PROPOSAL FOR
THE EFTEON LANDSCAPE PROGRAMME:
KIMBERLEY TRI-BIOME [KIMTRI]

Proponents:
South African Environmental Observation Network (SAEON): Arid Lands Node,
Sol Plaatje University (SPU): School of Biology and Agricultural Sciences
University of the Free State (UFS): Centre for Environmental Management, Soil-Crop-Climate Sciences
Stellenbosch University (SUN): School of Climate Studies; Global Change Biology Group in the Department of Botany and Zoology, Department of Sociology and Social Anthropology

In close collaboration with:
De Beers Group: Ecology and Biodiversity Management Section
South African National Parks (SANParks): Scientific Services Kimberley
South African Weather Service (SAWS): Kimberley Branch
McGregor Museum: Natural History, Archaeology
Ekapa Group: Environmental Management
South African National Biodiversity Institute (SANBI): Kirstenbosch National Botanical Gardens
University of Cape Town (UCT): Fitzpatrick Institute, Environmental and Geographical Science
University of Basel, Switzerland: Department of Environmental Sciences
Friedrich-Schiller-University Jena, Germany: Institute of Geography

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Table 1: Matrix of EFTEON components and environmental settings in the context of KIMTRI

List of Acronyms

ACSA- Airports Company of South Africa
ADU- Animal Demography Unit Virtual Museum
BirdlifeSA- Birdlife South Africa
DALRRD- Northern Cape Department of Agriculture, Land Reform and Rural Development
DENC- Northern Cape Department of Environment and Nature Conservation
DMR- Department of Mineral Resources
DWS- Department of Water and Sanitation
EDTEA- Free State Dept of Economic, Small Business Development, Tourism & Environmental Affairs
EFTEON- Expanded Freshwater and Terrestrial Environmental Observation Network
EO- Earth Observation
ESA- Ecological Support Areas
EWT- Endangered Wildlife Trust
FS- Free State Province
FS-ARD- Free State Department of Agriculture and Rural Development
GCBG - Global Change Biology Group, University of Stellenbosch
KIMTRI- Kimberley Tri-Biome Landscape Programme
NC-DEDAT- Northern Cape Department of Economic Development and Tourism
NC-DOE- Northern Cape Department of Basic Education
NC-Northern Cape Province
NRF- National Research Foundation
PHRA- Provincial Heritage Resources Authority
PRASA- Passenger Rail Agency of South Africa
SAEON-ALN- South African Environmental Observation Network - Arid Lands Node
SALDi- South African Land Degradation indicators
SANParks- South African National Parks
SANRAL- South African National Roads Agency
SASS- South African Scoring System
SASSCAL- Southern African Science Service Center for Climate Change & Adaptive Land Management
SAWS- South African Weather Service
SHRA- Social Housing Regulatory Authority
SPU- Sol Plaatje University
SUN- Stellenbosch University
UCT- University of Cape Town
UFS- University of the Free State
WESSA- Wildlife and Environmental Society of South Africa
WWF- World Wide Fund for Nature

EFTEON Background

The Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) is a large research infrastructure program hosted by SAEON. It is a modular, highly-networked research platform to support studies on coupled ecological-social systems across landscapes representative of major biomes and human transformed ecosystems. EFTEON landscapes should have a heavily instrumented core study site and a network of more lightly instrumented subsidiary sites, to provide supporting data and extrapolative power. A Critical Zone Observatory approach is implicit in the EFTEON design with a realm of interest extending from the groundwater to the atmospheric boundary layer.

Introduction to the Kimberley Landscape

Kimberley is a city located in the centre of South Africa, at the edge of the arid western half of the country, at the junction of three zonal biomes (Karoo, Savanna and Grassland). It is in the vicinity of four major tributaries of the Orange River (Gariep, Vaal, Riet, Modder), multiple intermittent drainage lines typical of arid regions, and numerous dryland wetlands. These features straddle the boundary of the Northern Cape and Free State Provinces. There are several towns and villages in the surrounding area with diverse histories of development.

Kimberley represents a city in socio-economic transition, with a gradual decline in influence and wealth derived from its historic mining industry for the past few decades, though increasing its importance as a provincial hub, and a national centre of academic learning.

Proposed core site: Benfontein Game Reserve

We propose the Benfontein Game Reserve, located 10 km south-east of Kimberley, as the central core site for the EFTEON infrastructure. This is where flux instrumentation is currently deployed, and the most intensive observations will be conducted. This reserve was established in the late 1800s and has hosted over a century-long history of diverse research projects, which have yet to be reviewed and collated. We provide a list of literature (Appendix B1 and B2) on some of the research that has been conducted in the core site and KIMTRI area in general.

A conceptual model for the KIMTRI Landscape Programme of EFTEON

EFTEON uses a modular approach that encompasses terrestrial ecosystems, freshwater ecosystems and anthropogenic environments such as urban systems, roads and mining. Furthermore, EFTEON, as a Critical Zone Observatory, measures and analyses biogeophysical parameters (carbon, moisture, energy) associated with the atmosphere, soil and water, and interprets these in the context of ecosystems and anthropogenic systems.

The EFTEON node approach brings together multiple stakeholders, many with legacy data sets, ongoing projects and predictive or interpretive algorithms, and all of whom have a variety of interests in generating and utilising information, and gaining from the opportunity to collaborate and synthesise the information to add value. This process is envisaged to occur over a decade or longer. Thus, a robust but simple, organisational framework is needed to provide longitudinal coherence to the work and to maximise the institutional memory of a dynamic and changing research body. To facilitate that all participants work towards a common goal over space and time, KIMTRI uses a hierarchical organisational model, which defines five levels and their interdependencies (Figure 1): *Impacts*, *Outcomes*, *Outputs*, *Activities* and *Inputs*. The logical model serves as a coordinating framework for the diverse stakeholders and participants in KIMTRI.

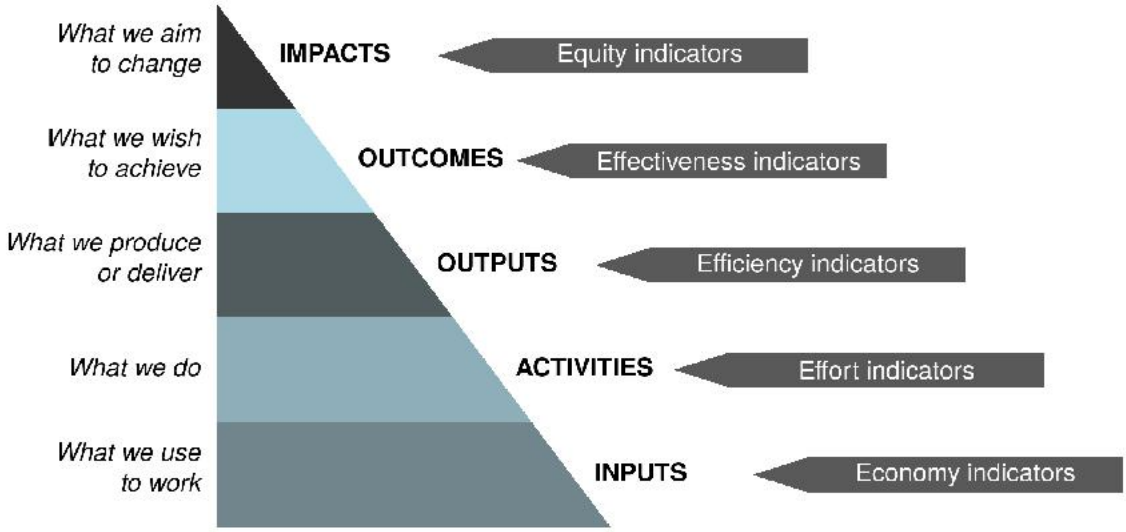

Figure 1: The logic model used as part of the KIMTRI proposal.

The rationale behind the logic model is that each lower level of the hierarchy serves the needs of the level above it. In the context of this proposal, we present the following theory of change:

- **Impact:** ***To provide a science-based, policy-relevant understanding of the socio-ecological consequences of environmental change on arid-zone biomes.***
  - This represents the 10-20 year vision of EFTEON in the KIMTRI landscape.
- **Outcomes:** ***An integrated consideration of the DRIVERS, PRESSURES and BENEFITS in the KIMTRI landscape*** (Figure 2).
  - This represents the 8-10 year work plan that guides participants in the KIMTRI landscape.
- **Outputs:** ***The datasets and derived products generated through the EFTEON infrastructure.***
  - Continuous automated measurements of abiotic variables (e.g. meteorological measurements, hydrological observations, satellite remote sensing).
  - Repeated manual measurements (e.g. biodiversity, productivity, soil).
  - Socio-ecological data (e.g. surveys, resource use, water abstraction)
  - Spatial data (e.g. satellite, aerial and drone footage)
  - Academic publications in peer-reviewed journals
  - Synthesised results for use in policy and management guidance and support
- **Activities:** ***The operational expenses of the EFTEON infrastructure.***
  - Fieldwork, laboratory processing, coordination, data capturing and cleaning, synthesis, analysis and publication.
- **Inputs:** ***The capital expenses of the EFTEON infrastructure.***
  - The apparatus, sensors and equipment installed through the program.

This long-term interdisciplinary approach requires synergies and complementarity between researchers, practitioners and stakeholders from many different backgrounds. To support the coordination between this broad community of practice, we developed a bridging object (Figure 2) to collaborate across the biophysical boundaries of all environmental features of the KIMTRI landscape. These include the three zonal terrestrial biomes (Grassland, Savanna, Nama Karoo), lentic wetlands, lotic rivers and human habitations.

For each of these environmental features, the EFTEON infrastructure will contribute to understanding:

- The **composition** of each environmental feature (i.e. what are the defining abiotic and biotic elements of the biomes?)
- The **structure** of each environmental feature (i.e. how are these elements are arranged in time and space, including relative prevalence?)
- The **function** of each environmental feature (i.e. what do these elements do, and how do they interact?)

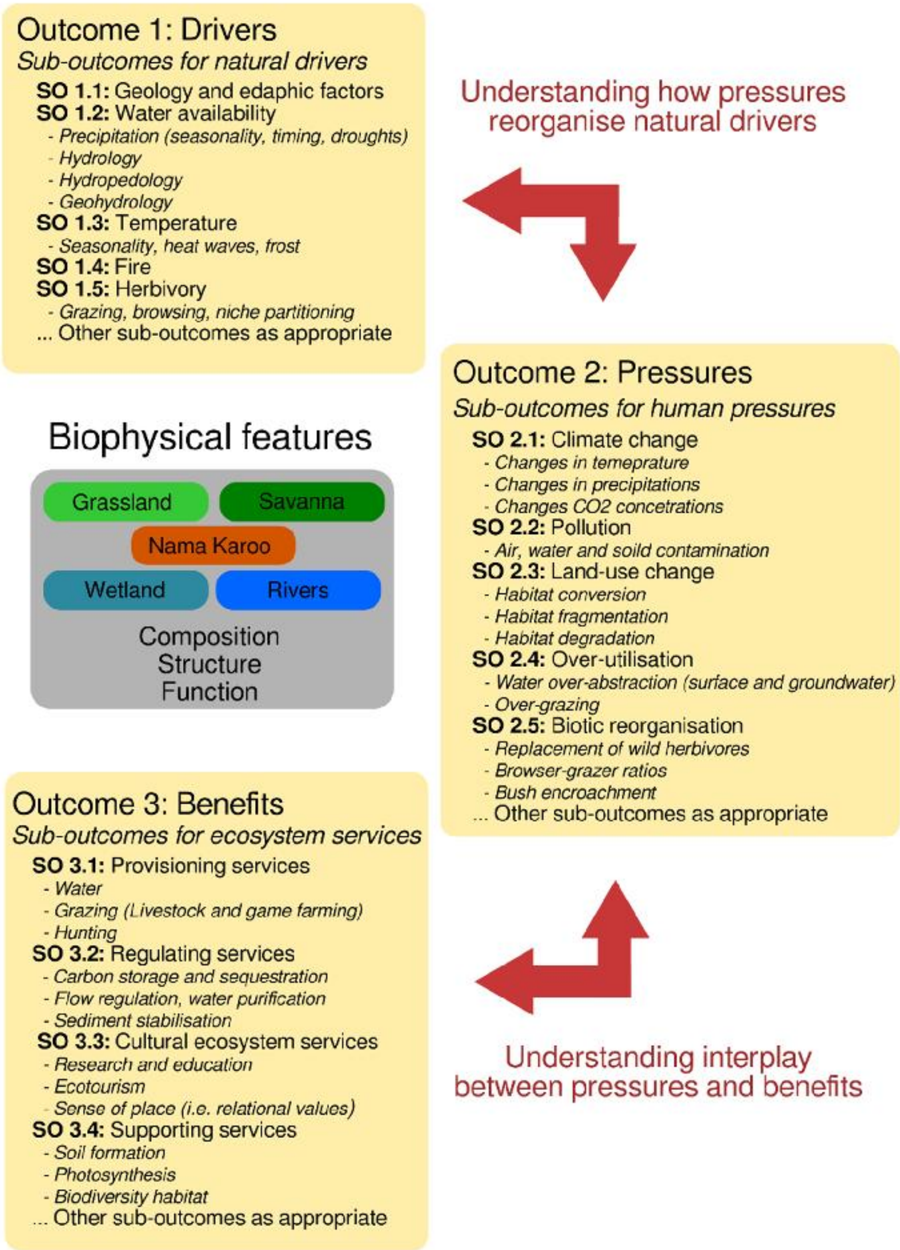

Figure 2: A conceptual model with the three suggested outcomes and ideas for sub-outcomes that collectively determine the geographic frame of the KIMTRI landscape of the EFTEON programme.

In the context of KIMTRI, we depict these three components in three environmental settings (Table 1).

Table 1: Matrix of EFTEON components (horizontal) and environmental settings (vertical across 3 pages) in the context of KIMTRI

Component→ Environment↓	**Geophysical & Geochemical**	**Ecological**	**Socio-ecological**
Terrestrial ● **Karoo, Savanna, Grasslands** ● **Soil, biodiversity, ecosystems, health**	● Climate, microclimate ● Soil characteristics ● Carbon, moisture, energy fluxes in the atmosphere and soil ● Soil nutrient and carbon dynamics measurement and modelling ● Drivers of climate change ● Indicators of change ● Wind erosion and atmospheric dust ● Drought, flood ● Effects of drought and rainfall on groundwater levels ● Indicators of change in soil quality and linkages to groundwater quality ● Palaeo-environmental indicators of past processes	● Land cover ● Ecological characterisation of populations and communities ● Ecological effects of sociopolitical and climate/environmental change ● Ecophysiological characterisation of dominant plant species ● Functional and mechanistic modelling of dominant plant species ● Dynamic Global Vegetation Modelling based on dominant plant functional types ● Niche-based modelling of key plant and animal species for predictive climate purposes ● Terrestrial ecosystem services ● Indicator species (or examples of such) ● Fire-driven systems ● Alien species, extralimital species ● Productivity ● Sensitivity ● Archaeozoology/ archaeobotany indicators of past species/ environments	● Processes and trajectories of systemic human and ecological transformation ● Land uses (agriculture, conservation, mining, urban/peri-urban) ● Effect of land-use on groundwater quantity and quality ● Characterisation of social systems ● Anthropogenic drivers of change ● Mitigation of and adaptation to change ● Conservation ● Ecosystem restoration ● Agriculture ● Ethnobotany ● Past human land use patterns in relation to local topography, pans, rivers, and changing palaeo-environments. ● Senses of place, indigenous ontologies

Freshwater ● **Rivers, Wetlands, Drainage lines, Groundwater** ● **Water quantity, quality, biodiversity, health**	● Hydrological processes and dynamics (river flows, wetland wet/dry regimes) ● Geohydrological processes and dynamics (groundwater levels, recharge based on rainfall, shallow-deep aquifer interaction, baseline water quality and water levels and temporal changes) ● Surface water quality ● Soil moisture processes and regimes ● Effects of damming, change of natural flows ● Geophysical processes that affect the integrity of river systems and wetlands ● Geochemical characteristics to inform wetland typology and understand effects on biotic communities ● Erosion ● Palaeo-environmental indicators of past processes	● Ecological flow ● Pollution ● Biotic communities associated with perennial aquatic ecosystems ● Biotic communities associated with ephemeral aquatic ecosystems ● Wetland ecosystem services ● Indicator species ● Alien species, extralimital species ● Productivity ● Sensitivity ● Food webs ● Dispersal ● Population genetics ● Archaeozoology/ archaeobotany indicators of past species/ environments	● Water requirements for domestic purposes, agriculture & industry ● Groundwater requirements and quality ● Impacts of water quality (pollution) on social-ecological systems ● Water cycle, including sources and effluent ● Water quality and sanitation ● Fishing ● Recreation/tourism in water bodies ● Mining along rivers or palaeo-channels ● Hydrologic budget ● Fine-scale wetland status determination (alteration determinations and impact analyses/ classification of all Freshwater features in KIMTRI domain) ● Understanding palaeoenvironments; lacustrine to arid scenarios. ● IKS: 'Watersnake'/noga ya metsi myths, sense of place and ritual danger in relation to water, rain, springs, rivers.

Anthropogenic ● **City, Towns, Villages, Rural** ● **Human enterprises, communities, health**	● Microclimate of urban systems ● Pollution by industry, landfills, effluents, mining and associated infrastructure ● Mine pits, dumps, disturbed land & associated infrastructure ● Microclimate and runoff from roads/rail ● Albedo and dust off croplands and mines ● Moisture of irrigated fields ● Rangeland condition ● Pollutants from landfills and effluents ● Thermal islands of solar power plants ● Industrial/mining archaeology – impacts on landscapes	● Historical ecosystem changes ● Habitat loss through development (urban growth, mining, expanding croplands, floodplains with irrigated fields) ● Toxic waste and pollution ● Habitat fragmentation by roads, fences, power lines ● Expansion of invasive alien and extralimital species ● Road kills ● Poaching ● Peri-urban overspills (e.g. wastewater, pollution) ● Past anthropogenic impacts on ecology.	● Urban/rural, town/village, commercial/communal farming ● Changing urban environment (e.g. Kimberley from mining to the provincial capital and regional centre) ● Change in ecological conditions that result from human actions in urban areas ultimately affect human health and well being ● The role played by urban socio-ecological systems in shaping changes and long–term sustainability ● Economics (commerce, agriculture, industry, government) ● Cultural and socio-economic history ● Archaeology ● Economic factors driving change, e.g. livestock farming to game farming, extensive to intensive agriculture ● Effect of anthropogenic activities on groundwater quality, quantity and aquifer structure ● Heritage appreciation and use in education and tourism ● Senses of place ● Impacts on heritage by mining and development
Approach	● Cross-cutting, multi-disciplinary (flux, remote sensing, ground-truthing, quantitative analysis, collection and curation of samples and data)	● Multi-disciplinary and inter-disciplinary, from specialised topic-specific to multi- and interdisciplinary collaborative data collection and synthesis, and mechanistic and predictive modelling	● Multi- and trans-disciplinary, including stakeholder engagements, economic analysis and socially oriented research

Site location of the KIMTRI landscape in the face of change

Large-scale environmental gradients

The KIMTRI landscape is one of the gradients of transition. The larger landscape is on the 400 mm rainfall isohyet, which separates the arid west of the country from the wetter east. Moreover, the landscape in general, and the Benfontein core site in particular, is at the interface of the Grassland, Savanna and Nama Karoo biomes (Figure 3 & 4).

Benfontein Game Reserve also straddles the provincial border between the Northern Cape and Free State provinces (Figure 3). This has consequences for the environmental governance of the landscape. For example, the biodiversity on the Northern Cape side of the border is prioritised as Critical Biodiversity Areas, which have stronger legal protection. In contrast, the Free State side is classified as Ecological Support Areas (ESA), which have lesser legal standing. This illustrates differences in relative prioritisation of biodiversity by the respective provincial authorities and offers an opportunity to contrast two forms of provincial governance.

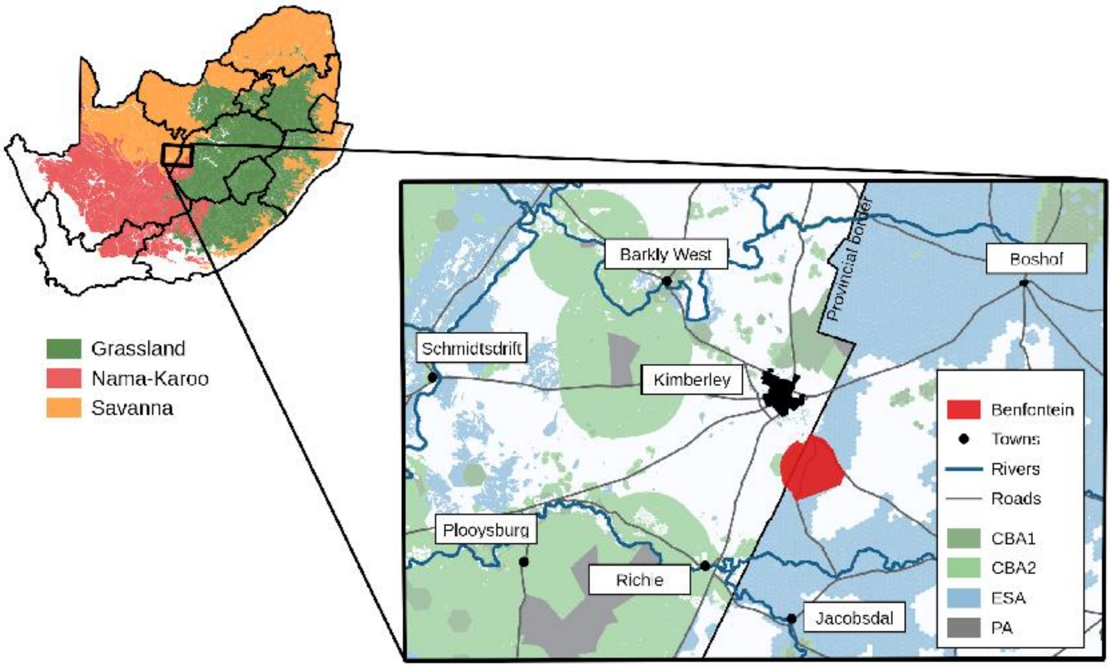

Figure 3: The geographic position of the KIMTRI landscape at the interface of the Grassland, Savanna, and Nama Karoo biomes (inset). The core site, Benfontein Game Reserve, straddles the provincial border between the Northern Cape and Free State Province. It is situated near protected areas (PA), Critical Biodiversity Areas 1 and 2 (CBA 1 & CBA 2) as well as Ecological Support Areas (ESA) identified by the Northern Cape and Free State provincial spatial biodiversity plans.

<u>Box 1 – EFTEON Cornerstone: General situational characteristics of the landscape</u>

The terrestrial, freshwater and anthropogenic environments of the KIMTRI landscape

The 60 km vicinity of Kimberley contains a diversity of environments:

Terrestrial Environments

Three biomes:

- Grassland (Bloemfontein Dry Grassland & Western Free State Clay Grassland)
- Arid Savanna (Kimberley Thornveld, Vaalbos Rocky Shrubland)
- Nama-Karoo (Northern Upper Karoo)

Conservation areas:

- Mokala National Park
- De Beers Game Reserves: Benfontein, Dronfield, Rooipoort
- Ekapa Game Reserve: Rooifontein
- Private and Communal Game Parks

Freshwater Environments

Several rivers crossing the landscape are part of Strategic Water Areas, the main ones being:

- Vaal River (perennial)
- Riet River (perennial)
- Modder River (perennial)
- Leeu River (ephemeral)

Pans, dams, weirs, water supplies:

- Numerous temporary depressional wetlands (pans) are scattered across all three biomes
- Several pans receive partly treated effluent water from Kimberley rendering them perennial wetlands (Kamfersdam, Dutoitspandam, Platfonteinpan)
- Farm dams
- Several small impoundments where water flow can be measured are the Ritchie-Weir (Riet River), the Driekopseiland-Weir (Riet River), the Douglas-Weir (Vaal River), and the Riverton Pumpstation (Vaal River)
- Groundwater, including the De Aar Strategic Groundwater Source Area

Anthropogenic Environments

- A small city (Kimberley) with a young university and old diamond mines
- Nearby small towns/villages (e.g., Ritchie, Jacobsdal, Koffiefontein, Barkly West, Boshof)
- Communal lands (e.g., Vaalbos, Pniel, Platfontein, Schmidtsdrift)
- Commercial farms (e.g., livestock, game, croplands)
- Mining (e.g., diamonds, lime)
- Tourism ventures in the city and adjacent on game farms, private and public protected areas
- Environmental research institutions (incl. KIMTRI landscape partners)

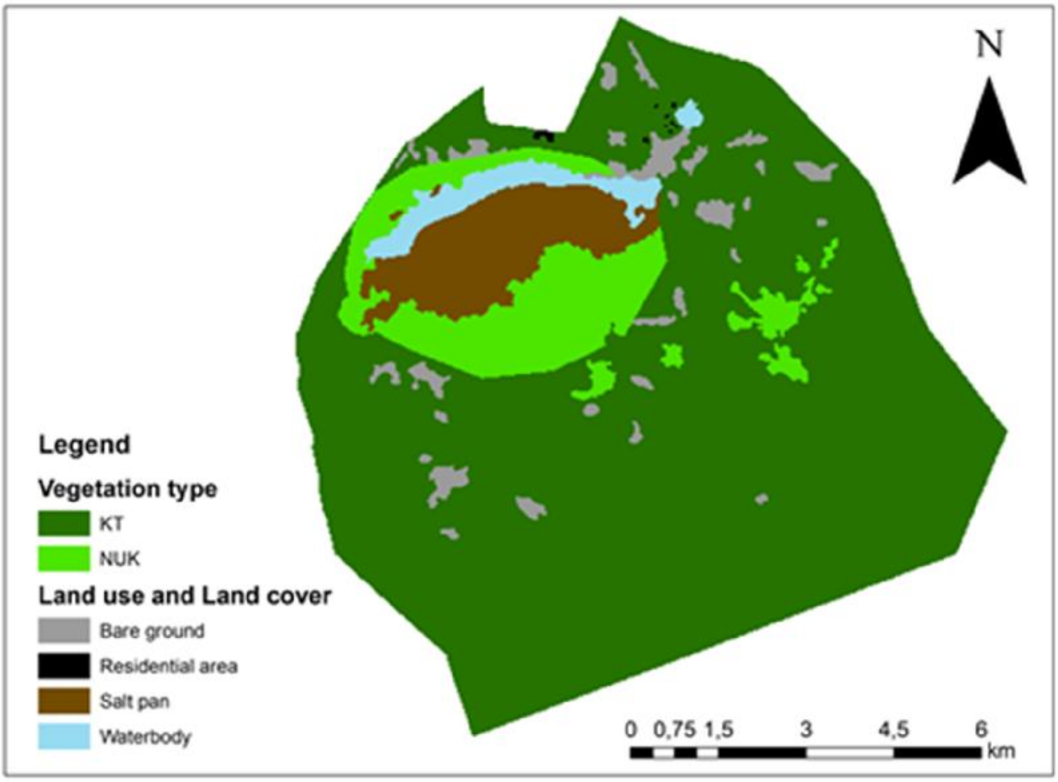

Figure 4: Map of the Benfontein Game Reserve showing the locations of vegetation types (KT-Kimberley Thornveld, NUK-Northern Upper Karoo) and land cover and residential areas in the reserve (preliminary map compiled by Buster Mogonong from remote sensing data).

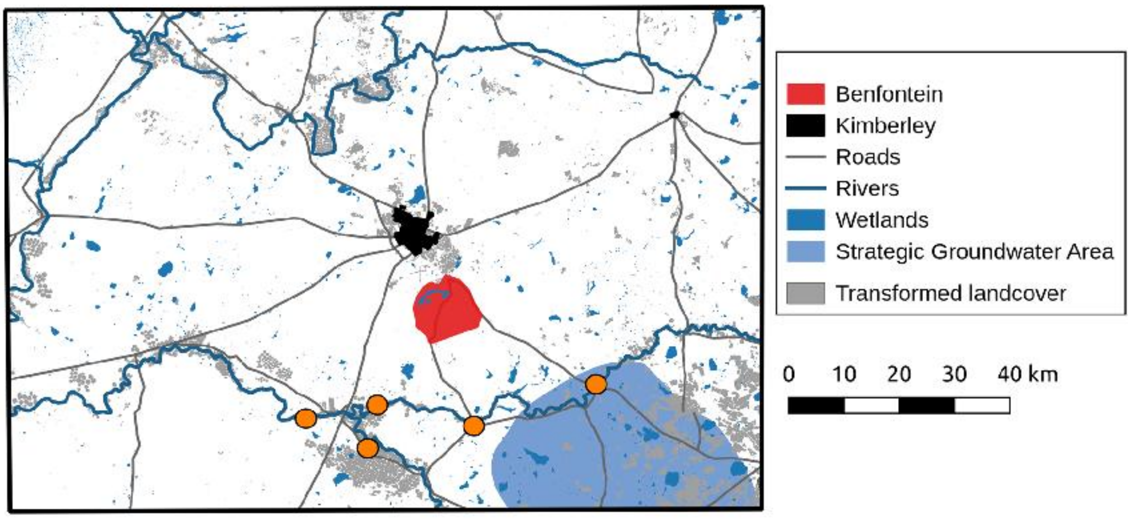

Figure 5: The water-related environmental features of the KIMTRI landscape centred around the core site, Benfontein Game Reserve. There are three main rivers in this landscape: the Vaal River to the North of Kimberley; the Modder River that flows from east to west; and the Riet River, which joins the Modder River south of Kimberley. Additionally, rain-fed wetlands (pans) cover large parts of the wider landscape, including the core site at Benfontein. Lastly, the De Aar Strategic Groundwater Source Area is to the south-east of the core site, illustrating the national significance of the area for sub-surface hydrology. (Orange circles on the map denote long-term monitoring sites by the University of the Free State, with historical data).

Stable and near-natural land-use

Since this is an arid landscape, it has not been widely transformed for cultivation and is, therefore, largely intact. Most of the transformed land cover is around the town of Kimberley (historically a mining town) and along the main rivers due to pivot irrigation (Figure 5).

Assessment of current land-uses

Principal land uses include commercial and communal farming of livestock and game, commercial rain-fed croplands on the Free State side of the provincial border, irrigation pivots, mining, and conservation areas as distinct and contrasting land-use types. Changes of land use and environment in the colonial and deeper human-scale past can be traced at several archaeological sites of renown, as well as in historical documents. The area is semi-arid, and despite several perennial rivers channelling water from wetter upper catchments, water scarcity is a principal constraint in the area. Also, rising temperatures as a result of climate change in this hottest part of South Africa pose further potential challenges for the living conditions for biota and people. Historical patterns of land degradation, mainly from mining and agricultural activities, exacerbate these conditions.

Opportunities to observe global change

In 2019, two test sites for EFTEON flux towers were established at Benfontein (Figure 6), one in the Arid Savanna, another in a patch of Nama-Karoo. This confirms the suitability of Benfontein as a core site and allows an initial evaluation of data from the two biomes (ongoing PhD project, Stellenbosch University). From the outset, this test was connected to a SUN project on Global Primary Productivity in the Arid Savanna site at Benfontein, and the context of soil and vegetation maps of the reserve and its surroundings initiated by UFS and SAEON. The outcome of these current studies will help inform the implementation of KIMTRI.

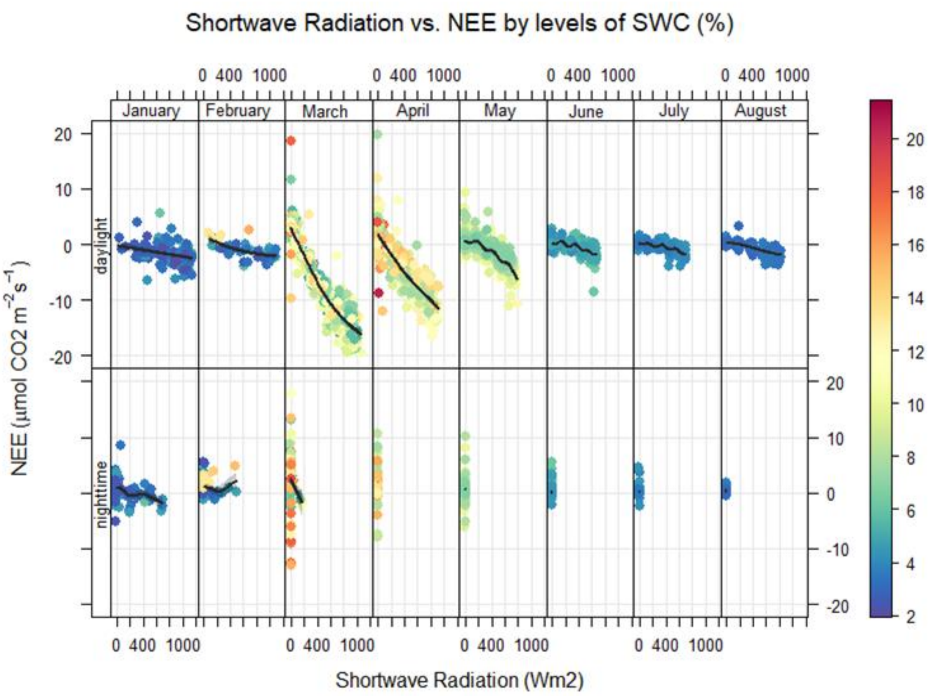

Figure 6: Short-wave Radiation vs Net Ecosystem Exchange of CO_2 (NEE) and Soil Water Content (SWC) measured at the savanna flux tower on Benfontein.

Box 2 – EFTEON Cornerstone: Landscape location in the face of global change

Natural conservation areas of reduced degradation: Benfontein became a game reserve in the late 1800s before surrounding land was extensively transformed, and it has a limited occurrence of alien species, such as *Prosopis* trees, but no extralimital game species (e.g. impala, nyala) nor targeted breeding programmes of hybrids (e.g. blue and black wildebeest) or unusual-features (e.g. white or black springbok). This implies an ecosystem with integrity still intact. Benfontein, like the three other De Beers game reserves nearby, therefore represents an ideal site for measuring global change and comparing that against numerous local environmental changes in surrounding areas.

Significant change processes across terrestrial ecosystems:

- Historic social, economic and land-use processes during the past two centuries
- Increasing mean, maximum and minimum temperatures, physiological challenges to species
- Increasing frequency of episodic deep black frost due to lower atmospheric humidity in winter
- Changes in mean annual precipitation and rainfall season (e.g. reduced rain in early summer, increasing drought frequency)
- River flow sedimentation changes due to impoundments and flow regulation
- Water quality changes due to industrial, urban and agricultural pollution
- Changes in wetland water regimes and salt mining
- Land clearing for mining, urban expansion, installation of other infrastructure and agriculture
- Land degradation due to unsustainable agriculture
- Bush encroachment by indigenous species
- Invasive alien plants
- Parks and game farms stocking with extra-limital, hybrid or feature-bred animals that affect ecosystem structure and functioning, and reduce beta-diversity and genetic diversity
- Application of toxins to poison vermin and locusts, collateral damage to non-target species, such as vultures
- Road kills, airport bird collisions

Recent modifications of land use:

- Examples of significant land-use change:
    - Vaalbos: from National Park to Communal Game Park
    - Mokala: from Commercial Farming to National Park
    - Kamfersdam: from dryland wetland to perennial wetland, filled with wastewater for feeding and nesting of flamingos
    - Platfonteinpan: receiving overflow wastewater from Gogga pump station
- Examples of shifting from cattle farming to game farming
- Expansion of irrigated croplands
- Expansion of small-scale diamond mining, including in riverbeds
- Urban development/degradation and expansion
- New large scale solar power generators, including a National Renewable Energy Development Zone
- Bush encroachment, e.g., Pniel Vaalbos projects, *Prosopis* expansion and control
- Free State dustbowl generated from dry crop fields causing significant wind erosion

Climate change hotspots:

- Transition Zones between Biomes

Major regional development plans, including:

- solar energy
- manganese mining
- expansion of Kimberley city
- urbanisation from across Northern Cape.

Environmental functioning under different land-uses

At a larger scale beyond the location of flux instrumentation, we propose finding sufficient features to include in the KIMTRI landscape within 60 km of Kimberley. The area stretches between Petrusburg in the east to Schmidtsdrift in the west, between Mokala National Park in the south and Vaalbos Communal Park to the north (Figure 7).

Benfontein Game Reserve as a core site also allows a unique opportunity for a comparative study of different land-uses. Mokala National Park is to the south-west, and the deproclaimed protected area at Vaalbos is to the west. Comparing these three biographically similar regions would allow the KIMTRI project to study the effects of formal government protection (Mokala), private protection (Benfontein) and communal management (Vaalbos) on the structure, function and composition of biomes.

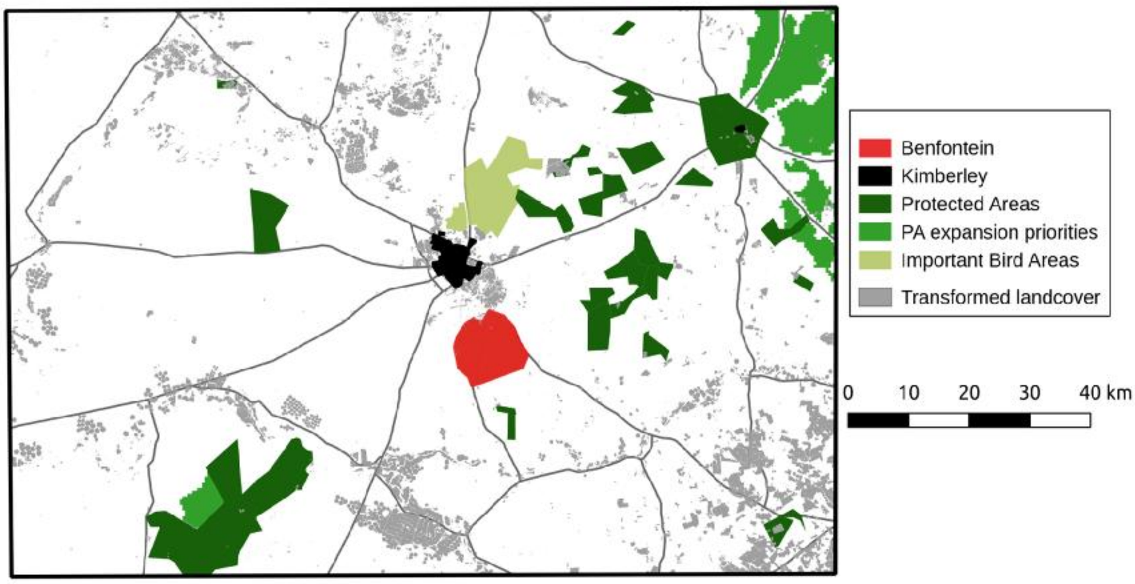

Figure 7: Protected areas around the Benfontein Game Reserve core site and the wider KIMTRI landscape. This map shows the formal protected areas in the national database of protected areas, protected area expansion priority areas and Important Bird and Biodiversity Areas (including Benfontein).

Carbon-water-production studies at the landscape scale

One of the central challenges facing the planet is the sustainable sequestration of carbon given limited water supply in semi-arid systems. With rising atmospheric CO2, for example, arid systems are suspected to be one of the fastest-growing carbon sinks globally (Poulter et al 2014). If verified, this has major implications for land cover change, land use, biodiversity and related management and policy support. The KIMTRI landscapes offer virtually unparalleled opportunities to explore these questions, with highly divergent structural ecosystem types in close proximity, and thus under a similar climatic regime. Existing infrastructure that can be leveraged include the EFTEON flux infrastructure itself, but which can be linked to near-distance remote sensing of vegetation production using narrow-band sensors mounted in-situ, and arrays of soil moisture sensors. The initial phases of such work are already underway and funded under an NRF-supported PhD based at the GCBG, Stellenbosch University. This combination of sensors will provide powerful insights into the vegetation type-specific patterns of production and water use and the impacts on soil water under a wide range of rainfall and temperature conditions. When placed into a modelling framework that combines modern dynamic global vegetation modelling techniques (e.g. Higgins and Scheiter 2009), and hydrological modelling, it should be possible to develop a well-integrated understanding of critical carbon-water-production relationships.

Socio-ecological systems within the landscape

To be forward-looking, this proposal considers a scenario-based approach, rather than focusing on single pressures. This allows us the opportunity to understand interactions amongst drivers, pressures and benefits. The scenarios are useful for understanding what might be happening in the landscape in the long run (i.e. next 20 years), and will further provide insights to questions such as:

- What are the plausible futures for the Kimberley area? For example, how new governmental developments affect population increase or decrease and impact on settlement expansion/contraction or land conversion.
- What changes are anticipated? Mine closure or new economic developments will significantly affect land use and land cover change.
- How human needs are affected under an increased or decreased population and with/without government intervention? This would greatly impact ecosystem services as pressures spill over into the environment.

The listed development scenarios would lead to a host of different socio-ecological effects in the region. Five possible developmental scenarios are identified for the KIMTRI landscape:

1. **Business as usual:** The change that has taken place over the past 20 years will continue to change the Kimberley environment at the same intensity and rate in the near future.
2. **Green recovery:** Under this scenario, the value of the environment is realised at local, national and international levels and environmental interventions such as post-mining rehabilitation take place, Kimberley becomes a hub for renewable energy (Figure 8), the reduction of carbon in the environment becomes increasingly important and the value (environmental and economic) of carbon sequestration increases. Programmes such as the Expanded Public Works programme are used to positively influence environmental rehabilitation such as post-mining rehabilitation and invasive alien control while providing an income to those caught in poverty.
3. **Kimberley Boom-town:** This scenario assumes significant economic growth and population increase as immigration into the region takes place as Kimberley develops, becoming a transportation hub between different industrial sectors and between southern Africa and other African countries. This expansion would require additional agricultural food production on rangelands as well as intensive crop production.
4. **Kimberley Ghost-town:** Emigration and economic recession as a consequence of local, national and international trends could lead to Kimberley becoming isolated and

receding into a Ghost-town as has happened to many arid and mining towns across the world.

5. **Worst-case scenario:** Under the Worst-case scenario, informal settlements mushroom around the city, illegal, unregulated mining and harvesting of natural resources destroy the environment while the pollution of soil, water and atmosphere continue unchecked.

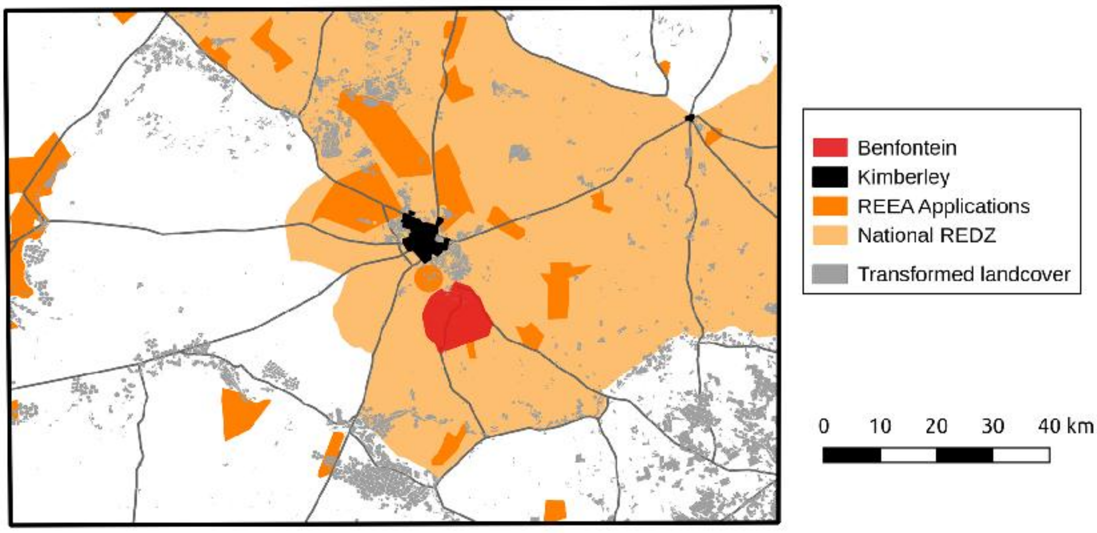

Figure 8: Renewable energy development in the KIMTRI landscape. The entire landscape is part of the Kimberley Renewable Energy Development Zone (REDZ), which has been identified by the national government for prioritised development of renewable energy infrastructure. To date, several Renewable Energy Environmental Authorisation (REEA) applications have been filed across the landscape.

Logistical and operational suitability

Physical infrastructure

There is currently flux instrumentation deployed at the Benfontein core site, as a pilot for the EFTEON program. The site is particularly suitable for micrometeorological observations because it is almost horizontal, very gently sloping, and, therefore, provides the topographical characteristics needed for accurate flux determination. The rest of the core site has a network of well-maintained access roads, which mean that most of the reserve is accessible to vehicles with reasonable ground clearance. The Benfontein core site also has easy access to an endorheic wetland, and there are existing boreholes that supply water to the buildings. There are existing river monitoring sites on the Modder and Riet Rivers (Figure 5), including gauging weirs and access for SASS and fish monitoring. SAEON has also facilitated a diatom project along the lengths of Vaal and Orange Rivers.

In terms of administrative support, office space is available at the SAEON Arid Lands Node, 10 km from the core site at Benfontein. Therefore, it would be able to accommodate four permanent staff members. Sol Plaatje University and the University of the Free State provide laboratory space for processing samples and the McGregor Museum and National Museum provide access to collections of local biodiversity.

Core site suitability for infrastructure

The core site at Benfontein has a flat topography, so it meets the assumption of horizontal heterogeneity and steady-state conditions necessary for accurate micrometeorological observations. Two flux towers have already been installed at the Benfontein Core Site, and they are producing accurate and reliable data (Figure 9). Moreover, the core site is easily accessible through a network of well-connected and well-maintained roads, which simplify the installation, operation and maintenance of environmental observation equipment.

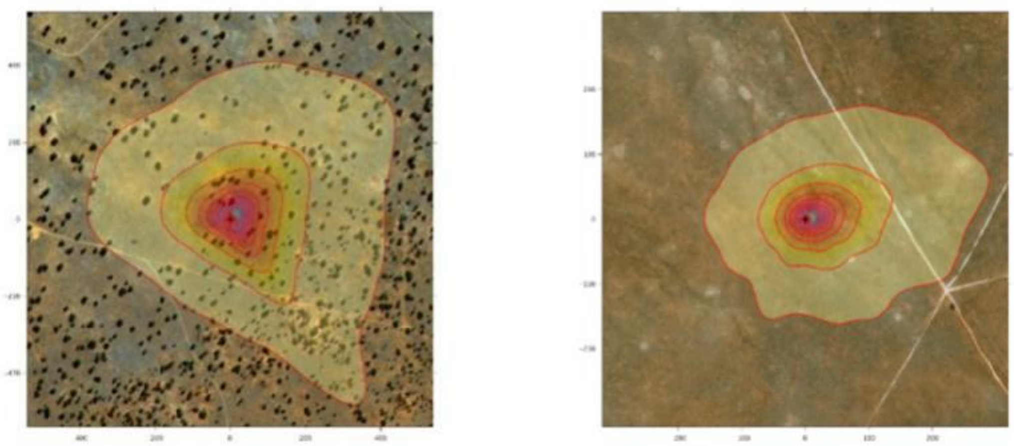

Figure 9: Mean data footprint over 6 months of flux-towers deployed in the Savanna of Benfontein at 13.5 m height (left, block size = 1400 x 1400m), and a flux-tower in the Karoo patch at 3.5 m height (right, block size = 600 x 600 m).

Existing data

The core site at Benfontein has a wealth of existing data that can be tapped. These records cover all aspects of the abiotic and biotic components of the environment and traverse multiple temporal scales, including the paleontological record all through to the present day (Box 3).

Core site security

The core site at Benfontein is perfectly secure for long-term environmental observation infrastructure. The land tenure is secure because Benfontein Game Reserve has been owned and managed by De Beers for over 130 years. The property is surrounded on all sides by game fencing and access is restricted by a code-activated electronic gate. Benfontein also has a full-time reserve manager permanently on-site (employed by De Beers), who ensures that the access roads, fences and other infrastructure are well-maintained. The core site has a long track record of hosting international research, and the landowners have accommodated and supported researchers on their reserve for decades. There is an existing Memorandum of Understanding between SAEON and De Beers, and De Beers is a key partner for this EFTEON proposal. The De Beers-SAEON Collaboration Committee has discussed and agreed on key components of the envisaged proposal, including long-term access for the duration of the project and allowing partner researchers access to the site (copy of MoU and committee meeting minutes attached).

<u>Box 3 – EFTEON Cornerstone: Existing long-term observational and experimental data</u>

Numerous projects (an abridged list is provided below) have been conducted at Benfontein and its immediate surroundings. These projects have never been reviewed or collated, so this would be a useful KIMTRI subproject.

- Archaeological and historical changes can be tracked at numerous heritage sites bearing cultural relics, fossils and pollen, and other palaeoenvironmental indicators at Alexanderfonteinpan, Driekopseiland, Wildebeestkuil, Canteen Koppie, Magersfontein, Deelpan Meriba, Uitzigt pan, Baden-Baden pan
- Over a century of weather records have been collected by SAWS, only 4 km from the northern boundary of the Benfontein Game Reserve
- McGregor Museum, in collaboration with Mammal Research Institute of the University of Pretoria, the Environmental Wildlife Trust, and several international institutions (e.g. Germany, Canada, USA), has conducted several projects, including on passerines, vultures, springbok, ground squirrels, aardwolf, black-footed cat, and many more
- The Fitzpatrick Institute of the University of Cape Town has conducted various ornithological studies at Benfontein in the past, and long-term and serial projects are currently being conducted on sociable weavers in the game reserve
- Experiments on *Vachellia erioloba* juveniles (camelthorn trees) were conducted in the 1990s. SANBI, in collaboration with SAEON, recently re-measured the study trees
- In February 2018, SAEON deployed a CSA weather station on the Benfontein Game Reserve, recording temperature, humidity, wind speed, wind direction, rainfall, leaf wetness, radiation, UV, soil surface temperature, and soil moisture
- SAEON, in collaboration with the Sol Plaatje University, is conducting plant phenological studies (two-weekly intervals) on Benfontein since October 2017
- SAEON, in collaboration with the University of Stellenbosch, is trialling measurements of carbon and moisture flux in two biomes at Benfontein since December 2019
- Stellenbosch University, in collaboration with SAEON, has initiated a SASSCAL-funded project on Global Primary Productivity at Benfontein, using visual records of plant photo-fluorescence and growth as well as records of soil respiration. This project is connected to the above-mentioned project on carbon and moisture flux
- Friedrich Schiller University, Jena, Germany, has initiated a component of the SALDi project (South African Land Degradation indicators) at Benfontein. This site is considered to be a suitable reference site to improve the understanding of land degradation due to human impacts, compared to climate-induced changes, particularly periodic droughts. In collaboration with SAEON, instruments were installed at Benfontein in March 2020, which assist with ground-truthing of remote sensing data. The SALDi project will contribute Earth Observation data and products, such as radar and optical time-series information collected since 2015, as well as various other statistical parameters from the EO time series
- The Ekapa mine is undertaking the rehabilitation of the De Beers Mine pit and has initiated environmental observations of Dutoitspandam
- The Centre for Environmental Management, UFS, has conducted several projects on pans and groundwater in the western Free State as well as collecting datasets on water flow, water quality and biotic indicators (including SASS) in the lower Modder and Riet Rivers
- The University of the Free State has analysed pollen from dassie middens on koppies as well as from pans to reconstruct the palaeoenvironments
- Given that aeronautics in South Africa has its roots in Kimberley, a long series of aerial

photographs is available to trace environmental changes over a century. Likewise, some photographs taken in this area since 1874 can serve to analyse changes in landscapes from fixed points
- Data on bush encroachment collected at Pniel and Magersfontein, can serve as a baseline for further studies.

Available support services

The core site at Benfontein is 10 km outside of Kimberley, which makes it easily accessible using upgraded national roads. The core site itself has basic accommodation for researchers (kitchen, bathroom, bedrooms, workrooms for field equipment storage and maintenance). However, priority allocation to these facilities is to researchers working on long-term projects in the game reserve. The rest of the core site is accessible through a well-connected network of roads, which makes it logistically easy to access remote field plots even when driving from Kimberley.

Kimberley is well-connected through national highways as well as a national airport. The city of Kimberley offers all the facilities that might be needed by researchers, including accommodation, hospitality facilities, conference venues, hospitals, and general retailers. The core site is within 10 km of the facilities of the SAEON Arid Lands Node, SANParks, laboratory facilities at Sol Plaatje University and research facilities and collection archives at the McGregor Museum. The core site is 150 km away from Bloemfontein, including the University of the Free State and the accredited water analysis laboratory at the Institute for Groundwater Studies.

Box 4 – EFTEON Cornerstone: Availability of facilities for staff and guest researchers.

- Offices and laboratory where EFTEON staff and instrumentation would be based: SAEON Arid Lands Node in Kimberley, is 10 km from Benfontein
- More extensive laboratory facilities: Sol Plaatje University, 10 km from Benfontein
- Other facilities in Kimberley include accommodation, schools, hospitals, hospitality facilities, conference venues
- Network of roads radiating in all directions from Kimberley makes accessing other study sites convenient
- Transport and accessibility to Benfontein Game Reserve:
    - N8 national road along the NE boundary
    - Kimberley Airport, 4 km N of the reserve
- Transport and accessibility within Benfontein Game Reserve:
    - Network of tracks maintained by De Beers in the reserve.

Suitability for human capital development

The partnership between SAEON Arid Land Node, Sol Plaatje University, University of the Free State and Stellenbosch University is well placed to fill the role of leading the process of coordinating the collaborative research platform of KIMTRI. All four institutions are actively building their investments in integrated interdisciplinary research on global change and will continue to do so over the next decade, at least. This platform builds on the legacy of existing data and knowledge that is thereby safeguarded and made available for further analyses across disciplines, space and time. In association with the other research institutions in the area, SAEON-ALN, SPU, UFS and SUN host and facilitate research and monitoring by other institutions to engage and contribute information more broadly. These partnerships facilitate the cross-sectoral extraction of relevant information for decision-making and policy development. In this way, we can effectively address interdisciplinary, large-scale and long-term issues.

EFTEON infrastructure hosted at the Benfontein core site will play a central role in developing the undergraduate and postgraduate programmes at Sol Plaatje University, the youngest university in South Africa. Its accessibility and safety will support practical undergraduate excursions and postgraduate research projects. This is also true for postgraduate students from the University of the Free State, Stellenbosch University and other universities. Benfontein has in the past supported multiple PhD students from the University of Cape Town, as well as students from French and Portuguese Universities.

In addition to the formal academic institutions, the core site will also support experiential learning for interns from the SAEON and SANParks offices in Kimberley, as well as interns based at the McGregor Museum. Moreover, the SANBI offices in Bloemfontein coordinate work on invasive species in the Free State and Northern Cape, so interns based at SANBI could also benefit from EFTEON infrastructure at Benfontein.

The core site at Benfontein is an Important Bird Area (also referred to as a Key Biodiversity Area). It is listed as a priority birding locality in the Roberts Bird App, a popular cell phone app for birdwatchers. Although access to the site is restricted, citizen scientists can gain access to the site with prior arrangement with the management at De Beers. Therefore, the Benfontein core site will also support citizen scientists who contributed to the South African Bird Atlas Project.

Stakeholder and community engagement

Identification of key stakeholders

We distinguish between two groups of core stakeholders: land-owners/custodians and EFTEON project proponents, but acknowledge that the interests of these groups overlap considerably.

Landowner and land custodians:

De Beers (land-owner)

- A full Collaboration Agreement exists between SAEON and De Beers, which, through a Collaboration Committee, regulates long-term access by SAEON (and its programmes, such as EFTEON) to Benfontein, Dronfield and Rooipoort game reserves
- Access by SAEON-affiliated researchers is also regulated through this agreement, requiring visitors/students to also register their projects with De Beers before getting permission to access; SAEON and De Beers will use a unified process for registering affiliated projects

SANParks

- Manages Mokala National Park, and the Vaalbos-Graspan-Holpan NP. Requires each researcher to apply for a research permit

McGregor Museum and National Museum

- Manage heritage sites

Communal land authorities

- Platfontein, Vaalbos, Pniel, Schmidtsdrift

Municipalities

- Sol Plaatje Local Municipality

- Frances Baard District Municipality (NC)
- Tokologo local - Lejweleputswa District Municipality (FS)
- Letsemeng Local - Xhariep District Municipality (FS)

Project proponents

- SAEON Arid Land Node
- Sol Plaatje University
- University of the Free State
- Stellenbosch University
- in collaboration with SANParks, SAWS, McGregor Museum, Ekapa Group, SANBI, UCT, University of Basel, Switzerland, and the Friedrich-Schiller-University, Jena, Germany.

Broad support by wider scientific community

Kimberley is home to several environmental research institutions, including South Africa's oldest museum (McGregor), SANParks, SAWS, DENC/DALRRD, DWS, and the notable recent additions, Sol Plaatje University (SPU) and the SAEON Arid Lands Node (SAEON-ALN). These research institutions, with offices in the Northern Cape, work in close operation with institutions based in the Free State such as the University of the Free State (UFS), the National Museum, and FS-EDTEA. Several other research institutions from elsewhere in South Africa and abroad are part of this Kimberley-based research network. Furthermore, diamond mining companies such as De Beers, Ekapa and Petra, as well as solar power stations, such as Droogfontein and Boshof, are also monitoring the environment and supporting research. Collectively, all these institutions have been conducting environmental research in the vicinity of Kimberley for more than a century.

Contact with communities and local residents and authorities

Kimberley has a long history of environmental research, as demonstrated by the annual Kimberley Biodiversity Research Symposium, which draws together researchers and practitioners from public, private and higher education institutions. Likewise, the annual Oppenheimer Research Conference serves as an important forum for network partners to exchange information and experiences. Therefore, this EFTEON proposal will fit into existing networks of local communities, residents and authorities. We anticipate the following linkages with stakeholders.

Engagement with communities and authorities

We expect the following agencies to benefit from the information that will be collected during the KIMTRI project, either for decision making, awareness or by complimenting their existing monitoring programmes. We also hope to engage with these stakeholders regularly to develop a partnership whereby information can be utilised and shared effectively:

- Northern Cape Department of Environment and Nature Conservation (NC-DENC)
- Free State Department of Economic, Small Business Development, Tourism & Environmental Affairs (FS-EDTEA)
- Northern Cape Department of Agriculture, Land Reform and Rural Development (NC-DALRRD)
- Free State Department of Agriculture and Rural Development (FS-ARD)
- Department of Water and Sanitation (DWS)
- Department of Mineral Resources (DMR)

- National Department of Agriculture, Land Reform and Rural Development (DALRRD)
- Northern Cape Department of Basic Education (NC-DOE)
- Agri-NC, Free State Agriculture, Farmers Unions and Associations
- National Research Foundation (NRF)
- NC Wetland Forum
- Medical facilities, e.g. specialists at various Kimberley hospitals
- South African National Roads Agency (SANRAL)
- Passenger Rail Agency of South Africa (PRASA) and TransNet
- Airports Company of South Africa (ACSA)
- Vaal-Gamagara Water Scheme & Sedibengwater pipeline
- Northern Cape Tourism Authority
- Northern Cape Department of Economic Development and Tourism (NC-DEDAT)
- Provincial Heritage Resources Authority (PHRA)
- Social Housing Regulatory Authority (SHRA)
- Northern Cape Hunters' Association
- South Africa Soil Surveyors Organisation
- Working for Water
- Working for Wetlands

Management of current and future land uses

Fine-scale information pertaining to the ecology and hydrological regimes in the region are scant. Therefore we hope to produce information that will improve existing online data platforms as well as help those parties involved in land use management and assessment processes:

- Consultants
- Mines
- Renewable energy companies
- Freshwater Biodiversity Information System
- Animal Demography Unit Virtual Museum (ADU)
- Fertiliser companies
- Pest control companies
- Eskom distribution
- Landowners (e.g. Farm owners)
- Agricultural Co-ops

Conservation organisations

We hope to partner with the following agencies to identify specific gaps where our research can benefit current gaps in information relating to their core strategic projects.

- Endangered Wildlife Trust (EWT)
- BirdlifeSA
- WWF South Africa
- Wildlife and Environmental Society of South Africa (WESSA)

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APPENDIX B: BIBLIOGRAPHY

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B2: Some literature concerning KIMTRI other than Benfontein (preliminary)

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APPENDIX C: KIMTRI SUBPROJECTS

Several research projects, other than the core activities of EFTEON, which focus on carbon-moisture flux, hydrological dynamics, productivity, biodiversity and in the socio-ecological processes, relate closely to the KIMTRI Landscape Programme. These are outlined in this section. They should all be read as being examples of the larger scope of KIMTRI as a large, collaborative programme conducted in and around Kimberley by local scientists and institutions collaborating with national and international institutions.

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C1: Groundwater baseline and shallow-deep aquifer interactions

Surina Esterhuyse (Centre for Environmental Management, University of the Free State)

Brief statement: The groundwater would develop a groundwater baseline for the area and assess shallow / deep aquifer interaction within Benfontein and the wider project area. Shallow-deep interaction will be assessed by identifying a shallow and deep groundwater borehole pair(s) within the study area and monitoring water levels and sampling basic chemistry (field parameters, full suite major and minor elements via ICP-MS) and isotopes (deuterium and oxygen-18) of the selected borehole pairs. Chemistry and water levels of other accessible boreholes within the study area must be sampled to develop a groundwater baseline of water levels and chemistry, to assess temporal changes of groundwater in the study area, and to assess shallow deep aquifer interactions.

Data to be generated: Groundwater chemistry: Field parameters, major elements, minor elements, isotopes (D, 18O). Groundwater quantity: Water levels, groundwater flow vector maps

Outputs: Groundwater baseline and conceptual model of shallow-deep aquifer interaction

Outcomes: The groundwater baseline will assess the effect of anthropogenic activities on groundwater. Shallow deep aquifer interaction will assess effects of underground anthropogenic activities such as deep groundwater withdrawal, artificial recharge or UOG extraction on deeper aquifers.

Impacts: Baseline information and shallow-deep interaction information will lead to better management of groundwater resources in the area.

Main stakeholders: Scientists, local and national government

Project connections between components (G,E,S) and environments (T,F,A) of KIMTRI (see Table 1 in main proposal): The shallow deep aquifer interactions project needs climate isotope data and will link with and use climate data from rainfall (chlorine concentrations in rainwater, rainfall figures and rainwater isotope data). This information and water level monitoring will be useful for assessing anthropogenic effects and planning future groundwater use and for protecting groundwater and linked environments when considering future development in the area (socio-ecological impacts). Soil baseline information can be linked to and confirm the groundwater quality baseline. Groundwater baseline information will in future tie in with regional groundwater monitoring network designs for UOG extraction in South Africa.

C2: Digital Soil Mapping of the Benfontein site

Johan van Tol (University of the Free State), George van Zijl (North-West University)

A detailed soil map of the Benfontein site will be created using advanced Digital Soil Mapping techniques (fieldwork completed in August 2020). Attributes of the soil map will include:

- **Pedological information**: Soil forms and families (Soil Classification Working Group, 2018), horizon and profile depth
- **Soil Chemical properties**: pH, Ca, Mg, K, Na, P and organic carbon
- **Soil physical properties**: Sand, silt, clay, bulk density and hydraulic conductivity.

The soil information can be used:

1) To develop erosion sensitivity maps for wind and water erosion as well as inputs in erosion prediction models.
2) To quantify carbon stocks for the Benfontein site.
3) To establish relationships between vegetation and soils in terms of nutrients and physical properties.
4) As inputs into hydrological models for water resource predictions.
5) Identify groundwater recharge areas
6) Improve our understanding of groundwater/soil water/surface water interactions, with special reference to arid wetlands (pans).
7) To establish the sensitivity of the soil to land-use and climate change.
8) Quantification of carbon-moisture-energy fluxes across the landscape.
9) To serve as a basis for extrapolating point measurements over the landscape.

We foresee that the soil mapping would later be conducted for the 'greater KIMTRI' site, to serve as basis for several other disciplines.

C3: Atmospheric Mineral Dust

Frank Eckardt and Johanna von Holdt (University of Cape Town), Nikolaus Kuhn (University of Basel)

Atmospheric mineral dust originates mostly from desert regions (Goudie and Middleton 2006). Surfaces which emit the most are fluvial in nature, bare soils but also those impacted by human activity including agriculture (Bullard et al. 2011, Ginoux et al. 2012, Prosepro et al. 2002). Atmospheric dust emissions are a function of terrestrial surfaces characteristics and their response to fluvial (climatic) and anthropogenic drivers. All types of dust emitting surfaces can be found in the southern African region, including South Africa. For example, dry pans and rivers have been established as dust emitters in neighbouring Botswana and Namibia (Vickery et al. 2013, Von Holdt et al. 2017). Agricultural areas and bare soils have been identified as emitters in the neighbouring North West and Free State Province (Wiggs et al. 2012; Eckardt et al. 2020).

In addition, dust emitted from mining operations and mine tailings, including historical and abandoned tailings facilities, has been of concern given its potentially detrimental effect on the environment and communities (Csavina et al., 2012; Ojelede et al. 2012). Mining has and still takes place in the region with diamond mining locally, large-scale iron ore production is less than 200km to the north-west and gold mining in the Free State. The monitoring of dust from mines and the determination of the extent of dispersion and contribution to mineral dust loads remains an ongoing national research objective.

The proposed KIMTRI location in Kimberley would open multiple opportunities for research, entailing process measurements, modelling and long-term monitoring, especially in response to climatic conditions, such as drought, and human pressures. The site offers natural and anthropogenic surface environments such as agriculture, mining, and pans, in line with drylands elsewhere. Results would be of interest to Kimberley, South Africa and beyond.

Long term monitoring at KIMTRI could entail passive fallout buckets and dust transport traps as well as particulate matter (PM) sensors which could identify background concentrations and aeolian contributions from local and regional sources. In addition, a systematic survey of wind emission thresholds and dust fluxes could be carried out by the collaborators with the University of Basel, using their Portable In-Situ Wind Erosion Lab (Pi-SWERL, Etyemezian et al. 2007). The Pi-SWERL also enables the collection of dust samples for further analysis, e.g. with regards to public health or off-site environmental impacts such as ocean fertilization. Further assessment of the interaction between surface roughness induced, e.g. by microtopography or vegetation, could be carried out by high-resolution surveying using Unmanned Aerial Vehicles (Krenz et al., 2019). Such a nested approach scaling up from point-measurements using the PI-SWERL, through field-scale monitoring and surface property assessment, to the analysis of dust emission events observed on satellite data, will enable a comprehensive assessment of the relevance of the interaction between climate and land use on dust emissions, the magnitude of the emissions and the composition of the dust itself.

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C4: Soil Moisture and Vegetation Dynamics Monitoring of the Benfontein site

Marcel Urban (FSU Jena), Buster Mogonong (SAEON), Hilma Nghiyalwa (FSU Jena), Kuda Musengi (SAEON), Gregor Feig (SAEON), Andreas Hirner (DLR), Ursula Gessner (DLR), Christiane Schmullius (FSU Jena), Joh Henschel (SAEON), Jussi Baade (FSU Jena)

The monitoring of the spatial-temporal dynamics of surface moisture content, as well as vegetation dynamics, is of high importance for understanding the environmental conditions and changes (e.g. impacts from droughts, vegetation growth dynamics). Savanna ecosystems, which are characterized by a mixture of grass, shrubs, trees as well as bare soil, are highly heterogeneous with seasonal dynamics. Mapping the individual land cover components are crucial for solving environmental issues such as soil erosion, bush encroachment, forage and browsing availability (Cho et al., 2017; Kaszta et al., 2016; Madonsela et al., 2017).

Within KIMTRI, we are using spatial high-resolution Earth Observation (EO) data from ESA's Copernicus program to monitor surface moisture and vegetation dynamics within the three different biomes at the Benfontein site. The Sentinel-1 and Sentinel-2 missions of the European Space Agency (ESA) Copernicus program has led to the increasing availability of open access Earth Observation (EO) information covering both, optical and microwave spectra. This opens new possibilities for the analysis of data with a higher spatial and temporal resolution for various applications (e.g. drought monitoring, vegetation cover analysis).

Urban et al. (2018) focused on surface moisture monitoring and vegetation cover analysis in the Kruger National Park using Sentinel-1, Sentinel-2 and Landsat-8 data. Moreover, in this current study, monitoring vegetation cover will be done by extracting the fraction and proportion of each cover type on pixel level by use of the vegetation continuous fields (VCF) concept, which provide a proportional per pixel tree, grass and non-tree vegetation cover estimate (Zeng et al., 2003) .

The preparation and production (e.g. data download, pre-processing, data cube ingest, etc.) of the EO data and products is part of the SALDi project (South African Land Degradation Monitor). The PhD thesis of Hilma Nghiyalwa (DAAD PhD at the FSU Jena) is focusing on vegetation dynamics and mixed pixel analysis in the Mokala National Park and Benfontein.

The subproject goals are as follows:

1) Analysing spatio-temporal variation of surface moisture content using high-resolution Earth Observation data as well as in situ observation
2) Monitoring of spatial and temporal variation of vegetation cover within different biomes (Karoo, Kalahari, Savanna)
3) Analysing how spatial and temporal patterns of surface moisture affect biodiversity within different biomes
4) Temporal analysis of typical pure pixels (pure grass, pure bushes, pure trees) by making use of optical and radar vegetation indices time series

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C5: Community phylogenetics of vascular plant species at Benfontein Game Reserve and Mokala National Park

Kunle Adebowale, Tendai Musvuugwa*, Precious Letebele, Elelwani Nenzhelele (Biological & Agricultural Sciences, Sol Plaatje University) * = Co-Principal Investigators*

Abstract

The loss of biodiversity at a rate higher than their discovery has created an urgent need for rapid means of documenting these important components of our natural resources. Given this backdrop, the application of molecular datasets like DNA barcodes for identification of unknown species is narrowing the gap in our biodiversity knowledge. However, the utility of DNA barcodes is limited by the coverage of the barcode database. Datasets from areas of high endemism and rare species are thus needed for a robust DNA barcode library. The Mokala National Park (MoNP) and Benfontein Game Reserve (BGR), both in the Northern Cape, are two such areas. This research is a step towards improving such libraries by generating and applying DNA barcodes data to assess patterns of vascular plant diversity in MoNP and BGR. Beyond the provision of primary barcode data for assessing vascular plant diversity in these landscapes, the project also provides an opportunity to test some predictions of ecological theory and the role of evolutionary processes on vascular plant community assemblage. The findings from this study hold potential to generate foundational information for effective conservation management of MoNP and BGR. At a broader scale, the research speaks to a number of objectives of the National Biodiversity Strategy and Action Plan, for sustainable and equitable utilization of South Africa biodiversity resources.

Direct relevance with KIMTRI

Because of the relatively small spatial scale of the study areas, and the distinct habitat types represented at MoNP and BGR, the study allows for integrating data from vegetation cover, soil mapping and other relevant parameters estimated by flux tower infrastructure (e.g. GPP and NPP). Integrating such data within a community phylogenetics analytical framework can give insight as to how historical and local processes play out over environmental gradients in space and over time, considering the mid to long-term nature of the bigger project. In summary, the project would contribute foundational biodiversity data into KIMTRI while also applying data generated from other aspects of KIMTRI to evaluate ecological and evolutionary hypotheses of species co-occurrence.

C6: Alien invasive vegetation monitoring at the Benfontein site

Kudakwashe Musengi (SAEON), Elelwani Nenzhelele (Sol Plaatje University), Helga van der Merwe (SAEON), Joh Henschel (SAEON), Buster Mogonong (SAEON)

Objectives

One of the significant threats to global biodiversity and the functioning of ecosystems is the spread of alien invasive plants. Monitoring the abundance and spatial structure of alien invasive plant populations is important for designing and measuring the efficacy of long-term management strategies (Hui et al. 2011). The spatial distribution of species reflects the dispersal processes and pathways of biological invasions and is also a strong predictor of extinction risk and range contraction (Gaston & Fuller, 2009). The spread and impacts of alien invasive plants have increased with the increase in factors such as land-use changes. Benfontein Game Reserve (BGR) was established in the late 1800s before surrounding land was extensively transformed, and it has a limited occurrence of alien species, such as Prosopis trees. Little information is available on the effects of habitat type and distance to urban settlements on the ability of alien plants to become established. The rapid invasion of Prosopis is attributed to the biological features such as the ability to produce large number of seeds that are viable for decades, rapid growth rates, edible pods that can be dispersed over long distance by livestock and wildlife as well as re-sprouting ability making it a destructive invader (Shiferaw et al. 2004).

Within KIMTRI, we will study some biological features of Prosopis species and other alien invasive plant species. We will focus on the number of seeds produced, seed dispersal through droppings of animals, soil seed banks, seed germination and stumping height of trees and coppicing ability of the alien invasive plant species.

The subproject goals will make good use of KIMTRI data and information as follows:
1. Identify factors (biotic and abiotic) that influence the spread of alien invasive plants
2. Provide insights to predict the areas most likely to be invaded by alien invasive plants
3. To quantify the impact of alien invasive plants on the ecosystem
4. Understand the impact/s of alien invasive vegetation species on native vegetation
5. Document all the alien invasive plants in the study area
6. Investigate the diversity and distribution of the alien invasive plants in the study area

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C7: Large Mammal Herbivores

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Ecological and Conservation Value of Herbivores

Large mammal herbivores (hereafter herbivores) are arguably the most conspicuous component of terrestrial savanna and grassland landscapes. These animals have enormous impacts on ecosystem structure and function, through consumption of large quantities of vegetation (Owen-Smith 1988), as well as through other behaviours like trampling (Sinclair et al. 2007). Their persistence in the fossil and sub-fossil record enables tracking such impacts over extended time scales (Gordon and Prins 2019; Codron 2020). Sustained use of large amounts of a finite resource (plants) also implies significant effects of exploitation competition, somewhat at odds with the high levels of herbivore species diversity found in savannas (Prins and Olff 1998). Long-term investigations of herbivore ecology are therefore, an important source of information about coexistence mechanisms and the maintenance of biodiversity in natural communities (cf. Chesson 2000).

In recent years, conservation efforts have improved the status of herbivore species, but many populations remain in a state of decline (Hoffman et al. 2015). Their future requires inputs not only from official government channels but from privately-owned (Clements et al. 2019), often small (Volenec and Dobson 2020) protected areas. Downsides to this include the negative consequences of habitat fragmentation (Fahrig 2017), and the introduction of non-native species and recessive morphological variants to protected areas (Child et al. 2019), potentially derailing evolutionary trajectories as well as inflating α-diversity at the expense of β-diversity. The proposed KIMTRI site Benfontein is considered, from a herbivore perspective, a relatively intact ecosystem that maintains much of its ecological integrity. For one, so-called 'colour variants' are absent from the reserve, and it is also home to one of the few remaining 'pure' (non-hybridized) black wildebeest *Connochaetes gnou* populations (an endemic to the central interior of South Africa). In addition, nearby fossil and sub-fossil deposits preserve a herbivore record that is potentially invaluable for deriving long-term environmental trends.

Objectives

This sub-project will investigate the effects of resource utilization by herbivores by combining long-term records from stable isotope analysis of incremental tissues (primarily horns and teeth) with observational and field experimental evidence for dynamics of resource use. Horns and teeth will be sourced from Late Holocene assemblages like Canteen Kopje (McGregor Museum collections) and Deelpan (Florisbad Research Station collections) in the regions around Benfontein, and from early 20th century collections (Florisbad) to construct a near-continuous record of resource use, at intra-annual scales, over several hundred years. Such series are key to extending the length of time over which forecasting models can be applied. Field experiments using short-term enclosures, housing either single- or two-species systems, will be used to study impacts of exploitation competition on parameters like resource utilization rate and food/habitat selection, and of resource use on vegetational community composition and structure. Observational studies will entail experimental procedures that extend the enclosure experiments using artificial feeding stations to track changes in habitat use over space (and time). Coupling of experimental and observational efforts will allow us to answer key questions about the effects of population density and community species composition on responses to environmental conditions, in particular those based on predictions of the marginal value theorem (Charnov 1976) and ideal-free distribution models of habitat selection (Fretwell and Lucas 1969; Rosenzweig 1991), as well as predictions of niche partitioning and limiting similarity theory (Kartzinel and Pringle 2020), which are all critical for herbivore ecology in low-density environments (Bradbury et al. 2015) such as the arid central interior of South Africa.

Links and Potential Collaborations within the KIMTRI Framework

Data from the fossil and sub-fossil component of this project complements the revised palaeoenvironmental reconstructions that will be produced from new palynological studies (Scott and Van Aarde), and indeed partly rely on those data in order to link trophic dynamics with environmental conditions. The impacts of herbivory on vegetation will also be studied within the context of local vegetation productivity in the region (Urban et al.), and coupled insights from these two sub-projects will also be useful for resolving proximal mechanisms for changes in ecosystem services (Seymour).

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C8: Long term observation of arthropods under a changing climate: which taxa are resilient and which ones most affected?

Rifilwe Modiba (Sol Plaatje University), Evans Mauda (Rhodes University), Kunle Adebowale (Sol Plaatje University)

South Africa is an ecologically diverse country (Mucina et al., 2005), encompassing nine biomes, with an extremely rich flora and high levels of endemism (Cowling and Hilton-Taylor 1997), in part, owing to its heterogeneous landscapes (Cowling et al., 1997). The Northern Cape has the highest number of the country's biomes at six out of the nine (Mucina et al., 2005). However, the province is poorly studied most notably when it comes to arthropods diversity. These biomes not only play a pivotal role in South Africa's tourism sector but also provide valuable ecosystem services, hence there is a need to protect them from anthropogenic changes.

Conservation in South Africa has historically been perceived as a luxury and the concern of the wealthy (Turpie et al., 2008), particularly since almost all conservation efforts focus on protected areas, which tend to be geographic, economic, and sociopolitical enclaves (Turpie et al., 2008). However, most of the biodiversity lies outside of the approximately six percent of the land area that falls within its protected area system (Turpie et al., 2008). As poverty and the demand for urban and agricultural land increases, habitats, and therefore, biodiversity, are increasingly under threat (Turpie et al., 2008). Creative management approaches are required to avert further loss of biodiversity and maintain the functional integrity of ecosystems (MA 2005), especially arthropods since, apart from being keystone species, they are largely used as indicator species. We intend here to use Benfontein Game Reserve (BGR) to carry out a long term monitoring of arthropods diversity.

Objectives

- Investigate invertebrate taxa that occur in Benfontein Game Reserve as part of a long term monitoring programme
- Investigate the influence of climate change on arthropod diversity and determine which taxa are mostly affected
- Determine other driving forces that influence arthropod diversity along with climate change
- Assess the taxonomic and phylogenetic diversity of arthropods across the landscape units of Benfontein using DNA barcoding profile
- Investigate phylogenetic clustering of arthropods along habitat gradients within the Benfontein Game Reserve.

C9: Apex predator guild monitoring

Beryl Wilson (MMK: McGregor Museum, Kimberley)

Ecological guilds are any group of species that exploit the same resources, or that exploit different resources in related ways. They can be viewed in terms of a fractal resource model. This concept arises in several related contexts, such as the metabolic theory of ecology, the scaling pattern of occupancy, and spatial analysis in ecology, all of which are fundamental concepts in defining guilds. It is not necessary that the species within a guild occupy the same, or even similar, ecological niches. However, resource limitations coupled with interspecific variation in morphology, physiology, and life-history traits may lead to niche partitioning among species. How generalist predators partition resources and their mechanisms, however, remain unclear across many ecosystems.

Predators such as carnivores and raptors can fill an important and diverse set of roles within their ecosystems and can exert top-down effects through consumptive and non-consumptive interactions and stimulate bottom-up processes through nutrient translocation across ecosystem boundaries. Changes in predator population dynamics, abundance, and distribution, therefore, may influence food web stability.

The establishment of KIMTRI with Benfontein as a focal point provides the opportunity for many individual and integrated opportunities to monitor and observe trophic relationships, and in our case, the apex predator guild in action in a semi-arid environment and surrounding areas. Subprojects are varied but may include (and are by no means limited to):

- using acoustic telemetry, stable isotope analysis, and visual surveys, combined with published diet and life history demographic information.
- determining spatial and isotopic niche overlap occurred among most species, with variability in partitioning among interspecific interactions.
- determining if predators would exhibit niche partitioning in space, time, and/or trophic interactions
- seasonal variability in habitat use, movements patterns, and trophic interactions may promote coexistence within this area.
- individual specializations and divergent phenotypes, which may lead to intraspecific variability in niche overlap with other predators.
- niche differentiation expressed across multiple organizational levels (i.e., populations and communities) coupled with behavioural plasticity among predators may promote high species diversity despite resource limitations, which may be important when species respond to natural and human-driven environmental change.
- the importance of understanding the potential impacts of changes in predator abundance in the extent of trophic redundancy within predator guilds and how this relates to ecosystem resilience

C10: Wetland inventory and ecological processes

Betsie Milne (SAEON), Doug Harebottle (SPU), Rifilwe Modiba (SPU), Ester van der Westhuizen-Coetzer (EKAPA)

This project sets out to produce a fine-scale wetland inventory of the KIMTRI domain. Apart from mapping all wetlands, we aim to classify wetland types and define the biotic communities and food webs associated with each habitat type. We also aim to study the processes that shape/maintain the communities and their interactions. We further aim to investigate the influence of climate change on the endorheic pans water retention rate over time using GIS.

Specific objectives include:

- Produce a fine-scale map to include all wetlands in the KIMTRI domain
- Develop a baseline habitat typology
- Analyse, characterise and estimate all specific current impacts on these wetlands
- Classify wetland land use zones to understand the cultural-, economical-, educational-, and recreational significance of each wetland as well as to identify possible future threats
- Characterise biotic communities in line with habitat typology
- Develop and implement hydrological, geophysical, geochemical and biotic monitoring parameters
- Develop an interactive platform for Citizen Scientists
- Study the food web structures in each habitat type
- Study the hydrologic regime of each habitat type
- Study branchiopod biogeography and population genetics
- Study movement patterns of waterbirds specifically related to transferors of plant propagules, including invasive aquatic fauna
- Assess criteria for waterbirds as indicators of wetland type
- Study changes of structure of the wetlands over time
- Study changes in the nutrient content of the wetlands over time
- Develop a catalogue of the aquatic invertebrates supported by these wetlands
- Influence of communities and surrounding industries on these wetlands

Stakeholders:

- Practitioners and decision-makers involved in mining and new developments
- Wetland scientists
- Conservation agencies
- Institutions doing integrated development planning for the relevant municipal districts
- Landowners

C11: KIMTRI Agronomic sub-projects

Johan van Tol, Elmarie Kotze, Angelinus Franke & Johan Barnard (University of the Free State, Department Soil Crop and Climate Sciences)

Several agronomic sub-projects are foreseen within the proposed KIMTRI research infrastructure. The focus of these sub-projects will be on the sustainability and productivity of different agricultural practices with special reference to climate change scenarios. The focus will mainly be on crop production practices. Research questions will include, for example:

1) What is the impact of different cultivation practices, e.g. maize/wheat rotations, lucerne production and pecan-nut cultivation on soil biology?
2) What is the long-term productivity of different conservation agricultural practices under irrigation and dryland production systems?
3) What is the impact of conservation practices on wind erosion in semi-arid areas?
4) How practical are current soil suitability guidelines for irrigation in different areas of the greater KIMTRI site?
5) What is the effect of different crop production practices on the release of greenhouse gasses, and how would increase in atmospheric gas concentrations affect these production practices?
6) How does irrigation influence soil health on the medium to long-term?
7) What are the perceptions of farmers towards the potential impacts of climate change?
8) How prepared are the farming systems of the greater KIMTRI site to the impacts of climate change?

We foresee that the EFTEON infrastructure will facilitate research sub-projects to address these and other questions. The infrastructure will therefore assist in capturing the effect of climate and land-use change on food production in the KIMTRI site.

C12: The effect of protected area establishment and degazettement on habitat integrity

Falko Buschke (Centre for Environmental Management, University of the Free State)

Context: Protected area coverage has increased globally, but quantifying the positive effects on biodiversity is limited by experimental constraints. Typical studies of protected area effectiveness compare biodiversity within a protected area to a similar site outside the protected area boundaries. While this is a convenient approximation, it is unclear whether any effects are caused by (a) the active conservation within the protected area or (b) degradation in the unprotected site or (c) unrelated environmental covariates.

Opportunity: The KIMTRI landscape offers a unique opportunity to study protected area effectiveness because it includes a newly established protected area (Mokala National Park, established in 2007), a degazetted protected area (Vaalbos, which was deproclaimed due to land rights claims), and privately protected area (Benfontein Game Reserve). All three sites have similar natural ecosystem coverage, so they allow for a natural experiment to compare:

- The effect of converting farmland to a protected area (compare the Mokala site before and after proclamation).
- The effect of converting a protected area to communal land (compare the Vaalbos site before and after degazettement)
- A suitable natural control site (a comparison to Benfontein during the same time period).

Experimental variables: This study would rely primarily on remotely sensed satellite data between 2000-2020. These include satellite-derived metrics of vegetation coverage; bush encroachment; NDVI and NDWI; human appropriation of NPP; and disturbance regimes (fire, overgrazing, land clearing).

- The primary goal of this study can be met using existing Landsat Data at a 30 m spatial resolution. However, the project would benefit from high-resolution aerial photographs or commercial satellite products, which might be acquired as part of EFTEON.
- Historical meteorological variables collated by EFTEON would be essential covariates for this study.
- Historical game counts collated by EFTEON would provide valuable interpretation value to this project.

C13: Ecosystem services project, centred on Benfontein Game Reserve

Colleen Seymour (Principal Scientist, South African National Biodiversity Institute)

Ecosystem services (ES) are the services that the natural environment (and by extension, biodiversity) gives to humans (Daily, 1997). These services are supplied at various scales: from local (for example, soil nutrient recycling, grazing, pollination) to regional (e.g. water quality and quantity, flood protection) and even to global (e.g. carbon sequestration and evaporative cooling, Davidson, 2017) scales.

Much of the time, humans are unaware of the value of ecosystem services to our lives, and they are only noticed when they break down. Species or aspects of environments that are key to ES provision are often underappreciated, if not completely unknown. Yet, the ability of the natural environment to provide ES is impacted by the state of the biodiversity providing the services. For example, if areas have been heavily grazed, the ability of the vegetation to limit erosion (Thornes, 2005), support pollinators (Tadey, 2015), cycle water (Wang et al., 2016) or even reduce flooding impacts (Lindquist and Wilcox, 2000) is compromised, and may collapse entirely.

Of particular interest in this project, is the interaction between global change (in the form of land use management decisions and climate change) and ecosystem services provided in the landscape around Kimberley. A key component to this research will focus on the camelthorn, *Vachellia (Acacia) erioloba*, the only tree to grow to any size on Kalahari sands with mean annual rainfall < 450 mm. This species appears to be exceptionally slow-growing (Seymour, 2008), yet is considered a keystone species, vital to the persistence of a variety of biota and ecological processes (Dean et al., 1999; Gubb, 1988; Kos, 2007; Seymour, 2009; Seymour and Dean, 2010; Seymour and Milton, 2003). The tree itself fixes nitrogen but has been shown to be associated with higher N content soils, owing to the interactions of wildlife and livestock with the tree and its shade (Dean et al., 1999). With its deep roots, it may be key in water cycling, through hydraulic lift (Scholes and Archer, 1997), making water available to shallower-rooted plants in its vicinity, and thus to the system in general. It is no doubt involved in Carbon sequestration and has been observed to be visited by a variety of different pollinators (C. Seymour, unpublished data). Support by savanna trees of pollinators and natural enemies of crop pests has been shown to be vital to the landscape at large, elsewhere (Henri et al., 2015; Simba et al., 2018), and it is likely that species like V. erioloba may also fill such a role in the Kimberley thornveld landscape. As part of KIMTRI, this project would aim to investigate:

1) What are the ecosystem services provided to the surrounding, regional and global communities by the biodiversity at Benfontein and surrounds, and what is their relative importance to the different communities (at different scales and different socioeconomic brackets or sectors)?
2) How does the quantity and quality of provision of these ecosystem services change with changes in:
    a. Climate
    b. Hydrological and atmospheric variables and
    c. Land use?
3) What is the cost (both in terms of biodiversity and monetary terms) of the degradation of these ecosystem services?

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C14: Palaeoenvironments

Andri van Aardt and Louis Scott (Department of Plant Sciences, University of the Free State, Bloemfontein)

Questions about long-term pre-historical environmental processes are relevant in a wide range of sub-disciplines in landscape studies with aspects relating to climate change, vegetation change, geomorphology, geochemistry, ecology, archaeology and anthropology. Palaeoenvironmental studies have previously been conducted in the KIMTRI region (e.g., Butzer et al. 1973; Butzer 1984; Scott 1976; Scott 1988; Scott and Nyakale 2002; van Aardt et al. 2016). Understanding past processes, however, remains elusive due to a lack of preservation of proxy materials, chronological sample resolution of deposits and the availability of expertise in the field of palaeo-sciences to investigate them. Such information becomes progressively vaguer with geological time. Relatively younger deposits of the Holocene and Late Pleistocene provide the potential for reconstruction of these environments in the region. Older sequences are not completely unavailable but harder to find, e.g., the Florisbad spring deposits (Scott et al. 2019). Proxies such as pollen, phytoliths and bio-geochemical contents can be derived from spring and pan deposits, of which some are available in the KIMTRI region and surroundings. These deposits can be dated by radiocarbon dating or other dating methods.

Objectives are (1) the re-sampling of late Holocene material at Uitzigt spring and nearby donga sequences in the Benfontein area, (2) the Baden-Baden spring near Dealesville, and (3) the Meriba spring near Petrusburg for analyses and radiocarbon dating.

These studies promise outcomes as peer-reviewed papers that will be useful in heritage studies, regional climate change and vegetation history and will also be applicable in conservation management.

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C15: Archaeology and heritage at the KIMTRI core site and the 'greater' KIMTRI area

David Morris (McGregor Museum & SPU) with colleagues at SPU and museum research partners.

Archaeology embraces a wide temporal span from deep time to the recent past and a trans-disciplinary spread of specialisations from palaeoenvironmental reconstruction to heritage issues in the present. The entire spectrum may find expression in sub-projects as part of a KIMTRI research network. Prospects are enhanced by the newly established Sol Plaatje University in Kimberley with its Heritage Studies Department and, as of 2020, a first cohort of post-graduate students.

Archaeology and Heritage components are indicated in Table 1 above (see main proposal).

<u>The following projects may be envisaged</u>:

1. Comprehensive baseline heritage survey: KIMTRI core and 'greater KIMTRI' area. (SPU project).

2. Pleistocene archaeology of Alexandersfontein Pan (Benfontein), linking to wider landscape contexts and projects: Pniel on the Vaal (archaeology and palaeoenvironments); Canteen Kopje (long-sequence and site formation studies); related palaeo-landscape research, western Free State. (Collaborating partners incl. M. Ecker & Toronto University; Wits, National Museum Bloemfontein).

3. Rock art sites on hills in Benfontein catchment in relation to sites in 'greater KIMTRI' landscape. (McGregor Museum/Wildebeest Kuil & SPU).

4. Local indigenous knowledge, e.g. wrt pervasive Watersnake myths (McGregor Museum & SPU)

5. Past human uses (including senses of place) in landscape oscillating through lacustrine to semi-arid scenarios. (All partners)

6. Colonial frontier histories including 1858 'Battle of Benfontein', and multifold events relating to diamond mining and the South African War. (McGregor Museum & SPU).

7. Heritage appreciation, educational and tourism opportunities of the KIMTRI core and hinterland based on intrinsic archaeological, palaeoenvironmental and historical points of interest and value, such as rock art, mid-nineteenth century resistance history, and the mineral revolution following discovery of diamonds. Inform environmental management in a heritage landscape threatened by mining (debris/gravels targeted by diggers). (McGregor Museum/Wildebeest Kuil & SPU; with partners in heritage, education, tourism and environmental sectors).