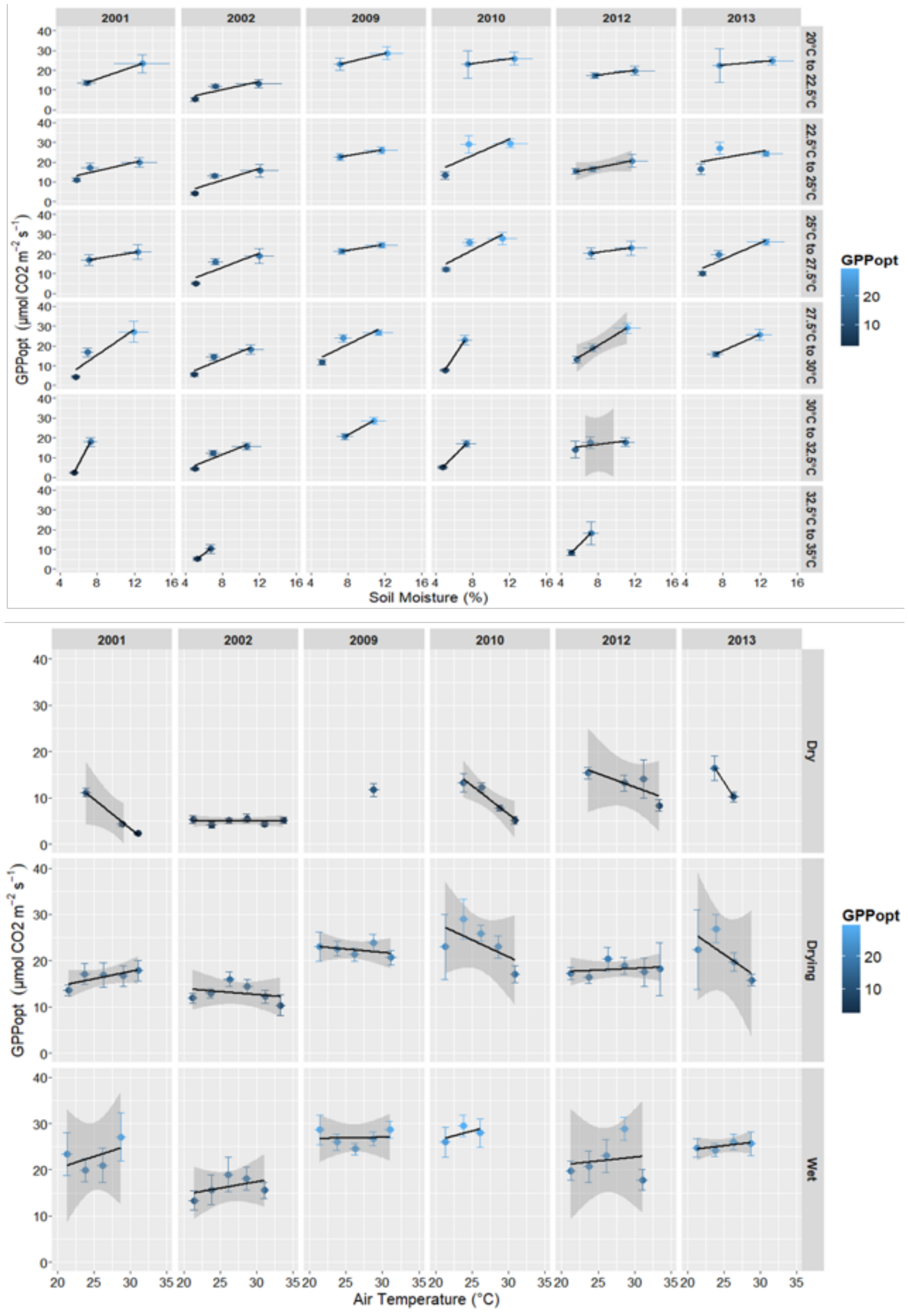

Figure 2.3: Functional relationship between optimum gross primary production (GPP_{opt}) and soil moisture across air temperature gradient and vegetative functional seasons (top) and air temperature across soil moisture gradient and vegetative functional seasons (bottom) in Skukuza.

response to the driving environmental factors across the growing seasons. However, the linear relationship weakened at some environmental threshold, becoming non-linear, and GPP_{opt} began to show diminishing response as NEE_{offset} increased. It appeared that even when conditions were no longer conducive for optimum photosynthesis, higher values of NEE_{offset} can still occur that could be ascribed to continued soil respiration activity. Soil moisture is also known to moderate the effects of other factors such as temperature on respiration processes (Yan et al., 2011).

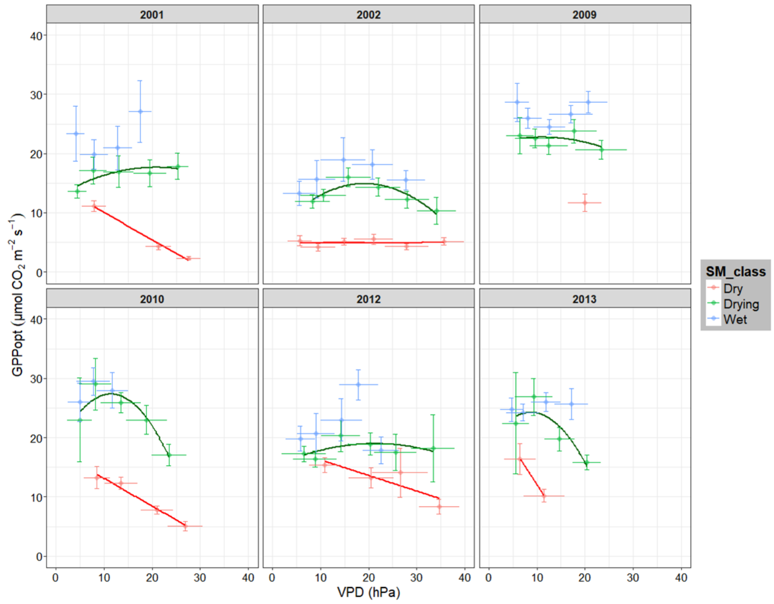

Figure 2.4: Functional relationship between optimum gross primary production (GPP_{opt}) and vapor pressure deficit (VPD) across soil moisture gradient and vegetative functional seasons in Skukuza.

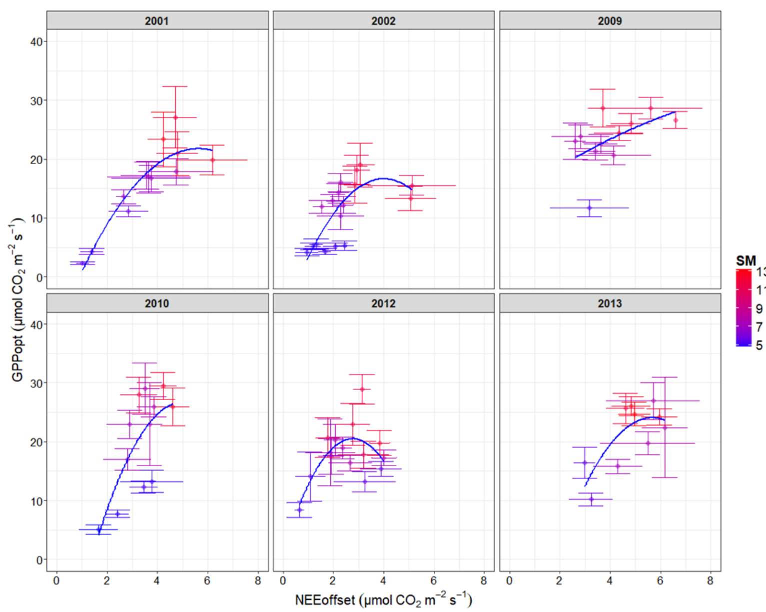

Figure 2.5: Relationship between light response parameters, optimum gross primary production (GPP_{opt}) and net ecosystem CO_2 exchange offset (NEE_{offset}), across soil moisture (SM) and vegetative functional seasons (growing seasons of six years) in Skukuza.

The analysis on the Karoo data focused on disentangling the impacts of climate from the impacts of human management, i.e. livestock grazing. Figure 2.6 plots the cumulative Net Ecosystem CO_2 Exchange (NEE) in the two Karoo ecosystems (i.e. Karoo 1, gently grazed reference site and Karoo 2, previously intensively grazed but rested site since approximately eight years) in two consecutive years. Both sites represent a source of CO_2 in the first year of measurement. In the second year of

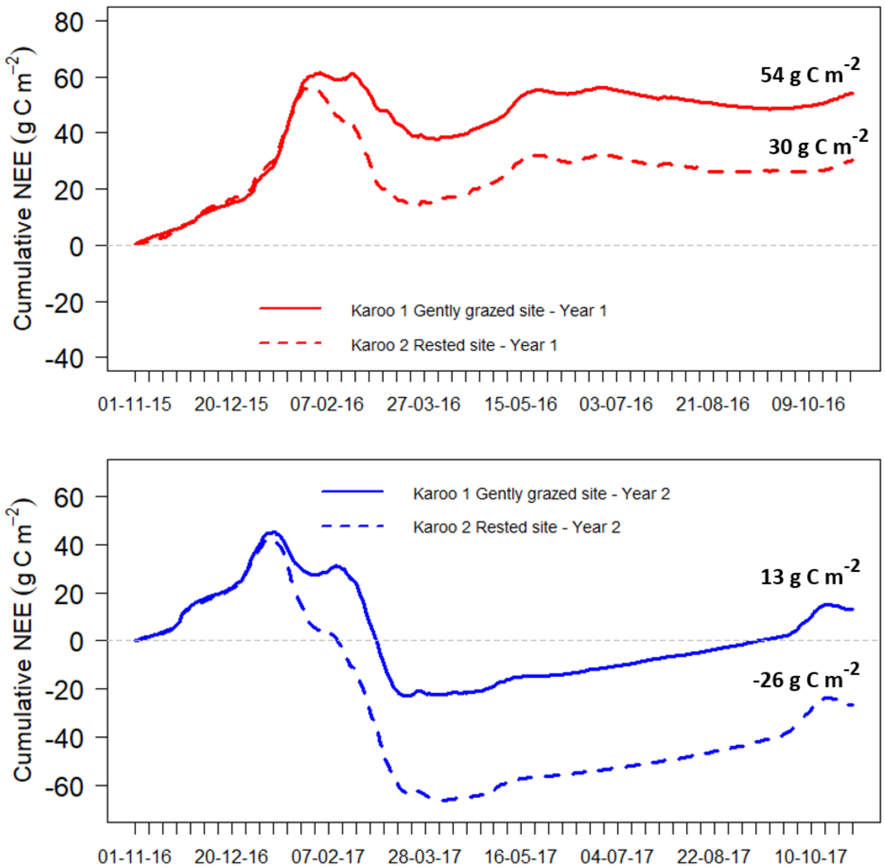

Figure 2.6: Comparison of cumulative CO_2 exchange at the two Karoo sites under different grazing intensities.

measurement, both sites had generally higher CO_2 sequestration mainly due to higher precipitation. The previously overgrazed site became a CO_2 sink in the second year while Karoo 1 was still an overall source of CO_2. The results suggest that livestock grazing has a significant impact on carbon exchange in savanna ecosystems.

Achieved results of South African collaborators

CSIR

- EC flux data provision from the previously existing EC flux towers in the KNP (Skukuza & Malopeni) dating back to 2001 and 2007, respectively;
- Setup and maintenance of the Agincourt flux tower (with support from WITS), including data provision from the tower;
- In-kind contributions to tower instrumentation;
- Continuous tower maintenance, joint development and collaboration with TI-AK;
- Provision of meteorological and flux data of the Skukuza, Malopeni and Agincourt towers to the SASSCAL database.

Forest Sense CC

- Acquisition and preprocessing of historical aerial photographs as well as further optical remote sensing imagery for the ARS AfricaE project sites;
- Design and implementation of UAV surveys over the Vuwani and Middelburg sites.

GADI

- Collaboration in the setup and testing of the two flux towers in the Karoo cluster, including site selection, preparation and security issues;
- Continuous maintenance of the towers & participation in the field work campaigns in Karoo;
- Management and training of field workers;
- Provision of long-term ecological data on the areas and input in student projects and joint research papers.

Rhodes University

- The planning of a common data policy and processing/integration of ARS AfricaE data;
- Joint development of curriculum and organisation of social-ecological modelling short courses;
- Student exchange programmes especially with HAW.

University of Venda

- Collaboration in the setup and testing of the flux tower at the Vuwani Science Resource Centre premises;
- Continuous maintenance of the Vuwani tower.

SANParks Scientific Services

- General support to the field campaigns conducted at the Skukuza and Malopeni sites;

- Provisioning of time-series and GIS data;
- Incorporating ARS AfricaE partners, i.e. Prof. Dr. Thomas Clemen and Ulfia Lenfers, into strategic discussions regarding current and future topics in managing the Kruger National Park.

Stellenbosch University
The work done under this subcontract is reported in detail under the final report of SP2.

Rhodes University
The work done under this subcontract is reported in detail under the final report of SP3.

WITS
See the following chapter

2.1.2 Socioeconomic surveys (Work Package 5)

WP5 (WITS) conducted socioeconomic surveys focusing on fuelwood use in local communities at the Agincourt field site in 2014, to complement earlier similar surveys. As shown in Figure 2.7, firewood was used by over 90% of households over the five years, and was the dominant energy source (used more than once a week) for 63% of households in 2014. Average annual consumption of firewood per user household was 2 558 kg, which equated to 2 132 kg per year when averaged across all households. Using a published conversion factor of 0,5, this equates to 1 066 kg of carbon appropriated by per household per year from the surrounding woodlands. The average number of households per village in the nine study villages was 974 in 2014, meaning that annual average village appropriation of carbon from the woodlands in the form of firewood equalled 1038 tonnes. Monthly wood removal from the woodlands around Agincourt village was monitored in nine permanent plots, each roughly 0,25 ha in size, along three transacts radiating out from the village. An average of 2,2 t of wood (or 1,1 t of carbon) was harvested per hectare per year. However, this varied with distance from village, ranging from ~1,9–3,5 t wood per hectare per year within 0,5-1 km from the village, and declining to ~0,9 t wood per hectare per year at 1,5 km from the village. The high rates of wood biomass removal within the one km radius of the village are not sustainable.

According to the original plan, the approach was to be transferred to the Western province of Zambia. However, the planned survey to analyse fuelwood consumption by local communities as well as the long-distance trading of charcoal was cancelled due to the Zambian partners dropping out of the project.

As a next step, the results of socio-economic surveys were to be combined with the WP3 modelling system, to run scenarios that can be communicated with local communities. However, due to personnel changes and some parts of the work taking longer than expected, this part of the work will be mainly transferred to be conducted under the follow-up project, EMSAfrica. Furthermore, during EMSAfrica, the household panel data sets hosted by WITS will be analyzed jointly by the WITS and HAW teams to develop the socio-economic component of the multi-agent based DSS. By that direct engagement with the WITS research team around Prof. Twine and the stakeholders EMSAfrica gets authentic access to stakeholders representing rural households in the region. In reverse, PhD students of Prof. Twine are getting taught in social-ecological modelling in annual short courses.

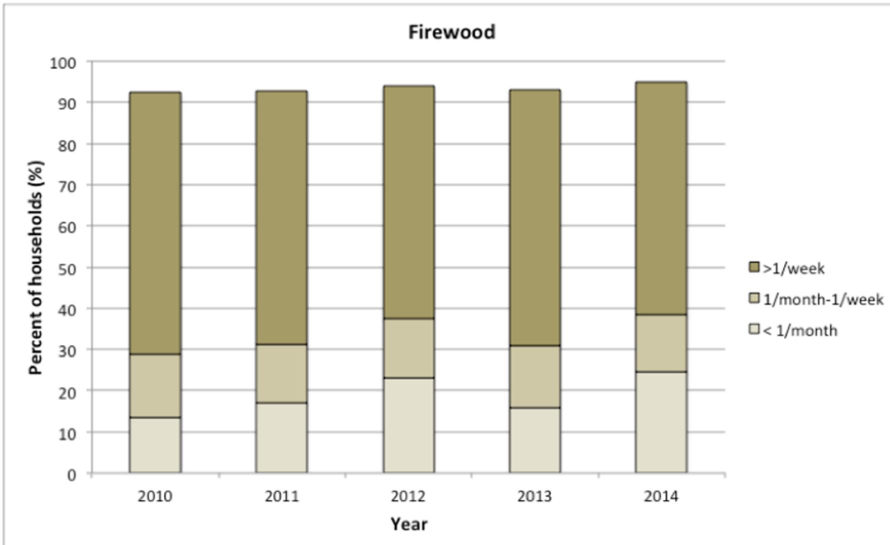

Figure 2.7: Frequency of household use of firewood 2010-2014.

2.2 Benefits and utilization of results

ARS AfricaE introduced a multidisciplinary approach, where EC flux data was linked with on-site ecophysiological measurements, and used together with remote sensing data to improve vegetation models. The infrastructure was established along an aridity gradient and under different management regimes, to allow the analysis of management impacts, and on the other hand the impacts of climate change in the ecosystem functioning in the long term. The integrative use of EC flux data will be further developed under the follow-up project EMSAfrica (e.g. the assessment and improvement of Dynamic Vegetation Models; estimates of future savanna carbon balance under different emission and land-use scenarios; further development of joint activities with the remote-sensing group).

By building a network of EC flux towers, the subproject team was directly involved in strengthening the South African long-term CO_2 biosphere-atmosphere monitoring infrastructure. Especially in savanna ecosystems, where productivity is strongly linked to rainfall, which in turn has large inter-annual variation, long-term measurements are needed to improve our understanding of the ecosystem carbon balance. Savannas cover 11.5% of the world's land surface, but still remain largely under-represented in global observational networks, although their estimated carbon storage potential of between 0.16 and 1.00 Pg C per year is globally significant.

The towers established during the ARS AfricaE project will be transferred to become part of the EFTEON network in collaboration with SAEON during the follow-up project EMSAfrica. This will enable South Africa to better conduct nationwide Greenhouse Gas (GHG) measurements, and have relevance in a variety of ecological and geochemical studies conducted in the country. The TI-AK team was also involved in the training of students and South African field staff especially in the technical aspects of EC techniques. Furthermore, the TI-AK team is supporting South Africa establish a link to the ICOS network.

The information provided by WP5 regarding fuelwood use in local communities is highly relevant for the development of sustainable land-use solutions, and will be used to construct a relevant decision-support system during EMSAfrica.

Subproject publications

3.1 Peer-reviewed papers and poster presentations

Berger, C., Bieri, M., Brümmer, C., Clemen, T., Hickler, T., Lenfers, U., Martens, C., Midgley, G., Scheiter, S., Schmullius, C., Stevens, N., Twine, W. (unpubl.). An interdisciplinary, multi-scale approach to climate-relevant ecosystem management support in Southern Africa. Submitted to *Climatic Change*.

Brümmer, C., Mukwashi, K., Falge, E.M., Mudau, A., Odipo, V., Schmullius, C., Lenfers, U., Thiel-Clemen, T., Thomas, C.K., Kutsch, W.,L., Scholes, R.J., Berger, C. (2016). Factors influencing inter-annual variability of growing season optimum gross primary production and ecosystem respiration in a semi-arid savanna ecosystem: A case study of Skukuza, South Africa. American Geophysical Union, Fall General Assembly 2016, abstract id. B13B-0566

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Appendices

A.1 Acronyms

aDGVM	adaptive Dynamic Global Vegetation Model
ARS AfricaE	Adaptive Resilience of Southern African Ecosystems
BMBF	Bundesministerium für Bildung und Forschung - German Federal Ministry of Education and Research
CSIR	Council for Scientific and Industrial Research (South Africa)
CzechGlobe	Global Change Research Institute of the Czech Academy of Sciences
DAAD	German Academic Exchange Service
DFG	Deutsche Forschungsgemeinschaft - German Research Foundation
DSS	Decision Support System
DST	Department of Science and Technology
DVMs	Dynamic Vegetation Models
EC	Eddy Covariance
EMSAfrica	Ecosystem Management Support for Climate Change in Southern Africa
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
EU	European Union
EVI	Enhanced Vegetation Index
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FLUXNET	https://fluxnet.ornl.gov/
FONA	Forschung für nachhaltige Entwicklung - Research for Sustainable Development
FSU	Friedrich-Schiller-University Jena
GADI	Grootfontein Agricultural Development Institute resp. The Small Stock Research Trust
GCBG	Global Change Biology Group
GCMs	General Circulation Models
GEO	Group on Earth Observations
GHG	Greenhouse Gas
GIS	Geographic Information System
GLMs	Global Climate Models

GPP	Gross Primary Production
HAW	Hamburg University of Applied Sciences
HLPD	High-level policy dialogue
ICOS	Integrated Carbon Observation System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
JWGU	Johann Wolfgang Goethe University, Frankfurt
KNP	Kruger National Park
LAI	Leaf Area Index
LLL	Limpopo Living Landscapes - Understanding the dynamics of ecological and cultural landscapes in the face of global change
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NEE	Net Ecosystem CO_2 Exchange
NEP	Net Ecosystem Production
NPP	Net Primary Productivity
PIs	Principal Investigators
RIs	Research Infrastructures
RU	Rhodes University
SA	South Africa
SAEON	South African Environmental Observation Network
SALLnet	South African Limpopo Landscapes Network
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land use
SAWS	South African Weather Service
SBiK-F	Senckenberg Biodiversity and Climate Research Centre
SDG13	”Take urgent action to combat climate change and its impacts”
SDG15	”Sustainably manage forests, combat desertification, halt and reverse land degradation, and biodiversity loss”
SDG17	”Revitalize the global partnership for sustainable development”
SEACRIFOG	Supporting EU-African Cooperation on Research Infrastructures for Food security and Greenhouse gas observations
SP	Subproject
SPACES	Science Partnerships for the Assessment of Complex Earth System Processes
SU	Stellenbosch University
SUCSES	Sustainability in Communal Socio-Ecological Systems
TI-AK	Johann Heinrich von Thünen Institute for Climate-Smart Agriculture
UBT	University of Bayreuth
UNFCCC	United Nations Framework Convention on Climate Change

UniVen	The University of Venda
VPD	Vapor Pressure Deficit
WITS	University of the Witwatersrand
WP	Work Package
WSC	Water Storage Change
WRF	WITS Rural Facility

A.2 Research site descriptions table

Research site	Location	Type (Mgmt)	Altitude (asl)	Rainfall	Temperature	Soils	Geology	Vegetation
Malopeni	-23.83°, 31.21°	National park (unmanaged)	385m	Summer rainfall season, (October-March). Average annual rainfall 473 mm	Summer max. Average 30.5°C, min. 19.4°C; winter max. Average 26.7°C, min. 12.4°C	Shallow sandy loam luvisol (alfisol)	Archaean basement granites and gneisses	Tree cover apprx. 30%, dominant species Colophospermum mopane, Combretum apiculatum, Acacia nigrescens. Grass/forb dominants Schmidtia pappophoroides, Panicum maximum.
Vuwani	-23.14°, 30.43°	Peri-urban	629m asl	500-1000 mm per year	Hot summers, mean summer temp. 24-26°C (max. 40°C), cool winters min 10 °C, mostly frost-free	N/A	Archaean complex: migmatite, gneis & ultrametamorphic formations	Lowveld Sour Bushveld
Agincourt/ Bushbuck-ridge	-24.82°, 31.21°	Village / communal area	534m asl	Mostly Nov-Feb; ranges from 800 mm year in the foothills of the escarpment in the west, to 550 mm year	Hot summers (mean max 40 °C); mild winters, seldom frost	Sandy, infertile soils on hill-crests and sodic clays in the footslopes	Granite and gneiss	Savanna woodland; Granite Lowveld Bushveld. Woody layer dominated by broad-leaf species such as Sclerocarya birrea, Terminalia sericea and Combretum collinum on the sandy hill-crests, and fine-leaf species such as Dichrostachys cinerea and Acacia swazica on the clayey sodic bottomlands
Skukuza	-25.02°, 31.49°	National park (nearest park border 10 km distance)	365m asl	Most rainfall Nov-Feb. Annual mean 547 mm.	Hot, rainy summers and warm, dry winters. Mean annual max 29.5°C, min 14.3°C	Clayey and fertile; ridgetop soils sandy, < 80 cm	Lowveld area; Archaean granite and gneiss of the Nelspruit suite	Wooded grassland (savanna). Ecotone site between Combretum and Acacia savanna. Sandy uplands dominated by Combretum apiculatum with fibrous grasses, e.g. Pogonarthia squarosa. On clayey soils predominant trees Acacia nigrescens, Sclerocarya birrea, grasses include Panicum maximum and Urochloa mossambicensis.
Karoo 1	-31.52°, 25.01°	Gently grazed (controlled)	~1300m asl	Rainy season mid-late summer, yearly long-term average 372 mm	Cold, dry winter daytime temp (14–25°C), night temp (−4–4°C)	Shallow lithosols; duplex soils with prismacutanic and/or pedocutanic diagnostic horizons	Mudstones and sandstones of the Beaufort group	Eastern Upper Karoo. Mixture of shrubs and palatable grasses. Most common species include Digitaria eriantha (36.6%), Pentzia globosa (7.8%), Sporobolus fimbriatus (6.5%), Eriocephalus ericoides (5.8%)
Karoo 2		Rested (overgrazed in the past)			Warm-hot summer daytime temp. (30–35°C) night (10–16°C)			Predominantly grasses of poor grazing quality. Most common species include Aristida diffusa (42.5%), A. congesta (12%), Tragus koelerioides (7.5%), Eragrostis lehmanniana (5.5%)

Site descriptions references

Agincourt: Twine et al. 2016; Mucina and Rutherford 2006; Shackleton et al. 2000
Karoo: J. C. d. Toit and T. G. O'Connor 2017; Du Toit and T. O'Connor 2014; Venter and Mebrhatu 2005; O'Connor and Roux 1995; J. d. Toit and Nengwenani 2016; du Toit, J., pers. comm. 03.04.2018
Malopeni: Kirton and R. Scholes 2009
Skukuza: R. J. Scholes et al. 2001; Barton et al. 1986; Colgan et al. 2012
Vuwani: DFED 2004; Odhiambo and Nemadodzi 2007
All sites (locations): Feig et al. 2017