SANBI
Biodiversity for Life
South African National Biodiversity Institute

National Biodiversity Assessment 2018

Supplementary Material

Compendium of Benefits of Biodiversity

Disclaimer: This work is not intended to be a comprehensive discussion on the benefits of biodiversity. Each of the clusters was undertaken independently and without any review or editing process.

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Contents

Acknowledgements: list of contributors and their affiliations 4
1. Introduction and overview 6
Context and aim of the compendium 6
Summary of key messages from each cluster 12
References 14
2. Biodiversity provides employment 15
Key messages 15
Introduction 16
Conceptual framework 16
Methodology 18
Results 20
Discussion and conclusion 22
References 23
3. Biodiversity contributes to food security 25
Key messages 25
Introduction 26
From the wild 27
On the farm 41
The cascade effect 49
References 55
4. Biodiversity assets are vital for the wildlife economy 61
Key messages 61
Discussion 61
References 64
5. Biodiversity stimulates innovation 66
5.1 Bioprospecting – new products from biological resources 66
5.2 Horticultural gems South Africa gave the world 75
5.3 Crop Wild Relatives – genetic material to support agriculture 84
5.4 Biomimicry – copying nature 89
6. Biodiversity assets are vital for South Africa's tourism economy 94
Key messages 94
Why Nature Matters for Tourism 94
Defining Tourism 94
What is Biodiversity Tourism? 95
References 104

7. Biodiversity provides medicine 105
Key messages 105
Background 106
South Africa's health care systems 107
Benefits of ATM in terms of jobs/opportunities 109
Value of medicinal plant material in use 111
The state of the medicinal plant resource in South Africa 112
References 113
8. Ecological infrastructure case studies 115
Key messages about ecological infrastructure 115
8.1 Inland water resources case studies 115
Inland water resources case study 1: Ecological infrastructure and drought in Cape Town 115
Inland water resources case study 2: EI and water security in the uMngeni River catchment120
Inland water resources case study 3: Socio-economic benefits of restoring EI in the uMzimvubu catchment 124
8.2 Coastal EI case studies – Kosi Bay and Cape Flats 130
Coastal EI case study 1: Kosi Bay 130
Coastal EI case study 2: Cape Flats 135
9. Biodiversity enables responses to climate change and natural disasters 146
Key messages 146
What is EbA? 146
Reference 147
10. Biodiversity enriches every-day life: spiritual and cultural uses of biodiversity 148
11. Biodiversity provides opportunities for citizen science 156
Key messages 156
South African biodiversity and the role citizen science plays in conservation 157
Species and taxonomic group focussed projects in the terrestrial realm 158
Citizen scientists are just as active on the coast and in the ocean as they are on land 173
A sample of monitoring in the inland aquatic realm 174
Projects focused on using technology to interact with citizen scientists 178
South African citizen science today and tomorrow 188
References 189

Note: some government departments changed their names in June 2019. This report may use both names, depending on context. Please refer to www.gov.za to see all the changes in government departments and ministries.

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1. INTRODUCTION AND OVERVIEW

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South Africa is one of the most biodiverse countries in the world. Such a wealth of biodiversity is a national asset that provides many benefits to people, contributing to human wellbeing and economic prosperity. There is substantial and interesting debate about the implications of thinking of nature as a service provider and ecosystems as factories, of valuing nature economically, and of how the different worldviews and values associated with nature produce equally diverse perspectives on issues such as conservation, equity, resilience and ways of achieving the global Sustainable Development Goals. The National Biodiversity Assessment (NBA) 2011 identified 'further research on the links between biodiversity and human wellbeing' as a knowledge gap and a research priority for strengthening future NBAs. The NBA 2018 Core Reference Group (primary technical governance structure for the NBA) acknowledged that a full assessment of benefits of biodiversity, ecosystem services or nature's contributions to people in South Africa is not within the ambit of the NBA. However, there was agreement to produce this **Compendium of Benefits of Biodiversity** as supplementary document to the NBA 2018. The compendium does not utilise international classification systems of nature's contributions to people or ecosystem services, but does illustrate the wide variety of ways that biodiversity and natural systems provide a foundation for economic growth and improved service delivery and human wellbeing – some of the primary intentions of South Africa's National Development Plan.

Context and aim of the compendium

Nelson Mandela, in the foreword for 'Building a new South Africa Volume 4: Environment, Reconstruction, and Development'[1] said: '*Our people are bound up with the future of the land. Our national renewal depends upon the way we treat our land, our water, our sources of energy, and the air we breathe. …Let us restore our country in a way that satisfies our descendants as well as ourselves.*' This recognition of peoples' reliance on the environment and biodiversity was further enshrined in the South African Constitution, which states that everyone has the right to an environment that is not harmful to their health or wellbeing and to have that environment protected for the benefit of present and future generations through reasonable measures. President Cyril Ramaphosa, at the launch of the Biodiversity Economy Operation Phakisa (August 2018), said: *"For millennia, the bountiful natural heritage sustained people in South Africa. It has fed them, healed them, sheltered them and provided the means and the inspiration for cultural expression. The destruction of our biodiversity – the loss of plant and animal species – has grave implications for our own survival and well-being. It affects livelihoods, health, and food and water security. It is our responsibility to treasure and preserve this great natural abundance and to fully realise its potential to provide a better life for all our people."*

South Africa is counted among the 17 megadiverse countries that host the majority of the world's species and has large numbers of species found nowhere else. The variable landscapes, seascapes and extensive coastline provide habitats for a wide variety of plants and animals. South Africa includes three of the world's 36 global biodiversity hotspots. The Cape Floristic Region's extraordinary plant diversity has resulted in it being declared a World Heritage Site. The Succulent Karoo is the only arid biodiversity

[1] Report from the International Mission on Environmental Policy published by International Development Research Centre, 1995

hotspot and has vast numbers of unusual unique succulent plants. The Maputaland-Pondoland-Albany hotspot on the eastern coast combines the diversity of six terrestrial biomes and six marine ecoregions.[2]

Such a wealth of biodiversity is a national asset that provides many benefits to people, contributing to human wellbeing and economic prosperity. Nature contributes to people in a wide variety of ways, from the cultural and spiritual connection with the natural world, to the health that comes from a clean and safe environment, the food that is grown from nature, water and climate protection that nature provides, as well as innovation and employment that arises from economies based on natural resources. Research conducted in 2017 (Turpie et al, 2017) valued just some of the many ecosystem services provided by natural ecosystems in South Africa. It found that ecosystem services related to livestock fodder, harvested resources, tourism, non-use value, carbon storage, pollination, pest control, critical habitats, erosion control, water flow regulation and water quality provided value worth R275 billion per year. This conservative valuation is equivalent to 7% of the country's GDP. Many of these ecosystem services are foundational to other economic sectors.

The benefits that people derive from biodiversity, ecological infrastructure, nature or the environment has been an area of study for many years, particularly since the Millennium Ecosystem Assessment (2000-2005). Language and terminology is continually evolving, with phrases such as 'ecosystem services' and 'ecosystem goods' being common and recently 'nature's contributions to people'. This latter thinking emerged from the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) process (see Box 1). The terminology for the underlying asset upon which the goods, services or contributions rely is also variable, with the use of 'ecological infrastructure' widely used in South Africa as it frames ecosystems as natural analogues of built infrastructure, thereby emphasising that human wellbeing is inextricably dependent on the natural environment as it is on the built environment. The terms 'benefits', 'services' and 'ecological infrastructure' are used throughout the NBA 2018 products and defined in the glossary of the synthesis report as follows:

Benefits of biodiversity: A general term meant to encompass terminology in popular use for various purposes, such as 'ecosystem services', 'ecosystem goods', 'ecological infrastructure', and 'nature's contributions to people'. The NBA 2018 authors felt that 'benefits' is a term that is currently understood well in South Africa by multiple audiences. The work on the term 'nature's contributions to people' (defined as: all the benefits, and occasionally losses or detriments, that humanity obtains from nature), underway through the Intergovernmental Platform on Biodiversity and Ecosystem Services, is fully acknowledged and efforts to find inclusionary terminology that encompasses the diverse world views on the human-nature relationship and further opportunities to incorporate non-monetary values into our discourse are welcomed.

Ecological infrastructure: Naturally functioning ecosystems that generate or deliver valuable services to people. Ecological infrastructure is the nature-based equivalent of built infrastructure, and is just as important for providing services and underpinning economic development. The concept of ecological infrastructure helps to focus attention on the integrity of the underlying stock of ecosystem assets that deliver ecosystem services and benefits, rather than simply the flow of services/benefits. One piece of ecological infrastructure may deliver several ecosystem services or benefits.

Ecosystem services: the benefits that people obtain from ecosystems, including provisioning services (such as food and water), regulating services (such as flood control), cultural services (such as recreational benefits), and supporting services (such as nutrient cycling, carbon storage) that maintain the conditions for life on Earth. Ecosystem services are the flows of value to human society that result from a healthy stock of ecological infrastructure. If ecological infrastructure is degraded or lost, the flow of ecosystem services will diminish. See also Benefits of biodiversity.

The main challenge today and into the future is how we maintain and enhance beneficial contributions of nature to a good quality of life for all people (Diaz et al, 2018). The economic valuation of ecosystem goods and services has been a popular approach to this challenge – with the rationale being that if a monetary value is given to something, then people can understand it more clearly and tend to treat it better. However, Pascual et al (2017) speak about how the different worldviews and values associated with nature's contributions to people produce equally diverse perspectives on issues such as

[2] For more information on South Africa's unique biodiversity, see Section 1.1 of the NBA synthesis report: South Africa's biodiversity profile.

conservation, equity, resilience and ways of achieving the global Sustainable Development Goals. This wide spectrum of values is rarely recognised or explicitly taken into account in decision making, where the economic valuation approach has dominated. Better understanding and recognition of the suite of values associated with nature's contributions to people is thus crucial in sustainability science.

Box 1: About IPBES and terminology emerging from the IPBES assessment processes

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES www.ipbes.net) was established in 2012 as an independent intergovernmental body open to all member countries of the United Nations, with the goal of 'strengthening the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human wellbeing and sustainable development'. Developed in the wake of other international assessments, specifically the Millennium Ecosystem Assessment and the Intergovernmental Panel on Climate Change, IPBES was designed to proactively develop assessments matched to policy needs, and to support capacity building across scales and topics (directly from Diaz, et al. 2015).

The following definitions are emerging from the IPBES process (taken directly from Pascual et al. 2017):

Nature: The non-human world, including co-produced features. Within the context of science, it includes categories such as biodiversity, ecosystems, ecosystem functioning, evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity. Within the context of other knowledge systems, it includes categories such as Mother Earth and systems of life.

Nature's contributions to people (NCP): All the positive contributions or benefits, and occasionally negative contributions, losses or detriments, that people obtain from nature. It resonates with the use of the term ecosystem services, and goes further by explicitly embracing concepts associated with other worldviews on human-nature relations and knowledge systems (e.g. 'nature's gifts' in many indigenous cultures).

From documentation relating to the IPBES consultation and capacity building workshop Bonn, Germany, 4–6 June 2018: The concept of nature's contributions to people is intended to broaden the scope of the widely used ecosystem services framework, including seeking to consider views on human-nature interactions held by disciplines with diverging perspectives as well as by other knowledge systems. It is not intended to replace the concept of ecosystem services. The concept of nature's contributions to people is intended to recognise diverse world-views on human-nature relations and by so doing also embrace the wider body of knowledge held by the social sciences, humanities and indigenous and local knowledge systems, thus giving a more scientifically sound integrated and inclusive perspective on how cultural lenses influence the perception of ecosystem services. The concept of nature's contributions to people also provides greater opportunities to incorporate non-monetary values/valuation into our thinking.

The National Biodiversity Assessment (NBA) 2011 recognised the issue of the values of biodiversity playing an important role in explaining or 'making the case' for recommendations or actions emerging from the NBA. NBA 2011 identified 'further research on the links between biodiversity and human wellbeing' as a knowledge gap and a research priority for strengthening future NBAs, and recommended research to improve understanding and recognition of ecosystem services, the links between biodiversity and ecosystem services, and the potential for integrated management of natural resources to contribute to job creation and poverty alleviation.

Biodiversity is a national asset and a powerful contributor to economic development and job creation. However, this is not always fully recognised in South Africa, especially in market transactions, national accounting, and the allocation of public sector resources; and biodiversity is commonly seen as being in competition with the socio-economic imperatives.

One of the aims of this Compendium of Benefits of Biodiversity is therefore to illustrate how biodiversity and our use of biodiversity contributes to the objectives in the National Development Plan 2030 (NDP), which has the primary goals of reducing poverty and inequality in South Africa. Objectives such as improving the economy and employment, building an inclusive rural economy, health care for all, and

many others in the NDP rely to some extent on biodiversity assets, ecological infrastructure and environmental sustainability and resilience.

A DEA-SANBI process called 'Making the Case for Biodiversity', initiated in 2010[3], combined market research with stakeholder analysis and engagement, and produced a rationale and set of messages that reposition biodiversity and ecosystem services as drivers of the green economy, and a platform on which solutions to service delivery and job creation can be built (see Box 2). This process helped infuse a new language for use by the biodiversity sector and in so doing, lay a foundation for the achievement of the sustainable use, restoration and conservation of biodiversity and ecosystem services. The 'Making the Case for Biodiversity' process also included documenting case studies that provide evidence and communicate the benefits of biodiversity well so that it is taken into account in policies and strategies (see case studies here). While the work concluded officially in 2015, 'Making the Case' thinking continues.

Box 2: More about the 'Making the Case for Biodiversity' messaging

Of the eight messages tested in the 'Making the Case for Biodiversity' process, one was a clear winner, with two others sharing second place:

Biodiversity is a national asset: Biodiversity is natural capital with immense economic significance for South Africa. Ecosystem services such as grazing and pollination underpin our agricultural industry. Estuaries provide nurseries for many of our fisheries, while wetlands naturally purify water. Our tourism industry relies on our natural infrastructure.

Biodiversity is our children's legacy: Every decision Government makes affects the future of biodiversity – a rich or impoverished natural world that we leave for our children and children's children. Nature has given us a world full of wealth – in the form of trees and water, fish and clean air, insects that pollinate and worms that aerate soil, plants that heal and connectedness with our traditions. But the more we take from this store of wealth, the less there is to nourish the next generation. By investing in nature we take care of our families.

Practical solutions: There are feasible actions that Government can take to protect and enhance our natural infrastructure.

These findings demonstrated that biodiversity messaging must first answer a rational need (the 'head' value), then satisfy an emotional need (the 'heart' value). The champions of biodiversity then need to demonstrate practical applications that warrant the allocation of scarce government resources (the 'how to' or 'hands' value). Messaging about biodiversity should address things that society **has to do** because they are national priorities; **wants to do** because they draw on an emotional element; and **can do** because the way forward is practical and implementable.

The central narrative to emerge from the 'Making the Case for Biodiversity' process was:
Biodiversity is the variety of life. Interconnected living things and natural systems provide a foundation for: economic growth (jobs), social development (service delivery) and human wellbeing (a better life). Biodiversity provides clean water, food, medicine and fibre. Biodiversity regulates & mitigates our climate; it protects us from natural disasters like floods, fires and coastal erosion. Biodiversity gives us places to play. Biodiversity empowers us to cope with change. The wealth of South Africans is built upon biodiversity.

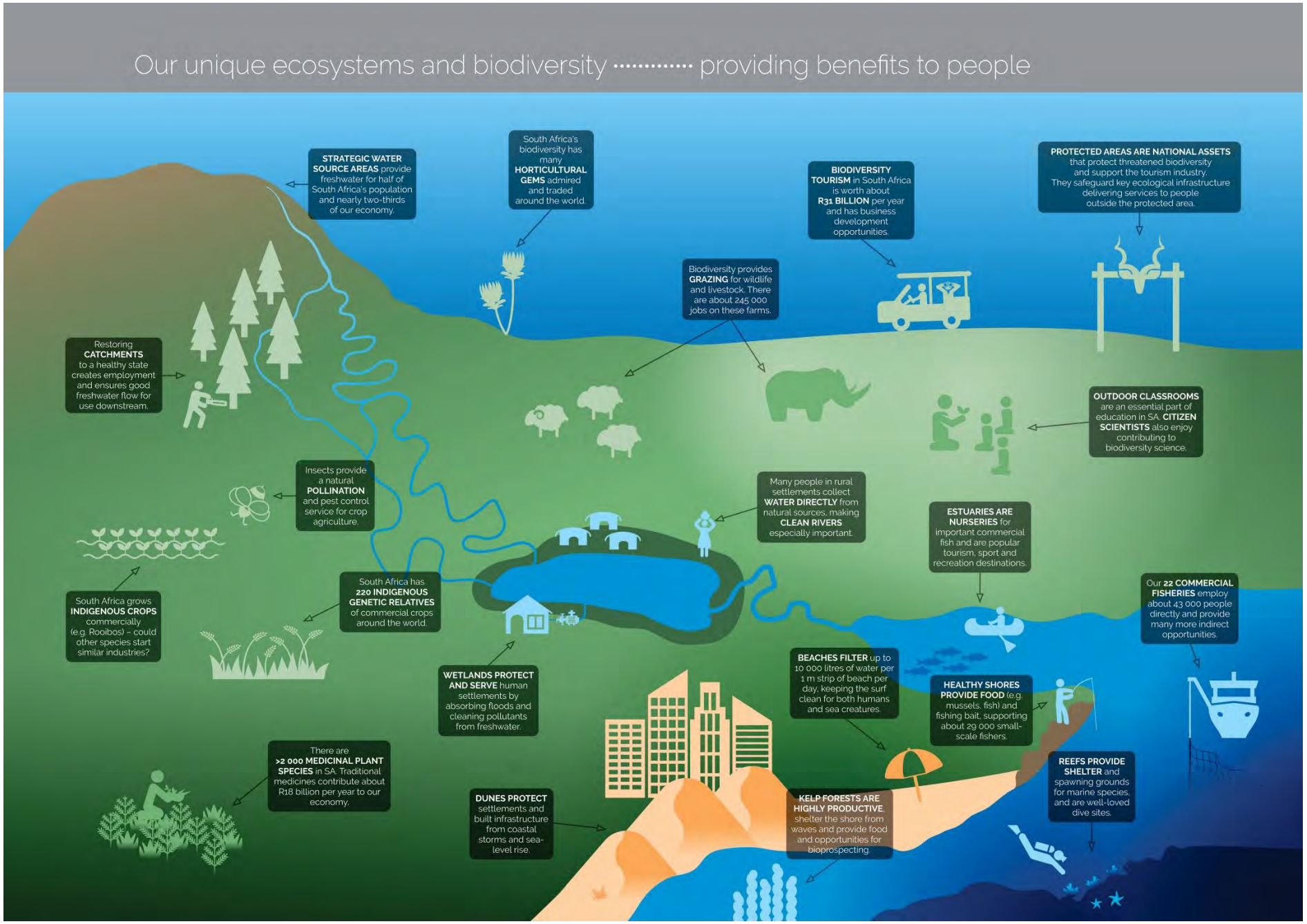
The aim for this compendium was not to undertake a comprehensive assessment of all benefits of biodiversity or nature's contributions to people. There is substantial work ongoing both in South Africa and internationally in this arena. The aim was to continue in the vein of providing the evidence for the 'have to – want to – how to' (head-heart-hands) biodiversity messaging important to South Africa's socio-economic imperatives. This work was undertaken in several clusters, each with several lead and contributing authors.

[3] The Making the Case for Biodiversity Project Phase I (2010-2011) focused on developing a set of core messages, followed by Phase II (2021-2015) which focused on developing a sector messaging strategy.

Rather than using international classification systems for ecosystem services or nature's contributions to people as a starting point,[4] the benefits of biodiversity were grouped into several clusters, identified through an iterative process involving the NBA Core Reference Group. Unlike the classes in a formal classification system, which must be mutually exclusive and comprehensive, the clusters were recognised to overlap and not to cover every benefit of biodiversity. Their primary purpose was to link biodiversity to national policy priorities and societal goals. This approach provided flexibility and facilitated collaboration across realms and themes in articulating the benefits of biodiversity in a way that speaks to a wide, non-scientific audience.

Each cluster of benefits of biodiversity had a lead author and contributing authors. Hyperlinks and reference lists for further reading are provided in each cluster. Work for each of the clusters was undertaken independently of the others, using varying methods and without a formal review or editing process. Future NBAs could further explore and formalise the work for the clusters of benefits of biodiversity presented in this Compendium and could also identify additional clusters.

[4] There are several of these, including the Common International Classification of Ecosystem Services (CICES, https://cices.eu), the Final Ecosystem Goods and Services Classification System (FEGS-CS, https://www.epa.gov/eco-research/final-ecosystem-goods-and-services-classification-system-fegs-cs), and an emerging classification system for nature's contributions to people associated with the IPBES.



Infographic illustrating some of the benefits of biodiversity across the landscape and seascape © SANBI (with thanks to Bianca Fizzotti for first design)

Summary of key messages from each cluster

This summary is the key messages from each cluster, but there is a wealth of additional information in the chapter for each cluster, so please take the time to delve into the chapters in more detail.

Overarching message: South Africa has globally exceptional biodiversity that provides a wide array of benefits to the economy, society and human wellbeing. Biodiversity-related jobs rival the mining sector in terms of numbers, and the biodiversity tourism industry is worth R31 billion per year. Intact ecosystems and high species diversity are essential for ecosystem services, healthy populations of crop pollinators and natural predators of crop pests, as well as for the survival of wild relatives of commercial crops and for the increased carrying-capacity of natural rangelands for both livestock farming and wildlife ranching (the latter worth R14 billion per year). The harvesting of edible plants, edible insects and medicinal plants from the wild is widely practiced in South Africa and is particularly important as part of the rural economy. Our natural ecosystems, plants and animals have influenced our cultural and spiritual development, and are woven into languages, place names, religion and folklore. This web of associations with biodiversity forms an important part of South Africans' national identity and heritage.

South Africa's biodiversity provides substantial **employment** in a range of sectors. For every one job involved in managing and conserving biodiversity, there are five jobs in economic sectors that depend on biodiversity. This means that continued investment in biodiversity conservation helps to provide sustainable employment, contributing to one of South Africa's primary national development goals. Jobs directly related to biodiversity total approximately 418 000, and this is likely an underestimate. This is comparable to the number of jobs in the mining sector and represents 2.6% of national employment. For every job dedicated to conserving biodiversity (e.g. in protected areas or conservation authorities), there are approximately five other jobs that depend on utilising biodiversity. These jobs are in sectors such as fisheries, wildlife ranching, biodiversity tourism, traditional medicine and indigenous tea production. Many biodiversity-related jobs are outside major urban centres and are labour intensive, contributing to rural development, poverty alleviation and inclusive growth. In a context where employment in traditional sectors such as manufacturing and agriculture is declining, biodiversity-related employment is based on a renewable resource that, if appropriately managed, can provide the foundation for long-term economic activity and growing numbers of jobs. This means that efforts to conserve and manage biodiversity should be seen not as a cost to the economy but as an investment in a resource that supports wider economic activity and employment.

Biodiversity is essential for **food security**. Biodiversity plays an important role in commercial agriculture, which supplies food in large quantities to the majority of the population. Natural patches that surround farms are the source of pollinators and natural enemies of agricultural pests. Fruit and vegetable crops, which are often pollinated by animals, contain nutrients that are important for health. South Africa is unique in that it uses two indigenous sub-species of bees for pollination, which are far more disease resistant than managed alien honey bees used in other parts of the globe. Natural predators also help to control pests that destroy crops. More than 70% of South African land is used as grazing for livestock or game, sectors that are extremely important to the South African economy because only 11% of our agricultural land is suitable for cultivation. In many parts of South Africa, the poorest people rely on foods collected directly from the wild, including 1 300 edible plant species and many edible types of insect. Numerous coastal communities rely on subsistence fishing for food, and South Africa's 22 commercial fisheries extract many species of seafood from the ocean. In addition to direct benefits, there are numerous soil, nutrient cycling and water-related ecosystem services that create the necessary environment for productive agriculture and that support the harvesting of wild species for food.

South Africa has a growing **wildlife economy** based on indigenous herbivorous mammals. There are approximately 10 000 wildlife ranches that engage in a range of commercial activities such as ecotourism, intensive game breeding, live game sales, trophy hunting and biltong hunting. Game meat and biltong are produced from 21 different species. The most recent estimates show that the economic contribution of the sector may be as much as R14.4 billion, directly providing 65 000 jobs. The fact that wildlife can be private or communal property has resulted in stable or increasing large mammal populations in South Africa. This industry relies heavily on biodiversity, and wildlife ranching is a vitally important land use for both socio-economic development and biodiversity conservation. However, it can have negative impacts on biodiversity if conducted too intensively.

Biodiversity resources are the source of economically important **innovations**. Bioprospecting and biotrade are the research and commercial application of indigenous resources. A survey of retail stores found 549 products containing indigenous South African species. Aloe, Rooibos, Honeybush, Baobab and Hoodia are just some local plants have been used in lucrative international medicinal, cosmetic or food products. Although the South African cut flower industry is small, many South African flower species are in high demand in global flower markets, such as strelitzia, protea and gerbera daisy. South Africa has a list of 1 593 species that are the wild relatives of commercial crops, which may be useful in the future for plant breeding or in developing new commercial food crops. Biomimicry is the process of learning from nature and emulating its forms and processes in engineered situations. Several biomimicry solutions have been gleaned from South African species, such as tougher ceramics based on the strong structure of abalone shells, wind turbine design based on whale flippers, and architectural cooling based on termite mounds.

Many local and international **tourists** travel in South Africa to take part in nature-based activities and to view and enjoy biodiversity. In 2015, the tourism industry was worth R249 billion or 3% of GDP. Tourist involvement in biodiversity and nature varies in intensity with some tourists seeking out nature-based experiences, such as scuba diving, hiking or game safaris, while others appreciate nature incidentally while enjoying other activities. In 2015, approximately 12% of international and domestic tourism demand in South Africa, or R31 billion, was based on biodiversity, and biodiversity tourism supported 88 000 direct jobs. For domestic travellers, it is estimated that a quarter of all day trips and 30% of overnight trips are focused on a biodiversity-related activity. The natural environment is a draw-card for international tourists and 14% visit a natural attraction while in the country. Birding, or avitourism, is a significant niche tourism sector that attracts as many as 40 000 tourists annually, who spend up to R618 million.

There are approximately 2 000 **medicinal plant species** in South Africa, and around 656 are commonly-traded. Remedies that use medicinal plants are based on centuries of cultural practice and indigenous and knowledge. The traditional medicine sector operates in parallel with allopathic medicine. Traditional medicines are used by 70% of South Africa's people, are essential to the work of some 200 000 Traditional Health Practitioners and provide a further ~93 000 income generating activities in the informal sector for harvesters and traders. It is estimated that the informal African Traditional Medicine (ATM) industry is valued at about R18 billion per year. As much as 40 000 tonnes of medicinal plant raw material are traded per year in the informal sector. Increases in volumes traded are having a negative impact of the threat status of a number of species: 82 medicinal plant species are threatened (14 Critically Endangered species, 19 Endangered and 49 Vulnerable) and a further 100 species are of conservation concern (e.g. Near Threatened, Rare or Data Deficient).

South Africa is a water scare country, and **ecological infrastructure** such as healthy catchments, wetlands and riparian areas supports numerous water-related ecosystem services, including regulating the flow and quality of water. Ecological infrastructure on the coast, such as dunes and kelp forests, provides protection of built infrastructure from natural hazards, and many estuaries provide a nursery function for important fish species. Maintaining functional ecological infrastructure in strategically important areas will secure and improve various ecosystem services important to South Africans. **Ecosystem-based adaptation** is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. Maintaining functional ecological infrastructure can contribute to ecosystem-based adaptation and help to protect people from climate change.

Experiencing nature has mental and physical health benefits and is important for South African's **everyday wellbeing**. Studies show that natural green spaces can improve the mental health of urban residents, and an active outdoor lifestyle can promote physical wellness. Natural areas in cities can help filter out air pollution and reduce urban heat effects. There are some exceptional natural areas that are associated with cultural and spiritual beliefs and are considered sacred sites. Biodiversity also provides opportunities for education (outdoor classrooms) and for ordinary citizens to contribute to biodiversity science across the country.

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2. BIODIVERSITY PROVIDES EMPLOYMENT

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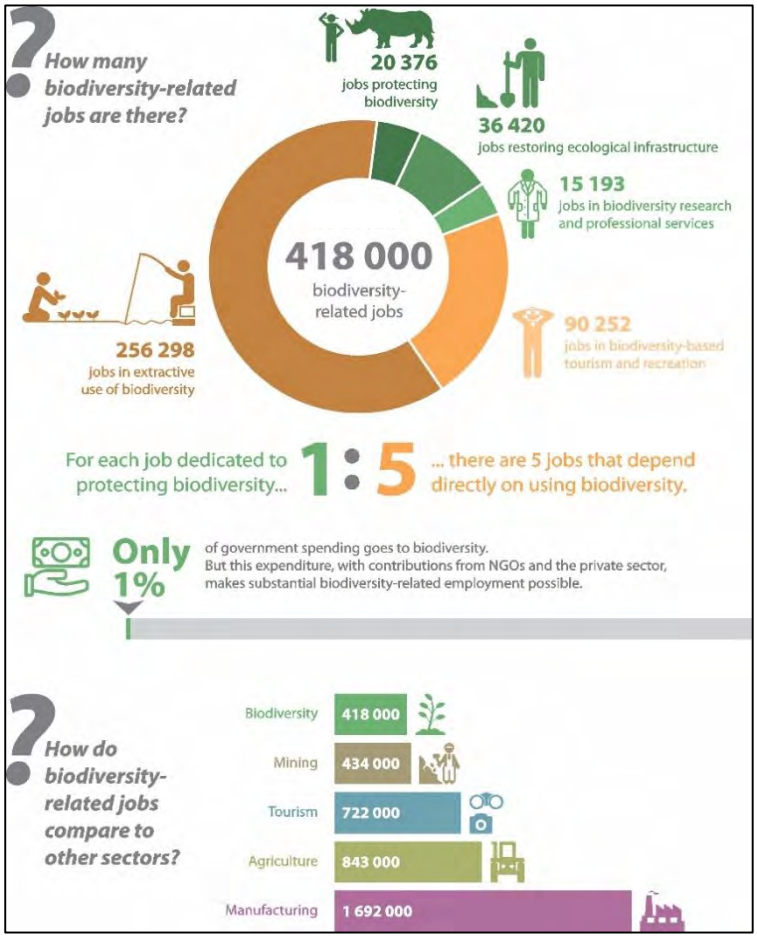
Note: This is a summary of Driver, A., Mukhadi, F. & Botts, E.A. 2019. An initial assessment of biodiversity-related employment in South Africa. Developed by the South African National Biodiversity Institute (SANBI) in collaboration with the Development Policy Research Unit. Working Paper 201902. DPRU, University of Cape Town.

Key messages

South Africa's biodiversity provides substantial employment in a range of sectors. For every one job involved in managing and conserving biodiversity, there are five jobs in economic sectors that depend on biodiversity. This means that continued investment in biodiversity conservation helps to provide sustainable employment, contributing to one of South Africa's primary national development goals.

Jobs directly related to biodiversity total approximately 418 000, and this is likely an underestimate. This is comparable to the number of jobs in the mining sector and represents 2.6% of national employment. For every job dedicated to conserving biodiversity (e.g. in protected areas or conservation authorities), there are approximately five other jobs that depend on utilising biodiversity. These jobs are in sectors such as fisheries, wildlife ranching, biodiversity tourism, traditional medicine and indigenous tea production. Many biodiversity-related jobs are outside major urban centres and are labour intensive, contributing to rural development, poverty alleviation and inclusive growth.



In a context where employment in traditional sectors such as manufacturing and agriculture is declining, biodiversity-related employment is based on a renewable resource that, if appropriately managed, can provide the foundation for long-term economic activity and growing numbers of jobs.

This means that efforts to conserve and manage biodiversity should be seen not as a cost to the economy but as an investment in a resource that supports wider economic activity and employment.

Introduction

As one of the most biologically diverse countries in the world, South Africa has an extraordinary wealth of biodiversity assets and ecological infrastructure. These biodiversity assets are ecosystems and species that generate social, cultural or economic benefits, including supporting livelihoods, providing the basis for economic activity, and contributing to human wellbeing. Ecological infrastructure refers to naturally functioning ecosystems that generate and deliver valuable services to people, such as freshwater, climate regulation, soil formation and disaster risk reduction. As the nature-based equivalent of built infrastructure, ecological infrastructure is just as important for providing services and underpinning socio-economic development.

South Africa also has an employment crisis. Unemployment was already high in the 1990s (Stats SA, 1998), and the poor state of employment has persisted and worsened over the last 15 years (Stats SA, 2015). Ongoing job losses are occurring within primary and labour-intensive sectors of the economy, such as manufacturing and agriculture.

There is some evidence indicating that jobs related to biodiversity may be substantial, and that the potential to generate future employment may be significant. A global study estimated that as much as 35% of the workforce in developing countries could be dependent on biodiversity (Nunes et al. 2010). The Green Jobs Report for South Africa projected that over 230 000 jobs could be created in the category of natural resource management over the long term (Maia et al., 2011). The Biodiversity Economy Strategy for South Africa includes ambitious targets for employment related to biodiversity (DEA, 2017).

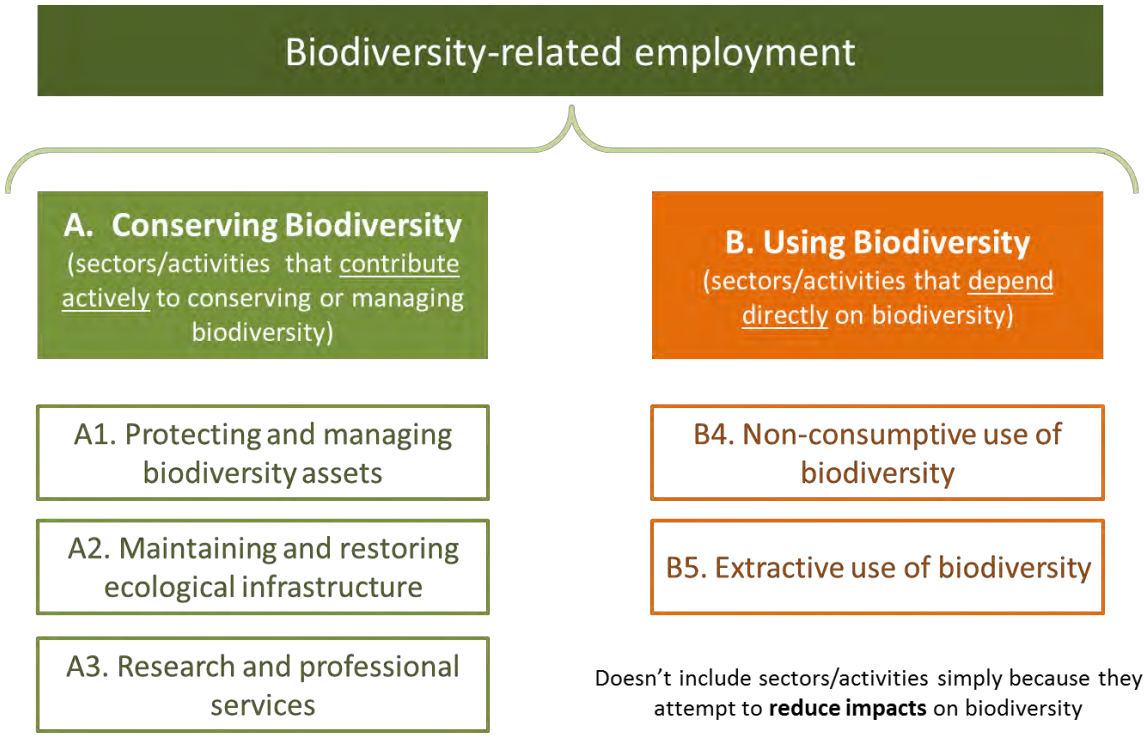
The extent to which South Africa's biodiversity assets and ecological infrastructure contribute to employment is currently not well quantified. However, biodiversity-related jobs could be a useful indicator of the socio-economic benefits of biodiversity. Therefore, this research was undertaken to investigate methods for estimating biodiversity-related employment in South Africa and provide an initial baseline estimate of the current number of biodiversity-related jobs.

Conceptual framework

The starting point for measuring jobs related to biodiversity is to conceptualise clearly what is meant by biodiversity-related employment, in order to guide the scope of the measurement. By clearly defining what is meant by the 'biodiversity economy', jobs linked to biodiversity-related economic activity could then be considered biodiversity-related employment.

The Economics of Ecosystems and Biodiversity (TEEB) project recognised two ways that business can be linked with biodiversity, firstly through business impacts on biodiversity and secondly through business dependence on biodiversity (TEEB, 2012). Businesses that attempt to reduce their impacts on biodiversity, for example through renewable energy or waste reduction, are considered part of the 'green economy' (UNEP, 2013). Businesses that depend on biodiversity are can be considered part of the 'biodiversity economy'.

South Africa's Biodiversity Economy Strategy adapts a definition for the 'biodiversity economy' proposed by the WWF (Van Paddenburg et al., 2012). This definition encompasses "businesses and other economic activities that either directly depend on biodiversity for their core business or that contribute to conservation of biodiversity through their activities" (DEA, 2017). Fundamental to this definition is that it sets out two broad categories of biodiversity-related economic activities: those that contribute directly to conserving biodiversity, and those that depend directly on using biodiversity. Given this definition, the diagram below shows the conceptual framework that was used to estimate biodiversity-related employment.



The conceptual framework used to estimate biodiversity-related employment.

The sub-categories of biodiversity-based employment were defined as:

A1. Protecting and managing biodiversity assets: Jobs directly involved in conservation of the country's biodiversity assets, both ecosystems and species. This includes management of protected areas and conservation areas, efforts to conserve particular species, and mainstreaming of biodiversity into planning and decision-making outside of the protected area network.

A2. Restoring and maintaining ecological infrastructure: Jobs aimed at restoring the functioning of ecosystems to improve their ability to generate and deliver valuable services to people. This includes a range of natural resource management and catchment management activities that contribute to maintaining healthy ecosystems, such as removing invasive alien plants to improve water supply, or restoring wetlands to improve water quality and prevent flooding.

A3. Research and professional services related to biodiversity: Jobs that contribute to knowledge of biodiversity, forming the foundation for effective management of biodiversity as well as innovation in the management and sustainable use of biodiversity. This includes the work of universities, other research institutions, biodiversity consulting services and biodiversity information management.

B4. Non-consumptive use of biodiversity: Jobs that depend on the enjoyment of biodiversity but do not involve extraction or consumption of the underlying biodiversity asset and can thus be sustained on a long-term basis. This includes nature-based tourism, some adventure sports, and the production of media and art related to biodiversity.

B5. Extractive use of biodiversity: Jobs that depend on the direct extraction or consumption of biodiversity, either for profit or subsistence. This includes game ranching and hunting, rangeland agriculture, harvesting of wild indigenous resources, biotrade, cultivation of indigenous species, processing or manufacturing of products based on indigenous resources, and bioprospecting. Some of these activities can, at least in principle, be compatible with the long-term persistence of biodiversity if they are appropriately managed.

Two broad categories and five sub-categories of biodiversity-related employment were identified

Methodology

The methods developed represent the first effort towards developing a standardised national methodology for measuring biodiversity-related employment, which could be repeated at regular intervals to measure trends in employment.

Other sectors generally use national survey data on employment, which is readily available at regular intervals and presents a convenient and cost-effective data source for measuring trends. However, a key challenge is that biodiversity-related jobs are scattered across various industry and occupational classifications that are conventionally used in the National Statistical System. Recognising that such data may only provide a partial picture, other data sources where considered.

Administrative data

Lists of organisations involved in biodiversity-related activities in different categories were developed, based on extensive working knowledge of the sector. Although the attempt was made to be comprehensive as possible, some organisations are likely to have been missed and further feedback will identify gaps. For the listed organisations, relevant external data sources on employment, such as annual reports or online organisational information, were identified and accessed.

For those organisations whose core mandate focuses on biodiversity, all employees were counted as contributing to biodiversity-related employment, including jobs in supporting functions such as administration, finance and marketing. For organisations that have part of their mandate related to

biodiversity, only those programmes or sections directly focused on biodiversity were included. Organisations for which biodiversity is a secondary part of their function generally do not have specific programmes or sections dedicated to biodiversity-related work. For these organisations an estimated proportion of the jobs in relevant programmes were included.

Levels of confidence are relatively high for administrative data for organisations whose core mandate is biodiversity-related, as it is a relatively straightforward matter to acquire total employment numbers for these organisations. For organisations with only part of their mandate related to biodiversity, or with biodiversity as a secondary mandate, more uncertainty is introduced because assumptions have to be made about which programmes or sections should be counted as biodiversity-related.

Existing sector estimates

The biodiversity economy includes several identifiable commercial or subsistence sectors or sub-sectors that depend on biodiversity (such as nature-based tourism, game ranching and hunting, fisheries and traditional medicine). For some of these sub-sectors, studies have been done estimating their size, their contribution to the economy and to employment. Relevant reports and papers were sourced to glean information about biodiversity-related employment where possible.

A challenge with existing sector estimates is that they come predominantly from grey literature, with varying degrees of reliability, and are frequently not up to date. The studies from which the employment numbers were drawn for this research were only those that were assessed to be credible and well considered. Nevertheless, overall levels of confidence in the sub-sector estimates are lower than levels of confidence in the administrative data. A further key weakness for this data source is that estimates are only available for a subset of biodiversity-related sectors, with many gaps, for example, indigenous horticulture, harvesting and processing of natural fibres, grass-fed livestock and pharmaceuticals based on indigenous species.

In the case of tourism, Stats SA produces an annual Tourism Satellite Account that quantifies the economic contribution of the tourism sector. As discussed in the section on results below, this was used as the basis for developing an estimate for jobs related to biodiversity tourism.

Survey data from the National Statistical System

In South Africa, labour market surveys are undertaken by Statistics South Africa (Stats SA). The Quarterly Labour Force Survey (QLFS) is a household-based sample survey which collates data from 30 000 households each quarter on the number of people who are employed, unemployed or not economically active. Those QLFS respondents who are employed are required to give a brief description of the type of work they do, which is used to assign each respondent to an industry and an occupation code. QLFS data are annualised as the Labour Market Dynamics Survey (LMDS).

Some of the QLFS codes at the more detailed levels can be linked to biodiversity. The industry or occupation codes were assigned to groups in which all, some, few or no jobs could relate to biodiversity. In some cases, this required a judgement call based on the description for each code, combined with knowledge of industries and occupations related to biodiversity. A proportion of the QLFS estimate was then taken, with 85% of the jobs in the category with ‘all’ jobs related to biodiversity, 40% in the category ‘some’, and 3.5% in the category ‘few’. The choice of these proportions was ultimately arbitrary but erred on the side of being conservative.

Results

The results based on administrative data, existing sector estimates and Stats SA data have varying levels of confidence, as well as different advantages and disadvantages for certain categories of biodiversity-based employment. Some data sources were more reliable for some employment sub-categories than others. The different data sources can be seen as complementary rather than as mutually exclusive alternatives. To create a total estimate, the most reliable estimates across the various data sources were combined. The total estimate of approximately 418 000 jobs thus draws on a combination of all three data sources.

Results based on administrative data

In general, administrative data are considered fairly reliable, provided that they can be comprehensively gathered. Since it was relatively easy to list organisations involved in sub-categories *A1: Protecting and managing biodiversity assets* and *A2: Restoring and maintaining ecological infrastructure*, this was the preferred data source for these categories. A total 96 organisations were listed across these two sub-categories, predominantly including public sector organisations and non-governmental organisations (NGOs).

Based on 2014 information, a total of 20 376 jobs were counted within *Sub-category A1: Protecting and managing biodiversity assets*, which includes the management of South Africa's more than 500 state-owned protected areas, as well as work beyond the boundaries of protected areas. Public entities and provincial conservation authorities accounted for the bulk of these jobs. A further 36 420 jobs were counted in *Sub-category A2: Restoring and maintaining ecological infrastructure*, with jobs related to the Expanded Public Works Programme (EPWP) making up most of these. These jobs are presented as full-time-equivalents, as using the total number of short-term work opportunities created would unduly inflate the figures in this category.

The difficulties in comprehensively listing organisations involved in *Category B: Using Biodiversity*, meant that administrative data was insufficient to provide a meaningful result in this category.

Results based on survey data from the National Statistical System

For *Sub-category A3: Research and professional services*, occupation codes from QLFS data are able to distinguish people working in various specific disciplines, include occupations such as botanist, zoologist, biological scientist or natural science technician. This sub-category also likely has a substantial private sector component in the form of specialist consultants, who may not be identified in the administrative data. For this reason, QLFS data is considered the most reliable data source for Sub-category A3. An estimate of 15 193 jobs in 2017 was made based on data extracted from the LMDS (comprising QLFS data pooled annually).

Employment in *Sub-category B4: Non-consumptive use of biodiversity* is primarily related to biodiversity tourism. Job numbers for this sub-sector were initially estimated using QLFS industry codes, particularly those relating to tourism accommodation, adventure sports and recreational activities. This gave an estimate of 86 000 based on 2014 data. However, SANBI subsequently commissioned a study to quantify the extent to which tourism relies on South Africa's biodiversity assets (Bac & Tlholoe, 2017). This study produced a model for employment in biodiversity-related tourism based on the Tourism Satellite Account published by Stats SA. The resulting finding was that 12.5% of all tourism jobs in the country could be attributed to biodiversity. Based on the Tourism Satellite Account for 2015, this amounted to 88 400 biodiversity tourism jobs, corresponding closely to the 86 000 estimated using the QLFS industry codes for 2014. Based on the most recently available Tourism Satellite Account for 2017 (Stats SA, 2018) as the preferred data source, employment in *Sub-category B4: Non-consumptive use of biodiversity* was updated to 90 252 in 2017.

Results from existing sector estimates

Estimates based on existing estimates for particular sectors were sourced for four sectors within *Sub-category B5: Extractive use of biodiversity*, and amounted to just over 256 000 jobs in total. The largest estimate was for trade in traditional medicine, for which an estimate of 133 000 jobs was available based on synthesis of the research findings from four seminal studies (Mander et al., 2007). The estimate includes harvesters, healers, and street traders, as well as jobs in transportation, wholesale, processing and packaging of muti. An estimate of 71 060 direct jobs in wildlife ranching and hunting was based on a detailed study led by the Endangered Wildlife Trust (Taylor et al., 2015), using updated hectarage of wildlife ranching in 2018. This estimate is restricted to permanent employment directly on wildlife ranches, and excludes temporary employment and employment in related industries such as wildlife translocators, fencing businesses, and taxidermists. A 2010 source for employment in fisheries was used (Feike, 2010), giving a detailed estimate of 43 458 direct jobs across 21 commercial fisheries, mostly jobs on vessels and in processing factories. Employment in the rooibos and honeybush tea industries was derived from estimates produced by the Rooibos Council (Rooibos Council, 2018) and the Department of Agriculture, Forestry and Fisheries (DAFF, 2016) and amounted to 8 780 direct jobs.

The results available from existing sector estimates do not represent the full set of biodiversity-related economic activities, and can thus be considered an underestimate of the number of jobs in *Sub-category B5: Extractive use of biodiversity*. Existing sector estimates that are available are based on surveys or first-hand information from industry stakeholders, which is reliable, although sometimes out of date. In future it may be possible to include employment estimates for additional sub-sectors if these become available, such as indigenous horticulture, harvesting and processing of natural fibres, grass-fed livestock and pharmaceuticals based on indigenous species. Further work to identify additional sectors for which estimates are already available, or could be developed, would be worthwhile.

Comparison and total estimate

Across all the different categories of biodiversity-related employment, a total of 418 000 jobs were counted (Table 1). This is likely to be an underestimate, given that there are probable gaps in this data, arising from factors such as missing organisations among the administrative data, limited availability of existing employment estimates for some sub-sectors and lack of knowledge about jobs indirectly based on biodiversity across wider value chains. Of the 418 539 total jobs, 17% (72 000) come from *Category A: Conserving biodiversity* and 83% (346 000) come from *Category B: Using biodiversity*, giving a ratio of approximately 1:5. This suggests that for every job dedicated to conserving biodiversity, there are approximately five jobs that depend directly on using biodiversity.

The best estimates available have been used; nevertheless, the date range for these estimates is broad, between 2007 and 2018. To facilitate tracking the number of biodiversity-related jobs over time, it was necessary to pin the total estimate to a particular year, recognising that this is somewhat arbitrary. We have chosen 2017, which is the date for the Tourism Satellite Account figures used for Sub-category B4 and the QLFS data used for Sub-category A3.

Table 1: Biodiversity-related employment estimates across the five employment categories, with the preferred data source and date range.

Category	Data source	Date	Estimate
A1: Protecting and managing biodiversity assets	Administrative data	2014	20 376
A2: Restoring and maintaining ecological infrastructure	Administrative data	2014	36 420
A3: Research and professional services	QLFS occupation codes	2017	15 000
Sub-total: Conserving Biodiversity			72 000
B4. Non-consumptive use of biodiversity	Tourism Satellite Account	2017	90 000

B5. Consumptive use of biodiversity	Existing sector estimates	Various	256 000
Sub-total: Using Biodiversity			346 000
TOTAL			**418 000**

Table note: Estimates based on QLFS data and existing sector estimates were rounded to the nearest '000 to reflect the relative uncertainty associated with these figures.

Discussion and conclusion

Methodological findings and recommendations

A key objective of this research was to establish a systematic, repeatable method for measuring biodiversity-related employment. A national indicator on biodiversity-related employment is feasible to develop and track over time, and could provide a meaningful measure of the socio-economic contribution of South Africa's biodiversity assets. Such an indicator would require a methodology that draws on multiple data sources.

Although administrative data are time-consuming to collect, they provide a reliable data source for biodiversity-related employment in the public and NGO sectors. Improvements could be made by ensuring a comprehensive list of biodiversity organisations, refining estimates where only part of an organisation's mandate is relevant, and exploring options for administrative data in other sub-categories of biodiversity-related employment.

The QLFS data are readily available and proved useful for estimating employment in Sub-category A3, so should also remain a component of the methodology. Further work could confirm the correct allocation of occupation codes to Sub-category A3 and refine the proportions used in these estimates. Engagement with Stats SA to better understand the codes should be explored.

Given the inherent limitations of using QLFS data to identify some categories of biodiversity-related employment, existing sector estimates are likely to remain an essential component of the methodology. However, there is no standard methodology for developing such estimates, and they tend to be undertaken on a once-off basis. Future work should identify additional sub-sectors for which existing estimates may be available, and prioritise sub-sectors for which estimates should be developed. A set of guidelines or requirements for developing credible sector estimates to contribute to the national indicator on biodiversity-related employment could be developed.

Key employment findings and policy implications

To put the initial total estimate in context, it is useful to compare it to other employment statistics at a national level. The estimate of 418 000 biodiversity-related jobs can be compared with approximately 434 000 jobs in the mining sector, 843 000 jobs in the agricultural sector, 1.7 million jobs in manufacturing (Stats SA, 2017) and 722 000 jobs in tourism (Stats SA, 2018). At 418 000 jobs, biodiversity-related employment represented 2.6% of national employment of 16.2 million in 2017 (Stats SA, 2017).

An advantage of biodiversity-related employment is that it is based on a renewable resource that, if appropriately managed, can provide the basis for ongoing economic activity in the very long term. In a context where employment in traditional sectors such as manufacturing and agriculture is declining, biodiversity-related sectors could provide a source of sustainable long-term growth. Tourism in particular is regarded as a rapidly growing sector globally and in South Africa, and is estimated to provide an increasing number of jobs nationally. National tourism and economic growth strategies could incorporate biodiversity tourism as an area for targeted support and investment.

This research did not extend to analysis of the spatial distribution and skills profile of biodiversity-related employment. However, a case could be made that many biodiversity-related jobs are located outside major urban centres, and that they are likely to include a substantial proportion of low-skilled jobs. This suggests that growth in biodiversity-related sectors could support rural development, poverty alleviation and inclusive growth.

A major finding of this research is that for every job dedicated to conserving or managing South Africa's biodiversity assets and ecological infrastructure, approximately five jobs depend on utilising biodiversity. The implication is that current efforts to conserve and manage biodiversity should be seen not simply as an end in themselves or a cost to the economy but rather as an investment in a resource that supports wider economic activity and employment. A key challenge is to ensure that activities in *Category B: Using Biodiversity* are sustainably managed and are not depleting the underlying biodiversity assets on which they depend. Many of the public sector and NGO jobs in *Category A: Conserving biodiversity* make an essential contribution in this regard.

Sub-category A2: Restoring and maintaining ecological infrastructure includes large numbers of employment opportunities related to managing and conserving ecological infrastructure, which currently take the form mainly of short-term work opportunities through government's Expanded Public Works Programme. However, restoring and maintaining ecological infrastructure is not a once-off activity but requires sustained effort, in the same way that most forms of built infrastructure (such as roads) must be regularly maintained if they are not to become dilapidated. Recognising this, alternative models for this type of employment should be considered, rather than restricting it mainly to short-term work opportunities.

In summary, key policy-relevant findings and recommendations of the work presented here include the following:

- South Africa's biodiversity assets provide substantial employment in a range of sectors, and should be seen as a public good that contributes to the economy.
- For every job dedicated to conserving or managing South Africa's biodiversity assets and ecological infrastructure, there are approximately five jobs that depend on utilising biodiversity
- Development based on biodiversity assets and ecological infrastructure has the potential to support growth in non-traditional sectors and to provide employment outside major urban centres.
- Public sector expenditure on managing and conserving biodiversity assets can be seen as an investment in a resource that supports employment rather than simply as a cost.
- Continued investment in managing and conserving biodiversity assets, led by the public sector, is essential to ensure that private sector economic activities that depend on biodiversity are sustainably managed and do not deplete the underlying natural resource base.
- Investment in restoring and maintaining ecological infrastructure should be approached as a long-term endeavour and should be seen as an opportunity to create long-term employment in labour-intensive activities.
- Biodiversity-related sub-sectors that are growing or have the potential to grow should be the focus of support through industrial policy and related interventions.

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3. BIODIVERSITY CONTRIBUTES TO FOOD SECURITY

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Key messages

From the wild
The harvesting of edible plants, edible insects and medicinal plants from the wild is widely practiced in South Africa and is particularly important as part of the rural economy. It is critical that natural habitat for these species is maintained in both rural and urban nodes, and that sustainable harvesting practices are encouraged, so that these indigenous species can continue to be harvested by future generations.
A plate of plants
- There are ±1300 edible species (6% of the total South African flora). - Most edible plants are eaten raw as snacks or cooked as vegetables. - The patterns of food preference are unique to the cultural groups of South Africa and for the country as a whole. - Apocynaceae, Fabaceae, Asteraceae, Iridaceae and Poaceae are the most important food plant families. - Buffalo thorn (*Ziziphus mucronata*) is one of the most popular edible plants in terms of distribution of use across cultures.
Fresh from the ocean
- SA's 22 commercial fisheries sectors produce ~600 000 tonnes annually and provide livelihoods for ~100 000 people. - Approximately 147 coastal communities in South Africa participate in small-scale fishing. - The value of recreational fishing is estimated at R1.6 billion.
South Africa's edible insects and biodiversity
- In South Africa, entomophagy is prevalent in Mpumalanga, North West, Limpopo and Gauteng provinces. - The mopane worm is a native species that in the wild has sporadic population outbreaks that are harvested. - Trading of mopane worms now engages thousands of people in harvesting, leading to overharvesting. - Given the value of mopane worms in reducing poverty and ensuring food security, developing low intensity practices to protect their natural habitat (mopane veld) is essential for sustainable use.
Tales of two Proudly South African beverages
- South Africa is developing crop production with indigenous species such as Rooibos (*Aspalathus linearis*) and Honeybush (*Cyclopia* spp.), which are an important part of the biodiversity economy. Ecologically friendly farming should be a requirement for the growing of sought-after native plant species and be based on scientific research. - Researchers and the experimental initiatives of farmers and harvesters in the natural distribution areas of the Western and Eastern Cape provinces converged with market opportunities to make Honeybush one of the most promising bioeconomies of the Cape Floristic Region.

On the farm
The visitors that pollinate our crops
- Insect pollinators are critical for most fruit and vegetable crops that are essential for good nutrition. Animal-pollinated crops (from peppers and tomatoes to other fruits and nuts) provide vital nutrients in our diets, and are responsible for 90% of vitamin C, and the majority of vitamin A and related carotenoids. - Ensuring a diversity of pollinating species live near crops, and strategically utilising our indigenous honey bee species at key times, means that the chance of pollinators being active when the crop is flowering is greater and leads to better crop yields. South Africa is considered unique in that we use two indigenous sub-species of honey bee (*Apis mellifera*). - By carefully planning new urban development, managing landscapes with the pollinators in mind, and using pollinator-friendly products and practices, pollinator's habitats and their food resources can simultaneously be protected
Pest control: the enemy of my enemy is my friend
- Utilising the natural enemies of crop pests can result in reduced farming costs, less resistance to pesticides, and fewer production losses. - Research has highlighted that many species of parasitic Hymenoptera involved in the biocontrol of major pests are in fact tight assemblages of closely related species that feed on different hosts and are adapted to specific climates. - Remnant natural patches are highly important as they often serve as vital refugia for native species.

To friend from foe: biodiversity associated with indigenous crops
- Due to increased demand it is often necessary to replace biomass from wild harvested species by farming to increase yields. Such farming practices can be ecologically friendly as in good pest control and sustainable yields, or unfriendly by forming monocultures prone to pest damage and relying on chemical control. - Rooibos commercial farming is plagued by several pest organisms that require new fields after three years to maintain yields with obvious impacts on the environment. In contrast the Honeybush industry, which is starting to be commercially farmed, is typically done in smaller fields, leaving rows of natural vegetation and encourages beneficial organisms that better controls pests - Ecologically friendly farming should be a requirement for the growing of sought-after native plant species and be based on scientific research.

The cascade effect
Fresh waters, fresh fish
- Estuaries and river mouths are critical nursery grounds where the young of many species of fish can live and grow in relative safety, until they are big enough to head out to sea. - Over grazing, excessive fire, alien plants invading wetlands and river banks, over-extraction of water for irrigation, and pollution (such as fertilisers or mine waste water) can all impact directly on the health of life in estuaries and river mouths, which impacts on the success of small-scale, recreational and large-scale fisheries.
Happy bees are healthy bees
- Two indigenous sub-species of honeybee in South Africa are actively managed by beekeepers who provide pollination services to the majority of pollination-dependent crops in the country. - The presence of high genetic diversity and a proportionally large remaining wild component is linked with the South African honey bee population being particular resilient against introduced diseases. South African beekeepers exploit this phenomenon by catching swarms in order to replace and increase their colony stocks. - Custodianship of forage areas and plants are thus import for honey bee food and active swarm production.
Grazing from the plains to the Karoo requires resilience and sustainability
- As much as ~70% of South Africa's land is used for grazing or browsing areas for livestock or game. - Rangelands provide an array of ecosystem services in addition to grazing for livestock and game. Among these are carbon sequestration, provision of forage plants and nesting sites for pollinators, control of soil erosion, and provision of wild medicinal and edible plants. - Rangelands with a healthy mix of indigenous species have better soil stability and diverse rangelands can bounce back faster after drought. - Worryingly vast tracts of our country's rangelands are degraded, commonly due to inappropriate grazing or fire management and alien invasive plants.

Introduction

South Africa's biodiversity estate is a rich source of foods for people. This is in terms of the individual plants or animals that we collect to eat or farm with commercially, as well as in terms of how healthy ecosystems provide various services that allow those species to thrive in the wild or be cultivated commercially.

Biodiversity contributes to food security in South Africa in two ways:

- Indigenous foods support subsistence livelihoods
- Biodiversity contributes to commercial food production

This body of material will make a direct link between the country's healthy biodiversity, and how it supports our food needs. According to the United Nations, people and communities are food secure when '… all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.' This means that the link between food security and biodiversity is complex.

South Africa is certainly a complex country in terms of food security. While some rural dwellers grow most of their food or collect it from the wild, the majority of South Africans need to have access to the food that is in circulation within a commercial food system to be food secure. This means they need to

be able to buy food with cash, meaning that they need some form of income (or social networks that allow similar support) in order to access the food in the food system. Some people often augment their food sources and livelihoods by depending on the natural environment to collect food, or natural products that can be sold as a source of income. In this case there is a very strong link to biodiversity, and if lost, it would impact markedly on their wellbeing due to an absence of food replacements.

When considering the links between biodiversity and food security, the lens needs to consider more than just where biodiversity supports agricultural production (farming or grazing, for instance) or wild harvesting of edible products. It needs to also consider how biodiversity supports livelihoods, jobs, and small businesses. All of this becomes part of a broader resilience for people needing to be food secure.

The wider benefits of biodiversity for food security can be considered in three ways:

1: From the wild
Plants and animals or their by-products that are collected directly from the wild. This can be for subsistence use as the case with a multitude of indigenous plant species, for small-scale commercial ventures such as mopane worm harvesting, or commercial enterprises such as commercial fishing.

2: On the farm
In many parts of South Africa harvesting from the wild has been replaced with producing food in agricultural landscape. However, there are still many links to biodiversity and maintaining elements of biodiversity in this transformed ecosystem has commercial benefits, such as sustainable and ethical large-scale food production with its related value chain and job creation. Examples here are crop pollination, pest control and sustainable farming of indigenous species. Note however that many South Africans conduct subsistence farming. Subsistence and small-scale farming depends even more heavily on biodiversity.

3: The cascade effect
Healthy ecosystem services provide not only the individual species of wild and commercial food sources, but also give various services that support their success and growth, such as nutrient cycling and water filtration. For instance, linefishers depend on marine species that spawn in freshwater and then mature in estuaries, all of which depends on healthy catchments and natural water flow regimes to ensure good water quality. Healthy ecosystem services provide not only the individual species of wild and commercial food sources, but also give various services that support their success and growth.

From the wild

Many South Africans obtain a substantial portion of their daily food from the wild, contributing to food security in rural areas and as a means of making a living. The people that harvest from the wild depend on nature's bounty and rely on the resources that underpin it being looked after in posterity. Overutilisation and degradation of these biodiversity resources can have important socio-economic ramifications. There is thus a direct link between human livelihood and wellbeing and the sustainable management of beneficial species to ensure their continued existence.

A plate of plants

The buffet of food plants available in the veld was the original source of sustenance for the people of South Africa (the Bantu and Khoesaan groups) and is still an important component of the diet today. Many of these plants were discovered (through trial and error, sometimes with life and death implications) at a time when they were greatly needed due to the shortage of other foods. There are

±1300 species (6% of the total flora) which have edible roots, stems, leaves, flowers, fruits, seeds or gums. These species are eaten fresh as snacks (especially fruits and roots), dried and pickled for later use, cooked as vegetables or enjoyed as sweet treats. Whichever way they are prepared and enjoyed, they are a nutritious necessity to South African diets.

The data presented here are based on information extracted from an inventory of all the edible plants in the flora of southern Africa region (Welcome and Van Wyk, 2018). The comprehensive inventory was compiled using 74 literature sources which are cited in the inventory and cannot be repeated here due to space limitations.

The most nutritious species are usually the most popular, which is why the baobab (*Adansonia digitata*) and marula (*Sclerocarya birrea*), which have fruits with high vitamin C content as well as leaves high in calcium (baobab) and seeds high in protein (marula), are so well known. There are other lesser known species that are also high in nutrients and many of these species have an important place in indigenous diets.

Ripe fruits of (left) baobab (*Adansonia digitata*) and (right) marula (*Sclerocarya birrea*) © Ashton Welcome

Edible species valued for their overall nutritional value include: wild sweet pea (*Vigna vexillata*), livingstone potato (*Plectranthus esculentus*), manketti tree (*Schinziophyton rautanenii*), Rooibos (*Aspalathus linearis*), sweet thorn (*Vachellia karroo*), klipuintjie (*Babiana dregei*), brandy bush (*Grewia*) species, peeling plane (*Ochna pulchra*), finger millet (*Eleusine coracana*), large num-num (*Carissa macrocarpa*), wild date palm (*Phoenix reclinata*), bush-tick berry (*Osteospermum moniliferum*), wild melon (*Acanthosicyos naudinianus*), white bauhinia (*Bauhinia petersiana*), and num-num (*Carissa bispinosa*). Fruits with high vitamin C content include: bird plum (*Berchemia discolor*), wild mango (*Cordyla africana*), brandy bush (*Grewia flava*), red-milkwood (*Mimusops zeyheri*), tortoise berry (*Muraltia spinosa*), mobola plum (*Parinari curatellifolia*), small sour plum (*Ximenia americana*), wild medlar (*Vangueria infausta*), as well as karree (*Searsia)* species. Edible plants with high protein content include the corms of raap (*Cyanella hyacinthoides*), the roots of pietsnot (*Grielum humufusum*) as well as the seeds of the wild melon (*Acanthosicyos naudinianus*), tsamma (*Citrullus lanatus*), and the gemsbok/marama bean (*Tylosema esculentum*). Leafy vegetables such as the heart vine (*Pentarrhinum insipidum*) and underground storage organs such as the Zulu round potato (*Solenostemon rotundifolius*) have high iron and calcium content. In some instances, edible plants could even be considered as functional foods due to the other uses they provide in addition to dietary nutrition. These functional foods include those which have been used to suppress hunger and thirst during long walks such as ghaap (*Hoodia*) species as well as those which have been used as stimulants such as kougoed (*Mesembryanthemum tortuosum*).

As much as these plants are valued for their nutrition, there is also a preference shown to specific plants for their taste and the way in which they can be prepared. The patterns of food preference are therefore unique to the cultural groups of South Africa and for the country as a whole.

The food plant heritage of South Africa

According to the 2017 State of the World's Plants report, 80% of food derived from plants comes from 17 plant families and the most important of these families are Poaceae (grass and cereal family), Fabaceae (legume family), Brassicaceae (cabbage/kale family) and Rosaceae (rose and deciduous fruit family). In South Africa, and Africa as a whole, there is a change to this pattern of the most important food plant families with Apocynaceae (stapeliad or milkweed family, which includes *Hoodia gordonii*), Iridaceae (the gladiolus and watsonia family of bulbs) and Asteraceae (the daisies) in the top five along with, Fabaceae (legumes), and Poaceae (grasses and cereals). Apocynaceae has proven to be an important as well as diverse food plant family with species being utilized by many South African cultural groups. People tend to show preference for certain species based on their personal lifestyles, but their dependency on certain plants are also seemingly driven by the environments in which they live. In the more desert areas of South Africa, the Khoekhoe people will be more dependent on the foods which provide them with water sources while in the grassland area, the Southern Sotho people are more dependent on the leafy vegetables to complement their staple food.

The table below is a list of several important food plants recorded as being used by cultural groups in South Africa, arranged according to plant parts and their use categories. The sources of information for each of the groups presented are: Northern Sotho (Quin, 1959); Southern Sotho (Moteetee, 2006); Swati (Dlamini, 1981); Tsonga (Liengme, 1981); Venda (Mabogo, 1990); Xhosa (Dold and Cocks, 2000); Zulu (Gerstner, 1938); and Khoekhoe (Archer, 1994).

Plant parts (use categories)	Important edible species for each cultural group
Underground storage organs (starchy vegetables; raw snacks)	Southern Sotho: qekoe (*Moraea stricta*) Xhosa: inongwe (*Gazania krebsiana*) Zulu: ibonda (*Plectranthus esculentus*); igontsi (*Ipomoea simplex*); obhombo (*Vigna vexillata*) Khoekhoe: !oeibie (*Grielum humifusum*); sanduintjue (*Moraea fugax*)
Leaves (vegetables-sometimes including the stems and flowers)	Northern Sotho: lerotho (*Cleome gynandra*); mokiti (*Citrullus lanatus*) Southern Sotho: leharasoana (*Sonchus dregeanus*); sehlahloa (*Papaver aculeatum*); sepatlapatla (*Erucastrum austroafricanum*) Venda: muṱhanzwa (*Pouzolzia mixta*); muvhazwi (*Obetia tenax*) Xhosa: ubushwa (*Arctotis arctotoides*) Zulu: imbabazane (*Laportea grossa*); imbobela (*Asystasia mysorensis*); inshungu (*Momordica foetida*); isangutshane (*Ophioglossum reticulatum*); isihlalakuhle (*Erucastrum austroafricanum*); isikwa (*Tulbaghia alliacea*)
Whole plants/stems/flowers (eaten raw as snacks)	Southern Sotho: *lenkileng* (*Asclepias multicaulis*-whole plants); *tsikitlana* (*Gazania krebsiana*-flowers) Khoekhoe: !oba (*Hoodia alstonii*-stems); gunu (*Orbea namaquensis*-stems, buds and flowers)
Gum (snacks-sweet treats)	Venda: muunga (*Vachellia karroo*) Khoekhoe: khus (*Vachellia erioloba*)
Nectar (snacks-sweet treats)	Zulu: umhlaba (*Aloe marlothii*) Khoekhoe: choje (*Aloidendron dichotomum*)
Fruits	Northern Sotho: mmilo (*Vangueria infausta*); morula (*Sclerocarya birrea*) Southern Sotho: monokotswai-wa-banna (*Rubus rigidus*) Swati: lisundvu (*Phoenix reclinata*); umganu (*Sclerocarya birrea*)

(eaten as snacks; used as vegetables when young; soaked in milk; ground to flour; made into alcoholic and non-alcoholic beverages as well as syrups)	Tsonga: inkanyi (*Sclerocarya birrea*); mbulwa (*Parinari curatellifolia*); mgula (*Diospyros mespiliformis*); muhakwa (*Strychnos madagascariensis*); nchungulu (*Carissa spinarum*); rhanga (*Cucumis melo*- young fruits are used as vegetables) Venda: mulahu (*Trichilia dregeana*); munombelo (*Englerophytum magalismontanum*); mupfuka (*Grewia microthyrsa*); muṱawi (*Syzygium legatii*); muṱhanzwa (*Ximenia caffra*); muvunḓambaḓo (*Pappea capensis*) Xhosa: ilitye (*Pappea capensis*); isiphinga (*Scutia myrtina*); isivusankunzi (*Carissa bispinosa*); umgwenya (*Harpephyllum caffrum*) Zulu: amabuye (*Parinari curatellifolia*); amasetole (*Manilkara concolor*); inqayi (*Mystroxylon aethiopicum*); ulusizimezane (*Grewia flava*); umdoni (*Syzygium cordatum*); umgwenya (*Harpephyllum caffrum*) Khoekhoe: i/guara (*Searsia burchellii*); kannip (*Hydnora africana*); koenoekam (*Diospyros ramulosa*); num-num (*Carissa bispinosa*)
Grains (beer and staple foods)	Southern Sotho: mabele (*Sorghum bicolor*) Zulu: amabele (*Sorghum bicolor*); uphoko (*Eleusine coracana*)
Seeds (snacks eaten raw or roasted)	Swati: ludvonca-loludliwako (*Sesamum alatum*) Tsonga: nthamula (*Tylosema fassoglense*)
Thirst quenchers	Xhosa: intsenge (*Cussonia spicata*) Khoekhoe: kamiemie (*Albuca canadensis*)
Tea	Southern Sotho: papetloana (*Helichrysum nudifolium*) Swati: luphephetse (*Athrixia phylicoides*) Tsonga: kofiyanhova (*Athrixia phylicoides*) Khoekhoe: balerja (*Mentha longifolia*)
Milk additives	Southern Sotho: mohlatsisa (*Euphorbia striata*)

See also an edible plant checklist in Welcome & van Wyk (2018).

As unique as each culture is in its preference to certain food plants, there are still many species common to all. Those species which are widely distributed were eventually discovered as being valuable sources of food for all.

An example of food for all is the buffalo thorn (*Ziziphus mucronata*). This is one of the most popular edible plants with regards to distribution of use across cultures. This species is either much enjoyed or seen as only something to eat when there is nothing better (probably due to the fact that there is not much flesh on the fruit). The edible fruits are mealy and sweetish when ripe and can be eaten raw or boiled and ground into a meal to make porridge. The fruit was once popularly roasted as a coffee substitute and also fermented into an alcoholic beverage. The seed is also edible and high in minerals. This species is popular because of its wide distribution. There are also other species that, although they are not as widely distributed, are so popular within their distribution range that they are even sold along roadsides.

Ziziphus mucronata **(buffalo thorn) fruit © Ashton Welcome**

Food plants on the market

There are many species recorded as being sold on the market. These include: fruits of the sour figs (*Carpobrotus edulis* and *Carpobrotus muirii*) and the Transvaal milkplum (*Englerophytum magalismontanum*), roots of the shepherd's tree (*Boscia albitrunca*), seeds of the narra melon (*Acanthosicyos horridus*), and the roasted nuts of the gemsbok/marama bean (*Tylosema esculentum*). Besides the plants which are being sold on the local market for household income, there are a few food plants which have gone beyond small roadside stalls and which have generated income on a larger scale.

A bag of Transvaal milkplums (*Englerophytum magalismontanum*) bought on the side of the road. © Ashton Welcome

The well-known *waterblommetjie* or Cape pondweed (*Aponogeton distachyos*) has found its way into many local restaurants and even food stores as a fresh or canned product. From local Cape (Khoikhoi) cuisine to country-wide distribution, this species is an excellent example of how our indigenous food plants can be a valuable resource not only for our diets but also for the country's economy. This tasty pondweed has also benefited the tourism industry since visitors love to try our local dishes. It is so celebrated, that there is even a festival dedicated to it each year!

Apart from the *waterblommetijies*, most of the plants that are sold on street markets are edible wild fruits and therefore the harvesting of these foods is sustainable. However, there are unfortunately some edible species which are not harvested in a sustainable manner and could therefore be or become threatened due to overharvesting.

The sustainable harvesting of food plants

Although it is not considered as being threatened, the shepherd's tree (*Boscia albitrunca*) is a protected species and should therefore not be harmed in any way. This tree has been valued across South Africa for its edible roots, fruits and even flower buds. The roots are roasted as a coffee substitute and also ground up to make a meal used for porridge or bread. The edible root, which is said to contain preservative properties, was also boiled and concentrated into syrup or made into a sweet drink. The root could also be used to ferment beer and to separate cream in milk. The flower buds were pickled like capers and the edible fruit was also used to make a non-alcoholic drink. The past use of the roots of this tree was destructive and must have contributed to its current protected status.

Being educated about our indigenous food plants will allow for us to not only celebrate and enjoy them, but also to ensure that we will always have them.

Fresh from the ocean

(See also 'Benefits of Biodiversity in the Marine Realm'. Chapter 2 in NBA 2018 Technical Report Volume 4: Marine Realm.)

Archaeological evidence suggests that anatomically modern humans (*Homo sapiens*) first began to use marine resources for food along the southern African coastline approximately 160 000 years ago (Marean 2010, 2014). This adds a novel perspective to our realisation of the importance of marine resource use in human evolution. Ideal environmental conditions on the tip of Africa are believed to have given rise to modern humans, as the remains of tools and ornaments (including abalone shells, cutting stones, ochre and shell necklaces, engraved stones) tell the story of early humans in this area who are believed to have evolved large brains (Marean 2010, Cunnane and Crawford 2014, Loftus et al. 2019). Consumption of highly nutritious, omega-3 oil-rich marine resources may have played a substantial role in the development of the increasingly sophisticated cognitive abilities of modern humans. Fishing is a key part of global and South African heritage and provides food security for many citizens. Approximately 312 000 tonnes of seafood are eaten annually in South Africa with an annual average per capita seafood consumption estimated at 6 kg in 2015 (Hara et al. 2017), with more than 770 marine species harvested in South Africa.

More than 3 000 **commercial fishing** right holders (across 22 commercial fishing sectors) deploy approximately 1 400 fishing boats annually in South Africa's exclusive economic zone (EEZ) (Moolla and Kleinschmidt 2008). It is estimated that annual commercial fisheries production is 600 000 tonnes (DAFF 2013, 2015) valued at approximately R6 billion (DAFF 2015). In 2013, the demersal hake trawl and small pelagic fisheries were ranked as having the highest economic value and landed tonnage and jointly accounted for 85%, 65% and 54% of South Africa's total catch, total tonnage and total direct employment respectively (Brick and Hasson 2016). Fisheries contribute 0.5% of South Africa's GDP and play an important role in providing livelihoods for more than 100 000 people (CLA Report 2010).

In 2016, South Africa's emerging **small-scale fisheries** sector had participation from approximately 147 coastal communities which translated into approximately 29 000 individual fishers (DAFF 2013). The total value of **subsistence fishing** is estimated to be around R16 million with the vast majority (approximately 85%) derived from line fishing (Hara et al. 2008). In addition to fish (such as Dusky Cob, White Steenbras, Spotted Grunter, Garrick), Rock Lobster, Abalone, bait organisms and other intertidal resources are also harvested. While small-scale fisheries contribute less than 1% to South Africa's GDP, the importance of this sector is in its provision of employment and food security – particularly protein – to poor coastal communities (Isaacs and Hara 2015).

> ***Small-scale fishing*** means the use of marine living resources on a full-time, part-time or seasonal basis using predominantly low technology fishing gear in order to ensure food and livelihood security through direct consumption and/or sale or barter of catch (DAFF, 2012).

Recreational fishing enjoys participation from between 700 000 (Baust et al. 2015) and 1 million fishers (Hara et al. 2008). The value of the recreational fishery has been estimated at R1.6 billion (Leibold and van Zyl 2008).

Despite the importance of fish for food security, 33% of global fish stocks were considered overexploited in 2015 (FAO 2018). Similarly, in South Africa many of our fishery resources are considered overexploited/collapsed (see Chapter 9 in NBA 2018 Technical Report Volume 4: Marine Realm), which undermines the potential for wild capture fisheries to support food and job security in South Africa.

Recreational fishers in Kalk Bay © Oswald Kwaten

Abalone, Agulhas sole, Cape hakes, Cape Horse Mackerel, linefish, netfish, oysters, Patagonian Toothfish, prawns, seaweed, sharks, small pelagic fish (Sardine, Anchovy and Round Herring), squid, tunas and Swordfish, as well as South and West Coast Rock Lobster are all important wild harvested stocks that are monitored in South Africa. Quotas and industry closure are important for ensuring sustainable supply of this biodiversity (DAFF 2016).

South African edible insects and biodiversity

Feeding the 9 billion people expected on planet earth in 2050 (Charles *et al.* 2010) will take extraordinary steps and futuristic advances in technology, or will it? Perhaps at least part of the solution lies in our past. Edible insects have been enjoyed by people from all corners of the globe for millennia (Van Itterbeeck and van Huis 2012). Modern advances in food production have, however, led to a drastic decline in entomophagy (insect consumption) in developed countries, although the practise continues in South America, many Asian countries and in Africa (Gracer, 2010). Paradoxically, there has been a resurgence in edible insect interest in Europe, the USA and Canada, even as consumption of insects and the insect populations themselves, decrease in Africa (Kelemu *et al*. 2015). Countries such as Belgium and Holland, are, at present, world leaders in research into edible insects, producing a growing body of evidence that supports the notion that edible insects have a role to play in feeding the world's population (Van Huis 2010). The world is now scrambling to source information about the species of insects that were used in the past, their nutritional value, ecology, life histories and environmental impact, in order to utilise them as a cheaper and more environmentally efficient means of feeding the world than the technologies we currently embrace (FAO 2012).

South Africa is in the enviable position of being able to use 21st century scientific solutions to life's challenges, while still being able to draw on the raw materials our forefathers valued for survival, comfort and luxury (Shackleton and Shackleton 2004). Despite modern pressures for development, we still possess large areas of natural or near-natural lands rich in natural resources: a biodiversity bounty. In addition, there remain many South Africans possessing the age old knowledge and skills to find and process a host of useful products originating from these untamed spaces (Van der Waal 1999).

Edible insects are one such product. All modern foodstuffs are based on past experience and due to the conducive climate and habitat in South Africa, people have, since Palaeolithic times, had a wide variety of edible insects to choose from. Now in the Anthropocene era, we are able to use our ancestors' experiences in collecting and preparing a diverse array of edible insects from the following families: lepidoptera (caterpillars such as mopane worms), hemiptera (stink bugs), orthoptera (crickets and grasshoppers), coleoptera (jewel beetles and weevils), hymenoptera (thief ants, bees and mopane bees) and isoptera (termites, both reproductive and soldiers) (Van Huis 2003). Globally, there are over 1,500 edible insect species providing up to 5–10% protein input annually, and other nutrients like fats, calories, vitamins and minerals (Yen, 2009). In South Africa, the consumption of insects: entomophagy is prevalent in Mpumalanga, North West, Limpopo and Gauteng (Teffo et al., 2007). According to the Food and Agriculture Organization (FAO), an increase in the global population calls for increased focus on non-timber forest products (NTFPs), including edible insects as a source of food (FAO, 2003). These products contribute between 5% and more than 90% of total household income (Shackleton et al., 2008) and play a vital role in improving food security and nutritional status in rural areas (Shackleton and Shackleton, 2004).

The northern provinces of South Africa including Gauteng, Limpopo, Mpumalanga and North West Province hold the greatest diversity of edible insects. Some, such as mopane worms and termites, are

known and loved by all people in these areas, whereas others, such as the lesser known “bophetha” (*Hemijana variegata*), a hairy caterpillar feeding on *Canthium armatum* (armed turkey-berry), are known only to rural people of Venda, Capricorn and Sekhukhune in Limpopo (Egan 2013).

In Africa, it has been estimated that 470 different species of insects are utilised for food (Kelemu *et al.* 2015), with most congregated in the Central African region. A comprehensive review of edible insects in South Africa is not yet available. In the Blouberg Municipality of Limpopo Province however, over 20 species of edible insects have lately been documented and indications are that people from deep rural areas in northern South Africa all have access to various unique edible insect species, specific to their region. Documenting these species should be a priority as this indigenous knowledge is rapidly dying out (Egan 2013). All these species are, to a greater or lesser degree, reliant on some natural vegetation in order for populations to thrive. Caterpillars in particular are dependent on a limited number of food plants, with some (e.g. “bophetha”), relying on a single plant species as their food source (Egan 2015). Habitat destruction is therefore a key driver of edible insect decline.

Edible insects (*Imbrasia belina*) eaten by the Pedi (© Bronwyn Egan). 1: dimenemene (Sepedi) *Macrotermes natalensis*; 2: bonito (Sepedi) *Sphingomorpha chlorea*; 3: bobilo (Sepedi) *Petovia marginata*; 4: bophetha (Sepedi) *Hemijana variegate*; 5: mamoshu (Sepedi) *Anacridium moestum*; 6: lebitsi (Sepedi) *Sternocera orissa*

In South Africa, the best known edible insect is the mopane worm (*Imbrasia belina*), also known by its Venda name of “Mašotša” (Ditlhogo 1996). A number of contributing factors including the development of mopane tree habitat, changing weather patterns and overharvesting, have led to the decrease of mopane worm harvests in South Africa (Baiyegunhi and Oppong 2016) and at present, much of the mopane worm produce appears to be imported from Zimbabwe and Botswana. This is not due purely to climate change, as these countries are affected as much as South Africa by this phenomenon, but also to development and/or overharvesting of the insect (Baiyegunhi and Oppong 2016). Thus, a much-needed source of income is no longer available to marginal communities in rural villages of South Africa.

Mopane worms are edible caterpillars of the emperor moth *Imbrasia belina* (Lepidoptera: Saturniidae) which are widely consumed in South Africa and neighboring countries (Timberlake *et al.,* 1996). Mopane worm is a non-timber forest resource (NTFP) that is valuable economically, socially and nutritionally (Hoskin et al., 2002; Stack et al. 2003; Madibela et al. 2008; Hope et al., 2009; Thomas 2013). These caterpillars have a long history of being an important traditional delicacy in southern African countries (Stack et al. 2003). These caterpillars contain raw protein (Madibela et al. 2009), fats, calcium and phosphorus (Motshegwe et al. 1998). They are recommended as food for infants (Ohiokpehai et al. 1996) as well as people who are suffering from anaemia (Akpalu et al., 2009).

Mopane worms feed predominantly on the mopane tree (*Colophosphermum mopane*) leaves (Illgner & Nel 2000). Mopane trees also provide various products like green manure, wood for tools, fence poles, firewood, construction, medicines and resin, rope, gum, livestock browse (Makhado et al. 2016). Sustainable use of naturally occurring mopane for mopane worm production would thus ensure economic benefits and conservation of natural habitat. The mopane tree and the mopane worm are thus valuable species that are of benefit to many people in South Africa.

Wild harvesting of mopane worms is unsustainable. The bivoltine (two generations per year) nature of mopane worm populations implies two harvests per year depending on the amount of rainfall (Illgner and Nel, 2000). In turn, outbreaks depend on climatic conditions, habitat, harvesting pressure, predation (Makhado, *et al*., 2009; Makhado, *et al*., 2012) parasites and diseases (Gardiner, 2003). These outbreaks are unpredictable confounding the development of sustainable harvesting practices crucial for harvesters and traders who depend on the worms for their livelihoods (Phiri et al., 2004). Harvesting has recently become more commercial (Gullan et al. 2005) with less than 10% of harvesting done for private consumption (Stack et al. 2003) and an estimated 9.5 billion mopane caterpillars harvested annually in southern Africa (Hollaran 2014). Trading and selling of mopane worms now engage thousands of people in harvesting (Stack et al. 2003) leading to overharvesting and consumption of early instar mopane worms. Many studies have focused on benefits of *I. belina* to livelihoods of households in South Africa (Stack et al. 2003; Hope et al., 2009; Thomas, 2013). These studies mention that the harvesting of natural populations of *I. belina* is ecologically unsustainable. Unfortunately, harvesting is done without understanding the ecology, on top of being subject to extreme variation in mopane worm supply, which together translate into an unsustainable food resource. Habitat destruction of Mopane woodlands as a result of habitat degradation mostly from communities not having any other option but to use Mopane's for fuelwood.

Is semi-domestication of the mopane worm the answer? Insects used as mini livestock to provide food for humans has advantages. It is likely that some management by the farmer improves insect abundance/yield. A project to investigate altering natural meta-population dynamics of mopane worm populations to reduce the variability in mopane worm supply for harvesting is currently being undertaken at the University of Venda. In South Africa, mopane worm has sporadic population outbreaks that are harvested. Given the value of mopane worms in reducing poverty and ensuring food security, developing low intensity practices to maximize long-term ecological and economic sustainability for harvesting is important. By preventing mortality of mopane worm cohorts at different life stages, this work will quantify the increase in yield by managing populations. Developing approaches to reduce the variability in mopane worm population outbreaks will lead to sustainable utilization and possible domestication of the resource. If substantial yield is achieved by management interventions, economic benefits from mopane worm will be improved and pressure on natural populations reduced. Another avenue that can be explored is using the rearing of mopane worm on community land by local residents as a method to buffer the effects of climate change, i.e. Ecosystem Based Adaptation. Late seasonal rainfall strongly influences the leaf flush of mopane, and often mopane worm moths emerge and lay eggs before mopane leaves are available. There is thus an opportunity to secure the availability of mopane worm by providing communities with eggs from other areas to use existing mopane when in flush.

One of the insects voted the tastiest by various tribes in Limpopo, including the Pedi, Venda and Shangaan, is the giant jewel beetle *Stenocera orissa* (lebitši) (Egan 2013). This coleopteran is roughly 4 cm long, brilliant black and pale yellow and frequents *Vachellia* trees (Acacia) in open savannah woodland (Shadung 2012). The beetle is collected in the early morning before the sun rises to heat the insects to the temperature necessary for high, strong, flight (Egan 2013). People in rural villages value the high fat content of the adult, which also has proven high-quality protein (Shadung 2012) as well as the eggs which are often laid in dark boxes after the gravid females are collected, and then eaten raw. The highly armoured adults are fried and enjoyed as a delicacy after the forewings are removed.

Throughout Limpopo Province and further afield, the merits of "dinhlamakura" (*Carebara vidua*, the thief ant) are proclaimed (Egan2013). The alates (reproductive males and females) of this ant species bear a remarkably round abdomen, distended with fat, and they are delicious once fried. The ants are also eaten live as they emerge from their underground nests with the first rains of summer. Due to the fatty nature of the insect, they can be stored for only a week before they spoil but they are so sought after that few remain for storage once they are captured.

"Dimenemene" are also not suitable for long-term preservation due to the rich fat in the abdomen of these misnamed white or flying ants. One of the most nutritious food sources for humans and animals alike, a number of species of these large mound building termites are enjoyed throughout South Africa (Kelemu *et al.* 2015). Usually it is the alates, captured on their nuptial flights, which are fried and eaten. In Venda, people make use of the soldier termites known as "makeke". Although this caste is not as delicious, owing to the large armoured head and pincer like mouthparts, the advantages are that they can be stored for longer and are available throughout the year, except during deep winter. While the "flying ants" or alates are captured using lights to lure them into open pots of water, the soldiers are caught by probing the termite mounts with long reeds or grass. The soldiers grab onto the grass with their mandibles and they are drawn out of the mounds in this manner in fair numbers (Colombier and Egan pers. obs. 2016).

Many people in Limpopo Province who, due to high pressure city jobs, do not have the time or access to the wild areas where they grew up, remember with nostalgia the grasshoppers they would feast on as children (Egan 2009). At least ten species of grasshoppers are edible in South Africa, and being generalists in their food and habitat, they are common and easy to find. It is usually children, who are quick and agile and have the time, who hunt the grasshoppers, capturing them by hand as they walk in groups and bringing them home to be roasted for the family. In Venda, another orthopteran is also held in high regard: crickets are caught at night while they call from their underground burrows, frozen in the torchlight that children use to hunt for them (Van der Waal 1999).

Crickets, grasshoppers, ants and termites are generally found in the same location year after year, however, edible caterpillars are outbreak insects and are particularly ephemeral in nature; their numbers and locality greatly influenced by temperature and rainfall (Dzerefos *et al.* 2009). A wide variety of emperor moths are eaten as caterpillars, with the mopane worm being the most famous. All moths lay their eggs on the food plant and it is vital that when the caterpillars hatch, the first leaves for the new season are budding, or the caterpillar will starve to death or only come into contact with older leaves which are too difficult to chew (Egan 2015). In cities, villages and farms, populations of the food plants that these caterpillars require in order to feed, are declining. In rural villages across Limpopo, land is cleared to build houses and informal settlements and trees are chopped for firewood. In cities, green belts are developed into malls or housing estates, and on farms, lands are clear felled and turned to intensive plantations such as pine, kiwis or avocados. Pesticides are necessary under these food production regimes, further impacting negatively on edible insects (Yen 2009). The natural veld that provides food and shelter to a large suit of indigenous insects is destroyed and in the process, the reservoir of edible insects available to us as a food source and as "raw" material to investigate for future

agricultural potential, is lost. Interestingly, in the Limpopo Province, *Agrius convolvulii*, the "makotopodi" caterpillar, which feeds on the *Ipomoea* genus and is therefore a pest of sweet potato, is controlled on some farms by allowing local people to collect the caterpillars for consumption (Egan 2013). Farmers are provided with a free pest-control service and nearby villagers gain a free source of protein.

In the recent past, entomophagy was seen as an interesting, vaguely alarming phenomenon practised by the rural people of the world – usually those who could not afford more nutritious and delicious foods (DeFoliart 1999). A diversity of research world-wide now supports the premise that insects are nutritionally superior to a number of the worlds' staple diets (Van Huis 2003). The Food and Agriculture Organisation is thus promoting entomophagy in a bid to add to the arsenal of weapons available to fight world hunger. In modern cultures however, insect eating is no longer practised and in order to overcome aversion to a food that is often rejected as offensive, researchers are investigating novel approaches to preparing insects (Meyer Rochow 2010).

In South Africa, our "wild" edible insects provide a unique base from which to work, and some South African companies are already investigating insects which can be used as feed for livestock, food supplements and in new products which cater to a modern lifestyle. These include entomilk© which is an insect based, non-dairy milk substitute and products from Entofarms which produce insect protein powder (pers. comm. Besser 2018). These foodstuffs are, however, based on the raw ingredients of "wild" insects, which first require documenting and then basic investigation such as proximate nutritional analysis before they can be processed into healthy products and made available in large quantities (Egan 2014). In addition, basic ecological analysis of these insects is vital so that overharvesting does not take place (Kelemu *et al.* 2015).

South African landscapes play host to a wide array of edible insects, a number of which remain undocumented. Without a database for this resource, nor an archive of the knowledge around finding, collecting and preparing these insects, we risk losing the wild genes of a food source that can play an important role in feeding our people. Our edible insect biodiversity can be nurtured in pesticide-free wild lands and then grown in cityscapes where space is limited. It is a resource which is proudly South African, of interest in the global arena, and worthy of more in depth investigation.

Tales of two Proudly South African beverages

The global trend towards 'healthy living' has opened up the market internationally and nationally for the introduction and establishment of natural and health products (Joubert et al. 2011; Anonymous (5) 2013; Anonymous (1) 2015). Rooibos, a warm herbal beverage, is brewed from the fermented leaves and branches of *Aspalathus linearis*, a species that is one of 9 000 that makes up the unique floristic treasure that is the Cape Fynbos vegetation of South Africa (Goldblatt et al. 2002). Enjoyed as a warm drink, it brings health, refreshment and soothing to millions of consumers across the globe. Rooibos is also included in a diverse range of health products, foods, beverages and cosmetics for local and global markets (Joubert & de Beer 2011). Honeybush is another caffeine-free hot beverage, this one made from the *Cyclopia* species, and is also indigenous to the Fynbos community represented by 23 species. Honeybush is recognised as one such a 'natural product' with the potential to grow exponentially as an internationally recognised health product (Van Wyk 2011; Anonymous (5) 2013).

Rooibos

Firmly rooted in the western belt of the Cape Floristic Region (CFR), the popularity and trade of Rooibos has branched out to overseas markets on every continent. It is striking that the red-brown tinge of Rooibos tea is so similar to the rust-red ochre colours of San Rock Art sites in the Cedarberg. The parallels

extend beyond the aesthetics. This area is known to be the centre of endemism for the plant species from which Rooibos is derived (*Aspalathus linearis*) (Dahlgren 1968). The Cedarberg has the highest density of rock art sites per square kilometer in the world, evidence of the presence of pre-colonial hunter-gatherers in that region (Parkington 2003). While there is no conclusive evidence to connect the first nations people of South Africa to the original use and knowledge of the Rooibos plant (Van Wyk and Gorelik 2017), there is no material evidence to the contrary. Indisputable evidence exists that the lineages of people and plant have co-existed in this landscape for generations.

Rooibos being harvested © Benny Gool, CapeNature

The complex social fabric of the Rooibos production area is interwoven with the histories and ecologies of Rooibos tea (Ives 2014a). As such, the region is a hub of biocultural heritage for many rural communities who populate the mountainous regions and plaints of this part of the Cape Floristic Region (Ives 2014b). These include small-scale commercial producers, large-scale commercial farmers and local residents who harvest wild Rooibos seasonally to supplement income from other sources. While most South African and global consumers are well acquainted with the Rooibos tea cultivated on large-scale commercial farms, few are familiar with the history and ecology of Rooibos and its crop wild relatives.

Harvesters of wild Rooibos, small-scale farmers and local residents, many of them descendants of the first nations peoples of the area, fondly remember the use of Rooibos as a household beverage and refreshing tonic, harvested and processed by elders from the veld surrounding their homes (Louw 2006). Some of these people are Rooibos producers themselves, and are members of local small-scale Rooibos producer organisations in Wupperthal near Clanwilliam, and in the Suid Bokkeveld, near Nieuwoudtville. At least one such organization has managed to sustain and enhance local livelihoods of marginalized land-users, offering a prime example of what is possible in South Africa's bioeconomy to respond to dual concerns of biodiversity conservation and livelihood security.

The Heiveld Co-operative is a community based co-operative in South Africa's Northern Cape Province whose core business is Rooibos production. The 58 members of the Heiveld are producers of cultivated Rooibos, and several are harvesters of the wild resource. Wild plants are harvested seasonally during autumn, soon after harvesting of the cultivated crop in summer. The practice of wild harvesting sustains family livelihoods, and is itself sustained by generational transfer of local ecological knowledge and experiential learning (Malgas et al. 2011). A limited number of people continue the practice of seasonal wild harvesting – the bulk of tea exported by the Heiveld to its international clients in Europe and North America is cultivated. Wild tea requires knowledge, skill and effort to harvest.

Local knowledge of the ecology of Rooibos is instrumental in traditional practices of wild Rooibos harvesting. To locate the tea, harvesters have to know where the populations are, how to get there, and when to harvest. This means that people have to know in what kinds of places the plants grow (habitat),

when the plants are ready for harvesting (referred to in ecology as the phenophase), and when not to harvest (e.g. when plants show signs of stress) (Malgas & Oettle 2007). Monitoring of populations is inherent in the seasonal harvesting, and it is down to individuals and the organization to support the maintenance of populations in the wild. When members join the Heiveld Co-operative, they sign a legally binding document committing themselves to the practices of sustainable harvesting based on scientific research findings commissioned by the Heiveld in 2001.

The conservation ethic with which wild Rooibos is managed in the Heiveld is not limited to the species in the wild. Emphasis is placed on soil conservation, integrated pest management, organic methods of plant protection and the sharing of knowledge about best practices. Cultivation practices are guided by experiential learning and training, and supported with mentorship by more experienced producers. Since 2004, the Heiveld has actively discussed and planned around predicated effects of climate change and its effects on the biodiversity of the region generally, and Rooibos and livestock rearing more specifically.

Wild Rooibos processed by the Heiveld is sold at a premium, and through a business model facilitated by the maintenance of dual Fairtrade and Organic certification (Nel et al. 2007). The economic gains to the community are threefold: firstly, members are paid higher prices for a unique, high quality product, and this relates into improved household income, higher wages for labour and more options when facing the stressors common to remote rural communities in South Africa, e.g. access to health, quality education and employment (Malgas et al. 2011). Through the Fairtrade business model, farmers are paid a portion of the premium price early on in the production cycle, eliminating the need for high interest credit or capital loans to buy seed and to cover other input costs. Secondly, organization development is supported with a portion of the premium, allowing the Heiveld to build and maintain strong institutions, and to facilitate sound governance in the operations of the company. Thirdly, investment in a response to needs in the community is a prerequisite for a portion of the premium, which means that benefits that accrue to the organization also extend to the broader community of the Suid Bokkeveld, bringing about change that was not otherwise forthcoming (Raynolds & Ngcwangu 2010; Nel et al. 2007).

At the time of writing this chapter, farms in the far south of the Suid Bokkevled have received less than 80 mm for the year – this is almost 50% of its usually low rainfall of 100mm per annum. Rooibos is a rainfed crop, and the socio-economic effects of declining yields experienced in the primary production area is especially acute at the margins, in the remote rural reaches of the Suid Bokkeveld (Smith et al. 2018; Ives 2014b). Drought, although understood to be a natural phenomenon in this part of the CFR, is exacerbated in recent years by longer, drier, hotter summers, a decrease in winter rainfall amounts and frequencies, less predictable seasonal changes, and more extreme weather events (Archer et al. 2008; Lötter 2015).

Food security is one of several complex challenges facing small-scale farmers during these drought years. While people and plants weather the literal storms with difficulty, the Heiveld and its interventions offer some buffering that aids survival of the crops and the people. Incomes from Rooibos and related activities are more diverse and more lucrative for members of the Heiveld Co-operative than had historically been the case during Apartheid South Africa, and even after liberation, when government aid was scant if at all available. Its excellent quality enhanced by traditional production practices, its premium price in niche markets, its ecological resilience during drought and its value among local land-users position Rooibos as a buffer against the socio-economic and environmental risks that all land-users in the Rooibos production area face.

The ecophysiological resiliences inherent in the wild populations, including their ability to withstand drought, pests and disease more easily than their cultivated counterparts, is to be found in the local

knowledge of people who work with Rooibos in these areas (Louw 2006). Research, historically focused on the economically important cultivated plants, has brought attention to the long overlooked wild crop relatives of one of the most valued commercial exports from South Africa's Fynbos ecosystems. Research reveals new and interesting information about the remarkable diversity within and across wild Rooibos populations. However, apart from the significant and necessary conservation action of conservation agencies, government authorities and academic researchers in this case, it is the local in situ decisions and actions that conserve the genetic and ecological integrity of the natural resource. Resilient, robust and red as the rocks of the Cedarberg, Rooibos has, in many ways, secured the livelihoods of the people who strive to conserve it, and the biodiversity that supports its uniqueness.

Honeybush

In 2012 the industry was valued at R10 million, forming part of the greater R400 million herbal tea market (Coetzee 2012). These occur from the Cederberg Mountains, southwards to the Cape Peninsula and eastwards to Port Elizabeth. In 2012, 95% of the Honeybush tea produced was sold in bulk on the overseas market (Joubert et al. 2011; Coetzee 2012; Anonymous (5) 2013). The main buyers of Honeybush are Germany and the United States, as well as the Netherlands and Bulgaria (Anonymous (5) 2013; den Hartigh 2011). Wild-harvesting still dominates the current supply to the market, with a rough estimate of 70% wild to 30% cultivated yield entering the market (Joubert et al. 2011; den Hartigh 2011; Anonymous (5) 2013; Anonymous (1) 2015). It is speculated that extensive wild-harvesting has resulted in many natural populations becoming extinct locally (du Toit et al. 1998). Of the 23 species of Cyclopia, only six are recognized for their economic value, with four species most frequently harvested for commercial purposes. Usually species are restricted to very small areas and then also to very specific habitats like high mountain peaks, marshy areas, shale bands and wet southern slopes.

Despite the rationale for the efficient agricultural production of a singular type of Honeybush for a steady, more predictable supply of biomass, the natural variation in products resulting from different species and regions may offer an untapped economic opportunity for niche marketing.

Unlike the more established Rooibos industry (developed since the 1950s), the Honeybush sector continued as a series of cottage industries until the mid-1990's (Joubert et al. 2008; Joubert et al. 2011). As with Rooibos, informal trade of wild plants would have preceded commercialization of the crops by several decades. More recently the production and distribution of Honeybush tea has undergone considerable growth and has, since the 1990s, entered the market more formally. Local research efforts by Dr Hanes de Lange from the then Kirstenbosch Botanical Gardens, and the experimental initiatives of farmers and harvesters in the natural distribution areas of the Western Cape and Eastern Cape converged with market opportunities to make Honeybush one of the most promising bioeconomies of the Cape Floristic Kingdom (Den Hartigh 2011; Coetzee 2012).

The complexity of the Honeybush market value chain should in future provide the South African economy with further direct benefits besides expansion of the agricultural sector (Anonymous (5) 2013). Growth in the Honeybush industry will create more job opportunities in several sectors, ranging from primary to secondary and tertiary production (Department of Trade and Industry 2007). The industry thus has the potential to provide a means of additional income for small- and large-scale farmers. Additionally, the Honeybush industry has 'lateral' growth potential for expansion at secondary and tertiary level processing (Khuzwayo 2011; Anonymous (5) 2013). Market related opportunities for increased processed Honeybush produce are vast. This includes diversification of fresh tea fermenting to processing for convenience products or developing a range of health products (Joubert et al. 2008).

Honeybush is now an important Fynbos crop species, much like its counterpart, Rooibos. However, where the Rooibos industry makes use of a single species, there are six species of Cyclopia that are used for brewing Honeybush tea. Four of those (*Cyclopia intermedia*, *C. genestoides*, *C. maculata*, *C. subternata*) are harvested most frequently for commercial purposes, with up to 70% being harvested from wild populations (Joubert, 2011; see 'From the Wild' section). While cultivation seems to be a clear response to the growing demand for Honeybush biomass, little is known about its basic ecology, including the relationships that exist between plants and insects.

It is speculated that extensive wild-harvesting has resulted in many natural populations becoming extinct locally (du Toit et al. 1998). Of the 23 species of *Cyclopia*, only six are recognized for their economic value, with four species most frequently harvested for commercial purposes. *C. intermedia* ('bergtee') is the dominant species harvested from wild mountain populations (Anonymous 2003), while other species, such as *C. genestoides* ('kustee') and *C. subternata* ('vleitee'), are mainly harvested from cultivated plantations (Joubert et al. 2011; Anonymous (1) 2015). The species used in the production of tea varies depending on the species found locally in the various areas. In the Western Cape, the main species used for brewing tea in the 1920s was *C. genistoides* in the Cape Peninsula and for Caledon (Overberg) and the George area *C. subternata* was mostly utilized (Marloth 1925; Joubert et al. 2008; Joubert et al. 2011). *C. maculata* grows naturally in the Overberg region, and along with several other species, is currently under evaluation for commercialization (du Toit et al. 1998; Coetzee 2012).

On the farm

Most food needed by South Africans comes from agricultural production. In addition, this sector creates important value changes and results in many jobs. Biodiversity plays a role, although sometimes hidden from view.

The visitors that pollinate our crops

Pollinators are animals that carry pollen from one flower to the female reproductive organs of another flower, leading to seed formation. The majority of these pollinators are insects, but some birds and mammals also play this role (Klein et al. 2007).

People need pollinators. Most of the crops that provide the bulk in diets across the world, like rice, wheat and sorghum are wind pollinated, but animal-pollinated crops are essential to good nutrition. Animal-pollinated crops (from peppers and tomatoes to other fruits and nuts) provide vital nutrients in our diets, and are responsible for 90% of vitamin C, and the majority of vitamin A and related carotenoids. In addition, treats like coffee, chocolate and vanilla, are also animal pollinated.

Although many "luxury" crops (e.g. coffee and chocolate) are animal pollinated, not many of us realise the importance of animal-pollinated crops to human nutrition. Although animal-pollinated crops may only represent just under 10% of the economic value of world crops (Chaplin-Kramer et al. 2014), they are vital for ensuring nutrients in our diets, and are responsible for 90% of vitamin C, all Lycopene and the majority of vitamin A and related carotenoids, for example (Eilers et al. 2011). Staple crop production (e.g. corn, wheat, rice, cassava, yam) provides most of the calories in the human diet, but are poor sources of most micronutrients. Dependence on these staple crops due to food systems failures and declines in diet diversity are responsible for micro-nutrient deficiency in 2 billion people worldwide, particularly in developing countries

Busy bee foraging on onion umbel in the Klein Karoo © Tracey Knowles

About 35% of global crop production by mass relies to some extent on animal pollinators and animal pollination is important for 85% of wild (i.e. non-crop) species. This means that animal pollination is vital for healthy ecosystems and their functioning, ensuring optimal nutrient and carbon cycling, water quality and quantity.

South Africa is considered unique in that it has two indigenous sub-species of honey bee (*Apis mellifera*) that can be managed by beekeepers to service the agricultural sector (Allsopp et al. 2008; De Lange et al. 2013; see also "Cascade Effect" section below). The advantage of using indigenous species as managed pollinators is that these colonies are far more disease resistant than managed alien honey bees used in other parts of the globe (Dietemann et al. 2009; Human et al. 2011). The primary way of replacing lost colonies or increasing colony numbers is to trap wild swarms. In this sense the ecosystem that either provides flowers for managed honey bee hives or supports the origin and attraction of wild swarms can be seen as valuable to ecological infrastructure.

Pollinators need a variety of plants and flowers for food

Honey bees, like humans, are more effective when they are healthy. Their immune systems thrive when they have access to a diversity of pollen (Alaux et al. 2010; Di Pasquale et al. 2013) and nectar (Negri et al. 2015) from various plant species. Not only does forage diversity maintain bee health, but good nutrition is linked to the ability of bees to learn. Bees that are fed pollen-poor diets or a low variety of pollen species as larvae become poor foragers (Schofield et al. 2015; Arien et al. 2015). Healthy ecosystems are able to provide such a diversity of forage to supplement the pollen and nectar that pollinators get from crop species.

Other pollinators

It is not just honey bees that are important pollinators of wild plants and crops. Other bees, flies, beetles, butterflies, bats and even types of rodents are also involved. The more pollinating species there are the greater the chances of successful pollination.

Although the use of managed pollinators can be important for good crop yields, work done in Hoedspruit mango fields found that having managed bees made no difference to the amount of fruit produced per tree. Yield was best predicted by distance to natural vegetation, which is the source of wild pollinators. Large fields in which trees were far from natural vegetation had significantly lower fruit production per tree (Bartomeus et al. 2013). Analysis of these and other similar data for over 40 crop species across the globe found that a diversity of pollinators yields much better fruit production than using honey bees alone (Carvalheiro et al. 2010, 2011).

How climate change disrupts pollination

Different pollinator species respond differently to climate change: some are changing their timing of peak activity quickly, others more slowly. A diversity of pollinating species means that the chance of pollinators being active when the crop is flowering is greater. A recent study (Bartomeus et al. 2013) analysed 46 years of data, tracking peaks in apple flowering and peak activity in the various pollinating bees. Some bees are changing the timing of their peak activity faster than apple flowering is changing. Other bees are changing more slowly – but the net effect is that the combination of different species of bee are still able to meet the crop's need for pollinators. In short, this variety of pollinating species ensures that apple pollination can still happen, although the species doing the pollination may have changed over the last 46 years. Similar findings have been made for communities of wild plant species and their pollinating bee communities.

Protecting our pollinators

The best approach to safeguarding pollinators is to avoid or at least minimize the loss in the first place. By carefully planning new urban development, managing landscapes with the pollinators in mind, and striving for use of pollinator-friendly pesticides and farming practices, pollinator's habitats and their food resources can simultaneously be protected. Even rangeland users can do their bit for pollinators by not overstocking livestock so that flowering plants can be maintained. Degraded pollinator habitats can be partially restored by the addition of flowering plant species. By using locally occurring indigenous species pollinator networks (links between all the plant and pollinator species) can be repaired. Work in mango fields in the Hoedspruit area found that planting patches of native plants (e.g. *Aloe greatheadii* and *Barleria obtusa*) in mango fields helped improve pollinator diversity and mango fruit yield in large fields (Carvalheiro et al. 2012).

Pest control: the enemy of my enemy is my friend

In agriculture there is a need to keep crops free from pests to maximize food production. Pests are insects or other animals, which cause damage, destroy crops or spread diseases to plants or animals. Pests are a constant cause for concern for farmers. Controlling pests such as insects, mites and weeds using other organisms (natural enemies) which feed on pests like for example wasps, ants, etc. consistutes 'natural pest control' and can help to protect crops.

The use of predators and parasitoids for biological control in agricultural crop protection can provide good control by preventing pest outbreaks and is a hidden ecosystem service. For example, control of spider mites by predaceous mite species in South African apple orchards saves the grower money by reducing the number of miticide applications required, and prevents the forming of pest resistance (Pringle 2001; Pringle and Heunis 2006). Another example are parasitic wasps which are functionally important organisms in natural as well as human modified environments. They make up more than 75% of the Hymenopteran order with approximately 240 000 species (Bonet, 2009) and are known to occupy a wide range of habitat types (Shaw, 2006). Gaigher et al. 2016 undertook insect surveys on six wine farms around Stellenbosch, Paarl and Wellington containing remnant Fynbos or Renosterveld vegetation, old fields and vineyards and found an astounding 237 species from 23 families (from 1194 sampled parasitoids) were found!

Their role as biological control agents thus makes parasitoids highly valuable within agroecosystems (Shaw and Hochberg, 2001). Parasitoids require the presence of host species for their reproduction, feeding and ultimately, survival. Additionally, for various species, adults are dependent on floral

resources as alternative sources of food and habitat. Due to their occupying high tropic levels and tendency towards specialization, these organisms are highly sensitive to changes in prey abundance, floral resources, microclimate conditions and nesting areas (Matos et al., 2016), making them particularly vulnerable to extinction (Shaw, 2006; Shaw and Hochberg, 2001). By promoting habitat heterogeneity within agricultural landscapes, farmers may potentially provide parasitoids with critical resources. These include nectar, pollen and alternative hosts, and undisturbed refuges, which are important for survival in disturbed landscapes, and which are needed during certain stages of their life-cycle, such as when overwintering (Landis et al. 2000).

Farmers' near invisible allies

Mites are tiny arthropods related to spiders, which occur in all habitats, and therefore play an important role in ecology. But they also are a valuable component in human developments such as agriculture. Mites can be beneficial by preying on agricultural and ornamental crop pests (Krantz, 2009). Some have also been established as effective weed control agents (Krantz, 2009). Non-predatory mites are effective nutrient cyclers. Many are also highly detrimental as disease transmitters to plants and animals and serious ornamental and crop pests (Krantz, 2009). These crops include tropical fruit, tea, nuts and berries.

The mite fauna of South Africa is poorly understood, due to a lack of enough researchers working on mites, as well as major taxonomic impediments. This is primarily due to their small size, making this group difficult to handle and identify. There is also the increasing threat of invasive mites occurring in South Africa, particularly through nursery material, therefore making a comprehensive inventory of mites very important. The identification of beneficial predatory mite species as well as their host plants will inform to what degree agriculture benefits from mite pest control.

Predatory mite 'hunting' on a grapevine leaf © Ken Pringle

Phytoseiid mites are large, fast and proactive predators feeding mostly on mites but also small insects, nematodes and fungi. Some would also eat plants, pollen and extrafloral exudates. Phytoseiids are the best studied group of predatory mites due to their success in controlling mites and thrips (Thysanoptera). Phytoseiids have been established as an effective biocontrol method for mites in many crops including vineyards. Specialist phytoseiids species assemble in response to pest kairomores and plant volatiles caused by herbivory (Sabelis & Dicke, 1985; McMurty & Croft, 1997). They have the ability to increase their population quickly as a response to the infestations (McMurty & Croft 1997; Croft, et al. 2004). Generalist phytoseiids are considered a more sustainable approach (McMurty, 1992; James & Whitney, 1993) due to specialists' tendency to over-populate and over-exploit the pest abundance, leading to emigration and starvation and contributing to unstable prey-predator dynamics (McMurty, 1992; Nyrop, et al. 1998; Jung & Croft, 2001). Generalists can move to an alternate food source when pests are absent (McMurty, 1992) instead of migrating. However, generalist phytoseiids are susceptible to pesticides (James, 1990). Phtyoseiids are also efficient at controlling eriophyids because they are able to detect them from a distance via the volatiles emitted by infested plants (Dicke, 1988; Dicke, et al. 1988; Aratchige, et al. 2004).

Predatory mites are considered an effective method in limiting herbivorous mite outbreaks (Sentenac, et al. 1993). Predatory mites are a natural source of control that should be utilised and encouraged. Pesticides that kill off predators should only be considered as the last resort (Smith Meyer, 1996). Mite pests that are not effectively controlled by their natural enemies, should still allow the predators as a control method by combining them with pesticides (Smith Meyer, 1996).

Parasitic wasps keeping fruit safe from flies

In South Africa, as elsewhere, fruit flies are causing significant production losses and incorporation of biocontrol into existing area-wide management methods is vital for effective management. Co-evolved parasitic Hymenoptera have proven their efficiency to control fruit flies (Wharton 1989, Wong et al. 1992; Ekesi et al. 2016) and are used to supplement Sterile Insect Technique (SIT a biodiversity friendly pest control method) in many countries. These wasps have several advantages: they maintain themselves in the field once released, they don't need costly application or baiting and can control source populations of fruit flies from alternate hosts (e.g. home gardens). In orchards, sanitation is an important management strategy, which is often neglected by growers. The use of augmentoria of parasitic wasps is widely adopted in Africa and other parts of the world, and combine both sanitation and biocontrol. Fallen fruits are placed in augmentoria (large netted cages), which then decompose and are used as compost. Fruit flies emerging from these fruits are trapped and eventually die, while the smaller parasitic wasps leave the cages through the mesh to infest more fruit flies (Klungness et al. 2005). These augmentoria have been tested extensively in Hawaii and the Indian Ocean Islands (Klungness et al. 2005; Deguine 2011). This method is not known in South Africa and therefore requires attention as it could be a novel solution to orchard sanitation with added benefits for biological control.

Parasitic wasp (Encyrtidae) that lays its eggs in vine mealy bugs

Preliminary surveys made in South Africa have highlighted a high diversity of parasitic wasps associated with various fruit fly species. This substantial diversity represents a promising pool to identify efficient natural biocontrol of these pests and for the application of augmentoria. However, the lack of knowledge on parasitic wasps is a strong impediment for further development of efficient pest control strategies, particularly for the Western Cape, where knowledge is generally lacking. Indeed, the diversity and the complexity of this group (small size, homogenous morphology) make putative identification impossible for researchers, leading to unreliability in research findings based on this material that can explain major failures of biocontrol programs (Wharton et al. 1983). DNA barcoding (Hebert et al. 2003), which can efficiently assist with species recognition of parasitic wasps (Haran et al. in prep) has not been undertaken for the majority of species and no efficient diagnostic tool currently exists for South African fauna. In addition, research has highlighted that many species of parasitic Hymenoptera involved in the biocontrol of major pests (including fruit flies) are in fact tight assemblages of closely related species that exhibit contrasting life traits (i.e. feeding on different hosts, adapted to specific climates (Muirhead et al. 2006, Rugman-Jones et al. 2009, Julsirikul et al. 2014, Kaiser et al. 2016). As a consequence, improvement of natural biocontrol of fruit flies, which is based on an accurate understanding of the

biology and ecology of these wasps, are in great need of a reliable clarification of the identities of species found in orchards.

Exact host associations also remain unknown for a large part of parasitic wasps (Wharton, 2000); there are many wasps associated with damaged fruit and fruit fly traps, but we don't know if they parasitize fruit flies, or how valuable they are for suppressing populations. Indeed, wasps emerging from fruit fly-attacked fruits may be the parasite of the target flies, but also the hyper-parasite of the parasitic wasp or a parasite of other flies feeding in the fruit (i.e. drosphilids). Therefore, assessment of biology based on traditional fruit-rearing methods remain limited and new methodological techniques are needed to understand the biology, ecology and parasitism rate of wasps controlling fruit flies.

Of the various habitat types that occur within farmland mosaics, remnant natural patches are highly important as they often serve as vital refugia for native species (Phalan et al., 2011). A study by Kets (2018) shows that native parasitoids such as those of the vine mealy bug which is a pest of vines (Wolfarther and Addison 2014) and those of red scale that attack citrus trees (Samways 1985), keep their pest hosts at lower infestation levels and form an integral part of integrated pest management programmes.

Healthy biodiverse ecosystems protect crops

Biodiverse soils prevent nasty Nematodes:

Nematodes occupy a large number of trophic levels in healthy soils and native species can thus be used to indicate soil health (Kapp et al. 2013; Louw et al. 2014). An outdated agricultural practice of fumigating soils before planting orchard trees, destroy the native nematode species and lead to selection for damaging nematodes. Nematodes can also be harnessed to fight insect pests by applying them as a liquid spray containing the infective juveniles of native entomophatongenic nematodes (nematodes that parasitize insects), preventing the use of chemical sprays that result in unwanted residues for export markets (Le Vieux and Malan 2013; Odendaal et al. 2015). There is an added benefit to using native species in spray formulations in that it negates the importation and quarantine of alien, potentially invasive, nematode species.

Healthy wetlands yield healthy sugarcane:

The sugarcane industry in South Africa generates R12 billion annually, and studies have shown that ecological infrastructure supporting healthy functioning of intact wetlands can be an important contributor to maintaining production levels of this important national crop. The sugarcane stalk borer, *Eldana saccharina* is the most significant pest on sugarcane grown in South Africa. This moth species preferred natural home is in wetlands where it eats and breeds on only a handful of wetland plant species. It has become a major pest of the sugar industry largely due to these natural habitats being destroyed to make way for sugarcane fields, and currently causes losses of up to R150 million each year. Currently there is an integrated pest management system being used to reduce the impacts form this important pest (Rutherford 2015). Wetlands containing papyrus and giant sedge act as a trap for *Eldana* as these are preferred as hosts by the pest. Using a push-pull system, moths are funneled away from the sugarcane to trap crops such as Bt-maize and native wetland species. An added benefit from these native plants is that *Eldana* that use them as food experience much higher parasitism by native parasitoids (insects that parasitize insect hosts) which are more numerous in wetland habitats than the sugarcane fields. By maintaining wetlands on their farms, sugarcane growers can reduce crop damage through natural pest control and increase water quality as ecosystem services (Rutherford 2015).

Diverse farming ecosystems handles pest better:

Through maintaining ecological infrastructure, fruit fly populations can be controlled in a more cost effective less toxic way. Fruit flies are notorious pests of mango, orange, peach, plum, apricot and apple producers. They lay their eggs under the skin of the fruit and then the larvae feed on the fruit until they are ready to pupate, making the fruit unfit for sale. When ready to pupate, the larvae drop out of the fruit into the soil below. This is when they are most vulnerable, and is the best time to stop the fruit flies from completing their life cycle.

In mango orchards in Hoedspruit, Limpopo, scientists (Henri et al. 2015) have learned that fruit fly pupae on the soil are preyed on more (mostly by ants) the closer they are to areas of natural vegetation. This shows us that maintaining buffers of natural vegetation alongside orchards allows for safe habitat and breeding grounds for natural pest control agents.

A study in the Hoedspruit mango orchards that placed fruit fly pupae out in the natural vegetation and in mango fields found that almost all fruit fly pupae were preyed on (mostly by ants) in natural vegetation, whereas in mango fields, the rate of predation was much lower, presumably because the mango orchard environment was not as conducive to fruit fly predators (Henri et al. 2015).

To friend from foe: biodiversity associated with indigenous crops

When any plant species are cropped as a monoculture and field size increases there is a greater potential food resource for pestiferous organisms, especially insects. This then leads to conflict between the farmer who wants to maximise production and profit, and native insects that explode in abundance to use the newly created food resource. For example, insect pests constitute a major biotic challenge to the cultivation of Rooibos. Surveys conducted by the South African Agricultural Research Council (ARC) during the mid-1990's revealed 110 phytophagous insect species on Rooibos, of which 40 species were thougth to be directly associated with Rooibos (Stals, 1997). Of these species, 21 can be considered pests (Hatting, 2009, 2015), with the three main pest species being a clear-wing moth, *Felderiola candescens* (Sesiidae), a leafhopper, *Molopopterus theae* (Cicadellidae) and a looper, *Isturgia exerraria* (Geometridae).

The South African Rooibos Council, in association with CapeNature, have started the Rooibos Biodiversity Initiative (RBI) to encourage best practices in the area. Guidelines for best practices presently refer broadly to land stewardship in the form of alien eradication, judicious chemical use, restoration of surrounding areas and compliance with the law regarding dam building and ploughing.

The Honeybush industry finds itself at an interesting point in its development as it continues to grow from the modest cottage industry it used to be. As the industry gears itself towards further commercialization it is of utmost importance that the store house of agrobiodiversity available to the industry is further taken into account. The shift from wild harvested biomass to cultivated stands represents a challenge to the industry to heed the growing demand for Honeybush. The question of its production being sustainable, and potentially an environmentally friendly supply remains uncertain. The end product will depend on how the current pioneers of the industry value the resource holistically and incorporate sustainability and agrobiodiversity principles into the future design of the industry – considering all aspects of the production chain, from its cultivation through to the processing and packaging of the final product.

Industry growth has been hindered over the past 10 years by a lack of a consistent supply to the expanding market (Anonymous (5) 2013; Anonymous (1) 2015). For the Honeybush industry to expand

and exploit its potential as a global herbal tea, a shift is needed from wild-harvesting to harvesting from cultivated stands (den Hartigh 2011; Coetzee 2012). With a shift from a market supplied by wild harvested biomass to one produced from cultivated stands, the industry is expected to continue growing at a steady rate (Coetzee 2012; den Hartigh 2011). Currently only approximately 300 ha of land are under cultivation (Anonymous (5) 2013), the resent economic research conducted by Hobson (2015) suggests that the industry has the potential to expand its export ten-fold from the then current average of 150 tons per annum to 1500 tons/annum. This however would then translate as 3000 ha of cultivated lands. If not on old fields this could mean significant biodiversity loss, especially if following the route Rooibos has taken.

Taking its cue from the Rooibos industry in terms of its current pest challenges and threat to the native vegetation, it seems only wise to purposefully and timeously develop the commercialization journey of *Cyclopia* spp. to understand its ecology in avoiding similar issues experienced by the Rooibos industry. Better understanding of the ecology of Honeybush can translate into shaping the industry accordingly, to maintain a functional proportion of the original, natural ecological balance within the agroecosystem.

Current research on insects associated with Honeybush is limited (Knipe & Rosenberg 2008; Joubert, 2011). Similarly, research focused on incorporating agroecology principles into agricultural practices to promote natural biological control of potential pests is also lacking. Nature along with all its elements and role players are in an intricate balance. Much can be learnt from the composition and interactions of associated invertebrate communities. One of many aspects that require considerable monitoring and management includes the potential of pest insects and their natural enemies. The potential ecosystem service and disservice that these groups of insects could render to a farmer are especially important to investigate. Slabbert (2016) examined the relationships that exist between wild and cultivated Honeybush and co-ocurring insect species. Her focus was on determining which of these are beneficial (as pollinators and predators of potential pest species), and potentially harmful (herbivores and disease vectors) to Honeybush plants, both in plantations and in the wild. The survey focused on two Honeybush species, *C. maculata* and *C. subternata*, in the Western Cape. The difference in insect species composition between the Honeybush sites can be attributed to environmental factors, such as water availability and the complexity or simplicity of the surrounding vegetation, water stress and vegetation simplicity rendering plants more vulnerable to insect damage. These environmental factors potentially play an important role in shaping the insect community associated with the two Honeybush species, and are thus potential factors that can be used to the advantage of the farmer in promoting conservation biological control.

***Cyclopia genistoides* near Pearly Beach in the Western Cape**
© Eleonore Slabert

The species diversity of natural enemy complexes associated with *Cyclopia* species need to be conserved in order to ensure high functional diversity for the regulation of potential pest population (see "Pest control" in this section).

Additional research is needed to determine the factors that will ensure ecological functioning within cultivated stands of Honeybush. These would include the critical size of cultivated fields to maintain sufficient levels of movement of natural enemies between natural vegetation and cultivated stands, and the size and quality of refugia habitat required to maintain substantial populations of diverse natural enemies (i.e. effective landscape-level habitat management). Research within commercial South African crops, such as mango plantations and vineyards (Gaigher et al. 2015; Henri et al. 2015 for more details), suggest distances ranging from 100 – 200 m for effective circulation of parasitoids and sufficient rates of parasitism within agroecosystems. If natural biological agents control is not sufficiently conserved within Honeybush plantations the resulting predation release of phytophagous arthropods could result in pest outbreaks. Should natural biological control be maintained within *Cyclopia* plantations the industry would require minimal, if any, external chemical pest control measures. This would avoid the insecticide resistance, one problem facing the dominant Rooibos species farmed. This combination of coarse- and fine-scale habitat management will promote sustainable, ecologically friendly production. This holistic approach suitable for the growing markets for ecologically and socially responsibly produce.

The cascade effect

Healthy ecosystem services provide not only the individual species of wild and commercial food sources, but also give various services that support their success and growth, such as pollination services, natural pest control, regulation and quality of river water flow, and genetic diversity.

Fresh waters equals fresh fish

(See also NBA 2018 Technical Report Volume 3: Estuarin Realm and Volume 4: Marine Realm.)

Estuaries and river mouths are critical breeding grounds for several commercial fish species and are nursery grounds where the young fish can live and grow in relative safety until they are big enough to head out to sea. Sediment-rich water flowing from rivers into the sea provides nutrients for these fish. Fisheries associated with muddy ecosystem types (e.g. prawns, sole and several other fish species) are supported by mud delivery and the maintenance of land–sea connections required for the completion of their life cycles.

Almost every aspect of a healthy estuary or river mouth is dependent on the rate in which freshwater flows into the system from upriver, and the quality of the water that does so. This means that environmental factors happening hundreds of kilometres upriver from a river mouth, can have a profound effect on whether or not life in the river mouth thrives or not.

For instance, if high altitude rain catchments in the Drakensberg Mountains, or river banks along the tributaries of a river downstream of these peaks, become degraded for any reason, it can impact on the fish living in the river mouths that benefit from this freshwater flow.

Overgrazing or excessive fire in grasslands, alien plants invading wetlands and river banks, overabstraction of water for irrigation, and flushing pollution such as fertilizers or mine waste water into rivers can impact directly on the health of life in estuaries and river mouths. This, in turn, impacts on the success of small-scale and recreational fishing, as well as the large-scale commercial fisheries. Furthermore, if a river mouth closes because of overabstraction of water up-river, or because of drought,

it impacts significantly on the survival of the fish population at this sensitive interface between land, freshwater, and ocean environments.

As noted in *From the Wild*, many small-scale fishers at the coast supplement their family's protein through this 'free' resource. Each day they are able to take a fish home for dinner, means there is more money in the household budget to spend on something else. For those who are economically marginal, this is a significant saving. The connectivity of land-freswater-estuaries-ocean is crucial to maintain the productivity of these fishery systems.

Happy and healthy bees equal happy humans

Where honey bees (*Apis mellifera*) are indigenous, they are important for pollination processes that sustain numerous indigenous plants and as managed pollinators of pollinator-dependent agricultural crops. Two sub-species of honey bees are indigenous to South Africa – *Apis mellifera capensis* and *Apis mellifera scutellata*. These two species are actively managed ('farmed') by beekeepers who provide pollination services to the majority of insect pollination-dependent crops in the country by moving their colonies (hives) to farms during the pollination season. Outside pollination season, however, beekeepers undertake practices that provide a honey flow, provide for colony build-up, or trap swarms to replace bees that abscond or die. Here the supply of the honey bee, and whatever else is necessary for the species survival from nature can be seen as a benefit from biodiversity over and above wild swarms that occur naturally next to crops (see 'Pollination of our crops' in this chapter)

These practices require a good availability and accessibility of forage resources for the honey bees – i.e. flowering plants supplying pollen (protein) and nectar (carbohydrates). In a study undertaken in South Africa from 2011 to 2014, the various forage resources important to beekeepers were investigated (http://www.sanbi.org/biodiversity-science/state-biodiversity/applied-biodiversity-research/global-pollination-honey bee-fo). It emerged that different regions in the country had a dissimilar reliance on certain forage resources, but forage resources could be roughly divided into 1) indigenous forage (sub-divided into plant species and vegetation types), and 2) exotic forage, sub-divided into *Eucalyptus* spp (formal forestry and other stands), agricultural crops and urban amenity plantings (urban gardens, tree lanes, etc.). These forage resources are all important for their complimentary preferred uses (honey flow, colony build-up, or swarm trapping), availability (varied flowering times) and accessibility (localities of occurrence and access to localities). Therefore an over-arching strategy for managing forage resources has to consider the importance of both indigenous and exotics plants, as well as use, availability and accessibility.

Status quo: Currently, honey bee forage resources (and therefore the sustainability of the managed pollination service) are threatened in South Africa. These threats do not only limit honey bee forage availability or accessibility, but also directly affect beekeeper livelihoods, pollination services, and put both wild and managed honey bee populations at risk.

Honey bees, both wild-occurring and managed, are important pollinators for farmers. Wild honey bees are trapped, then managed, therefore no wild honey bees equals no managed honey bees. It is therefore important to protect and conserve the honey bee communities themselves. But it is also critical to conserve the natural or farmed veld and trees that they feed on all year around, so that they can remain well-nourished and healthy in between 'working' seasons when they perform such an important pollination service for farmers.

There is immense pressure on South African beekeepers to find forage sites for their honey bees. Most beekeepers do not own or have control over land that provides adequate forage resources, but rely on formal or informal access to important forage sites on both public and private land. At times, land owners or managers might not allow beekeepers access to sites. For example, beekeepers are not allowed to place their managed colonies in most protected areas in South Africa, as visitor safety and the competition for floral resources with other flower visitors are concerns (although both issues warrant further study). Forage sites on privately-owned land are usually a beekeeper's best option and the rights to such forage sites are sacrosanct and may be inherited or even traded between beekeepers. Good interpersonal relationships between beekeepers and landowners are a vital part of a beekeeping business in South Africa. Beekeepers may also be forced to place their colonies on unsecured land where the colonies are prone to vandalism and theft. Vandalism and theft may be hindering beekeeping activities in certain areas in South Africa that have good forage, simply because damage to hives and honey harvest creates an unsustainable beekeeping business.

Honey bee hives place in a Fynbos habitat © Graham Hill

Harvesting wild honey bee swarms

South Africa has been fortuitous in protecting its wild and managed honey bee population, with threats such as diseases and pests having had little impact. The issue of securing forage resources for honey bees is, however, a relatively new problem and, as such, few examples of application exist.

Beekeepers constantly need to maintain their honey production and meet the high demand in commercial honey bee pollination of agricultural crops, hence their active involvement in replenishing of colony stocks regularly. In most European countries, as well as in the USA, this has resulted in extensive bee breeding programmes, an established trade in honey bees, and the introduction of many Apis bee species outside of their native habitats (De la Rúa et al. 2009). Honey bee breeding and inbreeding can dilute or reduce genetic resilience in honey bee populations (Zayed 2009), while the introduction of non-native bees has been shown to negatively affect indigenous bee species through disruption of pollination systems (Huryn 1997, Goulson 2003; Paini 2004). Introduced bee species can also increase the spread of diseases and pathogens (Thomson 2004). In South Africa, and most parts of the African continent, beekeeping is still reliant on the trapping of "wild swarms" (Dietemann et al. 2009).

Dietemann et al. (2009) attributes the "healthy and vibrant" African honey bee populations to the presence of high genetic diversity and a proportionally large remaining wild component, and the absence of selective bee breeding programmes. The South African honey bee population in particular has been resilient against introduced diseases, pests and pathogens compared to their Northern Hemisphere counterparts (Allsopp 2006; Human et al. 2011). A number of studies have also highlighted the importance of swarm trapping for the South African beekeeping industry in off-setting colony losses and increasing hive stocks (Johannsmeier 2001; Allsopp & Cherry 2004; Du Preez 2010; Mouton 2011; Masehela 2017).

Swarming is a natural part of the annual lifecycle of African honey bee colonies (Johannsmeier 2001) and reflects seasonal patterns of growth, development and movement of the colony (McNally & Schneider

1992). Swarming normally occurs in early spring-summer, in response to warmer spring and summer temperatures and increased forage resource abundance (Johannsmeier 2001). South African beekeepers exploit this phenomenon by catching swarms in order to replace and increase their colony stocks. The origin of trapped swarms is however unclear, and some would dispute that not all trapped colonies are "wild". Many of the colonies might have perhaps absconded from neighbouring colonies and are later trapped by new hive boxes (Allsopp 2006). In South Africa, where both indigenous sub-species of honey bees are managed, an absconded swarm is defined as a wild swarm. The sustainability of this practice remains unclear in South Africa, due to unknown figures when it comes to wild populations that beekeepers trap from. Since this practice depends largely on good forage and healthy landscapes for wild honey bees, one can only assume that it remains a viable practice for as long as the forage and landscapes are well looked after. Alternatively, South Africa, like most European countries, will soon find itself venturing into various breeding programmes to sustain their beekeeping.

Grazing from the plains to the Karoo requires resilience and sustainability

The term *rangeland* refers to any extensive area of land that is occupied by native herbaceous or shrubby vegetation which is grazed by domestic or wild herbivores (Encyclopedia Brittanica ref). They span several biomes and include grasslands, savannas, shrublands, deserts and marshes (Lund 2007). Importantly, they consist of natural vegetation, not forage planted by humans.

As much as roughly 70% of South Africa's land is used for grazing or browsing areas for livestock or game (i.e. as "rangeland"; Scholtz et al. 2013), because only 11% of our agricultural land is suitable for cultivation (RMRD, 2016). The livestock and game sector in South Africa is undeniably important to the country's economy, with the sector estimated to provide about 245 000 jobs on commercial farms (Meissner et al. 2013). Livestock are also a key resource for subsistence farmers, providing meat, milk, fertiliser, ploughing of croplands, and additional income (Dovie et al., 2006). For consumers, meat and dairy products constitute an important component of South African diets, representing on average about 27% of the mass of a consumer shopping basket (Meissner et al., 2013).

Livestock and game production can vary from extensive tracts of land with minimal management interventions to highly intensive farming with substantial management interventions such as: predator control, water management, fencing, supplementary feeding, medical interventions, vegetation control and more.

Rangelands cover ~70% of South Africa's land surface © Angus Burns

South Africa's rangelands seem to be supporting progressively fewer livestock over time, however. From the 1950s to the early 1980s, livestock numbers seemed to be stable or declining (Milton and Dean, 1995). Analysis of more recent data suggest that the trend for declining livestock numbers continues, despite the South African human population having increased from about 29 million in 1980 to roughly 56 million in 2016. Changes in number of livestock seem not to be driven by changes in rainfall (Milton and Dean 1995), and are likely driven by a change from livesock to game farming, and linked to degradation of the state of rangeland health. The number of head of game on agricultural land increased from fewer than 600 000 in 1964 to 18.6 million in 2007 (Du Toit 2007 in

Carruthers 2008), a trend that has continued (https://www.property24.com/articles/south-africas-game-farm-industry-is-booming/23254).

Rangelands are important for people and nature the world over as they are naturally functioning ecosystems that deliver valuable services to people. We have relied on rangelands for millennia, primarily as grazing for our livestock and wildlife, and for harvesting medicinal and edible plants from the land. Healthy rangelands maintain soil stability, improve water infiltration and foster plant diversity.

Worryingly vast tracts of our country's rangelands are degraded, commonly due to inappropriate grazing or fire management and alien invasive plants. Given that rangelands form large parts of the South African landscape, the health and proper functioning of these rangelands is crucial, not only in providing grazing, but also for water quality, erosion control and carbon sequestration. Carbon dioxide in our atmosphere can be lowered by taking carbon out of the atmosphere and storing it in terrestrial ecosystems – there is tremendous potential for increasing soil carbon through restoration of degraded rangeland soils. The voluntary guidelines for sustainable soil management report shows that about 33% of global soils are moderately or highly degraded due to unsustainable management practices. The importance of sustainable resource management becomes critical when dealing with the restoration of rangeland and conservation of ecological infrastructure

The relationship between rangeland diversity, water and drought

Just as with other ecosystem functions, a diversity of species helps ensure optimal ecosystem functioning. It turns out that rangelands with a healthy mix of indigenous species have better soil stability and reduced soil erosion. Reduced erosion in turn means less sediment in water run-off, resulting in better water quality. In a country like South Africa where droughts are common, water use efficiency is vital. A study in the dry grasslands near Bloemfontein (Snyman 2005) found that as the plant communities became more degraded, their water use efficiency declined.

(water use efficiency = the rate at which plant matter produces per amount of water transpired by plants)

Diversity is also important for resilience: more diverse rangelands can bounce back faster after drought (Tilman & Dowling 1994; Van Ruijven & Berense 2010). Once species diversity is lost, getting it back needs more than just time, but active intervention. A study over 20 years of grazing exclusion in heavily and moderately grazed Karoo rangelands near Prince Albert found that although the cover of palatable species in heavily grazed areas that had been rested was the same as areas that had only been moderately grazed, it was only one species, compared to five in moderately grazed plots (Seymour et al. 2010). The only way to restore rangeland diversity within management time frames would be to re-seed areas with seeds from palatable species, so maintaining rangeland health is a cost effective way to build climate resilience.

Factors that degrade rangelands

Rangeland degradation includes any negative changes to rangeland condition. Bush encroachment, a form of rangeland degradation, is the situation where woody species increase while herbaceous (grassy) species decrease, and has been recognised in southern Africa since the late 1800s (O'Connor et al., 2014). A recent study that used remote sensing found that in just over two decades (1990 – 2013), the extent of woodland in South Africa's grassland and savanna biomes had increased by about 5% (Skowno et al., 2017). There are a number of different causes of bush encroachment, many of which interact with each other. Fire suppression and heavy grazing in concert with heavy rainfall have been associated with

increased rates of bush encroachment; and elevated concentrations of CO_2 in the atmosphere associated with human industrial activities give woody plants an advantage over grassy species (Kraaij and Ward, 2006; Polley et al., 1997).

Rangeland degradation lowers the carrying capacity of South Africa's rangelands, that is, the number of stock that each ha of land can support. Bush encroachment is usually accompanied by an increase in species not palatable to stock in savannas. A study in the Molopo, North West found that the carrying capacity of bush encroached rangeland was about five times lower than that of non-encroached land (Moore and Odendaal, 1987). In the shrublands of the Karoo, heavy grazing is associated with lower perennial plant cover, with an increase in toxic shrubs. In the *Smaldeel* area of the Eastern Cape, where the vegetation is primarily sweet grass and bush, with some areas of karoo shrub and annual grasses, gross income per ha for veld in good condition was estimated to be over twice that of the income per ha for veld in poor condition (Danckwerts and Marais, 1989). In the Pongololand region of KwaZulu-Natal, although cattle fared similarly on land that had a history of heavy grazing to land that did not, during periods of drought, those on degraded rangeland lost condition (Fynn and O' Connor, 2000).

The soil structure of rangelands that have been overgrazed tends to break down, and degraded rangelands in poor condition also tend to suffer increased erosion, which in turn affects freshwater ecosystems through siltation and increased variability of run off. The process of degradation and change in plant species composition under heavy grazing appears to be self-reinforcing: overgrazing releases more resources (e.g. water, nutrients) to the species that survive overgrazing (i.e. toxic or ephemeral species), helping further to ensure, if not speed up, their establishment (Milton, 1995). Degraded areas have lower rainfall use efficiency (RUE) than areas that are not degraded (Snyman, 2005; Wessels et al., 2007). Furthermore, the state of a rangeland affects its ability to recover, with areas that have lost palatable species often never regaining them within timeframes of human management (Seymour et al., 2010).

Rangelands provide an array of ecosystem services, in addition to grazing for livestock and game. Among these are carbon sequestration, provision of forage plants and nesting sites for pollinators, and control of soil erosion. A recent study estimated the value of ecosystem services provided by South African ecosystems, and assessed the losses associated with degradation. Although South Africa's GDP increased by USD 250 billion in the two decades between 1990 and 2010, the value of the ecosystem services (ES) that our natural environment provided over the same period had declined by USD 65 billion (Anderson et al., 2017). These estimates are based on landcover change alone, and the calculated losses on the value of ES provided do not take into account the losses associated with soil erosion, loss of primary productivity and the costs of invasive species, so are likely an underestimate (Anderson et al., 2017). What is clear is that economic growth in South Africa between 1990 and 2010 has come at the cost of natural capital, which Anderson et al. (2017) compare to harvesting fish at unsustainable rates - they also point out that South Africa has a number of industries that are very dependent on natural capital. Declines in the value of Grassland, Savanna and the Nama-Karoo have a large effect on values for the country, overall, because these are among the three largest biomes. All biomes except for the Albany Thicket Biome had declined over the 24 years under consideration.

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4. BIODIVERSITY ASSETS ARE VITAL FOR THE WILDLIFE ECONOMY

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Note: the author drew on various literature sources and a report from RebelGroup Pty Ltd (consultancy contract to SANBI entitled 'Literature review and feasibility study for the categorisation and quantification of the wildlife ranching sector in South Africa (Q5351/2016)'). The consultancy project was led by Carol Poole, Matthew Child and Jeanetta Selier, with support from Andrew Skowno, Amanda Driver and John Donaldson.

Key messages

The livestock and game farming sectors occupy 70% of South Africa's land surface and provide approximately 250 000 jobs (2013*). The wildlife ranching sector (with activities ranging from hunting to tourism) is worth ~R14billion (Taylor et al. 2015) per year. Degradation of these rangelands lowers the carrying capacity for both livestock and wildlife, with associated decreases in other ecosystem services like water quality, erosion control and carbon sequestration, as well as the sustainability of jobs in these sectors. Both wildlife ranching and livestock farming are vitally important land-uses for both socio-economic development and biodiversity conservation, but can have negative impacts if conducted too intensively. Intensive farming of either game or livestock should not be done in biodiversity priority areas, and the certification of conservation-friendly wildlife ranching and rangeland management should be prioritised.

* see section on grazing in the 'Biodiversity contributes to food security' chapter of this compendium.

Discussion

South Africa is unusual in that private landowners can own wildlife[5] as property (Carruthers 2008). Such classification of wildlife as private property (or communal property in southern African countries) has contributed to a huge increase in wildlife numbers and is one of the reasons why southern Africa is the only region on the continent with stable or increasing large mammal populations (Craigie et al. 2010). Private ownership of wildlife is often labelled as 'wildlife ranching', which we define as all privately-owned land areas that derive commercial benefit from wildlife, encompassing a range of management approaches from active to passive (Taylor et al. 2015). As such, wildlife ranching land-use occupies a space between intensive agriculture and extensive biodiversity conservation and is founded on four (often overlapping and integrated) economic pillars: 1) animal husbandry (breeding and live sales), 2) hunting (both subsistence and trophy), 3) ecotourism and 4) game products (Cloete et al. 2015; Taylor et al. 2015). All wildlife ranching thus uses existing natural resources to produce renewable living stocks that can be periodically harvested as part of a broader green economy. As a by-product of this biophysical production system, ranches may provide additional services to individual consumers (e.g. recreational experiences) or the public (e.g. ecosystem services). Wildlife ranches also provide the raw material for secondary economic activities such as taxidermy, game product manufacture and visual

[5] The term 'wildlife' seems undefined as yet. A narrow definition might be limited to indigenous animals living in natural habitats. Broad definitions might encompass plants, unmanaged populations of non-native species and other elements of natural ecosystems. For the purposes of this summary, we are meaning primarily 'large mammal species'

media production. Wildlife ranches are thus a unique mechanism to unlock economic value from biodiversity.

There is some debate as to the magnitude of the industry: estimates of the extent of wildlife ranching in South Africa range from a lesser footprint of 170 419 km^2 comprising 8 979 ranches and 5.9 million head of herbivore (Taylor et al. 2015); to larger estimates of 205 000 km^2 (16.6% of the SA land surface), comprised of at least 10 000 ranches, with an estimated 2.5 to 18 million head of herbivore (Bothma & du Toit 2015). The term "herbivore" here is defined as medium to large herbivore species (typically 'game species'), ranging from duikers to elephants. Despite variable figures, even the minimum estimated area under wildlife ranching is more than the coverage of formally protected areas (78 100 km^2). As such, it is a vitally important land-use for both socio-economic development and biodiversity conservation.

The most recent estimate for the total economic contribution of wildlife ranching is R14.4 billion (R9.3 billion direct value generation and R5.1 billion purchasing inputs from other sectors), which accounted for 0.3% of Gross Domestic Product in 2015. It is likely that the return on assets for wildlife ranching will be higher than livestock farming, especially in arid areas, as wild herbivores are better adapted to their environments, thus requiring fewer resources. Additionally, wildlife ranching may provide more stable returns over time – particularly during highly variable climatic conditions and increasingly dry climates. Finally, the diverse range of possible income sources from wildlife ranching (see Figure 1) may also engender more consistent returns over time, as economic activities are fluid and adaptable depending on demand. For example, 52% of wildlife ranches engage in multiple economic activities (Taylor et al. 2015).

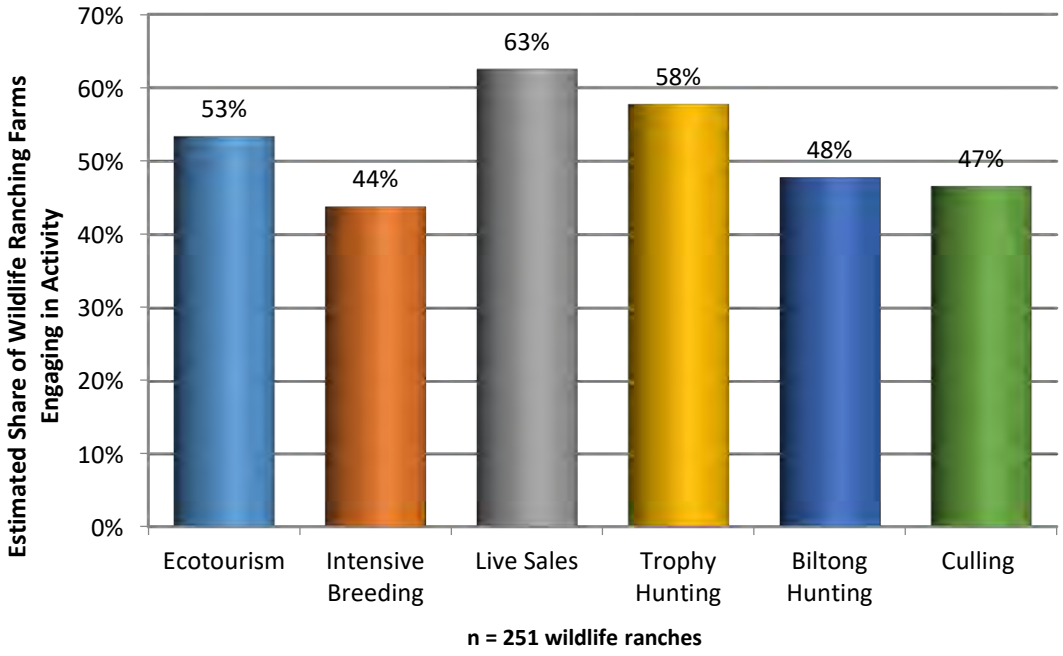

Figure 1: Functional activities from which wildlife ranchers derive commercial benefits
[Taken from RebelGroup 2017. Basic data from Taylor et al, 2015. Taylor et al determined the proportion of wildlife ranches engaging in each of these activities from responses received to a survey conducted among a randomised sample of wildlife ranches distributed around South Africa. Of the farms with exemption certificates (or certificates of adequate enclosure), about 48% engaged in only one of the commercial activities listed above, 14% engaged in two activities, 25% engaged in three activities, 6% in four activities, 3% in five activities and the remaining 4% in six activities.]

Diverse and adaptive economic activities may engender resilience to the wildlife ranching industry during unpredictable market fluctuations and global dynamics. It is imperative to link economic resilience to management that sustains ecological resilience too, and thus the capacity for the ecosystem to regenerate. Specifically, management should maintain diverse ecological functions through creating habitat heterogeneity and high species diversity, and ensure management is directed at the landscape scale rather than optimizing production in one species or ecosystem services (Allen et al. 2011). Additionally, a broad and diverse portfolio of activities in the sector provides a potential toolkit for rural communities to benefit from land re-distribution. This is particularly promising given the Department of Environment, Forestry and Fisheries' drive to develop wildlife economy hubs as part of the Wildlife Economy Lab under the Operation Phakisa initiative. Currently, the wildlife ranching industry employs over 65 000 people (Taylor et al. 2015), and is set to expand given government investment and infrastructure development. Expanding wildlife-based land-uses can also unlock international financial instruments, such as carbon credit schemes (Dinerstein et al. 2013) and thus contribute towards stabilising the viability of the industry. However, this must be carefully coordinated so as to actively work towards social inclusiveness and benefit-sharing from wildlife ownership (Spierenburg & Brooks 2014) as well as positive environmental benefits and biodiversity outcomes. The conservancy model may be most appropriate for taking this land-use model forward as a sustainable development tool (Lindsey et al. 2009), as it entails multiple land-owners working together towards a shared vision whilst unlocking greater economic opportunity over wider land-areas.

Utilising wildlife for food may also increase national food security. In 2014, an estimated 21 220 tonnes of game meat and a further 18 930 tonnes from biltong hunting across 21 species was produced (Taylor et al. 2015). Utilising native herbivores may have lower net carbon emissions than livestock production due to the lower inputs needed in production and lower shipment costs associated with supplying local and regional markets directly. Encouraging local production and consumption of game meat products is thus one mechanism to reduce carbon emissions and establish system feedback loops in social-ecological systems for greater overall sustainability (Leader-Williams 2002)

Wildlife ranching inherently relies on the diversity and adaptations of our indigenous ungulates, and reflects our natural heritage. The average number of herbivore species on wildlife ranches is 15 (Taylor et al. 2015), including many rare species or species of conservation concern (Child et al. 2016). However,

Nyala (*Tragelaphus angasii*) © John Donaldson

strategic regulation and coordination of the industry is needed to align the commercial objectives with broader species and ecosystem conservation goals and to promote management methods that would enhance the resilience of the social-ecological system (Allen et al. 2011). For example, the trade-off between increasing the commercial value of species through intensive management versus reducing the wildness and ecological functionality of populations (and thus their potential value to biodiversity) is one that should be carefully and transparently navigated between all stakeholders. For example, certification schemes could be used to ensure that harmful environmental 'externalities', such as predator persecution (Pitman et al. 2017), electric fence erection, inbreeding, alien species spread and overgrazing are minimised or offset by broader landscape-scale objectives (such as conservancy formation or corridor creation).

In summary, the wildlife ranching industry utilises biodiversity assets that are devolved to landowner rights to produce both economic and environmental benefits. There is direct value in increasing the abundance of ungulate species for sustainable utilization; while non-consumptive values include ecotourism, cultural services and ecosystem service provision resulting from a wildlife-orientated land-use. Wildlife ranching thus supports Sustainable Development Goals relating to inclusive and sustainable economic growth (goal 8), sustainable consumption and production patterns (goal 12), and protection of terrestrial ecosystems (goal 15). While challenges remain to ensure that the economic, social and biodiversity goals are achieved simultaneously and equitably, this is an exciting and unique frontier for South African communities, one with much opportunity for expansion and innovation.

Work is currently underway at SANBI to design frameworks to categorise the biodiversity and economic contributions of wildlife ranches that could be used to support green certification schemes and tax incentives. Such frameworks are examining aspects of on-farm management activities such as water management, landscape permeability, the level of management of species, and the management of the natural vegetation. When examined through a lens of four dimensions of impact (intensity, frequency, persistence and extent), these on-farm activities can be categorised in terms of their on-farm and landscape-level ecological impacts and support a more refined approach to incentives and regulation.

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5. BIODIVERSITY STIMULATES INNOVATION

Biodiversity resources have stimulated innovation for centuries. Humans have manipulated the genetic resources of plants and animals to breed versions more suitable for human use and consumption, a practice which is estimated to date back 9 000 to 11 000 years. We also use extracts from plants and animals to synthesise materials and medicine. More recently, humans are learning from nature's example in order to become more productive and sustainable. This chapter of the compendium intends to illustrate a few examples of innovation inspired by biodiversity.

5.1 Bioprospecting – new products from biological resources

Recommended citation for this chapter of the compendium:
Poole CJ and Crouch N (eds). 2018. 'Bioprospecting – discovery and commercialisation of new products from biological resources' chapter *in National Biodiversity Assessment 2018 Supplementary Material: Compendium of Benefits of Biodiversity*. South African National Biodiversity Institute, Pretoria. Report number: http://hdl.handle.net/20.500.12143/6491

Note: the authors directly summarised a report for the then Department of Environmental Affairs entitled 'The scope and extent of the utilisation of indigenous biological resources by bioprospecting industries in South Africa' (DEA, 2015), but some slight adjustments have been made to modernise text where necessary. It is noted that this is currently the best resource available, but it is likely that the facts and figures are out of date as this sector is changing rapidly.

Key messages

A 2015 survey found that there are 549 retail products that contain South African indigenous plant resources and/or bee products from just 24 South African species. There is likely large potential for growth in the bioprospecting sector, with potential for more retail products that make use of resources from indigenous species.

Introduction

Bioprospecting is defined by Wikipedia as 'the process of discovery and commercialisation of new products based on biological resources'. In South Africa, it is defined in Chapter 6 of the National Environmental Management: Biodiversity Act (NEM: BA) (Act No. 10 of 2004) as research on, or development or application of, indigenous biological resources for commercial or industrial exploitation and includes (South Africa, 2004):

- the systematic search, collection or gathering of biological resources or making extractions from biological resources;
- the utilization of information regarding any traditional uses of indigenous biological resources by indigenous communities; and
- the research on, or the application, development or modification of such traditional uses for commercial exploitation.

Many nations have legislated access to their biological and genetic resources for bioprospecting purposes. South Africa is one of these nations, with regulations in place to govern bioprospecting, access and benefit-sharing activities in accordance with its obligations as a signatory to the Convention on Biological Diversity.

Biological richness provides an important basis for economic growth and development, and the use of these resources in bioprospecting offers the opportunity to create additional employment in the country. Previously, the export and use of South Africa's biodiversity in the formal sector, particularly indigenous plant resources and bee (*Apis mellifera*) products, were not well documented. The effective implementation of the legislative provisions on the use of indigenous biological resources, and effectual support of small business development in this field are reliant on a sound knowledge and understanding of the bioprospecting market sectors.

Key findings from store sampling and industry reviews

DEA's 2015 report, which was the result of primary data collection from store sampling and industry reviews, provides a first economic overview of the formal commercial bioprospecting market in South Africa, with specific emphasis on the biotrade and use of indigenous plant and bee products. A bioprospecting commercial industry value chain was developed showing the key role players, from the resource to the end user (see Figure 2). The market knowledge was then utilised to identify possible areas of future development of this component of the economic sector in the country.

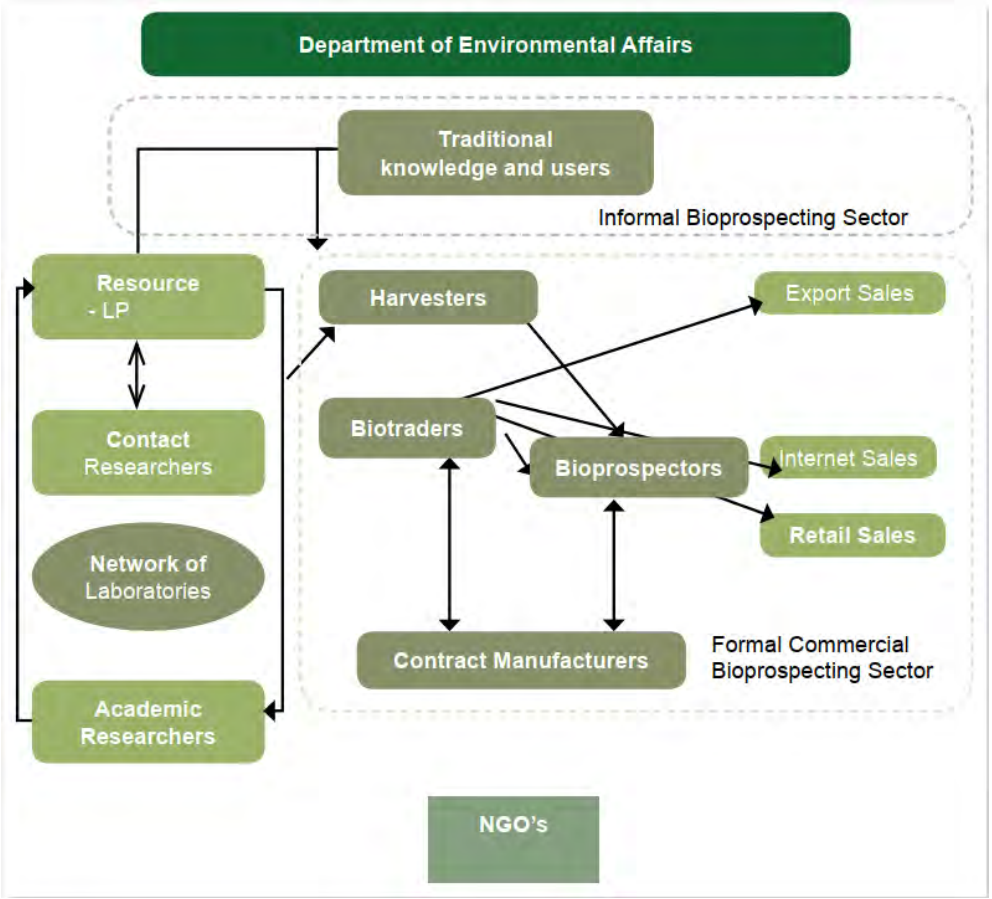


Figure 2: Bioprospecting value chain in South Africa showing the informal and formal commercial bioprospecting sectors which make up the overall bioprospecting value chain of the country. The informal bioprospecting sector value chain is not included in the market analysis (from DEA, 2015)

In a survey of retail and specialist stores and health shops across the country, 549 retail products were found to contain South African indigenous plant resources and bee products. The resources included in these products were limited to only 24 South African plant species (see Table 2, taken from DEA, 2015). The most extensive resource use in products was *Aloe ferox*, followed by bee products, *Aspalathus linearis* (Rooibos) and *Pelargonium sidoides*.

***Aloe ferox* tapper at work © John Donaldson**

Table 2. From DEA 2015 Table 3.1: Plant species, number of products and percentage of the 549 products found to contain these indigenous resources in the store survey linked to this market sizing; and Table 5.1: Cultivation vs. wild harvesting of indigenous plant resources used in the bioprospecting market

No.	Species	common name	Number of products	Percentage of all products	Wild harvested/ cultivated
1	*Aloe ferox*	Bitter aloe	146	26.2 %	***95% Wild harvested***
2	*Apis - Honey, Propolis or Wax*		93	16.7 %	
3	*Aspalathus linearis*	Rooibos	92	16.5 %	***1% wild harvested; 99 % cultivated***
4	*Pelargonium sidoides*	Rabassam	40	7.2 %	***Largely wild harvested; Some cultivation***
5	*Agathosma species*	Buchu	36	6.5 %	***>50 % cultivated***
6	*Adansonia digitata*	Baobab	25	4.5 %	***Wild harvested***
7	*Sutherlandia frutescens*	Cancer bush	25	4.5 %	***Insufficient data on percentages however: large-scale cultivation by Phyto Nova***
8	*Harpagophytum procumbens*	Devil's claw	24	4.3 %	***Wild harvested***
9	*Pelargonium graveolens*	Rose-scented pelargonium	19	3.4 %	***Insufficient data***
10	*Bulbine frutescens*	Snake flower, cat's tail	16	2.9 %	***Insufficient data to provide percentages although this species is sold in nurseries***
11	*Cyclopia spp.*	Honeybush (coastal)	15	2.7 %	***30% Cultivated 70% Wild harvested***
12	*Marine - Kelp, Cape seaweed, seaweed, sea bamboo*	Kelp	15	2.7 %	***Wild harvested***
13	*Hypoxis hemerocallidea*	Star flower, yellow flower	11	2.0 %	***Wild harvested***
14	*Kigelia Africana*	Sausage tree	10	1.8 %	***Insufficient data but wild harvesting seems most likely***
15	*Hoodia gordonii*	Hoodia	9	1.6 %	***Insufficient data***
16	*Sclerocarya birrea*	Marula	9	1.6 %	***Wild harvested – limited studies on cultivation***
17	*Sceletium tortuosum*	Kanna	7	1.3 %	***Insufficient data – possibly wild harvested with some cultivation***
18	*Siphonochilus aethiopicus*	Natal ginger, wild ginger	7	1.3 %	***Chiefly wild harvested***
19	*Warburgia salutaris*	Pepper-bark tree	6	1.1 %	***Insufficient data***
20	*Dioscorea dregeana*	Wild yam	3	0.5 %	***Insufficient data***
21	*Aloe arborescens*	Krantz aloe	2	0.4 %	***Insufficient data***
22	*Eriocephalus africanus*	Wild rosemary	2	0.4 %	***Insufficient data***
23	*Hypoxis rooperi*	African potato	2	0.4 %	***Insufficient data***
24	*Citrullus lanatus*	Tsamma melon, wild watermelon	1	0.2 %	***Insufficient data***

The internet search and survey of stores in South Africa indicated that bioprospecting products could be found in five of the bioprospecting market segments[6]: cosmetics, oils, food flavourant, fragrance and medicines (African and Complementary Medicines). Products were largely cosmetic (includes personal hygiene products), followed by complementary medicines. The oils and fragrance market segments had limited representation in the retail stores surveyed (Table 3).

Table 3. From DEA 2015 Table 6.1 – Number and percentage of bioprospecting products per market segment category, determined from the internet search and store survey

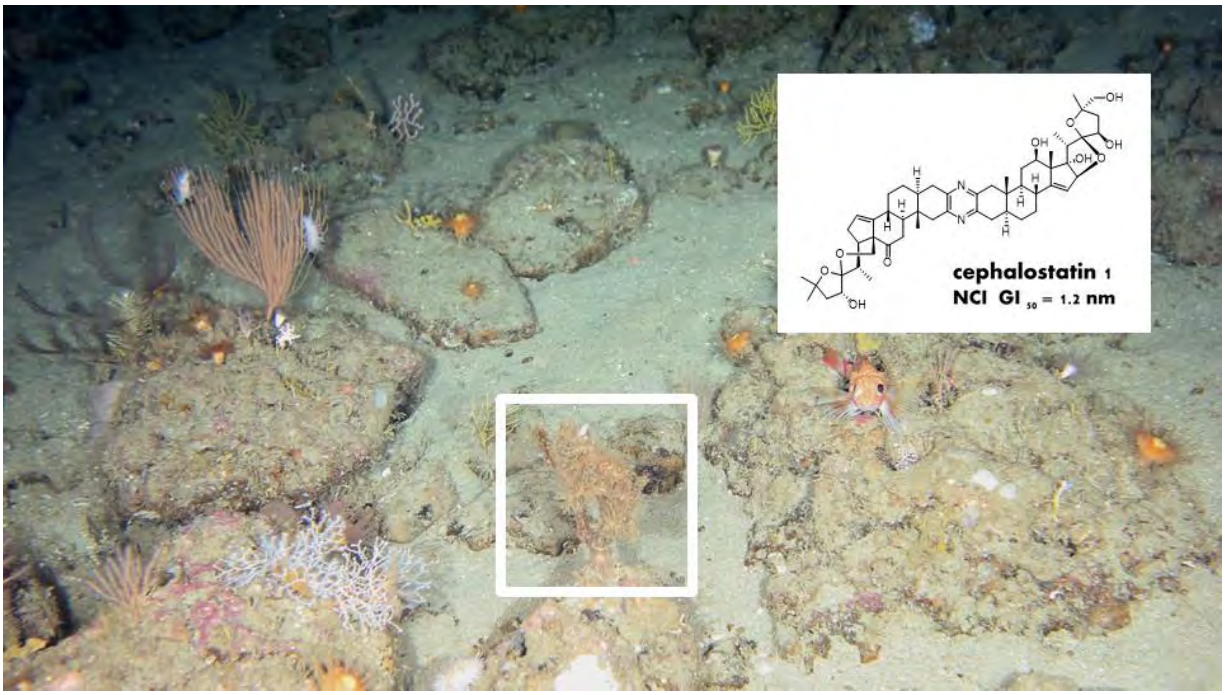
Category	Number of Products	Percentage of product
Complementary medicines	212	39 %
Cosmetic	164	30 %
Oils	3	1 %
Food flavourant	44	8 %
Fragrance	1	0 %
Personal hygiene product	125	23 %

A number of important plant-derived ingredients are used in the manufacture of cosmetics and personal hygiene products, including oils, fats and waxes, essential oils and oleoresins, plant extracts and colourants (Lubbe and Verpoorte, 2011). These plant derivatives variably contribute fragrances, colours, moisturisers, thickening agents and stabilisers.

Despite South Africa being a remarkably biodiverse country with a large number of plant species that could potentially provide new medicines, there are currently very few drug leads obtained from South African plants. This is despite the country having a large traditional medicine market that could potentially 'leap' products into the formal medicinal market. Those South African species which have made the 'leap' into the formal medicinal market have chiefly been developed beyond our borders and largely to the benefit of other nations (Drewes, 2012). These exploitations include:

- the antibiotic pimaricin (produced by the bacterium *Streptomyces natalensis*);
- EPs 7630 (Umckaloabo) from the plant *Pelargonium sidoides* (licensed to treat respiratory tract infections such as acute bronchitis since the 1990s);
- combretastatin from the plant *Combretum caffrum,* which has been shown to cause vascular disruptions of tumours in cancer patients and Phase 3 trials were underway in 2015,
- P57 isolated from *Hoodia gordonii* (isolated in 1977 by the citizen scienceIR as an appetite suppressant; but development on the active ingredient has subsequently stopped due to the difficulty with utilising this resource for this purpose (knowledge as of 2015)).

[6] 10 Segments were identified in the document South Africa's Bioprospecting, Access and Benefit-Sharing Regulatory Framework, Guidelines for Providers, Users and Regulators (Department of Environmental Affairs, 2012): medicines, industrial enzymes, essential oils, food flavourants, fragrances, cosmetics, emulsifers, oleoresins, colours, extracts and new plant varieties



Cephalodiscus gilchristi **(in the square) is a hemichordate worm that occurs predominantly on the south coast of South African in shallow depths up to 1 000 m (Atkinson and Sink 2018). It produces one of the most potent compounds (see inset) that have been tested against the National Cancer Institute's leukaemia cell line.**

With regard to essential oils, production in South Africa is dominated by the cultivation of exotic species (e.g. eucalyptus, citronella, lavender, etc.). However, there is a distinct industry in indigenous essential oils. There are a number of indigenous plant species that are under cultivation or wild harvested for utilisation or potential exploitation in this bioprospecting market segment, including *Eriocephalus punctulatus* (Cape Chamomile); *Eriocephalus africanus* (Cape Snowbush), *Geranium* and *Lippia javanica*. The use of South African indigenous plant resources in the oils value chain, like exotic species, is however also determined by the available market and, besides Buchu (*Agathosma*), this segment is very small and predominantly focused in the Cape.

Seaweeds in South Africa are commercially exploited solely off the Western and Eastern Cape coasts. According to Turpie et al. (2003) the commercial seaweed industry in the Western Cape is based mainly on kelp (*Ecklonia*, *Laminaria*), while the seaweed industry in the Eastern Cape is dominated by *Gelidium* spp.

Ecklonia maxima (sea bamboo)	This species of kelp is found in the southern oceans, from the extreme south of South Africa northwards to Namibia. Generally, *Ecklonia* is collected as beach-cast from seaweed concession areas on the west coast of South Africa. Most of this beach-cast kelp is dried and exported (Anderson *et al.* 1989, 2003). Beachcast yields have fluctuated between about 500t dry wt and 2 000t dry wt, with peaks in 1990/1991, 1996–1999, and in 2004 (Anderson et al., 2007). Kelp is also harvested fresh in smaller quantities, for the production of a liquid plant growth stimulant such as Kelpak. This fresh harvesting increased more or less steadily up until 2004, and then decreased slightly (Anderson et al., 2007). The bulk of the kelp collected is exported for alginate extraction. Small quantities are milled and used locally in animal feeds, fertilizer, and as a soil-binder/fertilizer used for stabilizing and revegetating artificially created embankments (Anderson et al., 1989).
Gelidium pristoides	*Gelidium pristoides* is harvested form the Eastern Cape coast of South Africa, collected from the subtidal fringe and from rock pools. The commercial operators developed a small agar processing plant for this species in Butterworth in the Eastern Cape, where the harvest from harvesters (almost all women) are processed. The *Gelidium* is dried on site, and then transported to a depot at Butterworth. Most of the *Gelidium* and *Gracilaria* harvests from southern Africa are sold to Japan.

The store survey of products containing marine resources showed that at least 15 products contained these species. Products were produced by Betlawap; Clicks; Ecoco; Flora Force; Loock Pharm; Medico

Herbs; Navita; Nutri Herb; Pegasys; PhytoLife; Vital and Willow. The difficulty with this segment of the bioprospecting market is that many of the products do not stipulate the actual species of marine resource included in the product, broadly referring to the product as containing 'kelp'.

Economic analysis

For the purpose of the 2015 economic analysis, the value chain was considered as three segments: a resource segment, a bioprocessing segment and a final market segment.

The size of the bioprocessing segment of the value chain, as measured by total revenue generated in the bioprocessing segment (primary and secondary processing of indigenous resources) of the bioprospecting market, was approximately R482 million in 2011. Of this, approximately R322 million was exported. The remainder, R160 million, was transformed into value-added products sold within the domestic retail sales market.

The total revenue produced from value-added products sold in the domestic retail market, and which contained bio-resources as an ingredient, was approximately R1,470 million in 2011 (Department of Environment, Forestry and Fisheries Bio-products retail database). These locally produced value-added products can be segmented into five product categories:

- Personal hygiene products (R585 million or 40% of products)
- Cosmetics (R555 million or 38% of products)
- Complementary medicines (R170 million or 11% of products)
- Food flavourings (R110 million or 8% of products)
- Oils (R50 million or 3% of products).

The importance of indigenous plant resources and bee products as an ingredient in these value-added product categories is revealed by the comparative values of retail sales of products with and without these indigenous resources as an ingredient. Products containing indigenous plant resources and bee products as an ingredient sell between 50-100% more by retail value than products without indigenous plant resources and bee products as an ingredient (Department of Environment, Forestry and Fisheries Bio-products retail database). This is clear evidence of a strong consumer demand for products containing indigenous plant resources and bee products as an ingredient.

The industry has a very significant scope for value addition. The farm gate prices of indigenous plant resources and bee products varied between R3/kg and as much as R70/kg, whereas the prices of extracts and concentrates (for example oils, powders, milled products) varies from R220/kg to more than R1 000/kg. This indicates a high price value addition from farm gate to bioprocessing.

The size of the resource segment (wild harvesting and cultivation) is estimated at between 2 000 and 2 800 tons per year at a weighted average price of approximately R50/kg. This equates to an estimated wild harvesting and cultivation revenue of between R41 million and R57 million per year.

The bioprospecting industry, based on export trends, has grown, on average, by 6% per year over the period 2001-2011. The potential market size of the bioprospecting industry, based on resource permit application data, is at least R2 150 million per year. This suggests that the current industry has reached only about 20% of its potential, and thus has a large growth potential.

The bio-resources economic sector for many reasons is an ideal development sector in the South African context with the potential for employment creation. There are several reasons for this:

- It realises the economic value of indigenous species;

- It facilitates rural economic development;
- It has very high value added potential;
- It has a high potential to earn foreign currency;
- It enables the development of new product markets;
- It is a 100% renewable industry if managed for sustainability.

Based on this data, the Gross Domestic Product (GDP) contribution of cultivation, wild harvesting and bio-trading in 2011 was approximately R82 million in 2011. Although this is currently a relatively small industry, the growth potential of the industry is large and there remains much potential for GDP growth. This GDP contribution will grow with market growth and may be expected to increase to between R115 million to R150 million per year by 2018. This will be highly beneficial to rural economic development.

The sector currently earns foreign currency through exports of indigenous plant resources. The total value of these exports was approximately R322 million in 2011.

The bioprospecting industry has a large growth potential. There is a large potential for local value adding in the contract manufacturing and bioprospecting sectors. The multiplier effect of cultivation and harvesting of indigenous plant resources is approaching 10. This is therefore a highly effective value adding sector, and investment in this sector will be accompanied by a large multiplier effect. Although the R332 million figure for exports seems like a fairly sizeable amount, the real value addition only takes place when these indigenous plant resources are blended into products such as cosmetics, personal hygiene products, oils, food flavourings and complimentary medicines. In the previous section we saw how R160 million worth of bioprocessed products enabled the sales of R1 470 million worth of value added products in the domestic retail market. From an economic perspective it would be desirable to realise as much in-country value addition as possible of indigenous plant resources and bee products.

The bioprospecting sector is an important job creation sector. Job creation occurs throughout the whole value chain. It is possible that an additional 700 to 1 700 new jobs may be created in this industry, by 2018, depending on the market growth trajectory achieved.

Following the bioprospecting value chain segmentation, three key segments require strategic intervention to remove industry supply constraints and achieve conservation goals. These segments are the (1) Wild harvesting segment; (2) Cultivation segment and (3) Bioprocessing segment. Activities to achieve strategic intervention goals include:

- Protect wild harvesting areas. Currently, estimates are that approximately 50% of bioprospected raw materials are wild harvested. Increasing demand for bioprospecting products will place these wild resources at increasing risk in the future. It is important to develop suitable resource plans for each key species, to develop sustainable harvesting practices, consistent permitting requirements and effective monitoring and compliance systems.
- Cultivation. Currently, approximately 50% of indigenous raw materials are cultivated. As cultivation is an agricultural activity, it holds the largest potential for growing the industry and creating formal jobs. In order to realise the market potential of this industry, the cultivation of bioprospecting products would have to grow by at least 500 hectares per year. A targeted agricultural development strategy would likely take a “hub” development approach. The benefit of such an approach is that it can facilitate the development of a node around which the cultivation of bioprospecting species may develop.
- Bioprospecting. A number of supporting actives are required to remove supply chain constraints, including: benefit sharing agreements, product quality control, SMME development.

Key findings and gaps

The **key findings and gaps** highlighted in the market sizing of bioprospecting of indigenous plant resources and bee products in South Africa are provided below, including:

- The level of wild harvested vs. cultivated indigenous plant resource utilised in this bioprospecting sector is poorly documented. To ensure sustainable utilisation of these resources, as the sector expands and grows, will require sound knowledge and understanding of the availability, abundance and location of these resources. Sustainable harvesting and management plans need to be developed based on this new knowledge. These plans need to be implemented in conjunction with sustainable use awareness and educational programmes, particularly for farmers entering this sector and wild harvesters of the resource. However, the entire market could benefit greatly from awareness and educational programmes related to sustainable and ecologically sound use of indigenous biological resources (IBRs).
- A number of the indigenous biological resources which are currently included in bioprospecting products or which the literature has highlighted as having potential to grow this bioprospecting market in South Africa have very little or no scientific literature to support the growth of the market for the product.
- Perhaps the most startling discovery related to this market sizing is the large number of commercialised products found within retail stores, specialist stores and health shops which contain South African indigenous plant resources and bee products. The number of these products far exceeded the initial estimates from the literature.
- Literature related to the entire value chain of an indigenous biological resource is extremely limited. The sector could benefit greatly from more studies which describe and expand on indigenous biological resource utilisation for bioprospecting, which would facilitate knowledge sharing and can ensure targeted strategic interventions by all the role players.
- The entire bioprospecting market of South Africa should be sized, including the use of other indigenous resource (i.e. animals, fish) and the informal market. This will provide a comprehensive overview of the value of this market sector to the Green Economy of the country, to GDP and to job creation.
- A number of the bioprospecting market segments are poorly understood and documented. These include the oils, fragrance, oleoresin, marine and industrial enzyme market segments. These require further investigation as there may be potential to grow the bioprospecting market in the country through use of our biological resources within these largely unexplored market segments.
- Despite South Africa being a remarkably biodiverse country with a large number of plant species which could potentially provide drug opportunities, there are currently very few drug leads obtained from South African plants. This is despite the country having a large traditional medicine market which could potentially 'leap' products into the formal medicinal market. This market segment of the bioprospecting market requires further investigation.
- The international market for indigenous plant resources are receiving greater benefits than the local bioprospecting market. The local bioprospecting market could benefit greatly from utilising these resources for value-add products and interventions. The bioprospecting industry has a large growth potential, particularly in the contract manufacturing and bioprospecting sectors. The growth of the bioprospecting industry is not constrained by the market, but rather by factors that constrain the supply of bioprospecting products. Following the bioprospecting value chain segmentation; cultivation, wild

Leminda millecra **– frilled nudibranch that produces cytotoxic activity that causes apoptosis (cell death) of cancer cells from a type of oesophageal cancer particularly common in the Eastern Cape.**

harvesting, and bioprospecting segments require strategic intervention to remove industry supply constraints.

Recommendations and way forward

- In order to realise the market potential of this industry, the cultivation of bioprospecting subjects would have to grow by at least 500 hectares per year.
- A targeted agricultural development strategy should take a "hub" development approach. The benefit of such an approach is that it can facilitate the development of a node around which the cultivation of bioprospecting species may develop.
- Increasing demand for bioprospecting products will place the conservation of these wild resources at ever-higher risk in the future. It is important to develop suitable resource plans for each key species, to develop sustainable harvesting practices, consistent permitting requirements and effective monitoring systems. SANBI and the provincial conservation agencies have significant roles to play in this regard.
- A number of supporting activities are required to remove supply chain constraints within this segment. These activities include:
    - A need for the traditional knowledge database which could serve as a repository for resource rents recovered for benefit sharing where the traditional knowledge linkage is not clear also needs to be developed.
    - Setting product standards through certification, labelling guidelines and other means can greatly support the development of the industry. This would improve the value experience of both wholesale and retail customers and lead to better prices and increased sales while protecting the brand of the industry.
- Providing business support by (1) establishment of an industry forum where all members can share information and which can serve as a conduit for business support (2) development of a mentorship programme and (3) development of an integrated research support programme.

References

For all references, please refer to:

DEA, 2015. The scope and extent of the utilisation of indigenous biological resources by bioprospecting industries in South Africa. Department of Environmental Affairs. Pretoria. ISBN: 978-0-621-42766-0

5.2 Horticultural gems South Africa gave the world

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Key messages

South Africa's flora is world-renown and ranges from horticultural gems to important medicinal plants to vital commercial crops. Many of South Africa's indigenous plants are still awaiting research to unlock their full potential and maximise the opportunities offered by our exceptionally rich floral wealth to ensure that local people benefit from this potentially valuable resource.

Introduction

Now who would have thought that our indigenous *Strelitzia reginae* (bird of paradise) had friends in high places? Not only is it one the most popular horticultural perennials around the world, it has also been crowned the flower of Los Angeles since 1952 − in celebration of the city's 171st birthday! This is food for thought and, by doing a bit of digging, one soon comes to the conclusion that South African plants have been going places since ancient times right through to the 21st century on a local and global scale.

Over many centuries, through trial and error, the indigenous people of southern Africa have built up a profound knowledge and appreciation of our local South African plants. The Khoisan, who are nowadays considered to be representing the most ancient of all cultures, were reliant on these plants for thousands of years for their survival. Plants were not only used for their medicinal value, but also for food, water, shelter, fuel and other necessities. For ages the 'secrets' of indigenous plants were privy only to the local people living in the region, but this has changed over the years with the emergence of modern science, technology and knowledge of the natural environment.

On a timescale, one can pinpoint global scientific and horticultural interest in South African plants to the late seventeenth and early eighteenth centuries, when major plant collections reached Europe. It was also during this time that Carl Linnaeus, who is considered the 'father of taxonomy', developed the principles of plant classification and nomenclature that are still in use today. Many of our plants, especially those used in the floricultural business, became world famous and have been collected, domesticated, cultivated and, unfortunately, also exploited by foreign horticulturists and entrepreneurs. An order by King George III of England to collect plants from South Africa was the reason that Francis Masson − a gardener at the Royal Botanic Gardens in Kew – got the feather in his cap for being the man responsible for putting ericas, several *Protea* species, *Strelitzia reginae*, pelargoniums, as well as bulbs such as ixias, freesias and gladioli, on the global map. He undertook two extensive trips during 1772 and 1786 and collected many South African plants that transformed Kew into a world-renowned garden.

Since then, hundreds of plant species have found their way across the globe and some achieved worldwide popularity due to their iconic appearance, sweet fragrance, delicate flowers and stunning colours. Zonal, regal and ivy geraniums have been decorating so many window boxes in Europe for centuries. The Cape primrose, Cape daisies, strelitzias, proteas and pincussions all made it onto this list of fame. Several species were also used as the source of genetic material for cut flowers that have been hybridized, registered with plant breeders' rights and distributed worldwide.

No matter how one looks at our remarkable indigenous plants, they have made their mark globally, whether it is by keeping the world spellbound with their beauty, by using them to produce drinks 'fit for the gods', or by utilizing them in the fight against disease – examples abound. Some have even gone so far as to become renegades and are classified as troublesome invasives in some countries!

The fifth most popular cut flower in the world

Although the South African flower industry is marginal, from an international perspective, our flora is diverse, unique and highly sought after by plant breeders. Species of the Cape flora, especially, rank among the world's favourites. Breeders have invested huge effort and expertise towards the production of new and exciting ornamental and cut flower selections. Species and hybrids of South African genera that are in high demand are: *Agapanthus*, *Arctotis*, *Crocosmia*, *Disa*, *Eucomis*, *Erica*, *Haemanthus*, *Ixia*, *Lachenalia*, *Leucadendron*, *Leucospermum*, *Lobelia*, *Mimetes*, *Nerine*, *Nymphaea*, *Ornithogalum*, *Osteospermum*, *Pelargonium*, *Protea*, *Rhodohypoxis*, *Serruria*, *Sparaxis*, *Strelitzia*, *Streptocarpus*, *Tulbaghia*, *Venidium*, *Watsonia* and *Zantedeschia.*

Flora expos in Europe and Asia, as well as the popular annual Hortifair in the Netherlands, has proven that South African ornamentals are in high demand. In the first eleven weeks of 2011, no less than 86 929 090 stems of 'gerberamini' (hybrids of our own *Gerbera* daisies) were sold on the Dutch Flower Auction, as well as 35 749 803 single-flowered freesias. This indicated that *Gerbera* hybrids were the top South African commercial cut flower and was ranked the fifth most popular cut flower in the world. But the accolades do not stop there – by winning the 35th gold medal in 42 years at the Royal Horticultural Society's Chelsea Flower Show, the 2018 South African exhibit showcasing our floral heritage, held the world in awe in 2018.

Water under the bridge

South Africa's indigenous plants are not utilised for decorative and commercial purposes only. The vast majority of the population, including traditional healers, use about 3 000 species as traditional medicines. At present, almost half of all commercial medicines worldwide are derived either directly from plants, or are modified plant products. During the late 1800s and early 1900s agriculture and extensive stock farming, among others, were some of the major industries in South Africa. Unfortunately, stock farming was plagued by serious and severe stock diseases which led to the deaths of thousands of livestock and game between 1890 and 1929. Scientists from the Onderstepoort

Veterinary Research Institute took up the challenge and did extensive research on the poisonous plants grazed by animals. These scientists were also ultimately responsible for putting their institute on the global map. Since 1994, plant chemistry in South Africa has thrived and many students with a keen interest in *muti* or medicinal chemistry, entered the field. The increase in knowledge and their research efforts were successful in validating the traditional use of a number of indigenous medicinal plants.

But, as life goes, it was not always all moonshine and roses and some of our indigenous species were exploited by foreign countries. This includes the antibiotic pimaricin that is produced by the bacterium *Streptomyces natalensis*, a product from *Pelargonium sidoides* registered under the name Mckaloabo, and combretastatin produced from *Combretum caffrum. Pimaricin is a fungal antibiotic* used worldwide against yeasts and moulds that has no effect on bacterial activity. It is added to food that undergo maturing over time, such as fruit and cheese. *A* group of Dutch microbiologists working for the Royal Dutch Yeast and Fermentation Industries in Delft, the Netherlands, collected the bacterium (*Streptomyces natalensis*) from soils around Pietermaritzburg in 1957 and ultimately pulled the carpet from underneath our feet in getting the British patent that was granted in 1957.

The exceptional medicinal plant, *Pelargonium sidoides,* has been used by the Zulu people for ages to treat gonorrhoea, diarrhoea and dysentery. Ironically, South African scientists missed out on a wonderful opportunity to unravel its potential and to commercialise it locally. The plant was taken to England in 1897 by Charles Henry Stevens, who suffered from tuberculosis. Today the extract of the plant, registered under the name Mckaloabo, is sold all over Europe, especially in Germany where it is used as a cure for pulmonary diseases and tuberculosis. The product is under patent to Spitzner Arzneimittel, Ettlingen, Germany and another patent was granted in 2010 to another German firm, Dr Willmar Schwabe.

The beautiful *Combretum caffrum* (bush willow) has its own story to tell and local historians believe that the San people and the Arabs had traded the bark for over 2 000 years. Apart from the fact that the bark extract has anti-cancer properties, it was most likely used as a general tonic to create a feeling of general wellbeing. It was also used by the Zulu people as a poison for their spears – emphasising the fact that many natural extracts could be potentially lethal if used in the wrong dose. In the early 1980s George Pettit, a professor and director of the Cancer Research Institute based at Arizona State University in the United States of America, first isolated the compound combretastatin from the root bark of the tree, which causes vascular disruptions of tumours in cancer patients. At present, combretastatin A-4 is the most potent naturally occurring combretastatin known and phase 3 trials are underway.

Hoodia – a thorny problem

Hoodia gordonii, a rare succulent plant that grows in the Kalahari Desert area, has long been known to the San people who chewed the pulp of the plant to suppress thirst and hunger while on long hunting trips. These effects were virtually unknown to the Western world until the early 1960s. Scientists from the Council for Scientific and Industrial Research (citizen scienceIR) were able to isolate an active component from *Hoodia gordonii* named P57 and gained a patent on it in 1998. They then granted a sub-license to Pfizer in order to do further chemical development on P57. Little did they realise what thorny problem they were tackling when an international outcry followed. Representatives of San clans demanded restitution of their right to communal intellectual property and they were eagerly supported by a global chorus of patent-law critics.

Needless to say, the sub-license was renounced in 2003 and a memorandum of understanding was signed with the South African San Council agreeing that Pfizer shall pay royalties. The citizen scienceIR then signed up another transnational as licensee called Phytopharm, and it was agreed that the San would receive royalties from the company during the drug's clinical development and when the drug is eventually marketed. However, that was not the end of the saga and things got out of hand when illegitimate *Hoodia* preparations in capsule and liquid form poured into the marketplace, sold by farmers, fly-by-night companies, as well as legitimate nutritional diet supplement companies. Not all the products were verified to contain pure *Hoodia gordonii* with quantified levels of the chemical constituents that produce the anti-obesity effects. As recently as 2017, studies done by Unilever Research & Development in the Netherlands indicated that no evidence exists that *Hoodia gordonii* extracts produced weight loss. They also found that increased blood pressure and nausea are some of the negative side-effects of the product. After spending more than 220 million rand on research, Unilever has now decided to discontinue research on the product.

As bitter as gall, but as good as gold

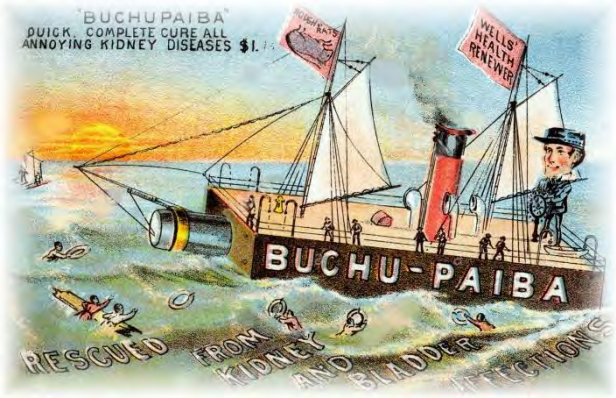
The relationship between people and aloes goes back many centuries and it was used for medicinal purposes in several cultures in countries such as Egypt, India, Mexico, Greece, Japan and China. Aloes are also some of the few identifiable plant taxa depicted in the rock art of the San people. The world-renowned *Aloe vera* has been traded between the Arabian Peninsula and Mediterranean for at least 2 000 years and the Egyptian queens Nefertiti and Cleopatra used it as part of their regular beauty regimes. It was also applied on the battlefield by Alexander the Great, and Christopher Columbus to treat soldiers' wounds. In the aftermath of the nuclear bombing of Japan in 1945, however, the plant's status was elevated irrevocably when a scientist reported that radiation burns treated with an aloe extract healed considerably faster than what could be expected from any other treatment. Since then, aloe preparations have also been applied to burns as a result of x-ray and radiation treatment.

South Africa has its own aloes to boast with. *Aloe ferox* plants from the Albertinia district in the southern Cape have been proven to have 36% more total amino acids in its gel and 20 times more of the bitter sap containing the beneficial substance aloin than *Aloe vera*. *A. vera*, in comparison, contains very little bitter sap and therefore very small amounts of aloin. The bitter sap has been harvested and exported to Europe and Asia for years for inclusion in a range of products, and bitters is particularly popular in Germany and Spain. *A. ferox* is now following in the footsteps of *A. vera* and the increase in the variety of food products containing *A. ferox* leaf mesophyll, such as confectionary and fruit juice blends, reflects this. *Aloe arborescens* is cultivated on a smaller scale in Asia, South America and Italy for both leaf exudate and mesophyll. This species is also wild-harvested in South Africa for export, especially to Japan, where the species is a popular medicinal plant. It has also been used on a large-scale in food products, especially in dairy products such as yoghurt and ice cream, in Asia and the United States.

Aloes are very decorative and highly collectable and have become popular in the horticultural and specialist ornamental plant trade. Artificially-bred aloe hybrids such as *Aloe*×*Gasteria* and *Aloe*×*Haworthia* crosses are very popular with Japan, the United States and United Kingdom being the major importers of living specimens.

Nothing new under the sun

Another endemic to the Western Cape's Cederberg region with a considerable reputation is buchu, or round-leaf buchu, which refers to the species *Agathosma betulina*. It is a famous medicinal herb and made its name internationally, particularly for its essential oils. However, to put things into perspective – it has been used for centuries by the Khoisan for a host of conditions. They specifically included buchu, as well as other aromatic herbs, in an ointment made of fat to lubricate their bodies to keep their skin soft and moist in harsh desert conditions. This ointment served as an antibacterial and antifungal agent and it also acted as an insect repellent, a deodorant and a natural tonic that promoted the general wellbeing of the body.



Europeans first got to know this miracle herb about 350 years ago when they came into contact with the Khoikhoi cultures in the Cape Colony. The Cape colonists brewed an alcoholic drink called buchu brandy or *boegoebrandewyn* and it became a sought after *boereraat* or remedy for colds and flu. The first apparent mention of buchu plants cultivated in Europe occurred in 1706, although the plants were referred to as a species of *Diosma*, meaning 'divine smell', and not buchu, By the mid-nineteenth century buchu-based medicines started to become popular in the USA, and as a tonic particularly as the active ingredient in Helmbold's Fluid Extract of Buchu. Buchu still remains a high value

crop and research done during 2011 indicated that fresh plant material was sold on the international market for about R35 per kilogram, buchu oil for about 700 euro per kilogram and buchu seed sells for about R20 000 per kilogram.

A trendy tea with kick … and doing it without caffeine!

'*There are those who love to get dirty and fix things. They drink coffee at dawn, beer after work. And those who stay clean, just appreciate things. At breakfast they have milk and juice at night. There are those who do both, they drink tea.*'
Gary Snyder

Rooibos tea has been used for ages and has been a traditional beverage of the Khoisan people from the Cederberg region in the Western Cape. Between the 1700s and 1800s settlers and migrants in the Cederberg area discovered that the fine, needle-like leaves of *Aspalathus linearis* make a tasty, aromatic tea. The leaves and fine stems were chopped with axes and bruised with mallets and then left in heaps to ferment. Once fermented, the Rooibos was spread out to dry in the sun, ready for use as a refreshing and thirst-quenching drink. Today, Rooibos is still processed in much the same way, but more mechanised and far more refined.

The marketing of Rooibos started in 1904 already when Benjamin Ginsberg, a Russian immigrant and pioneer in the Cederberg area, became interested in Rooibos. He came from a family who had been in the tea industry in Europe for centuries and he soon realised its marketing potential and started trading it from local farmers. Nowadays, one can find Rooibos tea in niche markets, such as specialty shops, cafés and supermarkets, all over the world – this ties up with the latest trend for things rich in antioxidants, free of caffeine and low in tannins. Rooibos tea has also been used as an ingredient in cosmetics, slimming products, as a colouring and as a flavouring agent in baking, cooking and in cocktails. Since 2004, Germany alone imported more Rooibos tea than what is used locally. In 2014 the registered company Rooibos Ltd distributed Rooibos to more than 60 countries around the world. The latest craze, which has now hit the United States, is to treat Rooibos as one would coffee by making Rooibos cappuccinos and red lattes.

From an obscure drink of the Kouga Mountains to a global industry

The use of *honigtee* (Dutch); Honeybush; *heuningtee* or *heuningbostee* (Afrikaans), for *Cyclopia* species was first recorded by Swedish botanist Carl Peter Thunberg during his travels in the Cape in the 1770s. A preparation made from the plant was used to restore health and to treat chronic lung conditions and pulmonary tuberculosis. Its common names reflect the sweet, honey-like scent of the plant when in full bloom. Honeybush remained mostly unknown outside its natural habitat and was commercialised only in the Langkloof area during the 1930s by a man called Nortje who sold processed *C. intermedia*, harvested in the Kouga Mountains, for less than 2 cents per kilogram. There was some increase in demand during World War II that raised its price to almost 5 cents per kilogram. Fifty years later, during the 1980s, advertisements in a farmers' magazine, *Landbouweekblad*, listed prices of R1.00 per kilogram. The first South African branded product was called, Caspa Cyclopia Tea, and it appeared on the market in the 1960s.

Organic and health foods, as well as foods rich in antioxidants, dominated the headlines of the global food industry in the 1990s and this coincided with the interest in Honeybush as a crop. The export market of Honeybush has grown slowly but surely over the past ten years and increased from 50 to 200 tonnes and, since 2008, Honeybush is sold in 25 countries. The main importers are the Netherlands, Germany, United Kingdom and the United States. Interestingly, countries traditionally known as tea-drinking nations, such as India, Japan and China, were added to list of importers.

Shrouded in myths and legends

You will have to dig deep to find another African tree that is shrouded in more mysteries and legends than the baobab (*Adansonia digitata*). One of the legends holds that when God was planting trees on Earth, he asked the animals to help him and gave every animal a tree to plant. The hyena was given the baobab, but was he was so disgusted by the tree that he simply shoved it into the ground upside down so that its roots forever appeared against the African sky.

The baobab occurs in many African countries and almost all parts of the tree are used in traditional medicine; more than 300 traditional uses have collectively been documented in Benin, Mali, Zimbabwe, Cameroon, the Central African Republic, Kenya, Malawi, South Africa and Senegal.

Germany, France and the Netherlands are particularly interested in baobab products that are used in food and beverages, and for the botanical remedies market segments. Natural health and cosmetic products are in great demand in the United States of America, Europe and Japan. The turnover of botanical remedies and dietary supplements almost doubled from 12.4 billion US dollar in 1994 to 20.3 billion US dollar in 2003. The oils extracted from baobab seeds are used in skin and healthcare products, and anti-oxidants, obtained from the baobab fruit pulp, are in substantial demand due to its anti-ageing properties.

Baobab, in its white powder form, is used predominantly in smoothies and porridge. It was approved for European markets only 10 years ago, but thanks to its purported levels of antioxidants, potassium and phosphorus, high level of vitamin C, calcium and fibre, it has seen its uses expanded into gin, beauty products and yoghurt.

Come dine with me, we're having waterblommetjiebredie

The endemic Cape-pondweed, locally known as *waterblommetjies*, is used in South Africa for its edible buds and flowers, especially in a famous traditional Cape dish, called waterblommetjiebredie – a stew that consists of onions, vegetables, wine and lamb. The flowers were used by Khoisan people for food.

It was introduced to Europe in the seventeenth century, and later into other parts of the world. It has since become widely naturalised in Australia, France and England. This species is grown as an ornamental in outdoor aquaria and water features and is very popular because it grows and flowers during the winter months. Unfortunately, it has escaped cultivation and invaded slow-moving freshwater creeks, rivers, lakes, dams and other water bodies. In North America it is naturalised in southern and western California. It is regarded as an environmental weed in Victoria and as a minor environmental weed or potential environmental weed in other parts of southeastern Australia.

No arguing with an elephant

Another truly South African success story is the exotic-tasting cream liqueur, Amarula Cream, sold by the South African Distell Group (Distell), and made from the tasty fruit of *Scelerocarya birrea* (marula) trees. It has been described as irresistible, creamy and vibrantly fruity on the palate. According to Fin24.com, estimates show that in 2009 Distell sold about 345 000 cases of Amarula, 276 000 of which were on the local market. In 2010, FIFA (International Federation of Association Football) accredited the product as one of two official alcohol products during the World Cup soccer tournament. Folklore holds that elephants can get drunk by eating the fermented marula fruit rotting on the ground and books have even been written asserting the truth of the phenomenon with eyewitness accounts of allegedly intoxicated pachyderms. No scientific grounds have been found to prove the truth of this story though, but one thing is sure – the sweet, nutritious fruit from the marula is a firm favourite of elephants, and who wants to argue with thousands of elephants in any case?

Banned! South African plants that overstepped the line

Guess which South African plants feature on the United Kingdom's first list of banned invasive species that was published in 2014? None other than the much-loved *Crocosmia*. Other botanical troublemakers are *Carpobrotus edulis*, *Macrocystis angustifolia* (giant kelp) and *Lagarosiphon major* (oxygen weed). And who would have thought that an innocent-looking plant such as *Carpobrotus edulis* could become the most threatening South African invader in Californian coastal areas? Furthermore, *Olea africana* subsp. *africana* (African wild olive) is regarded as a limited threat.

Carpobrotus edulis is also high on the New Zealand Pest Plant Accord list. Others are *Ochna serrulata* (Mickey Mouse bush), *Crassula multicava* (fairy crassula), *Plectranthus ciliatus* (speckled spurflower), *Polygala myrtifolia* (sweet pea bush), *Moraea flaccida* (Cape tulip) and *Lagarosiphon major* (oxygen weed). A hybrid of the white arum lily (*Zantedeschia aethiopica*), also called the green goddess, is also regarded as a troublesome nuisance.

Although no South African species are among Australia's six worst plants that demand compulsory removal, *Chrysanthemoides monilifera* (bitou bush) and three *Asparagus* species (*A. densiflorus*, *A. asparagoides* and *A. scandens*) feature on their important national list of Weeds of National Significance that was passed in 1999. *Asparagus densiflorus*, also called the bridal creeper by Australians, arrived in the country about 120 years ago and is regarded as one of the most serious environmental weeds of southern Australia. Its foliage forms an impenetrable mat in indigenous forests around Adelaide that leads to the extinction of numerous indigenous ground orchid and forest shrub species. Some South African bulbs and tubers were also not spared and freesia, watsonia, babiana, *Gloriosa superba* (flame lily) and *Zantedeschia aethiopica* (white arum) are listed on the invasive plant lists of individual Australian states. *Zantedeschia aethiopica* is regarded as a noxious, invasive, alien weed in Western Australia and it has created a huge problem around the Margaret River, south of Perth where huge stands have taken over pastures causing a danger to livestock due to its toxicity. Flame lilies have invaded coastal dunes in southeast Queensland, New South Wales and Victoria.

Some plants escape from gardens and cause havoc in the wild. Six species of *Watsonia* are tagged as such and have invaded the conservation area of Kings Park in central Perth. They also colonize road reserves in high rainfall areas, such as Melbourne. *Ochna serrulata* also managed to earn a very bad

reputation as a major weed and is ranked 22 on the list of the 200 worst invasive alien species in southeast Queensland. Grasses such as *Cynodon dactylon* (cough grass), indigenous to both Australia and South Africa, is regarded as a casual alien that has invaded river edges and wetlands in southwest Australia.

The last word has not been spoken…

The potential of so many of our indigenous plants are still awaiting discovery and research to unlock their full potential. We have made progress, for sure, but much can still be done on a national level to maximise the opportunities offered by the exceptionally rich floral wealth of South Africa to ensure that local people benefit from this potentially valuable resource. The importance of inspiring new scientists, botanists and horticulturists to replace those who will eventually retire can never be underestimated to ensure that future discoveries and contributions to botanical knowledge may add value not just for South Africa, but on a global scale.

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5.3 Crop Wild Relatives – genetic material to support agriculture

Recommended citation for this chapter of the compendium:

Mavumengwana Z and Raimondo DC (eds). 2018. 'Crop Wild Relatives – genetic material to support agriculture' chapter *in National Biodiversity Assessment 2018 Supplementary Material: Compendium of Benefits of Biodiversity*. South African National Biodiversity Institute, Pretoria. Report number: http://hdl.handle.net/20.500.12143/6491

Note: authors for this chapter summarised the document entitled 'National Strategic Action Plan for the Conservation and Sustainable Use of Crop Wild Relatives in South Africa'. Main authors of that report were: Domitilla Claudia Raimondo (SANBI) and Michelle Hamer (SANBI), Stephen Holness (independent consultant), Willem Janse van Rensburg (Agricultural Research Centre), Joana Magos Brehm (University of Birmingham).

Key messages

South Africa has 220 priority indigenous species, subspecies and varieties that are important relatives of commercial crops around the world. These crop wild relatives are an important resource of genetic material that can be used in plant breeding to enhance crop production. Several areas around South Africa have been identified as important areas for crop wild relative richness. The implementation of the National Strategic Action Plan for the Conservation and Sustainable Use of Crop Wild Relatives in South Africa (DAFF, 2016, which identifies priority actions for both in situ and ex situ conservation) should be a priority.

Introduction – What are CWRs?

Crop wild relatives (CWR) are wild species of plants that are closely related to crops. They are recognized as a vital component of agricultural biodiversity. CWR collectively constitute an enormous reservoir of genetic variation that can be used in plant breeding and are a vital resource in meeting the challenge of providing food security, enhancing agricultural production and sustaining productivity in the context of a rapidly growing world population and accelerated climate change (Maxted *et al.,* 2006). They have been used to improve the yields and nutritional quality of crops since the beginnings of agriculture. Farmers often plant them alongside domesticated crops to promote natural crossing of beneficial traits. Genes from wild plants have also provided cultivars with resistance against pests and diseases and improved tolerance to abiotic stresses.

In addition to using them in breeding, people also gather species from the wild and cook them. Throughout Africa, for example, people eat wild cowpea species (*Vigna* spp.), while in Madagascar, wild yams (*Dioscorea* spp.) are a rich source of carbohydrates. These can also be sold, providing rural households with an additional source of income. The potential value of CWR for agriculture and the need to protect these plants in their natural habitats (*in situ*) have been recognised globally. South Africa has the richest temperate flora globally, and the checklist of food and fodder CWR for the country lists 1593 Crop Wild Relatives for South Africa of which 258 taxa are of high priority for conservation (SANBI, ARC & DAFF, 2017).

Prioritisation of CWRs

A checklist of wild relatives of human food (including beverages) and fodder crops has been developed. The checklist includes both indigenous and naturalised taxa present in South Africa that are relatives of cultivated crops, with a focus on major crops, but also including some less established but potentially important crops. A total of 1593 taxa (species, subspecies and varieties), (or 7% of the total number of

plant taxa in South Africa) form part of this checklist. Four criteria were used to prioritise the food and fodder CWR i.e. socio-economic value of the related crop (at a global, continental and regional scale), potential for use of the wild relative in crop improvement, threat status and distribution (whether indigenous or naturalized and if indigenous, whether it is restricted to South Africa, i.e. endemic). A total of 258 priority taxa were identified including relatives of cassava (*Manihot esculenta*), rice (*Oryza sativa* and *O. gaberrima*), Rooibos tea (*Aspalathus linearis*), rye, (*Secale cereale*), sorghum (*Sorghum bicolor*) soya bean (*Glycine max*), sugarcane (*Saccharum officinarum, S. barberi, S. sinense*), sweet potato (*Ipomea batatas*), wheat (*Triticum aestivum*) and yam (*Dioscorea alata, D. bulbifera, D. cayenensis, D. dumetorum, D. rotundata, D. trifida)* (SANBI, ARC & DAFF, 2017; Department of Agriculture, Forestry and Fisheries, 2016).

Sweet potato, with 48 *Ipomoea* taxa, eggplant with 44 *Solanum* taxa and Rooibos tea, with 41 *Aspalathus* taxa are the crops with the highest number of CWR in South Africa (see Figure 3). The priority CWR list includes 220 indigenous taxa, 91 of which are endemic to South Africa. Eight of the taxa are included in the list of declared alien invasive species and this presents a conflict in terms of conservation for potential crop improvement value versus eradication in the interests of biodiversity conservation. The priority list includes eight taxa that have been proven to be readily crossed with a crop, and another 19 relatives that have been shown to produce fertile offspring when crossed with a crop. The relevant crops are rice, Bambara groundnut / earth pea/ cowpea, cucumber / gherkin / melon, eggplant, lettuce, watermelon, fonio, rye, coffee and dates (SANBI, ARC & DAFF, 2017).

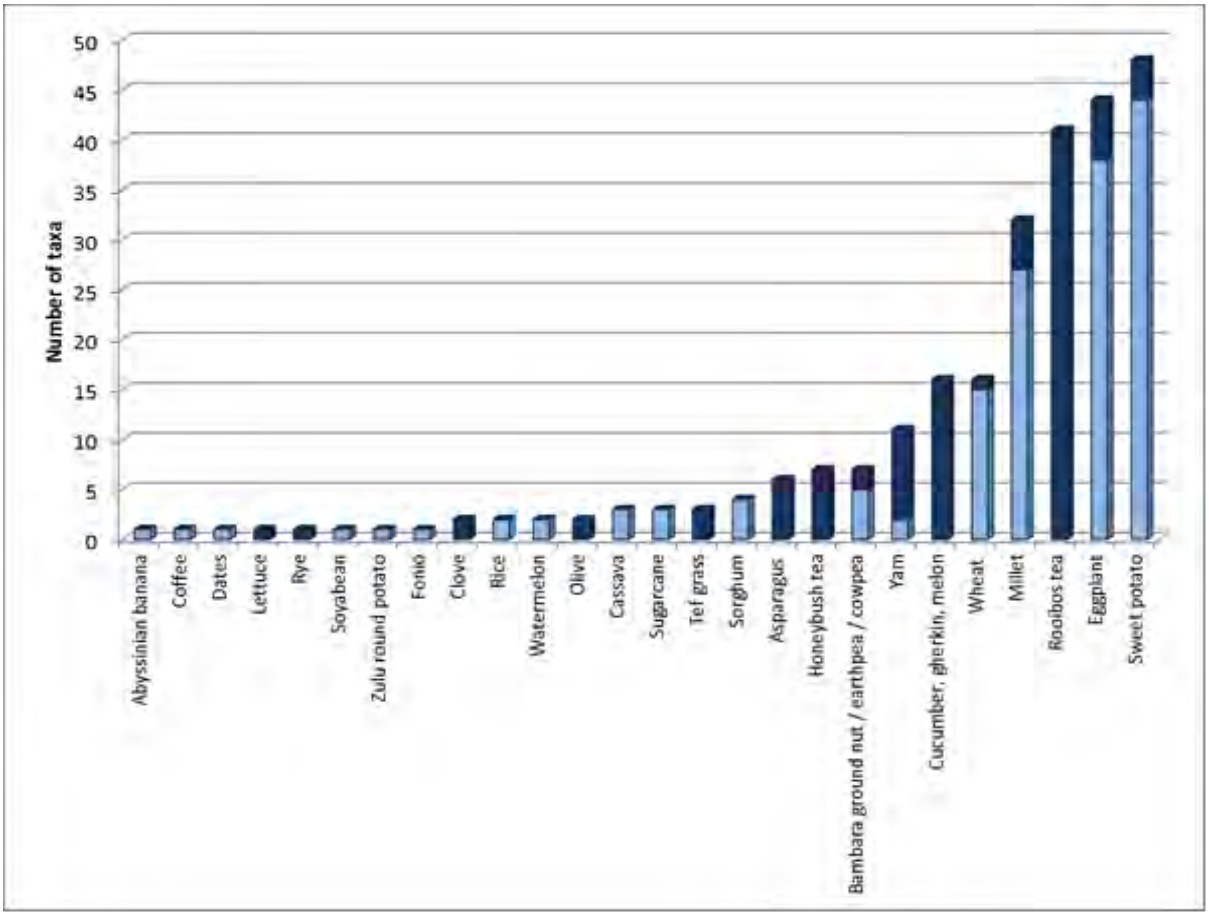

Figure 3: Number of priority CWR for food and fodder crops. Dark colour represents the number of CWR that are endemic to South Africa, while light colour represents indigenous, non-endemic and naturalized taxa.

Distribution of crop wild relative diversity

The northern summer rainfall parts of South Africa are important for CWR diversity. The Kruger National Park in Limpopo and Mpumalanga Province and the Isimangaliso Wetland Park in KwaZulu-Natal all exhibit high levels of CWR diversity. The Magaliesberg Mountains in Gauteng, the Cedarberg Wilderness Area and the Cape Fold Mountains of the Western Cape are also important areas for CWR richness (Figure 4).

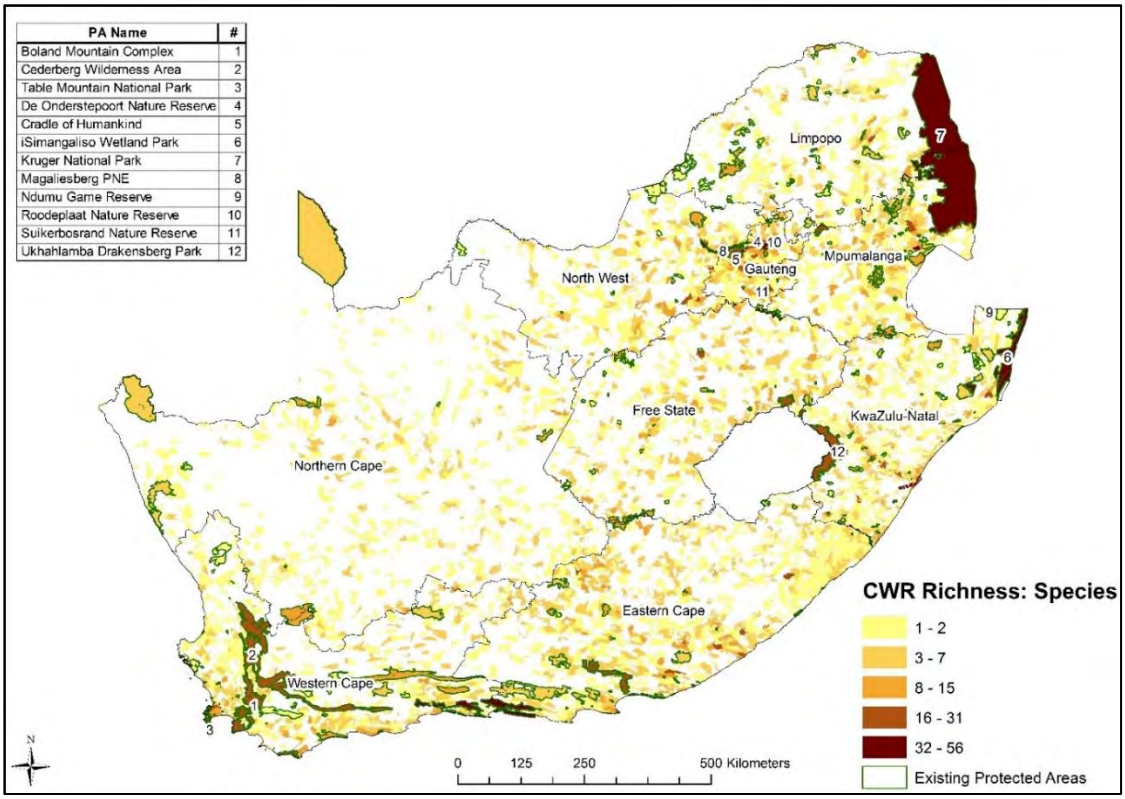

Figure 4. Richness patterns of priority crop wild relatives (CWR) in South Africa. Darker areas refer to higher richness (higher number of priority CWR). Protected areas important to CWR are shown.

Conservation of CWRs

As the world population increases, the need for long-term food security of high-yielding, highly nutritious crops becomes even more critical. Increasingly, plant breeders are turning to the wider crop gene pool to find the diversity required to cope with the changing biotic and abiotic environment while sustaining food security. Crop wild relatives can be conserved both *ex situ* (out of place) in genebanks, field collections and botanical gardens, and *in situ* (in place) in their natural habitat. *Ex situ* conservation of CWR is essential both to prevent the loss of CWR genetic diversity and to facilitate the use of their diversity in crop breeding. *In situ* conservation in complement, involves the maintenance and recovery of populations in their natural surroundings, and is necessary to ensure continued evolution, including the natural exchange of genes with each other and their cultivated cousins. The complementary conservation of CWR both *in situ* and *ex situ* is the best strategy to safeguard and make available the diversity of CWR, as well as to ensure their continued evolution (Crop Wild Relatives, 2016).

In situ Conservation

In situ conservation is the conservation in the natural surroundings and in the case of plant species. It is essential to maintain the evolution of the species and allow new diversity to be created through natural selection processes. *In situ* conservation is an efficient tool for conservation of CWR, in order to make CWR more accessible for crop improvement and other human uses and to ensure that the maximum genetic diversity of target species is safely conserved. The main general aim and long-term goal of in situ conservation of target species is to ensure their survival, evolution and adaptation to changing environmental conditions such as global warming, changed rainfall patterns, acid rain and habitat loss, through taking steps to protect, manage and monitor selected populations in their natural habitats so that the natural evolutionary processes can be maintained, thus allowing new variation to be generated in the gene pool. In 2016, SANBI, ARC & DAFF conducted a systematic biodiversity conservation plan to identify priority areas for in situ conservation of South Africa's Priority Crop Wild Relatives. Targets were set for taxa based on a systematic approach which ensures that sufficient populations are protected, priority protected areas where CWR-rich areas occur are identified, and areas that are critical for the conservation of priority CWR but which are not currently protected are mapped. Recommendations for formalising the protection of these areas were also made and are included in the National Strategic Action Plan for the Conservation and Sustainable Use of Crop Wild Relatives in South Africa (Holness et al. in press; DAFF, 2016) (Figure 5).

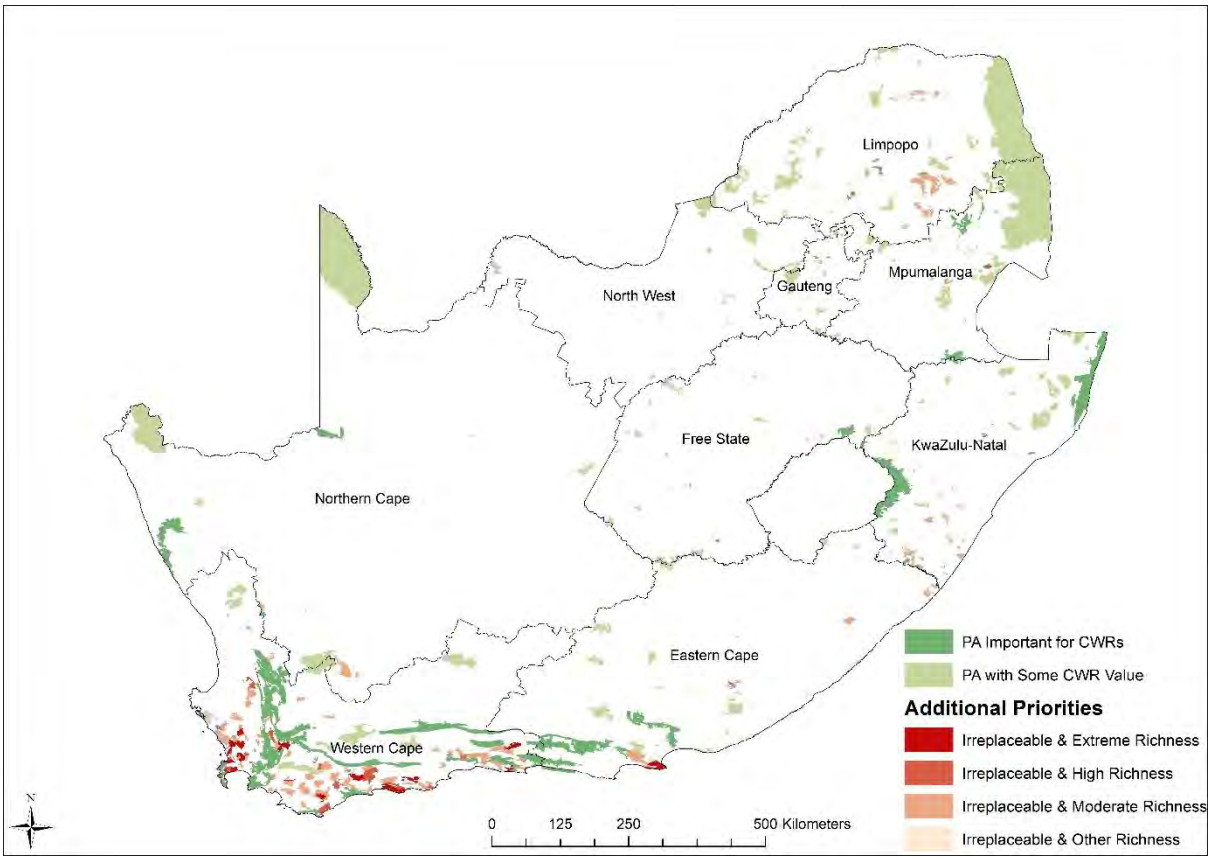

Figure 5. Priority sites for the *in situ* conservation of CWR in South Africa including important existing protected areas and additional priority sites outside of existing protected areas required to meet targets (Holness et al. in press).

Ex situ Conservation

Ex situ conservation of CWR enables their use in agricultural research and breeding efforts, makes them more accessible to breeders and other users, and allows them to be backed up in multiple locations. It is required to provide genetic material for crop improvement. One of the objectives of *ex situ* conservation is to preserve all different genetic adaptation patterns of a given species. Thus the incorporation of geographic and ecogeographic information to the seed collections is highly desirable. The inclusion of this information in databases of germplasm banks facilitates the design of sampling and collecting expeditions to improve the genetic diversity of existing collections. Collecting and storing CWR in genebanks makes them more accessible to breeders and enables their use in agricultural research and breeding. It also allows samples to be backed up in multiple locations, called safety duplication. Without *ex situ* conservation, it is difficult if to use CWR genetic material in breeding. A minimum of five different original populations should be represented in a gene bank for each of the prioritized CWR taxa, to adequately cover the genetic diversity of the species. Existing collections in the National Gene Bank indicate that only seven prioritized CWRs have five distinct populations conserved *ex situ*. Based on the poor representation of the priority CWR taxa in the National Gene Bank, sufficient samples to ensure that the genetic diversity for all 258 priority CWR taxa needs to be collected and has been prioritised as part of the National Strategic Action Plan for the Conservation and Sustainable Use of Crop Wild Relatives in South Africa (DAFF, 2016).

Conclusion

South Africa has the richest temperate flora globally, and the checklist of food and fodder CWR for the country lists 1593 Crop Wild Relatives for South Africa of which 258 taxa are of high priority for conservation (SANBI, ARC & DAFF, 2017). Plant genetic diversity is crucial for food-supply resilience and for the capacity of agriculture to adapt to climate change and natural disaster. National governments are encouraged to develop National Strategies and Action Plans for conservation and use of CWR (Crop Wild Relatives, 2016). South Africa has responded and produced a National Strategic Action Plan for the Conservation and Sustainable Use of Crop Wild Relatives in South Africa (DAFF, 2016) which identifies priority actions for both *in situ* and *ex situ* conservation. The Department of Environment, Forestry and Fisheries and the Department of Agriculture, Land Reform and Rural Development are encouraged to take up the strategy and ensure it is implements in the next 10 years.

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5.4 Biomimicry – copying nature

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Key messages

Gaining development and design inspiration from biodiversity can result in more sustainble products, processes and systems.

What is Biomimicry?

Biomimicry is the science of applying nature-inspired designs in human engineering and invention to solve human problems (https://biologydictionary.net/biomimicry/). Biomimicry is the practice of learning from (not just about) nature and then emulating its forms, processes, and ecosystems to create more sustainable products, processes and systems.

Humans have been gaining inspiration from nature for many thousands of years, yet as a formal concept 'biomimicry' – which explores how we can learn from nature to generate innovative solutions to human challenges – is more recent. The word itself was coined by Janine Benyus (author of the 1997 book Biomimicry) and originates from the Greek *bios* (life) and *mimesis* (imitation). Biomimicry is not new. Native peoples around the world were keen observers of nature and learned from the animals, plants, and natural cycles around them. But as the human population grew, we became colonisers, moving someplace else after using up the resources in one area. Today that is no longer possible, as the global human population is large and we are exhausting our ecological capital. Moreover, we have recognised that we have created enormous problems on our planet, for which we are urgently seeking answers. Janine Benyus calls this "the design challenge of our century." Biomimicry is providing some of the answers.

Across the globe, there has been a steady increase in biomimetic innovations helping to design and deploy products and services in more sustainable ways. There are ample examples of such innovations: the Shinkansen Bullet Train of the West Japan Railway inspired by the Kingfisher's beak, the Eastgate Building in Zimbabwe taking inspiration from termites' self-cooling mounds, and British Telecom using a biological model based on ant behaviour to overhaul its phone network. Such scientific innovations inspired by nature are a vitally important part of our transformation to a more sustainable future.

We often find our scientific explorations lack empathy for the 'objects' of their examination. For instance, recently there has been excitement about using spiders' silk for human benefit. One article proudly illustrates this scientific endeavour with photos of spiders pinned down alive in a laboratory while their silk is extracted. But this is not really the 'conscious emulation of nature's genius' that Benyus described. Mimesis within the context of its original Greek meaning requires the imitator to embody that which is being imitated. This goes to the heart of what makes us human: through perception, imagination and empathetic identification, we can share in what another feels and in doing so transform what we perceive into what we experience.

It is true that our analytical examination of nature is important, but only as part of a deeper, richer participatory engagement. If the deeper resonance of our nature is overlooked, such biomimetic

transformations fail to address the root cause of our unsustainable way of life. We deal with symptoms (carbon emissions, waste to landfill, ocean dead zones, social inequality, factory farming) while neglecting the underlying cause (attuning our self-other-nature relationship).

Much as charismatic animals such as rhino and whales are used as icons for conservation, so can species that hold the answers for sustainability challenges. These are very sexy stories; fascinating tales of the translation of the strategies and mechanisms of species into innovative sustainable solutions. What is the genius of place – the rich genius of the biodiversity of our place – that we will lose as we lose biodiversity?

Biomimicry a strong case for biodiversity

Biomimicry has its backbone on biodiversity. Nature with its biodiversity is like a big research and development laboratory with 4 billion of years' experience dealing with space and resource constraints, extreme conditions and disruptive changes. This is an extraordinary asset and creates endless opportunities to acquire inspiration from this laboratory for potential models, processes, systems, materials, shapes and organic compounds. They can be applied to solve global human problems concerning climate change, food security or health. Biomimicry is an excellent driver with a positive connotation to raise awareness of the need to protect nature and its resources.

The following general examples illustrate the outcomes and far-reaching value of using nature as a source for potential solutions for materials, constructive design and even for financial and management models:

- If you have ever tried to pick a mussel off a rock or pier piling, you have likely noticed that they know how to stick. Based on these natural adhesive abilities of the blue mussel, an American company came up with a way to use soy-based technology in the construction of hardwood plywood products (Columbia Forest products).
- Using the shape of the tropical boxfish, automotive designers achieved an aerodynamic ideal that consumes 20% less fuel and reduces as much as 80% nitrogen oxide emissions (Daimler-Chrysler's bionic car).
- Various animals have served for advanced designs in robotics like a new "biomechatronic" handling system based on the elephant's trunk (see Festo).
- The lotus effect refers to the lotus plant's ability to stay clean without using any energy source. This type of technology has been used in cleaning materials and paint (see Ipso).
- A burr plant served as design model to develop Velcro, replacing shoe laces or clothing zippers (see Velcro).
- To increase the efficiency and reliability and reduce noise for a new design of wind turbine blades, fins of humpback whales served as a model (see WhalePower).
- Concepts from the swarm theory were adopted to solve challenges in the decision-making process for credit and investment purposes (see Bank of England).

All these examples show how nature is highly successful in dealing with complexity and combining various elements to serve various functions, using optimisation and stabilising systems. Taken from: http://www.gaia.fi/news-blogs/blogs/biomimicry-links-business-to-biodiversity

Biomimicry examples relevant to South African ecosystems

- **Wetlands:** The Genius of SPACE Project is an example of mimicking wetlands to build innovative water and waste treatment solutions in the informal settlement of Langrug in the Western Cape. The project team created a hybrid system that integrated biodiversity into their engineering designs. The result is a network of traditional pipes and channels integrated with small wetlands, each about the size of a bathtub, containing water plants that pull out organic waste and other pollutants. Connected to the wetlands, small tree gardens also filter the water. Together, these living gutters remove excess nutrients and pollutants. This system solves water treatment issues while beautifying the landscape and eventually providing small-scale economic opportunities to the residents of Langrug, who have helped design, and now co-manage, the system.
- ***Mangroves:*** Living with roots directly in the salty coastal tidal zone is not easy, but various mangrove species have different strategies to cope. Red mangroves use the energy-free technique of evaporation, which wicks moisture from their leaves, creating a vacuum that sucks saltwater through their root membranes (which have an ultrafiltration system) up through the tree, leaving salt behind. The Aquaporin company is mimicking the fatty membrane channels commonly seen in nature. Their bio-inspired filters pass water through, excluding all other particles and ions. The goal is to use aquaporins as building blocks in water filtering devices to be employed in industrial and household water filtration and purification.
- ***Grasslands:*** Modern agricultural practices are enormously productive, but often only in the short term – after which the soil or water resources can be depleted or polluted through the constant irrigation, fertiliser and pesticide inputs. Almost all grains, dry legumes (pulses), and oilseed crops are annual crops, or 'annuals', which are planted from seed, grow to maturity, produce seed or fruit and then die, all in one year. Today, annual crops account for roughly 85% of the human population's food calories and the vast majority of planted croplands worldwide. To successfully grow annuals, farmers have to suppress or kill the vegetation (weeds) that compete with crops for sunlight, nutrients, and water, especially when the crops are seedlings. A grassland, on the other hand, is productive, resilient, self-enriching and ultimately sustainable. The Land Institute has been demonstrating that using deep-rooted plants that survive year-to-year (i.e. perennials) in agricultural systems that mimic stable natural ecosystems can produce equivalent yields of grain and maintain and even improve the water and soil resources. Led by a team of plant breeders and ecologists working in global partnerships, The Land Institute is developing new perennial crops to be grown in ecologically-functional mixtures known as polycultures. Their goal is to create agriculture that mimics many aspects of natural ecosystems in order to produce ample food and reduce the negative impacts of industrial agriculture. Many fruit, forage and some vegetable crops, including fruit trees, alfalfa, grapes, asparagus, and olive trees, are perennials that have been grown for thousands of years. The Land Institute is working to add perennial grains, legumes, and oilseed crops to the list. They are using two approaches to breed perennial grain, pulse, and oilseed crops: 1) Domestication of wild perennial plants; 2) Perennialization of existing annual crops

Biomimicry examples relevant to South African species

- ***Arum lily:*** A Cape Town civil engineer has developed a revolutionary new toilet that uses less than two litres of water for a full flush – saving around 700 litres of water a person every month. Jonny Harris designed the micro-flush toilet, called the 'Arumloo' and said the toilet mimicked nature, drawing inspiration from the function and beauty of the Arum Lily. "We've taken that vortex shape for the bowl of the toilet. The vortex shape is found repeatedly in nature and represents the easiest flow path for a fluid. By mimicking this vortex shape, and a circular flush motion, the toilet is able to use less water to clean the bowl and clear waste past the water seal."

- ***Shark skin:*** Conventionally, surface protection from biofilms is achieved through chemical means (e.g. antibiotics, sterilisers). Sharklet Technologies has a surface coating that is applied to walls or other surfaces, and helps the prevention of biofilm formation through diamond-shaped microscopic surface ridges without the need for chemicals. This innovation is inspired by the denticles on shark skin. The same surface has reduced drag effects that could have additional energy benefits for moving water over surfaces (e.g. through piping systems). Sharks move slowly in the ocean, but nothing attaches to them (unlike whales or turtles). Sharklet Technologies has found a way to fabricate a surface coating that mimics shark skin and resists the growth of organisms such as bacteria. Sharklet may be used in healthcare environments and on medical devices to help prevent the development of biofilms and hospital-acquired infections. The pattern itself may be manufactured onto the surfaces of medical devices, such as catheters, or manufactured as a durable film that may be applied to existing things, such as bed rails or tray tables in a healthcare setting.
- ***Humpback whale's tubercles (bumps) on flippers:*** WhalePower has developed a fan and wind turbine blade design using Tubercle Technology. This was inspired by the flippers of humpback whales (*Megaptera novaeangliae*), which have tubercles or bumps on the leading edges. Despite being 12-16m long and weighing 25–30 metric tons, humpback whales swim in circles tight enough to produce nets of bubbles only five feet across, which corral their shrimp-like prey. The whale's dexterity is due primarily to its non-conventional flippers. Whereas sheets of water flowing over smooth flippers break up into myriad turbulent vortices as they cross the flipper, sheets of water passing between a humpback's tubercles maintain even channels of fast-moving water, allowing humpbacks to keep their "grip" on the water at sharper angles and turn tighter corners, even at low speeds. Through wind-tunnel tests on model humpback flippers, researchers realised that the tubercles on the flipper delay the stall angle by approximately 40%, while increasing lift by 8% and decreasing drag by 32%. WhalePower is applying these lessons to the design of wind turbines and fans of all sorts – industrial ceiling fans and other HVAC systems, computer fans, etc. – to improve their efficiency, safety, and cost-effectiveness. The wind turbine blades require lower wind speeds, increasing the amount of time and the number of locations where they can actively generate electricity.
- ***Abalone shell:*** Various researchers (see article from LiveScience here) have been investigating the toughness of the abalone shell to see if ceramics could be made stronger. The abalone lays down sheets of calcium carbonate material between sheets of protein, which results in a shell that is 3 000 times stronger than its materials alone and is twice as tough as high-tech ceramics. Under stress, the sheets of calcium carbonate can slide and absorb energy – allowing the abalone shell to absorb a great deal of energy without failing. Researchers have been investigating the proteins involved in creating the unique structure, with the hope that it can be reproduced without using expensive or damaging processes. Products of the future will likely mimic the way the abalone creates its nano-scale architecture of hard mineral and soft polymer.
- ***Spider webs:*** Window collisions are a constant threat to all birds, as the characteristics of glass make birds see reflections of vegetation and sky in a window and respond as if the reflections are reality. Birds have the ability to see light in the ultra-violet spectrum, and some spiders incorporate UV reflective strands of silk in their webs to make them visible to birds. Alerting birds to the presence of a web preserves the spider's ability to capture prey without a bird crashing into and destroying the web. ORNILUX Mikado glass is new generation of Bird Protection Glass, and its crisscross patterned coating is nearly invisible to the human eye.
- ***Termites***: Termites maintain the temperature inside their nest to within one degree, day and night (while the temperatures outside swing from 42 °C to 3 °C). Eastgate Building, an office complex in Harare, Zimbabwe, has an air conditioning system modelled on the self-cooling mounds

of *Macrotermes michaelseni.* Designed by architect Mick Pearce, Eastgate uses 90% percent less energy for ventilation than conventional buildings its size, and has already saved the building owners over $3.5 million dollars in air conditioning costs.

- ***Hippo 'sweat'***: Perhaps one day we will understand the unique properties of the red-colored glandular secretion of hippos, which seems to function as a skin moisturiser, water repellent, antibacterial, insect repellent and UC protector at the same time. hippo – UV and antibacterial protection.

The Durban Resilience Strategy – a local biomimicry case study

Through a series of stakeholder engagement, biomimicry training and wetland assessment processes, the BiomimicrySA team working with Actuality, Biomimicry3.8, Futureworks, IPK, NEF, and Eco-pulse developed an urban planning resilience framework for the area (*Developing a Resilience Framework to Inform Urban Planning and Design in the Northern Spatial Development Plan Area, eThekwini Municipality,* April 2015). The basis is a wetland protection and restoration plan, combined with design principles and management guidelines for a development that functions like native ecosystems. This project included risk assessments, keys to resilience research, development of ecological performance standards (with the help of InVest modelling and hydrological modelling tools), developing design principles, critical biodiversity assessment, conflict resolution and stakeholder engagement processes. The high-level design will be unpacked for specific components of urban planning and design, land-use suitability planning (regional scale) and the conceptual spatial design (precinct scale).

The idea is to not only maintain critical open space to enable healthy function of ecosystems, but also for the built environment itself to contribute to healthy function. Biomimicry's Ecological Performance Standards (EPS) are a powerful framework for developers who want to lead in the practice of green design, and are seeking a coherent way to benchmark and communicate their success. How will we know when the development is functioning as well as the ecology of the place where it was built? The performance standards ask:

i. When we yield as much water as reference habitat
ii. When we hold as much sediment as reference habitat
iii. When we keep as much nitrogen on site as reference habitat
iv. When we keep as much phosphorus on site as reference habitat
v. When we attenuate floods at same level as reference habitat
vi. When we store as much carbon as reference habitat
vii. When critical biodiversity is protected and enhanced in measurable ways

The idea is that the urban system will contribute ecosystem services at a level equal to the reference ecological habitat for the area. Ecological performance standards targets become part of the key performance indicators for the development (which might also include social, economic, etc.), and are developed based on models of the local ecosystems so that the optimal environmental performance of the built environment will be measured against the same site ecosystem. The idea is that the entire development area - through a combination of both ecological infrastructure, preserved/restored critical biodiversity and mimicking healthy ecosystems in the built environment – will contribute to these EPS targets.
Read more about the Durban Resilience Strategy.

Many more projects and case studies can be found at https://www.biomimicrysa.co.za/our-projects/

6. BIODIVERSITY ASSETS ARE VITAL FOR SOUTH AFRICA'S TOURISM ECONOMY

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Note: The authors directly summarised several reports by Grant Thornton Pty Ltd (consultancy contract for SANBI entitled 'Undertake a quantification of tourism that relies on South Africa's biodiversity assets for NBA 2018, Bac & Thloe 2017, four reports). This project was led by Carol Poole and Amanda Driver from SANBI, with contributions from Kristal Maze, Deshni Pillay, Andrew Skowno, Lihle Dlamini, Prideel Majiedt, and Sizakele Sibanda. The authors and SANBI gratefully acknowledge the contributions from Statistics South Africa on this project, particularly inputs from Gerhardt Bouwer and Kevin Geddes, as well as contributions from Wavela Mthobeli from South African Tourism.

Key messages

Biodiversity assets make an important contribution to South Africa's growing tourism economy. Biodiversity tourism demand generated direct spend of R31 billion in the South African economy in 2015. Domestic tourism accounted for 52% of this demand (R16 billion) and foreign or inbound tourism for 48% (R15 billion). Biodiversity tourism accounted for more than 88 000 direct jobs in 2015 (or 12% of all direct tourism jobs). 45% of tourists from Europe and the Americas participate in biodiversity-related activities and attractions. There is scope for growth in this sub-sector, with the concomitant potential for job creation within the broader biodiversity economy. National tourism and economic growth strategies should incorporate biodiversity tourism as a focus area.

Why Nature Matters for Tourism

Tourism is a significant money-spinner for South Africa, drawing domestic and international tourists to various destinations around the country, which boosts the economy and creates jobs. The beauty and diversity of the country's natural environment is a large part of that tourism appeal. There is therefore a strong argument to be made for boosting conservation efforts in order to maintain a sustainable tourism sector.

South Africa's biodiversity, which contributes towards its tourism appeal, is made up of the various individual species that occur within its terrestrial, marine, and other aquatic ecosystems, as well as the complex ecological systems themselves.

Interest in South African scenery and biodiversity are expected to increase, and natural landscapes should therefore be managed in order to restore or maintain biodiversity to this end.

Defining Tourism

What is Tourism?

Tourism refers to 'the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited', according to the United Nations World Tourism Organization (UNWTO).

These visitors may be tourists (overnight visitor) or excursionists (same-day visitor), residents or non-residents, and tourism has to do with their activities, some of which involve tourism expenditure.

What is the size of SA's tourism sector?

Foreign tourism

Foreign tourism to South Africa is increasing, including growth from both overseas international visitors and visitors from the African continent. In 2016, total foreign tourist numbers totalled over 10 million, an average annual increase of 4.2% from 2010 (7.8 million in total that year). In 2016, a quarter of all the foreign tourists were from abroad (2.5 million), while the bulk of visitors were from African countries (7.5 million). Of the tourists visiting from overseas in 2016, most were from the United Kingdom (18%), followed by the USA, and Germany.

Domestic tourism

It is difficult to measure the exact size of the domestic tourism market in South Africa, owing to a shortage of accurate and reliable data, and conflicting figures from the main sources of data. SA Tourism and Stats SA figures vary widely, in terms of the actual number of overnight trips or tourists as well as in terms of the day-trip data. However, an overall trend is that domestic tourism numbers are down since 2007. This is driven primarily by economic constraints and 'belt-tightening' by South African citizens, and has significant implications for the supply of new, and use of existing, tourism assets and facilities in the country.

How much is South Africa's tourism sector worth?

Contribution to Gross Domestic Product: According to Stats SA, in 2015 the tourism industry directly accounted for 3.1% of South Africa's GDP, up from 2.8% in 2011 and 2.9% in 2005.

Jobs: Directly, tourism accounts for 4.5% of all employment opportunities in South Africa (2015). This is up from 4% in 2005 and 4.3% in 2010. The actual number of employment opportunities generated as a result of direct tourism spend in South Africa increased to 712 000 in 2015, from 507 000 in 2005. This is an annual compound growth of 3.4%.

GDP and Jobs: According to the World Travel and Tourism Council (WTTC), the travel and tourism sector in South Africa accounts for 9.3% of all economic activity (considering the direct, indirect and induced benefits to the economy, or the 'multiplier effect'). Tourism's total impact on the South African economy has increased from 8% in 2001, peaking at 10.1% in 2006 and stabilising around 9.3% in 2016. With the added impact of the multiplier effect, tourism's role in job creation is amplified significantly. According to the WTTC, nearly 10% of all employment opportunities in South Africa are to some extent influenced by the tourism sector (up from 8% of all employment opportunities in 2001).

What is Biodiversity Tourism?

Nature-based (a recognised term) tourist activities often involve wildlife, such as, scuba diving, hiking, and game safaris. These also often have cultural, educational, scientific and adventure opportunities. Wildlife tourism is considered a niche market in South Africa, along with adventure, cultural, business, medical, sport, rural, township and wine tourism. Bird-watching is one of the largest niche tourism markets in South Africa.

Some of the benefits of this sort of niche tourism include conservation of wildlife and natural surroundings, economic improvements such as job creation and increases in wages and salaries, as well as sense of place and overall human wellbeing.

Biodiversity tourism

This definition of biodiversity tourism was developed by the project team, based on the separate definitions of biodiversity and tourism: ***Biodiversity tourism is tourism that involves the use or enjoyment of biodiversity assets, including trips and visits by domestic and foreign same-day visitors and overnight tourists. This involves people partaking in and experiencing South Africa's ecosystems and species, including through using biodiversity assets for recreational or leisure pursuits. Biodiversity tourism activities therefore occur in or with one or more natural ecosystem and/or with one or more indigenous species***. In this context, biodiversity refers to ecosystems, and the species living in them.

The relationship between tourism and biodiversity assets (source: Bac & Thloe, 2017(2))

This may occur on a 'continuum', as not all of these activities take place in an environment that is completely pristine, or where the biodiversity assets are entirely natural. Tourism-related biodiversity assets may include a combination of natural and modified ecosystems, and a combination of indigenous and exotic species. For the purposes of this study, the analysis has therefore erred on the side of inclusivity in determining whether something is a tourism-related biodiversity asset.

Both domestic and foreign tourists enjoy biodiversity-linked activities, and it is the visitors from the Americas, Europe and Asia/Australasia that do so the most. Visitors from other African countries largely come to South Africa for other reasons.

Tourists interact with biodiversity assets with different levels of intensity (refer to Figure 6).

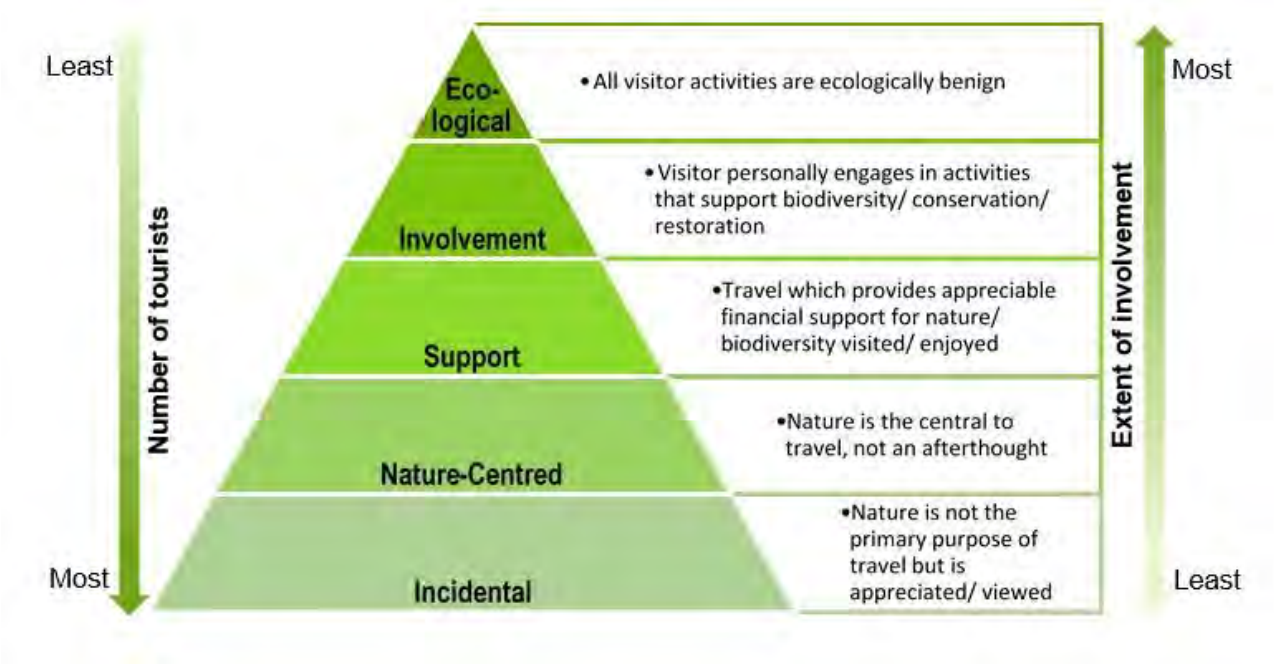

Figure 6. The extent of tourist involvement in biodiversity assets (source: Bac & Thloe, 2017 (2))

The kinds of activities and experiences involving biodiversity tourism include:

- Sightseeing and enjoying the natural beauty and related activities, such as game viewing, hiking, bird watching and scuba diving.
- Species-specific activities, like shark-cage diving, hunting, or whale watching.
- Recreation and relaxation in nature such as going to the beach, sports (e.g. swimming, mountain biking, or trail running), cultural activities (e.g. open-air concerts or art exhibitions), cruises and picnicking.
- Overnight stays in or alongside biodiversity assets, including camping and caravanning, game lodge visits, self catering or B&B, hoteling, and so forth.

The value of biodiversity tourism

One aim of the Grant Thornton consultancy was to provide a methodology for the measurement of biodiversity tourism in South Africa. The resulting approach incorporates the use of the Tourism Satellite Account as produced annually by Stats SA and includes the application of existing data and statistics, sourced from South African Tourism and Stats SA that relate to biodiversity tourism, to the Tourism Satellite Account. A comprehensive biodiversity tourism model was developed in MS-Excel and includes all relevant and available data relating to biodiversity tourism and is updateable as new information becomes available. The latest available Tourism Satellite Account data is for 2015 and thus, at present, the model calculates biodiversity tourism's share of South Africa's Gross Domestic Product ("GDP") and Gross Value Added ("GVA") for 2015.

Total demand for biodiversity tourism

Using this model, it has been calculated that in 2015 biodiversity tourism generated total direct demand of R31 billion. Domestic tourism accounted for 52% of this demand (R16 billion) and foreign or inbound tourism for 48% (R14.9 billion).

The direct contribution of biodiversity tourism to the South Africa's gross domestic product (GDP) was R14.8 billion in 2015 or nearly 0.4% of the country's GDP. Biodiversity tourism accounted for more than R1 billion of taxes on products and accounted for more than 88 000 direct jobs in 2015 (or 12% of all direct tourism jobs).

Domestic biodiversity tourism

In 2016, tourism activities that are based on biodiversity assets are incorporated in around 30% of all activities undertaken by domestic tourists whilst on an overnight trip and around 25% of all day trips.

For domestic overnight tourists, beach activities are the most popular biodiversity tourism experiences, followed by visiting a mountain area, partaking in wildlife activities and visiting parks and gardens. For domestic day travellers, the most popular biodiversity tourism activity are trips that include wildlife followed by visiting parks/ gardens and only then visiting a beach.

Foreign biodiversity tourism

In 2016, 14% of all activities undertaken by foreign tourists whilst visiting South Africa incorporated a biodiversity asset. This is equivalent to around 4 million biodiversity tourism activities.

For foreign tourists, nature-based attractions remain the most visited biodiversity-based assets but the data indicate that there is increasing demand for wildlife activities. More than 45% of tourists from the Americas and Europe already participate in these key activities/attractions. There should be further potential to grow biodiversity tourim demand from the foreign tourism market.

It may be possible to encourage more tourists visiting from African countries to participate in biodiversity tourism activities/attractions, as currently only 2.5% of African land arrivals and 18% of African air arrivals visit a natural attraction whilst in South Africa and less than 10% of African air arrivals and less than 1% of African land arrivals partake in wildlife activities.

Examples of biodiversity tourism from the 'Big Five Ecosystems'

South Africa's different realms (terrestrial, freshwater, estuarine, marine), and the cross-realm coastal environment, all contribute to biodiversity tourism in different ways.

Terrestrial ecosystems: Game Reserves

Ecotourism-based game reserves contribute significantly to local economies, and are increasingly providing more economic value for landowners.

In the Eastern Cape, for instance, some landowners regard ecotourism as more beneficial for the local community in terms of employment and empowerment that traditional farming, and that it is more economic and ecological sustainability. Game reserves there, many of which were farms that have been converted from agricultural activities such as livestock farming, offer visitors a combination of safari-type experiences with hospitality services and wildlife experiences.

Visitor preferences show that many tourists are attracted to the game, scenery and landscape diversity as well as the accommodation and the service standard offered at the various game reserves. Visitors said they found the beaches, rivers, mountains, and dune fields among the most attractive nature features, and preferred landscapes that did not show signs of human intrusion (Sims-Castely, Kerley and Geach, 2004). Private game reserves therefore spend significant amounts of money to remove fences and other man-made structures, as well as clearing alien vegetation and rehabilitating heavily eroded

areas in order to achieve the required wilderness environment. About 20 million hectares of farmland in South Africa has returned to its natural state (Cloete, Van der Merwe and Snaayman, 2015: 27).

A 2004 study in the Eastern Cape showed that by changing from farming to game-based ecotourism, a property's employment opportunity increased by a factor of 3.5, with an average wage increased from R5 498 to R31 263 per annum. Ecotourism generates 10 times more income per hectare than mohair farming, 15 times more than livestock and game farming, and 30 times more than boer goat farming (Sims-Castle et al, 2004).

Game ranches usually stock charismatic species that have commercial benefit, but these properties also provide habitat for many species of mammals, birds, fish, insects and plants that are not commercially exploited. Tourists prefer natural features when visiting game farms, which has encouraged owners to restore and conserve land in its natural form – which in turn contributes to biodiversity conservation.

Terrestrial ecosystems: Charismatic Draw-cards

The 'big five' and other charismatic species attract tourists to conservation areas in sub-Saharan Africa, and some travellers are willing to visit several protected areas to see less observable or threatened species.

International tourists are drawn by the 'charismatic megafauna', biodiversity in general and the scenery in a place, and to a lesser extent birds. Local tourists are more interested in biodiversity or scenery in general, than charismatic megafauna, and have a bigger interest in birds than their foreign counterparts.

Wildlife areas could be managed in order to appeal to a broader market through providing biodiversity experiences beyond charismatic fauna, including attractive plant life, rare or Endangered species, and high bird diversity.

'Birding' in South Africa

Bird watching (avitourism) is a significant niche tourism market in South Africa, according to a study done for the Department of Trade and Industry (DTI) in 2010. This niche form of tourism is defined as 'travel outside a person's usual environment for the purpose of viewing birds in their natural habitats'.

According to this 2010 study, birding is gaining popularity in South Africa, and is one of the fastest growing nature-based tourism activities in the world. Bird-watching tourism attracts high-spend domestic and foreign tourists, and has potential to contribute significantly to the country's tourism revenue and GDP. This niche activity attracts between 21 000 and 40 000 tourists per annum. Of these, between 8 000 and 16 000 are international visitors, who cumulatively spend between R309 million and R618 million annually.

However, there are still insufficient data and industry-wide planning to successfully take advantage of, and further develop, this growing market segment.

Ordinary citizens can make big contributions to monitoring biodiversity through their tourist activities. Here young citizen scientists learn to use the BirdLasser application on their phones to capture bird sightings and locations. © SANBI

Coastal, Marine and Ocean Tourism

South Africa has extensive coastal and ocean environments that have considerable tourism potential. In 2013, the direct value of South Africa's marine ecotourism sector was estimated at R400 million and the indirect value estimated at R2 billion (DEA 2015). Coastal tourism contributed an estimated R26 billion to South Africa's national income (Turpie and Wilson 2011).

Examples of marine biodiversity tourism potential in South Africa:

- The Boulder's Beach penguin colony, found within the Table Mountain National Park, is valued at around R311 million per annum and projected to generate R6.8 billion over the next 30 years while creating 885 jobs (van Zyl and Kinghorn 2018)
- The estimated direct value of land-based whale watching sector was valued at R80 million (overall value of R400 million) in 2013. Boat-based whale watching provided employment to 184 people and attracted 42 812 tourists with a direct value of R21 million (overall value of R105 million) in 2013. Tourism centred on seals (viewing and snorkelling) employed at least 30 people in 2013 and had a direct value of R5 million (estimated overall value R25 million). In the same year, shark diving created approximately 249 jobs and had a direct value of R113 million (overall value estimated around R571 million) (DEA 2015).
- The annual sardine run: between May and July each year, the southern African pilchard (*Sardinops sagax*) does its annual migration from the colder waters of the Cape into the warm sub-tropical waters of Eastern Cape and KwaZulu-Natal and northwards. This 'sardine run' has an estimated value of R 5.4 million. Over and above leisure tourists who travel to see the spectacle, the sardine run attracts a range of special interest travellers including commercial divers, academics and filming professionals.
- 'Blue Flag' beaches: according to WESSA (the Wildlife and Environment Society of South Africa) the 'Blue Flag' eco-label is 'an international symbol of quality for beaches, boats and marinas that meet a standard of excellence in the areas of safety, amenities, cleanliness, environmental information and environmental management'. For 2018, South Africa had 66 Blue Flags, 46 of which were for beaches (the others are for marinas and boats). Most of the Blue Flag beaches are in the Western Cape (30); the rest are in the Eastern Cape (7) and KwaZulu-Natal (9) (WESSA 2018). The suspension of blue flag status of beaches in Durban as a result of deteriorating water quality, led to a loss of an estimated R100 million per year (Lucrezi and van der Merwe 2015).

Ranking biodiversity tourism assets

The Grant Thornton consultancy aimed to list categories of biodiversity tourism assets in the country and rank them in order of importance according to the number of visitors the assets receive over a period of time. As SA Tourism collects data on the activities of foreign tourists and Stats SA collects data on the activities of domestic tourists, it is not possible to obtain an overall picture of the tourism industry in South Africa. These entities utilize different research techniques, questionnaires and definitions which makes it impossible to compare or combine this data. It is for this reason that there is a differentiation between biodiversity tourism assets utilized by foreign and domestic tourist categories.

For foreign tourism based on SA Tourism data, there are 4 broad categories of biodiversity tourism assets. In order of the most visited, these biodiversity tourism assets are 1) nature-based attractions; 2) partaking in wildlife activities; 3) visiting a beach; and lastly 4) participating in an adventure activity (see Figure 7).

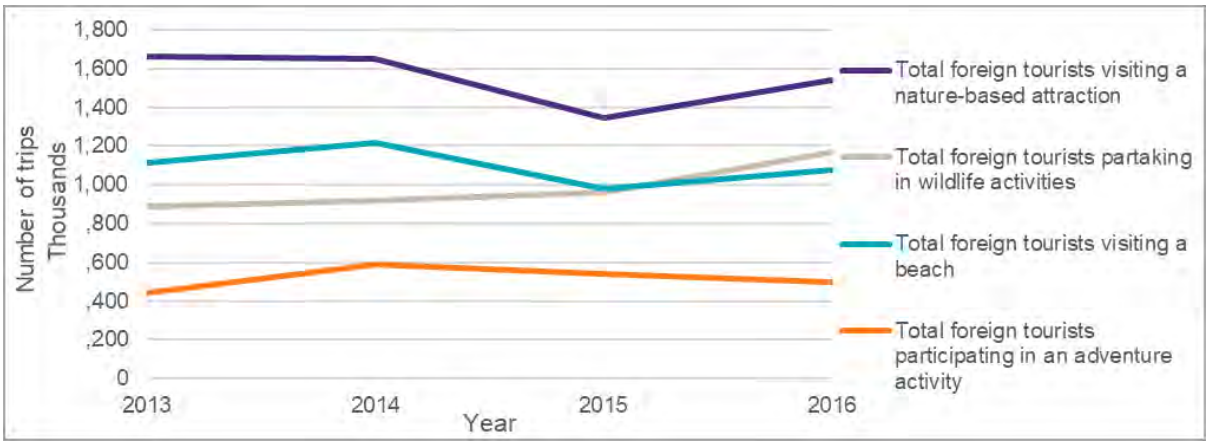

Figure 7. Number of foreign tourists visiting biodiversity tourism assets (2013 to 2016) – source SA Tourism and Model to Measure Biodiversity-based Tourism by Grant Thornton

More information is available for the tourism activities undertaken by domestic visitors as compared to foreign visitors. For Domestic tourism, as per Stats SA's survey methodology, there are 8 categories of biodiversity tourism assets, and these are ranked in importance in Figure 8 (for overnight) and Figure 9 (for day trips).

For domestic visitors, the ranking of most important biodiversity tourism assets is:

1. Beach
2. Parks and Gardens
3. Wildlife
4. Mountain areas
5. Watersports areas
6. Adventure activity area
7. Outdoor/ nature-based attractions
8. Hunting

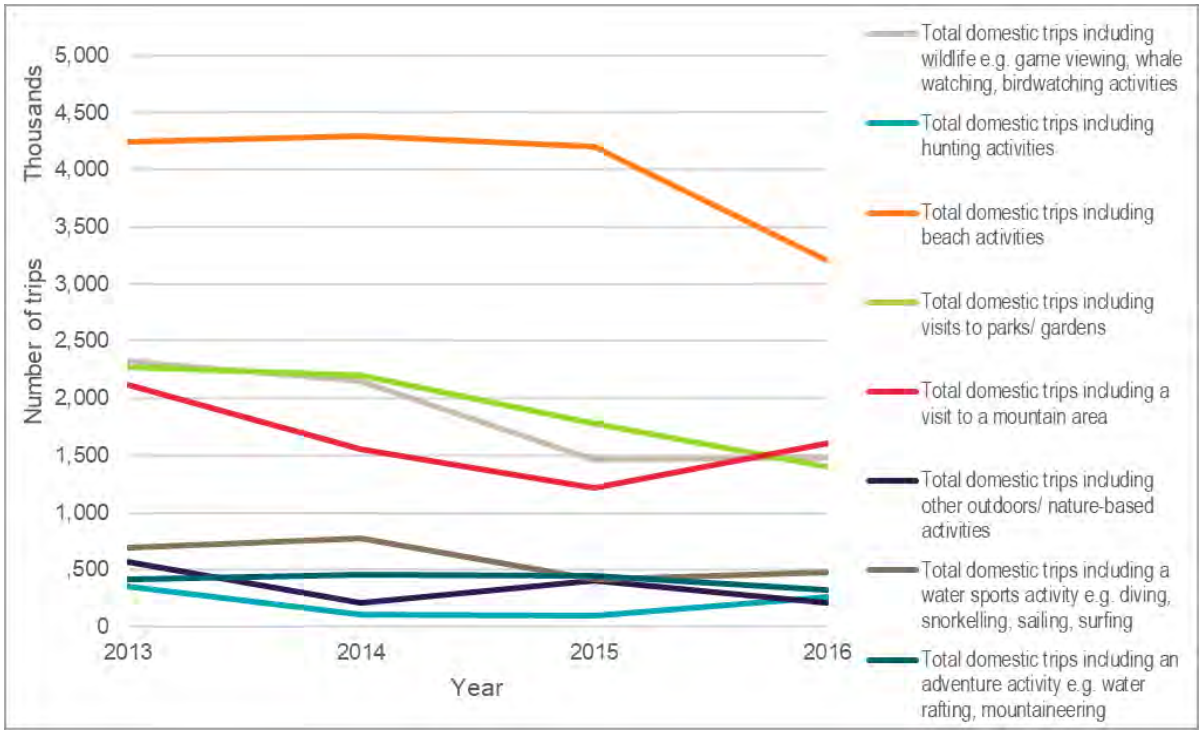

Figure 8. Number of domestic overnight tourists partaking in biodiversity tourism activities (2013 to 2016) – Source Stats SA and Grant Thornton Model to Measure Biodiversity-based Tourism

South Africa's many pristine beaches are popular tourist destinations © Oswald Kurten

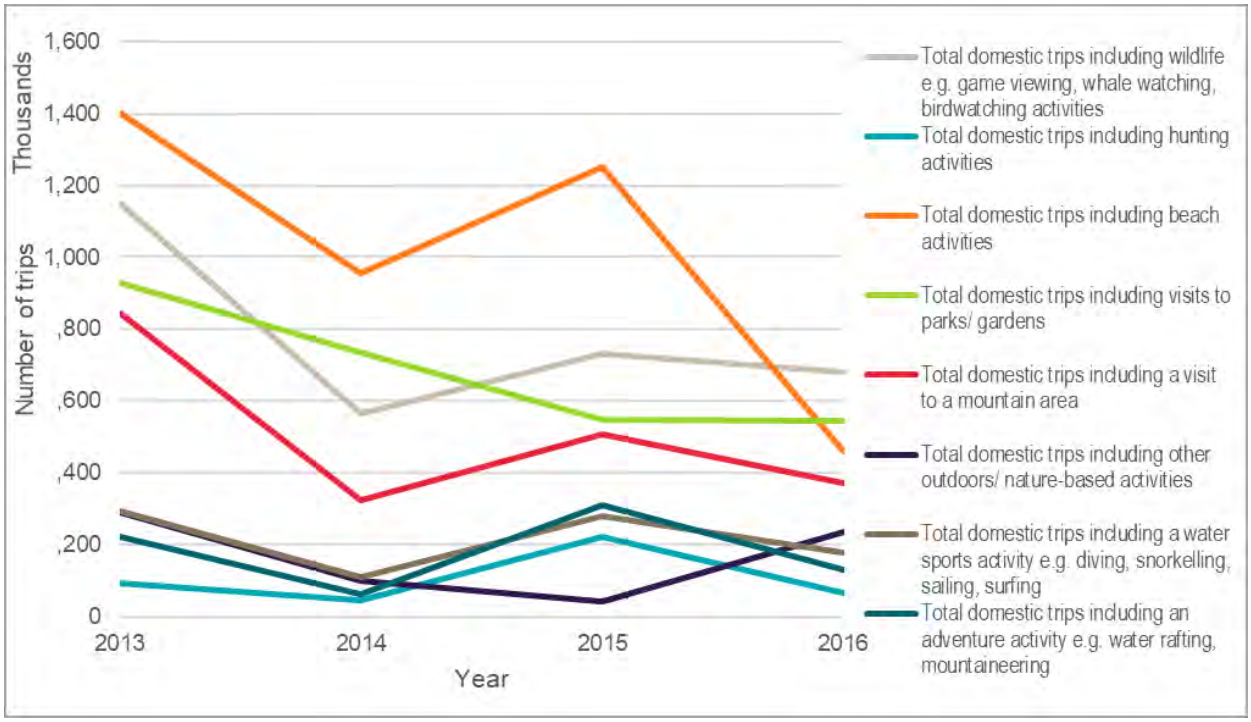

Figure 9. Number of domestic day tourists partaking in biodiversity tourism activities (2013 to 2016) – Source Stats SA and Grant Thornton Model to Measure Biodiversity-based Tourism

If, in the future, there is one reliable and consistent data collection agency for both foreign and domestic tourism data with a common interview tool (questionnaire and definitions) it would be possible to determine South Africa's most important biodiversity tourism asset overall.

References

The Grant Thornton consultancy resulted in 4 main reports, which can be cited as follows:

1. Bac, L. and Tlholoe, G. 2017. Introduction to South Africa's Tourism Sector. Consultancy report compiled by Grant Thornton PS Advisory (Pty) Ltd for the South African National Biodiversity Institute in support of the National Biodiversity Assessment 2018. Unpublished report.
2. Bac, L. and Tlholoe, G. 2017. Review of past work on biodiversity-based tourism. Consultancy report compiled by Grant Thornton PS Advisory (Pty) Ltd for the South African National Biodiversity Institute in support of the National Biodiversity Assessment 2018. Unpublished report.
3. Bac, L. and Tlholoe, G. 2017. Developing a Statistical Model to Measure Biodiversity-based Tourism. Consultancy report compiled by Grant Thornton PS Advisory (Pty) Ltd for the South African National Biodiversity Institute in support of the National Biodiversity Assessment 2018. Unpublished report.
4. Bac, L. and Tlholoe, G. 2017. Categorisation and Identification of important biodiversity-based tourism Assets. Consultancy report compiled by Grant Thornton PS Advisory (Pty) Ltd for the South African National Biodiversity Institute in support of the National Biodiversity Assessment 2018. Unpublished report.

References used directly are:

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7. BIODIVERSITY PROVIDES MEDICINE

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Note: authors for this chapter drew on a report from Ground Level Landscapes and Zuplex Botanicals (consultancy contract to SANBI entitled 'Undertake a scoping exercise and review regarding the value of medicinal plants to the South African Economy') and other literature; and several workshops and consultations were held with various experts (see Acknowledgements for the full list of contributors to this chapter of the compendium).

Key messages

Medicinal plants are essential to the work of some 200 000 Traditional Health Practitioners and provide a further ~93 000 income generating activities in the informal sector for harvesters and traders. It is estimated that the informal African Traditional Medicine (ATM) industry is valued at about R18 billion per year and that ~70% of the population use ATM, often in combination with allopathic medicine. The most recent Red List assessment (2013) recorded that 134 (20%) of the 656 commonly traded medicinal plant species are of conservation concern (declining rapidly). Evidence from medicinal plant markets indicate that the size of the traded components is decreasing and supply lines are becoming increasingly irregular, which has stimulated trade in plant material from neighbouring countries. This decline not only represents a loss in biodiversity, but may ultimately be linked to a loss in health benefits and the attrition of livelihoods. Urgent work is needed to determine which of the approximately 150 medicinal plant species considered heavily utilised are under increasing pressure both from trade and from habitat loss. Interdepartmental cooperation is required to stimulate small and large-scale cultivation efforts, and an increased focus on research and long-term monitoring of trade in medicinal plants to better understand patterns of use.

Draft recommendations for actions going forward include:

- Very accurate figures on the use and market of medicinal plants are not easily available due to out-dated studies and/or the lack of primary studies. It is imperative that **further primary research and long-term monitoring** is undertaken, particularly in the following areas:
    - % of South African population using ATM
    - Quantities used per person
    - Tracking the size or thickness, market stock and price/kg of plants in the market
    - Tracking which traded material is coming from outside the South African borders (as this speaks to dwindling availability of the material in South Africa)
- **Cultivation** – the growing of medicinal plants instead of relying on wild harvest. There is evidence that small-scale cultivation is more viable than large-scale, but there may be a need for both. The way the plants are dealt with within metropolitan areas (with a whole supply-chain behind them) is likely to be very different to that in many rural areas where the THP themselves collect the plants and prepare the medicine. Linked to this, the cultivation of particular plants may need to be different in different regions, due to different ecology of the medicinal plant. SANBI should encourage that there is inter-departmental work on this issue. Developing cultivation might need to include:

    - Developing a list of species that require a feasibility study for large-scale cultivation – i.e. to supply key species used in large quantities in the urban markets. This large-scale cultivation will likely require subsidisation.
    - Each District focussing on its own biodiversity, its own healers, what grows well where, etc. and developing small-scale cultivation based on their own needs. Writing up some local case studies should be prioritised, as this will show the economic benefit and make the case for subsidies for starting local cultivation projects.

- **Registration and regulation of THP/ATM**. The South African Health Products Regulation Authority have established a task team to look at regulations for ATM. Investors look towards investing in something that is regulated and has a clear path to market growth. On the other hand, over-regulation can lead to the informal chain being formalised, and benefits being concentrated to fewer people. There is a need to tease out the role players and stakeholders in the multiple 'pipelines' of harvesting, retailing, prescribing and using ATM's; and to investigate whether a certification could be a possibility and therefore a higher value attributed to the products (at least plan for a certification eventuality)[7]. Intellectual property issues also need to be considered.
- **Training and campaigns for sustainability**. Campaigns could include the encouragement of THPs to procure sustainably sourced materials (many of them are very invested in the sustainability of the resource and have intuitive ecology knowledge); helping local communities conserve their own resources; and improving language and messaging so that decision makers and policy makers understand the 'benefits of biodiversity that are in peril'
- Update the **Red List status** of all medicinal plants as soon as possible (SANBI)
- Develop **biodiversity management plans** for certain medicinal plant species

Background

The traditional medicine sector in South Africa is one of the economic sectors that relies heavily on biodiversity assets and our natural environment. With this in mind, a consultancy was advertised to 'undertake a scoping exercise and review regarding the value of medicinal plants to the South African Economy'. Ground Level Landscapes in consortium with Zuplex Botanicals were appointed for this consultancy in March 2017.

The scope of work of the consultancy was as follows:

1. Undertake a review of existing work done on the direct and indirect contribution of indigenous medicinal plants to the South African economy – including their value in reducing reliance on the South African allopathic healthcare system (equivalence value), their job creation value, informal market value, cultivation value, formal biotrade value, and any other economic aspects.
2. Undertake a scoping exercise to determine what metrics are best used to evaluate the socio-economic value of medicinal plants to South Africa, making sure that finding data to do the measurements is realistic and that the metrics are repeatable so that such metrics can be tracked over time. Estimate an appropriate budget for undertaking such metrics at regular intervals (e.g. a low-cost option, medium cost option and high-cost option).

[7] David Newton would suggest the authors read reports such as the "FairWild Standard" (http://www.fairwild.org/standard) to develop an idea of how their numerous metrics and conclusions can be synthesised into a systematic harvest and trade management system.

3. Quantify, where possible, certain metrics (i.e. find the data and do the analysis) in consultation with SANBI (after the scoping in item 2 has taken place).

The consultants completed their work to the satisfaction of SANBI in August 2017 and produced a comprehensive report entitled 'Understanding the diverse economic value of medicinal plants to the South African economy'. SANBI then contacted several experts in the fields of health and medicinal plant biodiversity, and requested their input on how to use the information from the consultancy report for the NBA and potentially for a formal Summary for Policy Makers. The deadline for comments from the experts was end November 2017, and several comments were received. Other experts declined to comment at that stage, but were willing to be involved in a workshop during early 2018.

The SANBI team for the project, Domitilla Raimondo (Threatened Species Unit Manager), Neil Crouch (Biodiversity Economy Liaison), Mandy Driver (Senior Policy Advisor), Andrew Skowno (NBA Lead) and Carol Poole (Manager: Biodiversity Research Projects) met on 14 December 2017 to discuss the way forward and concluded that the SANBI team would write a summary of the work to date.

A workshop was then held on 17 July 2018 with the SANBI team and experts in the health and biodiversity sectors, with the objective to comment on and improve the SANBI summary. This summary has therefore now been improved as a result of that workshop and is now distributed for further comment as part of this Compendium of Benefits of Biodiversity.

The keys facts and statistics from the consultancy report can be summarised under the following headings:

- South Africa's healthcare systems
- Benefits of African Traditional Medicine in terms of jobs/opportunities
- The value of the medicinal plant material in use
- The status of the medicinal plant resource in South Africa

South Africa's health care systems

As a developing country, South Africa faces multiple challenges in the healthcare sector including a heavy burden of communicable diseases such as HIV/AIDS and tuberculosis, issues concerning maternal and child mortality, and non-communicable diseases of lifestyle including cancer, diabetes and obesity. In South Africa, healthcare services and products are provided by public and private allopathic[8] healthcare systems, by African Traditional Medicine (ATM)[9], and by Complementary and Alternative Medicine (CAM). This report will only address ATM in relation to the allopathic healthcare system. The CAM sector in South Africa is likely very substantial, and in the past ATM might have been mixed with CAM. However, the criteria for registration of CAM was published in 2016, and therefore in the future the two streams will be more clearly distinguished. For the purposes of this report, the focus is on ATM and the use of South Africa's indigenous medicinal plants species.

The allopathic healthcare system's key facts are in Table 4 and the ATM system's key facts in

Table 5.

Table 4: Allopathic healthcare in South Africa – key facts

[8] Allopathic: in the context of this report, we use the word allopathic to refer to the "western-style" / "conventional" / "formal" system of public or private healthcare in South Africa with the use of drugs or surgery

[9] African Traditional Medicine definition: The sum total of all knowledge and practices, whether explicable or not, used in diagnosis, prevention and elimination of physical, mental, or societal imbalance, and relying exclusively on practical experience and observation handed down from generation to generation, whether verbally or in writing (ATMSA, 2008)

	Fact/Statistic	Citation / accuracy notes
Citizen spend on allopathic health care (private and public)	R332 billion in 2016 (8.5% of GDP)	Rispel, 2016
Annual public health care budget	• R168.4 billion (2016/17); 187.5 billion (2017/18); R205.4 billion (2018/19) • Health will be 12.2% of government spend (2018/19); was 11.9% in 2017/18 • The only higher budget allocation in 2018/19 is for Basic Education (R246.8 billion) • Estimates indicate that the level of public health spending will increase from roughly 4% of GDP currently to 6.2% of GDP by 2025/26, assuming that the economy grows at an annual rate of 3.5%	• Budget Reviews 2016; 2017; 2018 • R205.4 billion ÷ R1,671.2 billion (BR 2018) R187.5 billion ÷ R1,563 billion (BR 2017) • Budget Review 2018 • Econex 2016
Annual private spend on allopathic health care	• R163.6 billion	• Our calculation: Rispel 2016 total spend (R332 billion) minus 2016/17 government budget for 2016/17 (R168.4 billion)
% of population dependent on the public health sector and/or ATM versus those who have medical aid	• 83-84% (as only 16-17% have private medical aid) • Nearly a quarter (23.2%) of South African households had at least one member who belonged to a medical aid scheme. However, a relatively small percentage of individuals in South Africa (17.4%) belonged to a medical aid scheme in 2016.	• Council of Medical Schemes QR Sep 2015 in Mediclinic Annual Report 2016 • StatSA 2016 General Household Survey. Note: https://africacheck.org/reports/does-sas-private-healthcare-sector-only-provide-care-for-16-of-the-population/ While it is true that the majority of South Africans do not benefit from private healthcare, it is misleading to equate medical scheme coverage (or lack thereof) with exclusive use of a particular healthcare sector. Depending on needs, people use a combination of private and public health care services. In addition, it is likely that when medical savings schemes are depleted, people turn to out-of-pocket or the public healthcare system.
Doctors per 100,000 lives	World average is 152.2; SA is 64.2. There is also large disparity between the public and private sectors, and between rural and urban areas.	Econex, 2016 (stats from 2014) Are there reliable figures that highlight the pressures on doctors not in private sector?
Cost of a visit (private)	Depends on procedure. Wide variety of rates, ranging upward from R430 for a standard General Practitioner consultation.	Discovery Health, 2018

Table 5: African Traditional Medicine in South Africa - key facts

	Fact/Statistic	Citation / accuracy notes
% of population using ATM (but see also text below box)	• 70-72% • Total population is 55.91 million • Therefore the range is 39.13-40.25 million people	• Seems to be a basic percentage used by several people: (Mander, 2007; Dold and Cocks, 2002; Bannerman, 1983). There is no official Stats SA question. There is some debate about this statistic, so should be listed for further primary research. • Stats SA mid-year estimates 2016 • Our calculation: 70% or 72% ÷ 55.91 million. Note: it is very likely people use a combination of allopathic and ATM. Many people likely do direct collection of ATMs for home use to deal with common ailments rather than purchasing ATMs or consulting a THP
% of population consulting THPs	• 70.7% of households favoured public clinics and hospitals, 24,3% of households said they would first consult a private doctor. The least favoured were traditional healers (0,1%), pharmacies (0,3%).	• Stats SA (2012)
Average number of visits per annum to a	Range 2.4 – 4.8	The exact number of visits is variable with Mander revising his estimate from an initial 3 visits per annum (1998) to 4.8 (2007). This is also consistent with Walwyn and Maitshotlo (2010) and personal communication with Gwala (2017). In reality one individual may consult 5 times and another not at all.

Fact/Statistic		Citation / accuracy notes
Traditional Health Practitioner (THP[10])		
Cost of a visit and per annum spend	• Each visit is conservatively valued at R200 (low end) R350 (intermediate) R2 500 (high end) per visit according to location / reputation and includes cost of dispensed medicine together with the consultation • Conservative is 2.4 × R200 = R480 pa. • Intermediate is 3 × R 350 = R1 050 pa • 4-8% of household annual income Almost ¾ of the poorest quintile spent >10% of their household expenditure in the previous month on THP.	• Walwyn and Maitshotlo, 2010. Mander et al., 2007; Gwala pers. comm. (2017) Note: there is no prescribed rates. Sometimes payment is in goods not cash • Our calculation using lowest range of visits × lowest cost • Our calculation using 3 visits × intermediate cost • Mander (1998) as part of his KZN FAO study Nxumalo et al (2011)
Spend on THPs (note: spend on THPs is a proxy for total spend on ATM as there is more evidence of the former)	• Conservative estimate: R18.782 billion p a; Intermediate estimate: R41.086 billion p a Note: the consultants also estimated THP revenues as approximately R16.8 billion (200 000 THP x R84 000 annual income – see Section 2.2 below), and recommended that this more conservative figure is used. • 5.6-12.4% of allopathic health care spend (using conservative R16.8 billion, it is 5%).	• This is calculated from estimate of population utilising ATM (39.13 million people) × cost per annum (R480 or R1 050). • Calculated by dividing results by the R332 billion spent on allopathic healthcare (Rispel, 2016)
Spend on THP relative to government health spend	• 10-22% equivalent of government health care spend	• Range calculated by conservative and intermediate estimates ÷ R187.5 billion health budget in National Treasury BR 2017

It is important to note that the allopathic healthcare sector cannot be compared directly with ATM as an alternative. Although it is true that ATM is in demand and used by many people, the medicines do not meet the same regulatory standards of allopathic medicines. One of the reasons for allopathic medical care being more expensive is that it bears the cost of expensive formal trials required to prove the efficacy and safety of said medicines, and expensive hospital infrastructure, inter alia. Thus it is hard to directly compare these two systems as they are run in very different ways and according to very different business plans. However, it is important to contextualise both of the systems. In addition, it is important to note that other Complementary and Alternative Medicines (CAM), such as Homeopathy and Chinese Traditional Medicine, are not addressed in this report, and are also used in South Africa. If the natural resource base of medicinal plants was no longer available to support ATM, then the state would need to provide additional (allopathic) public health care resources to those currently using ATM, if the same overall health care levels were to be maintained.

Benefits of ATM in terms of jobs/opportunities

The draft Biodiversity Economy Strategy (DEA, 2015) speaks to the potential for more jobs in the medicinal plant sector. Although this is primarily in the formal biotrade sector, it is important to understand the current statistics about the ATM sector in terms of jobs and opportunities (Table 3).

Table 6: Jobs and opportunities in African Traditional Medicine

Fact/Statistic		Citation / accuracy notes
Number of THPs in South Africa	200 000 – 300 000; accepted number is 200 000. Note: many THPs work part time.	Gwala, 2017; Mbedzi, 2017; ATMSA, 2008. National and provincial offices have been set up by the DoH to regulate and register THPs as per the THP Act No. 22 of 2007

[10] Traditional Health Practitioner definition: a person registered under the Traditional Health Practitioners Act No. 22 of 2007 in one or more of the categories of traditional health practitioners, namely Diviner, Herbalist, Traditional Birth Attendant and Traditional Surgeon

	Fact/Statistic	Citation / accuracy notes
Estimated income of a THP	Approximately R84 000 p.a. Represents R16.8 billion in income (i.e. people are making a living; it is contributing to livelihoods) Note: Costs can vary depending on the reputation of the THP. Another qualifier would be the fact that THAs (Traditional Healers Associations) make no differentiation between full time and part time practitioners - some are very busy while others are only part time and may practise to augment their income while working in other jobs (Mander, 1998; Grantham pers. comm.) This is likely a very conservative estimate of income (Jon McCosh, pers. comm.)	Calculated by consultants using various references, see Section 9.3.2 in Ground Level Landscapes and Zuplex Botanicals, 2017. A Accepted number of THPs is 200 000 B A reasonable assumption is 5 clients per week equating to 20 per month C Each visit is conservatively valued at R200 (low end) R350 (median) R2 500 (high end) D Extrapolations from quoted 2007 THP annual revenues to 2017 was R75 141 E Cross checking D and using the median visit value of R350 equates to an annual revenue of R84 000 [20 visits @ R350 = R7 000 × 12 months = R84 000] E Total projected value is 200 000 THPs × R84 000 = R16.8 Billion. Mander et al., 2007 estimated an average of R38 491 p.a. Assuming a 7% annual increment (allowing for real inflation) at a constant annual growth rate (CAGR) over ten years their current annual earnings would be R75 141, which relates to the amount projected in item D of R84 000.
Number of income generating activities for the other informal trade (i.e. not THPs, only plant harvesters and traders – either street or shops)	93 099 income generating activities in the informal sector in 2017 Note: it is likely much higher, and more work is being done on this currently (Vivien Williams, pers. comm.)	Extrapolated estimate, undertaken as follows: A. Mander et al., 2007 estimated 66 000 harvesters and traders B Assuming a very conservative constant annual growth rate (CAGR) of 3.5% per annum over a ten year period due to a contracting economy whose potential growth of 6% has been reduced to between 1-2% C This equates to some 93 099 income generating activities in the informal sector in 2017.
Number of street traders in South Africa	• 3 000	• Mander et al., 2007 (note: need national primary research to obtain more recent statistics)
Estimated income of a street trader	• Approximately R18 000 p.a. • Represents R54 million in income [3 000 × R18 000] (i.e. trading is contributing to livelihoods)	• Mander et al., 2007 estimated an average of R7 941. Assuming a 7% annual increment (allowing for real inflation) at a constant annual growth rate (CAGR) over ten years their current annual earnings would be R17 885
Number of plant harvesters	• 63 000 Note: many also do part-time street trade. Animal harvesters are different.	• Mander et al., 2007 (note: need national primary research to obtain more recent statistics)
Estimated income of a plant harvester	• Approximately R18 000 p.a. • Represents R1.23 billion in income [63 000 × R18 000] (i.e. harvesting of wild plants is contributing to livelihoods) Note: the mark-up from harvester to trader is unclear. Research is needed to understand economics of harvesters versus traders	• Mander et al., 2007 estimated an average of R7 941. Assuming a 7% annual increment (allowing for real inflation) at a constant annual growth rate (CAGR) over ten years their current annual earnings = R17 885
Estimated income of muthi shops	Consultancy report did not include this. Surveys are likely inaccurate due to people not answering questions about income.	The dominance of muthi shops is less, and street traders are increasing – Vivien Williams pers. comm.

Important to note in additional to the statistics above is that people do self-medicate from personal collecting of ATMs. This issue should be flagged for future research, as it is very hard to quantify. The General Household Survey might be one method to provide an estimate.

In our surveys of 1100 households in former homelands of the NE part of the country in 2010, 12% of households in the study area harvested wild medicinal plant products. Based on descriptions

(rather than field measurements), these households harvested an average of 51 kg bark, 69 kg roots and 27kg of greens per year. Overall, riparian and wetland areas accounted for 47% and 4% of the value of medicinal products harvested respectively (Turpie et al 2010).

Muthi market © John Donaldson

Value of medicinal plant material in use

Table 7 shows key facts about indigenous medicinal plant material in use in South Africa.

Table 7: Medicinal plant material use in South Africa

Fact/Statistic		Citation / accuracy notes
Number of medicinal plant species in the country	2 062 (10.1% of national flora)	Williams et al., 2013 Note: this work is ongoing and the list is growing
Number of medicinal plant species recorded in common trade	550 – 700 recorded in common trade (656 is published figure in Williams et al., 2013).	Williams et al., 2013. Note: the main traded plants are remaining fairly stable (Williams pers. comm. 2018)
Informal trade of MP – annual tonnage of medicinal plant raw material	• 29 347 tonnes dispensed from THPs as part of consultation • 2 345 tonnes purchased independently from muthi[11] shops • 9 193 tonnes purchased independently from street vendors • Total: 40 885 tonnes of raw material from the wild Note: some might be from outside SA borders; it is hard to differentiate. These are conservative estimates (McCosh pers. comm. 2018)	Section 9.3.3 of consultancy report. These figures are extrapolated and based on assumptions from Mander et al., 2007; Mander, 1998; Cunningham, 1988. (Note: need national primary research to obtain more recent statistics.)

Value of informal ATM (THP + independent purchases)	• R17.96 billion p a; includes:
	  • Value of THP visits & medication = R16.8 billion pa
	  • Trade from muthi shops = R149.4 million p a
	  • Trade from street vendors / markets = R1.02 billion
		Our calculations.
		• See section 2.2 above
		• Section 9.3.4 of consultancy report. Estimating new number of stores and extrapolating from 1998 figures
		• Section 9.3.4 of consultancy report. Extrapolated from Mander, 2007
		Notes: These figures are turnover. Cannot quantify the cost of purchase and overheads, and therefore cannot calculated "profit" or take-home income. The extent of overlap between THPs, shops and street vendors is unknown. Given the lack of primary data, it is reasonable to add these figures.

Formal trade of MP material (export and domestic)	• The size of the resource segment (wild harvesting and cultivation) of the commercial bioprospecting market is estimated at between 2,000 and 2,800 tons per year at a weighted average price of approximately R50/kg.	• DEA, 2015 (Is this only medicinal plants? Also unclear how much is wild harvested and how much is cultivated.)

[11] Sometimes spelled "muti"

	• DEA, 2015 report that medicinal plants share of domestic retail market was estimated at R170 million of value-added products in 2011. Extrapolation from 2011 to 2017 at a constant annualised growth rate of 6% gives the value as R241 million in value-added products containing medicinal plant ingredients • In summary, the total medicinal plant biotrade is valued at R2.95 billion in 2017/18 and of this, the projected portion of listed medicinal plants is valued at R241 million per annum.	• Extrapolation by consultants from DEA 2015 • Extrapolation by consultants from DEA 2015 (see Table 9.1 in consultancy report)
The value of total trade in MP	• 43 658 tonnes pa; by adding: 1) Informal Sector 40 885 tonnes p.a. 2) Formal sector 2 800 tonnes p.a. 3) Combined 43 685 tonnes p.a. • R20.91 billion p a [R2.95 billion in formal (Table 9.1 from consultancy report, extrapolated) + R17.96 billion informal]	• Mander et al., 2007; DEA, 2015; DAFF, 2016. See Section 9.5 C commentary. It was decided to exclude the higher export figures submitted by DAFF (2016) for this exercise and use DEA (2015) data. • Our calculation (Note: given dated nature of the data, this is best estimate)
Value of informal ATM versus government spend	• 9.5%	• Our calculation: Informal ATM (R17.96b) ÷ gov health spend (R187.5b)

It is interesting to note that there is significant cross-border trade in medicinal plant material included in the statistics above. South Africa benefits from our neighbours' indigenous medicinal plant resources, as we import species where our resources are low. Mander et al. (2007) mentions, "The trade in plants from Mozambique and Swaziland to South Africa is vibrant, with many traders in the street markets of Durban and Johannesburg coming from these countries. Estimates indicated that at least 40 tonnes of *Warburgia* was being imported into South Africa from these countries." Neighbouring countries also import material from South Africa.

Myles Mander recommends that tracking the size or thickness, market stock and price/kg of plants in the market (suggest Durban and Joburg as regional representatives) should be undertaken annually.

The state of the medicinal plant resource in South Africa

Table 8 shows key facts about the state of medicinal plants in South Africa.

Table 8: Conservation status of medicinal plants in South Africa

Fact/Statistic		Citation / accuracy notes
Medicinal plant species conservation status	• 2 062 plant species (10% of SA's flora) are used for traditional medicine. 82 (3.9% of total) species are threatened – i.e. listed as Critically Endangered (C), Endangered (EN) or Vulnerable (V). This includes 14 Critically Endangered species, 19 Endangered and 49 Vulnerable. • A further 100 species are of conservation concern: 37 are Near Threatened, 36 Declining, four are Data Deficient as they are suspected to be threatened but insufficient information is available to place them in a category of threat, 21 species are either Rare or Critically Rare, and two are Extinct in the Wild. • 656 (32%) of South Africa's medicinal plant species were recorded in traditional medicine markets. 134 of the traded species (20.4%) are of conservation concern (declining rapidly). 56 of the traded species are threatened (7 are Critically Endangered). 78 species are classified as Near Threatened, Data Deficient, Rare or Critically Rare, or as Least Concern but with evidence of population decline.	• Williams et al, 2013; from 2009 IUCN Red List evaluation of SA flora • Driver et al, 2012 (NBA 2011).
Red List Index	Currently, based on the RLI, less than 2.6% of the medicinal species in South Africa (i.e. <0.3% of the total national indigenous flora) are predicted to be at risk of extinction if no remedial and/or preventative conservation actions are taken. Hence, while medicinal plant harvesting poses threats to the persistence of socio-economically valuable species, such harvesting is not a significant driver of plant population decline nationally within the context of all (combined) factors threatening South Africa's flora	Williams et al, 2013, but read more below.
Dwindling availability and local extinctions	A wide range of species are showing signs of unsustainable harvesting, with the size of the traded components (e.g. bulbs) decreasing, distances to harvesting source increasing, supply becoming increasingly irregular and some plants becoming	Mander et al. 2007; Williams et al, 2013; Gerstner, 1938; Mander,

of medicinal plants recorded	unavailable in certain markets. There is also documented extirpation at local (e.g. *Warburgia salutaris, Alepidea spp.*) and provincial (e.g. *Siphonochilus aethiopicus*) levels which has stimulated the trade in plants from Mozambique, Swaziland and Zimbabwe to South Africa. Unsustainable medicinal plant use in South Africa is, however, not a recent concern, with many since the mid-20th-century anticipating extinctions and recommending mass cultivation by state nurseries. This suggestion has not been acted on by either national or provincial governments.	1998; Botha et al., 2004; Marshall 1998 and Crouch et al., 2000.

Williams et al (2013) explains how their findings reveal a need for greater emphasis on focussed population level research on prioritised medicinal plant species to determine whether the harvesting of the species is actually causing critical population changes. This is because species undergoing decline as a result of unsustainable harvesting may have to undergo substantial changes in population size before their threat status changes sufficiently to be measureable by the Red List Index.

It must be noted that SANBI will be re-assessing the Red List status of medicinal plants, however this will not be achieved soon as red listing is a complicated process. The question, therefore, is whether we can determine which of the 148 currently heavily utilised medicinal plant species are under increasing pressure both from trade and from habitat loss.

South Africa does not have an active monitoring programme to determine the status of medicinal plants in the field. However, it is strongly suspected the resource is rapidly dwindling. In light of the above motivation of the importance of the medicinal plant trade for health care in South Africa, SANBI is currently investigating quick options to include updated estimates of habitat loss and medicinal plant use to include in a Summary for Policy Makers to highlight the critical state of South Africa's medicinal plant resource.

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8. ECOLOGICAL INFRASTRUCTURE CASE STUDIES

Key messages about ecological infrastructure

Ecological infrastructure refers to naturally functioning ecosystems that generate or deliver valuable services to people, such as freshwater, climate regulation, soil formation and disaster risk reduction. Ecological infrastructure is the nature-based equivalent of built or hard infrastructure, and is just as important for providing services to people and underpinning socio-economic development. Ecological infrastructure includes, for instance, healthy mountain catchments, rivers, wetlands, coastal dunes, and corridors of natural habitat, which together form a network of interconnected structural elements in the landscape. South Africa has abundant ecological infrastructure, providing opportunities to support development and unlock economic potential. Ecological infrastructure's value is seldom captured in market transactions and we tend to under-invest in it. The range of benefits provided by ecological infrastructure to the public includes: enhancing investments in built infrastructure, complimenting national parks and protected areas, supporting rural development, job creation and job security, and supporting water and food security.

The following are real-life case studies of ecological infrastructure in action in actual places in South Africa. Three of these case studies relate to inland water resources: Cape Town water supply catchments, uMngeni catchment and uMzimvubu catchment. The fourth and fifth case studies relate to coastal ecological infrastructure using Kosi Bay and the Cape Flats as examples.

8.1 Inland water resources case studies

Recommended citation for this chapter of the compendium (all three inland water case studies):
Maze K, Cindi D, Gola N, Mphoba M, Layne T, Davids S, Nemutamvuni K, Maphumulo S, Zungu J, Makama D, Tau M, Driver A, Smith T, Marsh A, McLeod N, Matela S, Shata T, Nsibande T, Botts E & Ginsburg A. 2019. 'Inland water resources case studies' chapter *in National Biodiversity Assessment 2018 Supplementary Material: Compendium of Benefits of Biodiversity*. South African National Biodiversity Institute, Pretoria. Report number: http://hdl.handle.net/20.500.12143/6491

Inland water resources case study 1: Ecological infrastructure and drought in Cape Town

South Africa is a semi-arid, water-scarce country with variable rainfall (DWS, 2017). Droughts are a regular feature of the country's climate, and occur when lower rainfall than average falls over a certain period (DEA, 2017). Between 2014 and 2017, drought was experienced in many parts of the country, and became particularly acute in the Western Cape (DWS, 2018). Increased water demand from a growing population was coupled with lower water supply due to the severe drought, and water in major dams dropped to only 20% (City of Cape Town, 2018a; Stafford et al., 2018). This resulted in the "day zero" campaign where residential water usage was restricted to 50 litres per person per day (City of Cape Town, 2018a), and agricultural allocations were reduced (Pienaar & Boonzaier, 2018), to delay the day when taps would run dry. Demand-side management helped to avert day zero during the drought by reducing summer water usage to less than 60% of that during

pre-drought years (City of Cape Town, 2018a; Figure 10). Water shortages did not only have social impact on the city residents, but also economic impacts on industry and agriculture. Estimates are that the drought resulted in R5.9 billion loss of Gross Value Add and 30 000 job losses in the agricultural economy (Pienaar & Boonzaier, 2018).

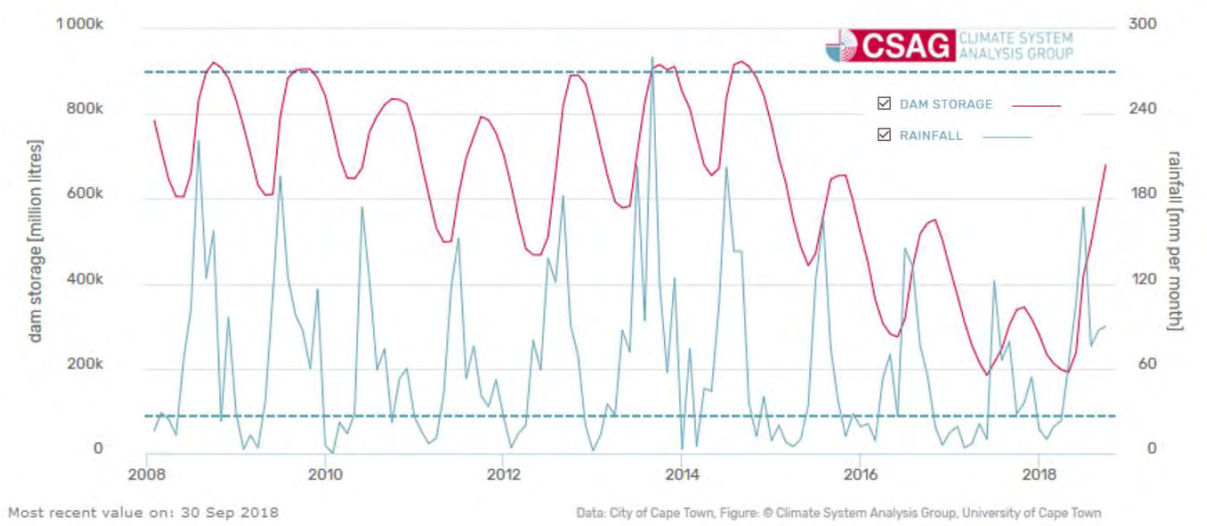

Figure 10: Dam storage levels of the six major dams of the Western Cape Water Supply System, and monthly rainfall from 2008 to 2018. Source: Climate Systems Analysis Group, University of Cape Town, http://cip.csag.uct.ac.za/monitoring/bigsix.html.

While demand-side reductions helped to stave off the effects of drought this time, improving the supply of water is necessary to protect against future droughts, which are predicted to become more frequent and intense under climate change (DEA, 2017). In addition, the population of South Africa continues to grow and it is expected that water demand will exceed water supply in Cape Town by 2021 (Stafford et al. 2018). Cape Town receives its water supply from the Western Cape Water Supply System (WCWSS), a complex arrangement of built infrastructure including six major dams and several minor dams, interlinked by water transfer systems, pumping stations, tunnels and water treatment plants (City of Cape Town, 2018b; Stafford et al., 2018).

The rivers that supply water into this system originate from the Boland Mountains, a strategic water source area with the highest mean annual rainfall per unit area in the country (Le Maitre et al., 2018; Box 4). The catchments of the Berg, Breede and Riversonderend rivers supply almost all of Cape Town's water (CER, 2016). As a result, mountain catchment areas are an important form of ecological infrastructure that deliver water into the built-infrastructure system on which more than 4 million people living downstream depend (CER, 2016). Although the Boland Mountains strategic water source area is under pressure from large-scale plantations and cultivation, it remains in largely natural condition (70%, CER, 2016) and able to provide good quality water (City of Cape Town, 2018b). However, wetland ecosystems in this water source area are under greater pressure than other ecosystems, and 79% of wetland ecosystems are Critically Endangered (CER, 2016). Wetlands are particularly important ecological infrastructure for delivering water-related ecosystem services. Wetlands play an important role in flow regulation, sediment regulation, water purification and groundwater recharge (WWAP/UN-Water, 2018).

One of the most serious threats to the ecological infrastructure of these catchments is invasive alien plants. Latest estimates show that nearly 138 000 condensed hectares (the equivalent area that invasives would take up if they occurred at 100% density cover) in the Berg and Breede primary

catchments are covered with alien plants (Le Maitre et al., 2016; SANBI & CIB, 2018). Invasive alien trees, mostly pine and eucalyptus, use as much as 20% more water than indigenous Fynbos (Stafford et al., 2018). As a result, these catchments lose about 6% of their runoff to invasive alien plants each year (Le Maitre et al., 2016). A recent modelling exercise showed that removing alien plant species from seven priority sub-catchment areas could save more than 50 million m^3 of water each year (Stafford et al., 2018). At the current costs of alien clearing, this would cost R372 million over 30 years (Stafford et al., 2018). Compared to other supply-side interventions, such as desalination or groundwater extraction, catchment management is a cheaper option (Figure 11). Other ecological infrastructure restoration and maintenance efforts, such as the restoration of priority wetlands in the catchments, will also help to improve the provision of water-related ecosystem services (Stafford et al., 2018).

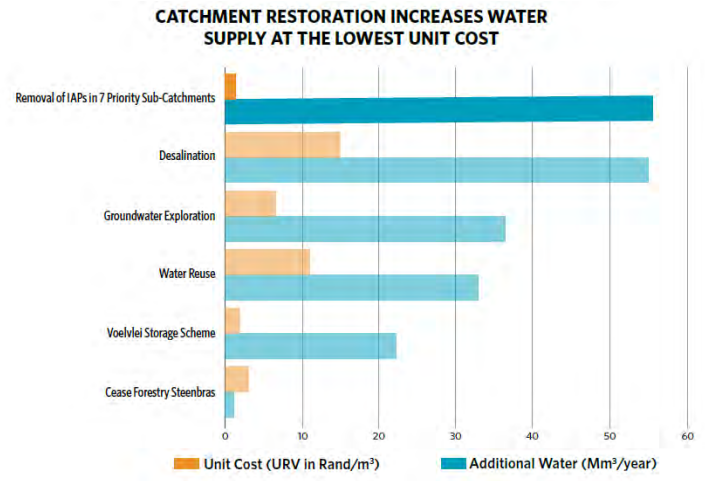

Figure 11: The additional water gained (mm3/year) and unit cost (Unit Reference Value (URV) in rand/m3) of different water supply alternative to address water shortages in the Western Cape Water Supply System. Source: Stafford et al., 2018.

Box 3: Invasive alien plants and water security

An Invasive Alien Plant is a species that has been intentionally or unintentionally introduced outside of its native range. Once established, these species spread, degrading natural ecosystems and threatening ecological infrastructure (SANBI & CIB, 2018). Alien invasive plants are a significant threat to water security throughout South Africa because they tend to use much more water than natural vegetation (Everson et al., 2007). Estimates in 2016 showed that invasive alien plants cover at least 1.5 million hectares, leading to a reduction in water flow of at least 1 444 million m^3 (Le Maitre et al., 2016). Should the spread of invasive alien plants go unchecked, this problem will increase substantially in the coming years (SANBI & CIB, 2018).

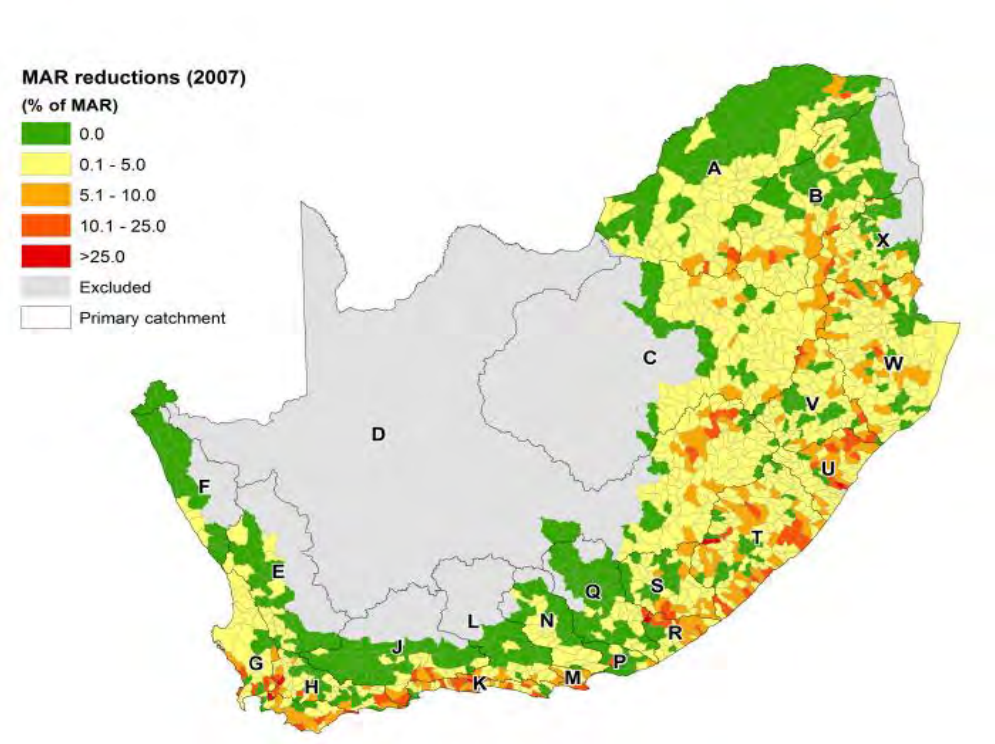

Figure 12: Estimates of the reduction in mean annual runoff due to invasive alien plants. Source: SANBI & CIB 2018; Le Maitre et al. 2016.

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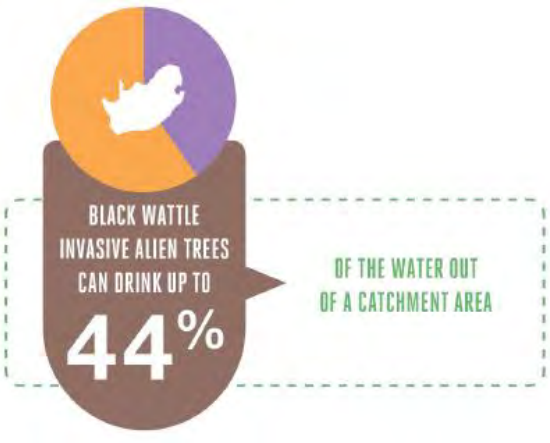
Inland water resources case study 2: EI and water security in the uMngeni River catchment

The uMngeni River arises in the foothills of the Drakensberg Mountains and runs about 200 km southeast to its mouth near the city of eThekwini (Durban). The river is the primary source of water for the expanding urban areas of Durban and Pietermaritzburg (Jewitt et al., 2016). A population of about 4.2 million people rely on this system for all their water needs (Nel et al., 2017), including basic drinking water, residential, commercial and industrial use, as well as water to support the extensive tourism economy. The uMngeni River is also the setting for popular water-based recreational activities, including the well-known Midmar Mile swim and the Dusi Canoe Marathon (SANBI & WCT, 2015).

The demand for water from the uMngeni River system has already begun to exceed supply (Jewitt et al., 2016; Mander et al., 2017). During the 2016/2017 drought, water restrictions were needed to ensure continued availability of water. Over the years, an increasing number of expensive engineered solutions have been put in place to provide water to the urban users. There are four large dams on the uMngeni River, as well as an inter-basin transfer scheme that moves water from the uThukela catchment (Jewitt et al., 2016; Mander et al., 2017). Sewage and industrial effluent also affect water quality, which has led to higher spending on water purification and on health costs (Jewitt et al., 2016).

Rain that is collected within the uMngeni River system falls within a catchment spanning about 4 400 km^2 (Mander et al., 2017). Therefore, the way that the ecological infrastructure in the greater catchment is used and cared for has an impact on the amount and quality of water in the river, and consequently on the water security for the downstream population. The source of the uMngeni catchment falls within one of the most important Strategic Water Sources Areas (SWSA) in the country, the Southern Drakensberg SWSA (Le Maitre et al., 2018; Nel et al., 2017; Box 4). There are numerous wetlands in the upper reaches, including the Ramsar-listed uMngeni Vlei (Mander et al., 2017), many of which have been impacted by artificial drainage, land transformation and overgrazing.

Much of the land surface of the uMngeni catchment is still in relatively natural condition and retains its potential to deliver water-related ecological services. The upper catchment is largely agricultural, with livestock farms and plantations the predominant land uses. However, there is significant infestation by alien vegetation, particularly wattles (Mander et al., 2017). Research in the area has shown that a dense stand of mature wattle trees upstream can cause a decrease in streamflow by 44% (SANBI, 2015a; Everson et al., 2007; see Box 3).



Box 4: Strategic Water Source Areas

South Africa is a water scarce country and more than 98% of our freshwater resources have already been allocated (WWF-SA, 2013). More than 50% of South Africa's water supply comes from less than 10% of the country's land area (Le Maitre et al., 2018). The areas that contribute a disproportionately high amount to surface water or groundwater are called Strategic Water Source Areas (SWSAs; Le Maitre et al., 2018). A total of 22 surface water SWSAs have been identified across the country, as well as 37 ground water recharge SWSAs. The SWSAs are vitally important ecological infrastructure for water security because they supply water that sustains at least 51% of the population and 64% of the economic activity (Nel et al., 2017). Generally, more than 90% of water made available in urban centres originates from Strategic Water Source Areas (Le Maitre et al. 2018). Only 11% of the land area of SWSAs is currently under formal protection (Le Maitre et al. 2018; Nel et al., 2017). The SWSAs are under threat from land degradation, large-scale cultivation and plantations, alien plants, mining, pollution and contamination, and climate change (CER, 2016).

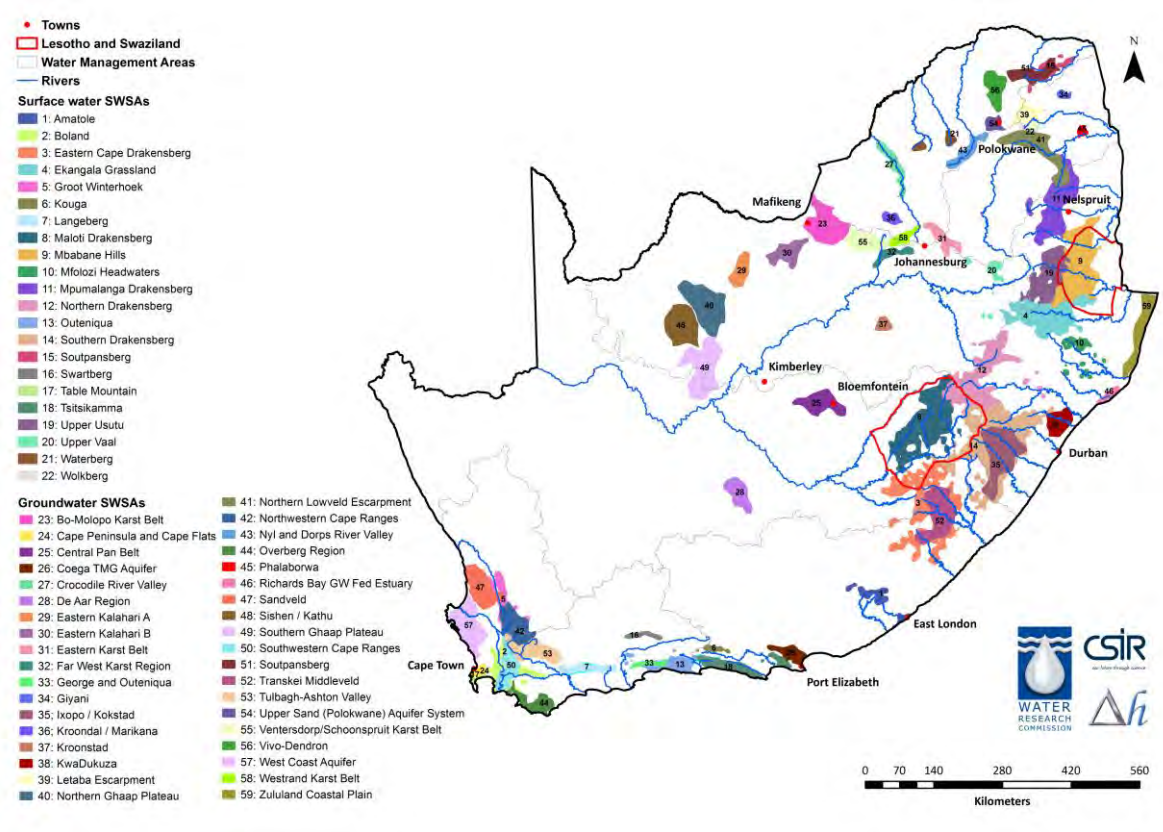


Figure 13: The Strategic Water Source Areas for surface water and groundwater in South Africa. Source: Le Maitre et

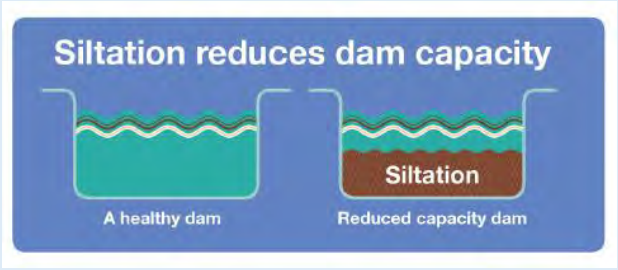
Realising that the water supply from the uMngeni was insufficient and the water quality was deteriorating, various organisations began looking at investment in ecological infrastructure as an alternative solution (UEIP, 2016). Engineering options were becoming progressively less feasible and more expensive. Investing in the ecological infrastructure in the catchment could take advantage of the water-related services provided by natural ecosystems. The uMngeni Ecological Infrastructure Partnership (UEIP) was conceived as a collaborative partnership to protect and restore the ecological infrastructure for water security benefits in the catchment (SANBI & WCT, 2015). It was launched in 2013 with a memorandum of understanding that has thus far been signed by 23 like-minded institutions (Jewitt et al., 2016). A wide range of partners are involved, including various tiers of government, non-government organisations, industries, and academic research institutions, who

have committed to working in partnership to realise a strategy for restoration and protection of the catchment (UEIP, 2016).

Research is an important part of the UEIP strategy (UEIP 2016). In 2016, a Green Fund research report developed a framework for investment in ecological infrastructure in the catchment (Jewitt et al., 2016). Based on hydrological modelling and cost-benefit analysis, the project determined which sub-catchments should be prioritised for protection and restoration to gain the largest benefits in terms of improved water-related ecosystem services. It found that investing in ecological infrastructure was a financially competitive way to improve water supply in the uMngeni (Dini et al., 2015; Jewitt et al., 2016). Functioning ecological infrastructure could also help to limit erosion, which would protect built infrastructure (Box 5). The small Henley Dam in the uMngeni system has already been decommissioned because it had lost most of its capacity to sediment that was eroded from upstream due to poor land-use practices in the catchment (Jewitt et al., 2016). Restoring natural vegetation upstream could reduce sediment loads.

Box 5: Ecological infrastructure protects built infrastructure

Ecological infrastructure is complementary to built water infrastructure like dams. Investing in ecological infrastructure can lengthen the lifespan of existing built infrastructure and can sometimes reduce the need to build additional infrastructure. Poor catchment management upstream, such as overgrazing, illegal ploughing or draining wetlands, can create erosion that is washed downstream where it is deposited in dams. This siltation reduces the dam's capacity over time. There have been several cases around South Africa of dams affected by siltation, such as the Mapochs Dam in Limpopo, which filled up in 10 years after being scooped clean of previous silt (SANBI, 2015b) and the Mount Fletcher Dam in the Eastern Cape that lost 70% of its capacity in just four years (SANBI, 2013). South Africa, like other countries, doesn't have many viable site options for new dams, so we need to take care of existing dams and make sure they function for as long as possible (WWAP/UN-Water ,2018).



Investing in ecological infrastructure means devoting time, effort, finances and/or making decisions in support of maintaining functioning ecological infrastructure and restoring degraded ecological infrastructure for a suite of social, economic and ecological benefits (SANBI, 2014). Investing in ecological infrastructure would also have a range of other ecological and socio-economic benefits, such as improved water quality, flood attenuation, improved rangeland condition, climate change adaptation, poverty alleviation and many more. Restoring ecological infrastructure and dealing with alien invasive plants is labour intensive, so such investment also has the added potential to create jobs. Furthermore, maintaining ecological infrastructure in good condition is cheaper that restoring it after degradation.

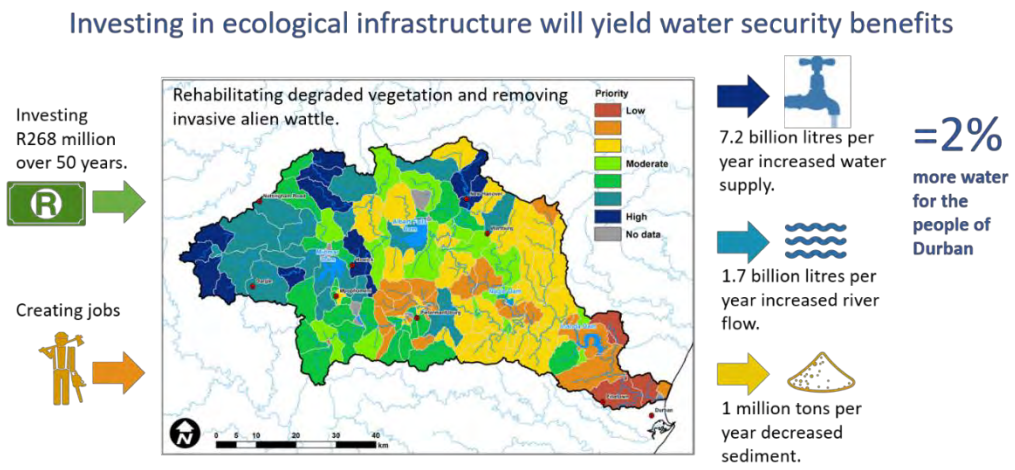


Figure 14. Estimates of the water yield increases that could be achieved from investing in ecological infrastructure in the greater uMngeni catchment. Source: Created from information in Dini et al., 2015.

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Inland water resources case study 3: Socio-economic benefits of restoring EI in the uMzimvubu catchment

The uMzimvubu catchment and river system lies along the northern boundary of the Eastern Cape, with its source in the rugged Maloti-Drakensberg watershed on the Lesotho escarpment, extending more than 200 km in a south easterly direction through deep wild thicket gorges to its estuary at Port St Johns, where it joins the Indian Ocean (ERS & citizen scienceA, 2011a). The catchment falls within the Maputaland–Pondoland–Albany Hotspot, a region of globally recognised high biodiversity and endemism (ERS & citizen scienceA, 2011a). The catchment is part of a Strategic Water Source Area (Le Maitre et al., 2018; Box 4) and is designated as a "vulnerable" Freshwater Ecosystem Priority Area (ERS & citizen scienceA, 2011a). The drainage basin forms the northern portion of the uMzimvubu–Tsitsikamma Water Management Area, which has the highest mean annual runoff in South Africa, comprising nearly 15% of total river flow in the country, 40% of which is from the uMzimvubu system (ERS & citizen scienceA, 2011a; DWS, 2017). The catchment is largely rural with a high dependence on the productive potential of the land and overall environment. The catchment's ecological infrastructure provides people with a range of benefits – water quantity and quality being the most important according to a ranking exercise by regional stakeholders in 2012 (Figure 15). Natural ecosystems are also recognised as providing subsistence food production, grazing, tourism and climate change mitigation, among other benefits (Figure 15).

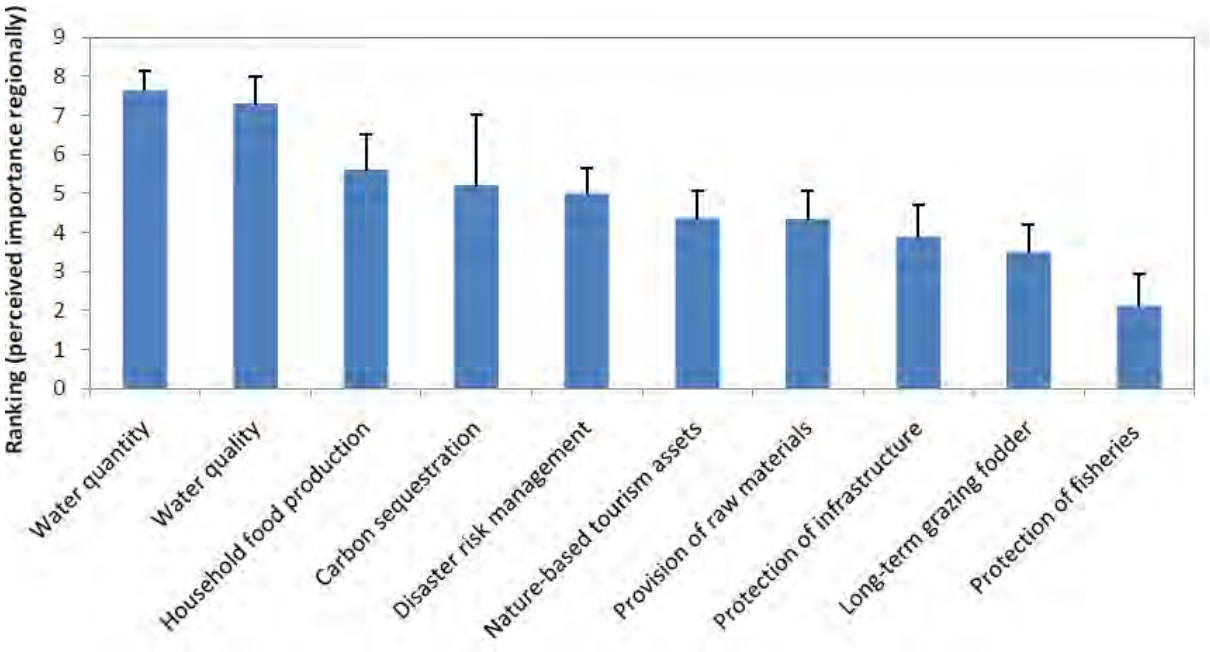

Figure 15: Ranking of ecosystem services in uMzimvubu catchment by regional stakeholders. Source: ERS & citizen scienceA, 2011b.

The upper catchment is threatened by increased erosion, largely due to loss of grass cover from extensive overgrazing, as well as development of roads and agriculture (ERS, 2012; Sigwela et al., 2017). This results in increased run-off intensity, with increased turbidity and excessive erosion within the river channels and deteriorating water quantity and quality (ERS 2012; DWS 2017). The increased silt export encourages activities such as illegal sand mining which further degrades the landscape (ERS, 2015; DWS, 2017). Loss of sound groundcover exacerbates the impacts of extreme

events, such as flooding which damages crops, infrastructure and the local economy (ERS & citizen scienceA, 2011a; ERS, 2012; Sigwela et al., 2017; DWS, 2017).

Most of the challenges in this catchment are a result of poor governance that results in poor natural resource management (Sigwela et al., 2017; Sissie Matela, ERS, pers. comm., 2018). To respond to this governance challenge, a number of organisations formed the uMzimvubu Catchment Partnership Programme (UCPP), a voluntary alliance of organisations including the state, civil society, communities and academics (ERS & citizen scienceA, 2011a; UCPP, 2013). The main focus of this catchment partnership is on conserving the entire uMzimvubu catchment, from source to sea, through sustainable restoration and maintenance of the landscape, in a manner that supports economic development and people's livelihoods, and enhances the flow of benefits from ecosystems goods and services to people and nature (ERS & citizen scienceA, 2011a; UCPP, 2013; SANBI & WCT, 2015). In 2011, the UCPP developed a 20-year plan which would support this vision for the catchment, which was agreed on by 35 diverse catchment partners (ERS & citizen scienceA, 2011a).

The first five years of the strategy from 2013-2018 involved active learning, i.e. piloting projects through which to learn the best strategies for maintenance of the ecological infrastructure of the catchment (ERS &citizen scienceA, 2011b). The UCPP has engaged in a wide range of learning exchanges and action days to share lessons from its work. In early 2017, the South African National Biodiversity Institute (SANBI) supported the convening of a catchment-based research, development and innovation platform for ecological infrastructure in the uMzimvubu. This learning platform builds on and amplifies the existing activities of the UCPP, and further harnesses the potential for lesson sharing and co-ordination efforts across the wider catchment (SANBI, 2017).

Three key initiatives have emerged out of the initial five-year UCPP pilot phase, all aimed at better managing healthy landscapes for improved livelihoods:

Rangeland restoration for landscapes and livelihoods

A model of rangeland restoration for landscapes and livelihoods has emerged over years of efforts to rebuild local governance and land management systems to underpin and sustain active landscape restoration efforts and investments (UCPP, 2016). The model addresses overgrazing and improves rangeland condition by supporting and rebuilding grazing associations to better manage and monitor grazing. Local implementing non-governmental organisations, co-ordinated by Environmental and Rural Solutions (ERS) through a Green Trust grant, enabled revitalization of traditional rangeland governance systems (like *maboella* controlled grazing custom that manage compliance with local usage by-laws) into grazing associations, which sign seasonal conservation agreements. The grazing associations are provided with various incentives in return for compliance with sustainable grazing practices.

One of the most successful incentives has been improved access to the commercial meat market through mobile auctions (UCPP, 2016), facilitated by the UCPP partners and social enterprise Meat Naturally Africa Pty. Meat Naturally harnesses the private market to provide fair value for cattle that graze on locally managed lands and positively support rangeland restoration model by linking commissions on cattle sales to compliance levels with conservation agreements (full compliance means commission as low as 3%, while there is a 6% commission for no compliance).

Livestock sales through the mobile auctions have generated nearly R20 million for over 550 households during this pilot phase (UCPP, 2018). This makes a notable contribution to the local

economy, and together with the rangeland restoration has shown a variety of ecological and socio-economic benefits. Eight grazing agreements have been signed, leading to improved management of over 6 000 ha of grasslands. Community surveys show perceived benefits such as improved rangeland quality, cattle health and quality of life (Figure 16). Based on auction statistics and recent survey data, market value and turnover are increasing over time, as are involvement of women and youth (Dartmouth AFSP, ERS & MNA, 2018a; Figure 17).

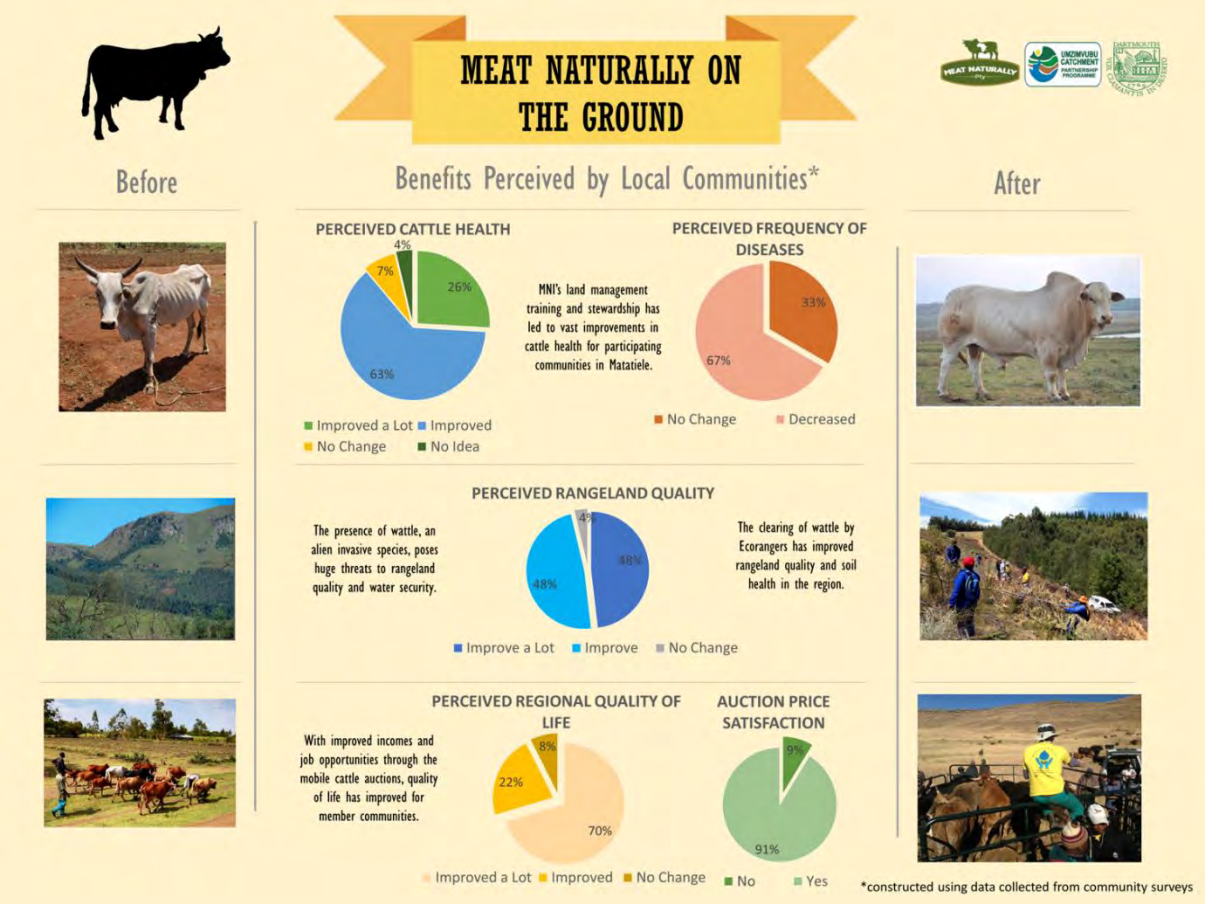

Figure 16: Local communities' attitudes towards the Meat Naturally initiative at uMzongwana. Source: Dartmouth AFSP, ERS & citizen scienceA (2017).

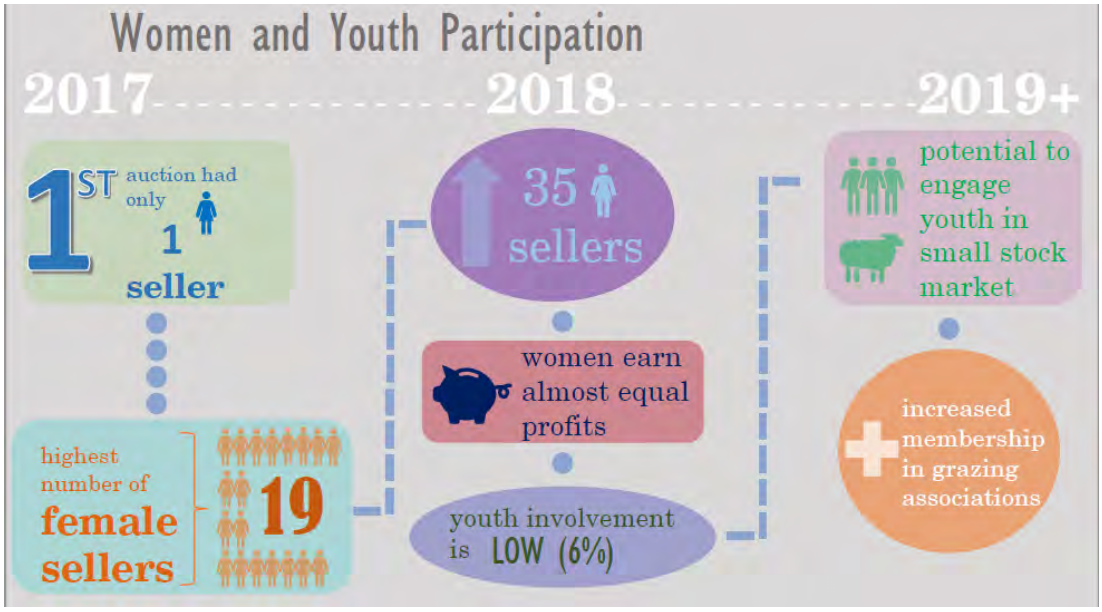

Figure 17: Involvement of women and youth in mobile auctions. Source: Dartmouth AFSP, ERS & MNA (2018a).

Alien plant control for water and people (exploring value chain opportunities)

The upper catchment of the uMzimvubu has over 30 000 ha of intense wattle infestation, which threatens grassland integrity and function, water flows, grazing capacity and consequently local livelihoods (Box 5). The UCPP partners have been instrumental in conducting alien clearing, including putting in applications for large government programmes such as Working for Water and the Expanded Public Works Programme to implement ecosystem-based management interventions. It is estimated, based on an ecological production function developed by Le Maitre et al. (2000), that the amount of water replenished from wattle clearing in and around Mzongwana village alone is 1.9 million kilolitres (Dartmouth AFSP, ERS & MNA, 2018b). That is equivalent to the annual water needs of 9% of the population that live in the upper catchment of the uMzimvubu (ibid.). This amount of water is now able to flow back into the system for utilisation by indigenous vegetation, animals, and people, or by aquatic ecosystems as the vital ecological reserve.

An important link is made between post-clearing management and the grazing programmes. Grazing and herding cattle on land post-clearing suppresses regrowth of alien species and aids grass growth, with minimal additional costs - thus ensuring better outcomes for investments made in invasive alien plant clearing (UCPP, 2016). New partners have been brought on board to explore the extended value chain for using alien plant biomass to create charcoal and other products.

Water stewardship: protecting the Strategic Water Source Area

A potential protected area of almost 48 000 ha of montane grassland is being proposed along the South Africa/Lesotho boundary, which forms the upper watershed of the uMzimvubu (ERS, 2018) (Figure 18). This protected area would help to protect the ecological infrastructure of the Strategic Water Source Area (Box 4). This communal area comprises six traditional authorities, and would include land use agreements under a formally declared Protected Area. Co-management systems will allow communities and their leadership to improve governance and increase their responsibility

towards sustainable natural resource use within and surrounding the protected area. Integrated land management will help to reduce degradation, improve response strategies for stock theft, and lead to better landscape productivity. However, since the land tenure of the area is vested with national government for use by the communities, formal declaration is complex under the National Environmental Management: Protected Areas Act (Act 57 of 2003) and progress towards this protected area is still ongoing (Thembanani Nsibande, ECPTA, pers.comm., 2018).

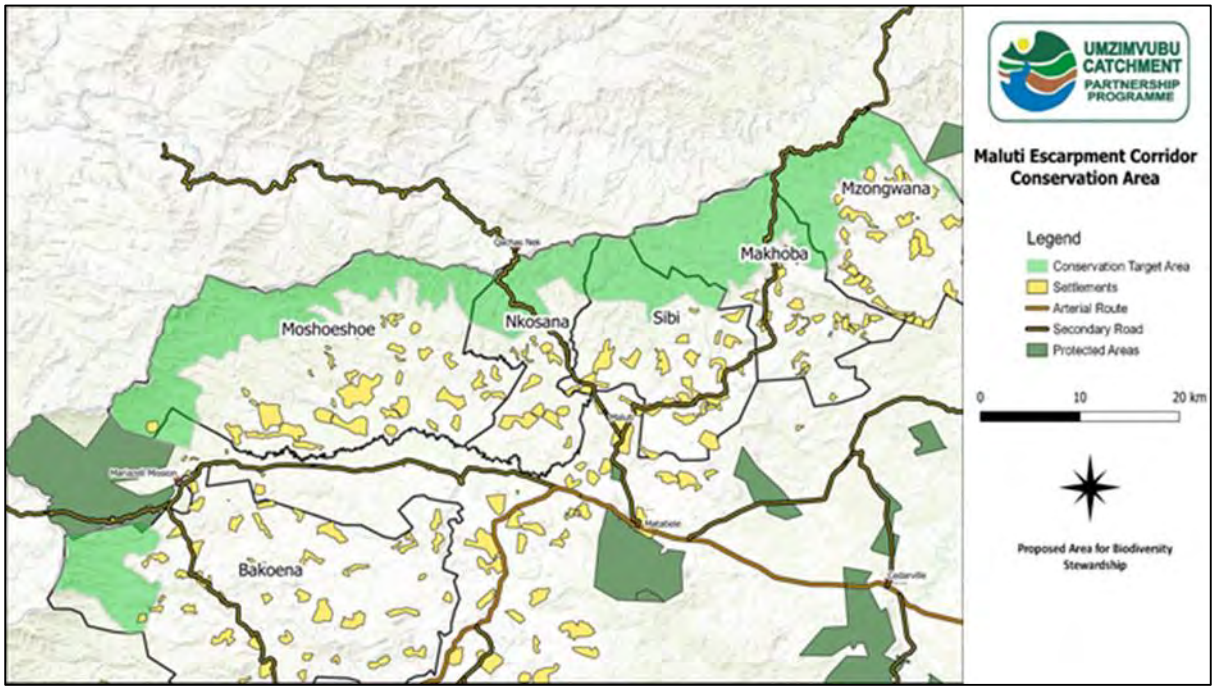

Figure 18: Proposed watershed stewardship protected area in the upper uMzimvubu catchment, spanning two SWSAs, six traditional authorities, and over 70 000 ha of montane grassland along the South Africa-Lesotho watershed. Source: ERS, 2018.

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8.2 Coastal EI case studies – Kosi Bay and Cape Flats

Recommended citation for this chapter of the compendium (both coastal case studies):
Perschke M, Sink K and Harris LR (2019). 'Coastal EI case studies - Kosi Bay and Cape Flats' chapter *in National Biodiversity Assessment 2018 Supplementary Material: Compendium of Benefits of Biodiversity*. South African National Biodiversity Institute, Pretoria. Report number: http://hdl.handle.net/20.500.12143/6491

Ecological Infrastructure (EI) plays an important role for communities that reside along the 3113-km long South African coastline. Coastal ecosystems that can function as EI in South Africa include sandy beaches and dunes, rocky reefs and rocky shores, kelp forests, seagrass beds and estuaries (Harris et al., 2019a,b). The coastal EI features are spread along the South African shore and can deliver a multitude of different ecosystem services e.g. food provision, water storage and provision, water purification, air quality regulation, coastal protection, symbolic and aesthetic values and recreation (Liquete et al., 2013). Yet, the precise EI types and the associated service flow varies from location to location and really depends on the needs and activities of the different coastal communities. For example, rural areas are more likely to still depend to a high degree on coastal EI features that fulfil their basic needs for food, warmth and shelter. Whereas in an urban context, food production usually has lesser importance and coastal EI features that deliver recreational services might be greatly valued by the residents. In the following two case studies, different coastal communities and the EI features in their reach will be discussed: two small communities in Kosi Bay in KwaZulu-Natal, and the communities of the urban Cape Flats of Cape Town in the Western Cape. Thereby, two geographically distinct places in a rual and an urban context are looked at for the presence of EI features, the flow of ecosystem services and benefits and the implications of the human-nature interactions for both: people and nature.

Coastal EI case study 1: Kosi Bay

The study area

Kosi Bay is located in Umhlabuyalingana, the northernmost coastal municipality of KwaZulu-Natal (Stats SA, 2018a) (see Figure 19). It includes a series of four interlinked lakes that run parallel to the coast for about 10 km. The coastal communities of eNkovukeni and KwaDapha are situated between the shore and the lakes (Hansen et al., 2015). The total number of inhabitants was slightly over 400, with little formal employment in 2011 (Statistics South Africa, 2011a, 2011b). As a result, residents strongly depend on the local natural resources (Kyle et al., 1997b; Napier et al., 2005) for their basic needs like food, shelter, medicine and warmth (Kyle, 2013).

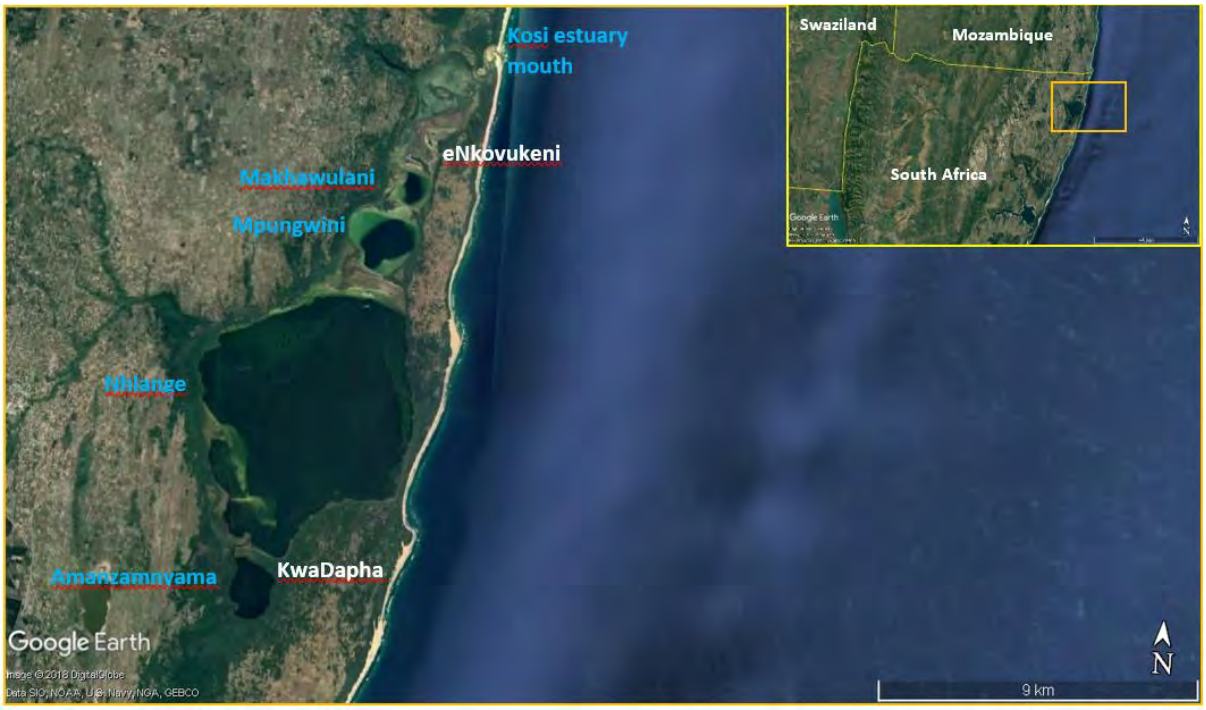

Figure 19. The orange rectangle in the upper right corner indicates the location of the study site (Kosi Bay) in Northern KwaZulu Natal, South Africa with local suburbs (white) and prominent ecological features (blue). (Underlying maps from Google Earth Pro, 2018a and b)

The coastal ecological infrastructure features

The coastal EI that can be found within this coastal zone includes:

1) Inshore rocky and coral-covered sandstone reefs parallel to the sandy beaches that contain some of the most southerly coral reefs in the world (Celliers and Schleyer, 2008; Harris et al., 2012; Ramsay and Mason, 1990).
2) Several rocky patches scattered in between the predominantly sandy shore that have a high abundance of a variety of different intertidal invertebrate species (Kyle et al., 1997a).
3) Sandy beaches that are the part of the only nesting grounds for the Near Threatened loggerhead and Critically Endangered leatherback turtles (Nel et al., 2013). The morphodynamic type of the beaches ranges mostly from reflective to intermediate, with a few dissipative-intermediate sections, meaning that the beach width and surf-zone width tend to be relatively narrow with medium to coarse sand and a moderately steep slope, sometimes with cusps, although there are some wider and flatter sections (Harris et al., 2011).
4) Dunes (mostly parabolic) with associated dune forests that form one of South Africa's rarest vegetation types (Guyot, 2005; Trimble and van Aarde, 2011) and are among the highest dunes in the country (Tinley, 1985).
5) Kosi Bay estuarine lake system covers around 415 ha and the vegetation mainly consists of reeds and sedges followed by mangrove forests and swamp forests (Van Niekerk and Turpie, 2012). Many of the estuarine tree species are part of the protected tree list of the Department of Water Affairs (Van Niekerk and Turpie, 2012).

The following table lists the five different coastal EI types of the study area, the linked ecosystem services and benefits that are currently flowing from the EI and associated livelihood aspects:

Table 9. Kosi Bay coastl EI and its services, benefits and livelihood aspects

Coastal EI type	Local ecosystem services and benefits	Livelihood aspects
Coral reefs	▪ The provision of **habitat** for a variety of fish species (Floros et al., 2012; Harris et al., 1995) that support local subsistence fisheries and recreational fishing activities (Barbier et al., 2011); ▪ **Recreational** ecosystem service flow as for example diving and snorkelling (Siyabona Africa, 2017) that leads to **nature-based tourism** and employment in the area; ▪ **Research** e.g. Celliers and Schleyer (2008); Ramsay and Mason (1990); Riegl et al. (1995)**;** ▪ **Protection** of the coastal communities from storm events through wave attenuation (Barbier et al., 2011; Elliff and Silva, 2017).	*Diving industry staff;* *Research-associated staff;* *Fishermen*
Rocky shores	▪ **Food** provision, with subsistence harvesting of invertebrates such as limpets, red bait, mussels and oysters by local communities (Kyle et al., 1997a); ▪ **Research** e.g. Kyle et al., (1997a)**;** ▪ **Protection** of the local communities from flooding and erosion by attenuating wave energy in case of major storm events.	*Fishermen;* *Food gatherer;* *Conservation staff;* *Research-associated staff;*
Sandy beaches	▪ **Food** provision (Chadwick et al., 2014; Ngubane and Diab, 2005; Sunde, 2014) e.g. subsistent invertebrate harvesting of ghost crabs and mole crabs by local communities (Kyle et al., 1997b); ▪ **Nesting** ground for two turtle species (Nel et al., 2013) and associated **nature-based education** and **tourism** (Chadwick et al., 2014); ▪ **Spiritual** value for the local Tembe-Tonga population (Sunde, 2014); ▪ **Nature-based tourism** associated **recreational activities** (Chadwick et al., 2014); ▪ **Research** e.g. Harris (2008), Mitchell et al. (2005), Le Gouvello et al., (2017a, 2017b).	*Fishermen;* *Food gatherer;* *Tourism-associated jobs e.g. tour guides, vendors, drivers etc.;* *Conservation staff;* *Research-associated staff;* *Turtle monitors;* *Coastwatch workers*
Dunes	▪ Harvesting of natural resources for **food** by the local people (Guyot, 2005); ▪ Cutting of wood in dune forests for **fuel** (Guyot, 2005); ▪ **Protection** of the local communities from flooding and erosion in case of major storm events (Barbier et al., 2011).	*Gatherers;* *Conservation staff*
Estuarine lakes	▪ **Food** provision through traditional spear and fish-trap fisheries (Felgate, 1965; James et al., 2001; Sunde, 2014) as well as through invertebrate harvesting of the local communities (Ngubane and Diab, 2005; Pedersen et al., 2003); ▪ **Nursery** for many fish species (Kyle, 2013) that are used by the local communities; ▪ **Medicine provision** out of estuary resources used by traditional healers (Kyle et al., 1997b; Sunde, 2014); ▪ **Fresh water** provision for agriculture (Umhlabuyalingana Municipality, 2017); ▪ Wood cutting for **fuel** by local people (Van Niekerk and Turpie, 2012); ▪ Fish traps are perceived as **cultural heritage** of the Tembe-Tonga people (Sunde, 2014; Umhlabuyalingana Municipality, 2017); ▪ Local people have an **ancestral relationship** to the place, perform **rituals** and maintain several **sacred sites** (Sunde, 2014); ▪ **Recreation** like recreational angling from small boats and the shore (James et al., 2001) or snorkelling in the river mouth, canoeing, hiking, or horse riding (Siyabona Africa, 2017) and associated **nature-based tourism** (Umhlabuyalingana Municipality, 2017);	*Fishermen;* *Wood cutters;* *Food gatherer;* *Jobs in agriculture;* *Traditional healers;* *Tourism associated jobs e.g. Tour-guides, lodge and camping-ground keepers and staff, drivers, vendors etc.;* *Conservation staff;* *Research associated staff*

	▪ **Research** e.g. James et al. (2008) or Pedersen et al. (2003); ▪ **Protection** of the associated communities from flooding during extreme weather events (Barbier et al., 2011); ▪ **Water purification** of agricultural runoff (Barbier et al., 2011).	

Current state and future opportunities

The coastal communities of KwaDapha and eNkovukeni highly benefit from the service flow of the listed local coastal EI (see above Table 9). For instance, all five EI features play a key role in the nutrition of the residents as they either support the provision of edible resources or directly provide food. For centuries the locals, mainly descendants from the Tembe-Tonga clans, fish in the Kosi lake system with fish traps and spears (Felgate, 1965; James et al., 2001; Sunde, 2014). The traps are semi-permanent structures traditionally made from local plant material and occur from the Kosi mouth into the lakes Makhawulani, Mpungwini and Nhlange (Kyle, 2013) (see Figure 19). The rocky and sandy shores have also always been harvested by woman and girls who come down to the shore during spring low tides to collect oysters, mussles, limpets, redbait and crabs (Kyle et al., 1997a, 1997b). Furthermore, the local communities have a deep ancestral relationship to the sea, perform rituals linked to the use of marine resources and have several sacred sites along the coast and the lakes (Sunde, 2014). Another cultural ecosystem service is the opportunity for nature-based recreation and tourism (Umhlabuyalingana Municipality, 2017). One example being the recreational fishing activities in the estuarine lake system that take place either from small boats or the shore (James et al., 2001). Again, the beneficiaries of those nature-based recreational opportunities are the local people as livelihood options are created through tourism by e.g. the park administration, tour operators or the accommodation sector. Furthermore, most coastal EI features have the capacity to buffer flooding and erosion and thereby shelter the property and life of the local people (Kyle, 2013; Spalding et al., 2014; Umhlabuyalingana Municipality, 2017). In total, with the provision of food, supplementary livelihoods and shelter, the importance of the coastal EI to the communities in Kosi Bay is invaluable.

To secure the sustainable flow of the described essential ecosystem services the coastal EI features should be naturally functioning and in good condition. Luckily, the protection of natural assets is already a major priority within the study area as it is situated in the iSimangaliso Wetland Park in Maputaland, a protected area in northern KwaZulu-Natal. iSimangaliso Wetland Park was declared a UNESCO World Heritage Site in 1999 and a Ramsar site in 1991 (Solano-Fernandez et al., 2012), and since the expansion of South Africa's Marine Protected Areas in 2019, it is now the largest MPA along the South African coast. Thanks to the local environmental protection efforts, the coastal EI features can be generally regarded as being in good ecological condition (Sink et al., 2012). The continuous service flow of naturally functioning ecosystems can be crucial especially in times of climate change. The changing climate is expected to increase risk to people and ecosystems in the Umhlabuyalingana Municipality alike as a higher frequency of extreme weather events, sea-level rise and droughts can be expected (Umhlabuyalingana Municipality, 2017). Yet, thanks to well-managed development in the study area, the resilience of the coastal ecosystems to sea-level rise, for example, is still high (Harris, 2008). If kept in good state, the present residents and future generations will continue to benefit from the coastal EI features in Kosi Bay.

A number of activities within the coastal zone put pressure on the coastal EI and the associated delivery of ecosystem services. An increase in numbers of fish traps, the use of more efficient, modern material for their construction and the use of gillnets increased fishing pressure and has led to the overexploitation of fish resources (James et al., 2008; Kyle, 2013; Van Niekerk and Turpie,

2012; Van Niekerk et al., 2019). Other pressures on the coastal EI include intensive subsistence invertebrate harvesting (Sink et al., 2005) coastal disturbance, illegal developments in the coastal zone, recreational boat fishing, recreational shore fishing and shipping (Chadwick et al., 2014; Sink et al., 2012). Also, invasive alien species have been reported in the estuarine system (Miranda and Perissinotto, 2014). Unsustainable wood harvesting is a significant pressure on the local mangrove forest (Van Niekerk and Turpie, 2012) and these forests are also reported to be sensitive to climate change (Eeley et al., 1999). Most of the listed pressures are closely related to the listed ecosystem services (Table 9), highlighting the importance of keeping resource use sustainable for these services to persist. This suggests that once a certain threshold of ecosystem service flow is passed, the excessive use of the same can convert into a threat to the underlying EI and thereby threaten the continuous service flow itself. Therefore, to reduce the existing and avoid creating additional pressure on the valuable coastal EI, sustainable practices should always be applied.

One way to alleviate pressure on the coastal EI features is to reduce the dependency of the local communities on the natural environment through the creation of supplementary livelihoods (see Harris et al., 2019b). As mentioned above, the nature-based recreation- and tourism-associated services have a great potential to offer new forms of income in the study area (Umhlabuyalingana Municipality, 2017). A local turtle monitoring programme has been especially successful with regards to nature conservation and supplementary livelihood creation over the last decades. Through the programme, the overexploited food-provisioning service based on turtles and turtle eggs was transformed to a cultural ecosystem service based on turtle eco-tourism (Sink et al., 2012), also providing supplementary livelihoods by providing seasonal jobs for turtle monitors. Trained members of the community take tourists to experience leatherback and loggerhead turtles laying eggs at night (Fairer-Wessels, 2017). Starting with about 20 people that could be offered regular (seasonal) employment, the impact of the turtle program has grown susbstantially over the last 50 years and the park's revenue associated with turtle conservation was estimated at R 500 000 annually in 2010 (Hughes, 2010). Most of the income generated stays with the local communities through direct or indirect employment (Fairer-Wessels, 2017; Hughes, 2010). In addition, the creation of the turtle conservation program helped to alleviate the pressure on the Near Threatened loggerhead and Critically Endangered leatherback turtle species (Nel et al., 2013). Following this success story, other eco-tourism-based livelihood options could be explored in the area to equally benefit both, people and nature.

Coastal EI case study 2: Cape Flats

The study area

Cape Town is the capital city of the Western Cape province and is situated at the west coast of South Africa. The metropolitan area is part of the Cape Floristic Region with a unique and vast variety of endemic species, making it an outstanding biodiversity area (Born et al., 2007; Cowling and Pressey, 2001; Goodness and Anderson, 2013). This case study focusses on the EI within the coastal strip between the Cape Flats' suburbs of Mitchells Plain, Khayelitsha and Macassar (from west to east) in the northern False Bay area (see Figure 20). The communities of the study area are stricken with high unemployment rates and low education levels and therefore, even though situated in an urban context, still partly depend on the natural resources of the surrounding area (Petersen et al., 2014, 2012).

Figure 20. The orange rectangle in the upper right corner indicates the location of the study site in the False Bay area of Cape Town, South Africa with local suburbs (white), protected areas (yellow) and major recreational centres (green). (Underlying maps from Google Earth Pro, 2018a, b)

The coastal ecological infrastructure features

Coastal EI features that support local communities with a variety of ecosystem services include:

1) One sub-tidal reef in the eastern part of the study area and some areas of kelp forest along the shore that form a habitat for a variety of threatened fish species including Red Stumpnose, Galjoen and Red Steenbras (CCT, 2014a; WWF and SASSI, 2018).
2) Vast sandy beaches that cover most of the northern shore of False Bay and are mainly classified as dissipative beaches, meaning that they are flat and wide with fine sand and a broad surf zone (Harris et al., 2011, 2019a). Major recreational centres for adjacent communities include the Monwabisi resort, Mnandi resort and Strandfontein (see Figure 20).

3) The coastal dune system, which is an integral part of Cape Town's environment (TDA, 2017). Some of the dunes are vegetated with Cape Flats Dune Strandveld, an endemic and Endangered vegetation type (Rebelo et al., 2011).
4) Sand and limestone cliffs that formed in the Holocene period during a time of extensive erosion as a result of sea-level rise (Walters, 2011).
5) The Lourens River mouth and the Eerste River mouth, two relatively small estuaries (around 10 ha) that consist predominantly of sand and mud banks but also contain patches of reeds and sedges; the Eerste River mouth even has some intertidal salt marshes (Van Niekerk and Turpie, 2012).

The following table lists the five different coastal EI types of the study area, the linked ecosystem services and benefits that are currently flowing from the EI features, and associated livelihood aspects:

Table 10. Cape Flats coastal EI and its services, benefits and livelihood aspects

Coastal EI type	Local ecosystem services and benefits	Livelihood aspects
Reefs and kelp	▪ **Nursery function** for fish species (CCT, 2014b) that in turn supports the local recreational, subsistence and commercial fisheries; ▪ **Protection** of the coastal communities from storm events through wave attenuation (Brundrit, 2009; Elliff and Silva, 2017); ▪ **Water purification** through nutrient cycling and carbon fixation (Blamey and Bolton, 2018). ***Note:*** *The total economic value of direct and indirect ecosystem services flowing from temperate reefs and associated kelp forests in South Africa have been estimated to be R5,8 billion per year* (Blamey and Bolton, 2018).	*Fishermen;* *Conservation staff*
Sandy beaches	▪ Harvesting of marine flora and fauna for **food**, **bait** and **medicine** by the local people (Petersen et al., 2012) including subsistence fishing activities like shore-based angling and beach-seine netting (CCT, 2015a; Lamberth, 1994). ▪ A great diversity of **recreational services** is offered e.g. bathing, fishing, surfing, kayaking, swimming, walking, sunbathing, observation of birds and mammals and various beach-related sports (CCT, 2015b, 2014b); ***Note:*** *The value of cultural services delivered by the city's beaches was estimated R77 million per annum* (CCT, 2015c). ▪ Space for **cultural, religious or spiritual ceremonies** of the nearby communities (Loyiso Dunga, personal observation, CCT, 2014b); ▪ Opportunities for **research** e.g. Callaghan et al. (2015), Griffiths et al. (2010), Lamberth (1994); ▪ Regulatory and supporting ecosystem services including **water filtration and nutrient cycling** (McLachlan, 1989; McLachlan et al., 1985).	*Fishermen;* *Lifeguards;* *Shark spotters;* *Tourism-associated jobs e.g. vendors of food, crafts and beach equipment etc.;* *Beach cleaners;* *Conservation staff;* *Researchers*
Dunes	▪ **Grazing of cattle** for livelihood purposes of the local people (Environmental Evaluation Unit UCT, 2005); ▪ Informal harvesting of vegetation by local communities for **food** e.g. sour fig to make jam (Petersen et al., 2012; van Wilgen et al., 2016) and informal hunting of e.g. buck, birds and other wild animals (Environmental Evaluation Unit UCT, 2005; Petersen et al., 2012); ▪ **Water filtration, storage and provision** through an underground aquifer accessed by local communities (Barbier et al., 2011; Cartwright, 2008; O'Farrell et al., 2012; Segun et al., 2010)	*Cattle keepers;* *Hunters and Gatherers;* *Wood cutters;* *Traditional healers;* *Conservation staff;* *Environmental education staff;* *Tour-guides*

	▪ Wood as a source of **fuel** for the local communities (Environmental Evaluation Unit UCT, 2005); ▪ **Medicinal plants** for local traditional healers or trade and cut **flowers** activities by local people for trade (Petersen et al., 2012; van Wilgen et al., 2016); ***Note:*** *Wild medicinal plant material supports the living of around 15000 individuals and the cities informal trade in wild medicine is worth US $15.6 million/year (Petersen et al., 2014).* ▪ **Environmental education** (Environmental Evaluation Unit UCT, 2005; Matthews, 2009); ▪ The dunes add to the **aesthetic** value of the city (TDA, 2017); ▪ **Tourism** and **recreational activities** like bird watching, walking, picnicking (Environmental Evaluation Unit UCT, 2005); ▪ **Cultural connection** of adjacent communities (Ferketic et al., 2010), political and religious gatherings (Environmental Evaluation Unit UCT, 2005; LivingIslam, 2018; Matthews, 2009) and initiation ceremonies of the Xhosa-speaking communities (Environmental Evaluation Unit UCT, 2005); ▪ **Carbon sequestration** of dune vegetation (Barbier et al., 2011) might mitigate the effects of the air pollution problem created by burning of fuel by local communities (Environmental Evaluation Unit UCT, 2005). ▪ **Connectivity** service when functioning as a biodiversity corridor (CCT, 2012; Environmental Evaluation Unit UCT, 2005; Holmes and Pugnalin, 2016) and thereby supporting ecosystem-service delivery of adjacent natural features; ▪ **Coastal protection** from erosion, wave damage, flooding, wind stress and over wash (Barbier et al., 2011; Defeo and Mclachlan, 2013; TDA, 2017). ***Note:*** *The direct economic risk of sea-level rise to the whole City of Cape Town (loss of public infrastructure, private property and tourism revenue) in a moderate scenario was estimated at R5.2 billion (Cartwright, 2008).*	
Cliffs	▪ **Aesthetic** scenery value (Matthews, 2009); ▪ **Recreational activities** like walking, bird watching and fishing (Environmental Evaluation Unit UCT, 2005); ▪ A prime **research** site as fossilized animal bone assemblages from the late Pleistocene are present in the area (Environmental Evaluation Unit UCT, 2005; Klein, 1975).	*Conservation staff;* *Researchers*
Estuaries	▪ **Nursery** for marine fish species used by local communities (CCT, 2014a; Clark et al., 1994). ▪ **Recreational activities** of local communities like fishing and swimming (C.A.P.E. Estuaries Programme, 2015); ▪ **Research** e.g. Clark et al. (1994), Snyman et al. (2002); ▪ **Water purification** by e.g. salt marshes (Barbier et al., 2011) being used for water treatment in the Eerste River mouth in combination with the Macassar sewage plant (CCT, 2014b); ▪ **Protection** of the coastal zone from storm events through wave attenuation, erosion control and water retention of estuarine vegetation (Barbier et al., 2011)**;**	*Fishermen;* *Conservation Staff;* *Researchers*

Current state and future opportunities

From the earliest days the local EI features substantially supported the people that occupied the area that is now the city of Cape Town. The San hunter-gatherers, Khoi herders and then European settlers benefitted from the abundant wildlife and the existence of fresh water from earliest known

records (Anderson and O'Farrell, 2012; Goodness and Anderson, 2013). The high level of biodiversity within the city continues to contribute substantially to its economy (Turpie et al., 2003). The total value of a selected set of ecosystem services (hazard regulation, recreation and tourism, water purification and waste treatment, space for biota, aesthetic value and sense of place) provided by Cape Town's EI was estimated at an average of R4 billion per annum, which in 2012 equated to 10-25% of the total annual municipal budget (de Wit et al., 2012). The economic value of the coastline alone was estimated R375 million per year, not including port activities, shipping, fishing and international tourism (CCT, 2014a). Yet, the actual value of Cape Town's EI features for the wellbeing of Cape Town's citizens, especially for the vulnerable communities of the Cape Flats, is considerably higher and cannot be fully expressed in monetary terms.

The coastal EI features in the study area support the livelihoods of the local communities, provide recreational and cultural opportunities, regulate water quality and shelter people from extreme weather events (see Table 10). Even though the Cape Flats are placed in an urban context, they still partly depend on the local EI for their basic needs. For example, four of the five listed EI features directly or indirectly support the provision of food that is harvested by the residents and contributes to the communities' nutrition (CCT, 2015c, 2014b, 2014a; Clark et al., 1994; Environmental Evaluation Unit UCT, 2005; Petersen et al., 2012; van Wilgen et al., 2016). The aquifer below the dunes that provides water for agricultural purposes of the local communities is also highly important (Cartwright, 2008; Segun et al., 2010). In addition, many individuals within these communites have a deep connection to certain places in the dunes and along the sandy beaches where religious, cultural or spiritual ceremonies take place (CCT, 2014a; Environmental Evaluation Unit UCT, 2005; LivingIslam, 2018; Matthews, 2009). Furthermore, many nature-based recreational activities that contribute to the health and wellbeing of the population take place in the study area, e.g. fishing, swimming, walking, bird watching or pickinicking (C.A.P.E. Estuaries Programme, 2015; CCT, 2015a, 2014b; Environmental Evaluation Unit UCT, 2005). Note that the value of cultural services delivered by the city's beaches alone was estimated at R77 million per annum in 2015 (CCT, 2015c). Of high importance to local communities are the regulating services of water purification and coastal protection. The water purification service is used, for example, for water treatment in the Eerste River mouth in combination with the Macassar sewage plant (CCT, 2014b).

Proper protection of the coastal zone will be very valuable. It has been reported that the frequency and intensity of storms along the Cape coast are increasing and so are sea levels, which in turn increases the probability of high wave-energy events (Cartwright, 2008). The worst wave-energy events happen if extreme high tides that are exacerbated by an extreme storm event strike the coast and pushed by a sea-level that has risen over time due to climate change (Cartwright, 2008). Infrastructure located directly at the coast, like the recreational centres of False Bay, is especially exposed and at risk to those events (Brundrit, 2009). The vast dune fields

Figure 21. The output of a GIS inundation model that demonstrates the exposure of Cape Town's coasts to worst case storms. The yellow square indicates the coastal dunes in the study area that protect the adjacent communities from major storm events. Map from Brundrit (2009).

of the Cape Flats are in a prime position when dealing with extreme events or climate-change effects. In the case of a tsunami, for example, the coastal dunes in front of the Cape Flats are predicted to act as an effective buffer to dissipate wave energy (Cawthra and van Zyl, 2015). Moreover, the dune system protects the communities against possible worst-case storm scenarios associated with sea-level rise, as shownin Figure (Brundrit, 2009). In terms of wellbeing, the delivery of the coastal protection service is essential for the vulnerable communities of the Cape Flats because they often don't have sufficient financial means to support themselves in the case of property loss (Allsopp et al., 2014; Arkema et al., 2017). The direct economic risk of sea-level rise calculated for the entire City of Cape Town (loss of public infrastructure, private property and tourism revenue) in a moderate scenario is estimated at R5.2 billion (Cartwright, 2008). Therefore, to avoid even greater costs in case of an extreme event, EI features that are connected to the coastal protection service should be conserved or restored if degraded.

As has been demonstrated, the variety of ecosystem services delivered by coastal EI in the study area is vast and a healthy state of the valuable coastal ecosystems to secure continous service flow is crucial. Four protected areas can be found within the study area (see Figure 21). The Helderberg Marine Protected Area is situated on the north eastern shore of False Bay between the Eerste River and the Lourens River mouth (Chadwick et al., 2014). It consists of 4 km of mainly sandy shore, extending 500 m offshore and is declared a no-take zone (Chadwick et al., 2014). The Macassar Dunes Conservation Area borders the suburb of Khayelitsha (Layne, 2013). The protected area has a size of 1000 ha and includes more than 178 plant species, many of which are used in African Traditional Medicine (Layne, 2013). The Wolfgat Nature Reserve borders the suburb of Mitchells Plain (Layne, 2013). The Reserve covers 248 ha and protects unique coastal lime and sandstone cliffs (Layne, 2013). The coastal strip bordering the Wolfgat Nature Reserve to the west and Strandfontein resort to the east is part of the False Bay Nature Reserve (CCT, 2015d). Thanks to the density of conservation areas along the coast, the majority of the coastal EI in the study area is still in a natural or semi-natural (good) ecological condition (CCT, 2015c; Holmes and Pugnalin, 2016). Unfortunately, this isn't true for the two estuaries, with the Lourens River Mouth being in a fair and the Eerste River Mouth being in a poor ecological condition (Van Niekerk et al., 2015).

Even though most ecosystems in the study area are still in a good ecological condition, there are many pressures on these valuable coastal ecosystems at the urban edge (Holmes and Pugnalin, 2016). The demand for coastal services by the growing urban centre (Stats SA, 2018b) is rising and the unsustainable consumption of ecosystem services can easily convert to a threat to EI. This can be seen seen for example in the decrease of surfzone fish through unsustainable shoreline angling in the Helderberg MPA (CCT, 2014b). Examples for activities that impact the dynamic dune-beach system include plant collection, air pollution, sewage pollution, dumping, off-road vehicle use, sand mining, and poaching (CCT, 2014a, 2002; Ferketic et al., 2010; Rebelo et al., 2011). In addition, trampling activities reduce the physical dimension of the beaches and dunes and can destabilise the dynamic system (Barbier et al., 2011). The spread of invasive species is also considered a threat to coastal biodiversity (Pfaff et al., 2019). On-going urban development is another pressure that requires management if the benefits of coastal EI are to be maintained (O'Farrell et al., 2012). About 75% of Cape Town's coastline has been developed within 100 m of the high-water mark (TDA, 2017). Urban development in the dunes and beaches prevents sediment exchange and natural inland retreat of the coastal zone (Spalding et al., 2014). When coupled with sea-level rise, this causes coastal squeeze where beaches diminish over time as they are gradually inundated and lost (Defeo

et al., 2009). In addition, the valuable aquifer and also the local rivers, estuaries, beaches and waters are polluted and modified through urban development and associated urban and industrial runoff (Hay et al., 2016; CCT, 2014a; Quick and Pistorius, 1994; Sparks and Mullins, 2016; Van Niekerk and Turpie, 2012) and litter (Pfaff et al., 2019). Coastal hazards associated with climate change (Musekiwa et al., 2015) represent an additional threat within the study area. To prevent further degradation, sustainable practices should always be applied and single ecosystem services that have the potential to alleviate pressure through the overexplotation of the coastal EI features should be considered for further investment. Furthermore, effective management of pressures and threats has the potential to increase the benefits of coastal EI in this study area, e.g. clean-up activities can have a positive impact on the recreational service flow and can even create employment.

There is potential to increase the flow of several ecosystem services in this study area in a way that could also provide supplementary livelihoods and help reduce the immediate dependency of local communities on the natural resources within their reach. Cultural services like nature-based education, recreation and diversified coastal tourism could be offered sustainably at a much bigger scale (Environmental Evaluation Unit UCT, 2005; Manuel, 2006; O'Farrell et al., 2012; Walters, 2011). Nature reserves and protected areas could provide environmental and information centres, necessary infrastructure for recreational activities and consider ecotourism possibilities (Manuel, 2006) like scenic tours and bird and marine animal observations (CCT, 2014b). There is also potential for cultural services like eco-tourism, diving and educational activities at the local reef (Blamey and Bolton, 2018; Principe et al., 2012) in the Helderberg MPA. Furthermore, activities to control invasive species also serve to protect and enhance ecosystem service delivery and can provide much needed employment (Manuel, 2006; van Wilgen et al., 2016).

Another ecosystem service with potential to grow in a controlled way is the provisioning service of plants for food and medicine (see also Cluster 6 of this Compendium above). The harvest of local flora and fauna is essential to the local communities of Cape Town. Approximately 261 tonnes of wild biological material are collected by *amagqirah* and *amaxwhele* (Xhosa-linked traditional healers) and Rastafarian herbalists per year (Petersen et al., 2014). This supports the living of around 15 000 individuals and the city's informal trade in wild medicine is worth an estimated US $15.6 million per year (Petersen et al., 2014). To maintain and increase this ecosystem service, wild harvesting should be regulated, and nurseries established (Petersen et al., 2014). In doing so, the pressure on the local environment can be better controlled and sustainable agriculture activities can create jobs, opportunities for research, and may even offer a possibility to upscale the trade of indigenous products.

Because ecosystem services are generally provided for free by the EI features and contribute substantially to the economy and wellbeing of the City of Cape Town, it is of great importance to invest in their maintenance to avoid far greater costs of replacing them, and to create even bigger economic value (de Wit et al., 2012). Furthermore, through the investment in conservation activities, additional jobs could be created that can help to alleviate the problems of unemployment and poverty as has been shown in the Working for Water programme, for example (Holmes et al., 2012; Turpie et al., 2008).

Conclusion

It has been shown in both case studies that the local communities benefit highly from the ecosystem services delivered by coastal EI in their reach, even though the variety of ecosystem services they

receive is very different and depends on the local context for each community. To maintain these benefits, effort is needed to keep these coastal ecosystems healthy or restore degraded coastal EI. The two case studies thus echo two of the NBA 2018 Marine Priority Actions (Sink et al., 2019): (1) Strengthen MPA financing and governance to enhance equitable flow of benefits from South Africa's expanded MPA network; and (2) Effectively communicate the value of South Africa's marine biodiversity through improved co-ordinated messaging that articulates benefits, in order to build support for marine conservation and mobilise people to sustainably use marine biodiversity. They also echo almost all of the NBA 2018 Coast Priority Actions (Harris et al., 2019b), particularly to: protect, restore, and maintain coastal EI as part of a national coastal restoration plan to strengthen climate resilience and sustain ecosystem services and key benefits; and diversify and create more job opportunities for coastal communities from the benefits of biodiversity to supplement their livelihoods. There is a need to strengthen the non-consumptive benefits from biodiversity within these communities to reduce reliance on natural resources and diversify economic opportunities. Thus, a joint approach is recommended of: creating supplementary livelihoods and additional jobs by strengthening MPA financing and governance to alleviate some of the dependence on natural resources and rehabilitating and restoring degraded coastal EI; and communicating the benefits of and need for sustainable use of coastal resources. Consumptive use of biodiversity will always be necessary, but the more the communities can benefit from the non-consumptive uses, the better, for both nature and people.

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9. BIODIVERSITY ENABLES RESPONSES TO CLIMATE CHANGE AND NATURAL DISASTERS

This chapter is a direct summary from:

DEA and SANBI, 2017. Ecosystem Based Adaptation (EbA): Guidelines in South Africa. Department of Environmental Affairs, Pretoria.

Key messages

Well managed ecological infrastructure can buffer human settlements and built infrastructure against extreme events like floods and droughts, playing a crucial and cost effective role in disaster risk reduction.

What is EbA?

Ecosystem-based Adaptation (EbA) is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change (CBD definition). Strategies within EbA need to consider ways to manage ecosystems so that they can provide the services that reduce vulnerability and increase resilience of socio-ecological systems to both climatic and non-climatic risks, while at the same time providing multiple benefits to the society. It uses the range of opportunities for the management, conservation and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. All EbA activities thus by definition draw upon ecological infrastructure.

Well managed ecological infrastructure can buffer human settlements and built infrastructure against extreme events like floods and droughts, playing a crucial and cost effective role in disaster risk reduction. Ecosystem-based Disaster Risk Reduction (DRR) is the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development (IUCN definition).

Ecosystems and associated ecological infrastructure are most effective in mitigating the impacts of frequent low intensity and slow onset events. Natural and engineering solutions are important complementary strategies for coping with the kind of extreme events that are expected to be more frequent under future climate scenarios.

The Department of Environment, Forestry and Fisheries and the South African National Biodiversity Institute have recently developed South Africa's Ecosystem Based Adaptation Guidelines as a result of a collective contribution from many organisations and individuals. The guideline provides the main guiding principles and criteria for achieving EbA, safeguards that should be put in place to support EbA implementation, and provides information for prospective EbA stakeholders like project or programme managers, policy makers, funders and researchers.

EbA reduces vulnerability to both climate and non-climate risks and provides multiple economic, social,
environmental and cultural benefits, including:

- Promoting healthy ecosystems that play an important role in protecting infrastructure and enhancing human security, acting as natural barriers and mitigating the impact of extreme weather events.
- By protecting and restoring healthy ecosystems to be more resilient to climate change impacts, EbA strategies can help to ensure continued availability and access to essential natural resources so that communities can better cope with current climate variability and future climate change.
- Protecting, restoring, and managing key ecosystems helps biodiversity and people to adjust to changing climatic conditions.
- Complementing and enhancing climate change mitigation interventions.
- Managing, restoring and protecting ecosystems can also contribute to sustainable water management.

Reference

DEA and SANBI, 2017. Ecosystem Based Adaptation (EbA): Guidelines in South Africa. Department of Environmental Affairs, Pretoria.

10. BIODIVERSITY ENRICHES EVERY-DAY LIFE: SPIRITUAL AND CULTURAL USES OF BIODIVERSITY

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Note: the authors state that this is by no means a comprehensive list of all spiritual and cultural uses of biodiversity in South Africa. There are several literature sources for the detailed work ongoing in this regard. This summary is meant to provide a few examples from different cultures in South Africa.

Key messages

There is increasing evidence that interacting with nature brings measurable emotional and mental benefits to people as well as physical benefits, and that a decline in this interaction can cause deficits (Soga & Gaston, 2016). Natural spaces and indigenous species have huge value and significance to South Africans no matter whether we live in an urban or rural environment. Biodiversity plays a key role in our overall perception of life, as well as a role in our enjoyment of life. Our natural ecosystems, plants and animals have influenced our cultural and spiritual development, and are woven into the languages, place names, religion and folklore supporting spiritual and cultural life. This web of associations with biodiversity forms an important part of South Africans' national identity, and ensuring the conservation of ecosystems and species is vital for the sustainability of this identity.

Introduction

Nature and biodiversity play a key role in our overall perception of life and, in some societies, people believe in a vital spiritual connection with an animal, plant or place. Our natural ecosystems, plants and animals have influenced our cultural and spiritual development. These influences are woven into languages and place names, as well as the religion and folklore supporting spiritual and cultural life. This web of associations with biodiversity forms an important part of South Africans' national identity (Dold and Cocks, 2012). In this summary, we explore some key examples of the use of species or places for spiritual or cultural purposes. It is by no means an all-inclusive list, and the examples chosen are just a few from different regions in South Africa meant to illustrate the variety of uses of species and places in different South African cultures.

Examples of South African species important for spiritual or cultural practices

Plant examples

Several indigenous plants are important in the Xhosa culture, including: *Cymbopogon validus* grass is used to make brooms, which are hung above a house door as a talisman against lightning; *Tulbaghia violaceace* (locally known as itswele lomlambo, isivumbampunzi, wild garlic) is used via an infusion that is sprinkled around the home as a protection from the evil spirits; and branches of the sacred wild olive tree (*umnquma*) are used as a platter for consecrated meat (*intsonyama*) of ritually sacrificed animals. In Zululand, young leaves of ilala (*Hyphaene coriacea*) are used to make a variety

of items for local use and sale to international tourists such as brooms, baskets, washing baskets, hats, jewellery containers and toys. In the traditional Zulu wedding, the bride's gifts to the groom's family members (umabo) usually consist of sleeping mats (amacanci) and traditional beer strainers (amahluzo) made from incema (*Juncus kraussii*). A twig of umlahlankosi or umphafa (*Ziziphus mucronata* subsp. *mucronata*) is widely used in the Zulu culture to fetch the spirit of a dead person from the spot where they died and carry it to their home. Leaves and stems of *Helichrysum odoratissimum* and *H. stenopterum* (both species are called impepho) are burned as an incense by both sangomas and ordinary people to communicate with ancestors.

Cymbopogon validus as a talisman

Xhosa women use the *Cymbopogon validus* grass to make brooms. It is widespread and common throughout the eastern regions of South Africa. The Xhosa name for this species is 'irwashu'. Handles of the brooms are made of 'gumtree' *Eucalyptus* saplings.

The main cultural uses of grass brooms are as a traditional wedding gift, as a protective talisman against lightning (Cocks and Dold, 2004). The broom is a representative of traditional Xhosa culture and signifies respect to the ancestral faith in the newlyweds' home. The presence of the small broom in the home serves to protect the inhabitants from lightning, most often attributed to sorcery. A broom purchased or gifted for this purpose is not used for cleaning, but is hung above the door as a talisman.

Talinum caffrum for protection against bad luck

Talinum caffrum (porcupine root) is an erect or sub-erect perennial herb, up to 40 cm tall, growing from a swollen tuber-like root. Xhosa people in the Eastern Cape use an infusion of the tuber of *Talinum caffrum* as a ritual wash, steam treatment and emetic (causes vomiting) for protection against evil spirits and bad luck. The dried tuber is burnt as incense in preparation for a court case to ensure positive results. It is also used in the preparation of a lucky charm called *isiphondo* (Dold and Cocks, 2012).

Tulbaghia violaceace as protection against evil spirits

Tulbaghia violaceace, locally known as itswele lomlambo, isivumbampunzi, and wild garlic, is a species of flowering plant in the onion family Alliaceae, indigenous to southern Africa (KwaZulu-Natal and Eastern Cape Province). Xhosa people in the Eastern Cape use the infusion of the whole plant and sprinkle it around the home, particularly outside the doors and windows and at the entrance to the byre as a protection from the evil spirits (Dold and Cocks, 2012).

Perceptions of thicket vegetation

Ihlathi lesiXhosa, locally known as thicket vegetation, is considered to be a sacred place where the ancestors communicate with their living descendants by means of messengers *(izithunywa)* in the form of birds, mammals, insects or even the wind (Cocks and Told, 2012). Certain animals that are forest inhabitants like birds and snakes are believed to be representatives of the ancestors.

Several religious rituals, facilitated by diviners *(amagqirha),* take place in the *ihlathi lesiXhosa.* The diviner is reportedly shown the site in a dream beforehand and it is in the *ihlathi lesiXhosa* that gifts of traditional beer, cooked maize and tobacco are presented to the ancestors. Plant and animal materials necessary for traditional medicine, customs and rituals to appease the ancestors are believed to be available only in *ihlathi lesiXhosa* (Dold and Cocks, 2012). These plants and animals are considered sacred and they are imbued with the spiritual power of the ancestors.

Modjadji cycad cultural and spiritual values and conservation in South Africa

The Modjadji cycad is one of the largest cycads in South Africa. *Encephalartos transvenosus* is being protected in Modjadji's Nature Reserve which is found to the north of Tzaneen. People of Balobedu said *Encephalartos transvenosus* is "Modjadji's palm" and they named it after the Rain Queen. The Rain Queen or Modjadji is the queen of Balobedu. Queen Modjadji is a real person and she is known by her power of making rain. Sometimes the Encephalartos plants are commonly called bread palms because the stem is used to make crude bread. The people of Bolebedu use these plants as sacred and they also use it to receive the royal protection from their Rain Queen that is why they respect these plants. (Netshiheni, 2007).

Modjadji cycad (*Encephalartors transvenosus*) © John Donaldson

Animal examples

South African animals also have spiritual and cultural significance. An interesting example is that of the Southern Ground-Hornbill (*Bucorvus leadbeateri*), which is viewed in some cultures as a signifier of death/destruction/loss/deprivation, while in other cultures it is perceived as a protective influence against evil spirits, lightning and drought. In the Zulu culture it is widely believed that if amankankane (hadedas, *Bostrychia hagedash*) fly over a homestead while making their usual loud call, a death will occur in that homestead. Snakes are particularly revered – for example *Lamprophis fuiginosus* (African house snake) is considered as representative of ancestors by the amaMpondomise (a Xhosa tribe).

Cultural beliefs and practices related to birds

Birds play a significant role in the lives of people across virtually all cultures in South Africa. In most cultures, significant beliefs have developed in relation to birds, usually as a result of direct and regular contact with specific bird species, especially in cases where such birds possess prominent visual, auditory or behavioural characteristics.

The Southern Ground-Hornbill (SGH) (*Bucorvus leadbeateri*) is the epitome of a species that has been in regular contact with many different cultures over a prolonged period of time, and that has all the characteristics that could result in the development of a large number of cultural beliefs and practices (Coetzee *et al.,* 2014). *Bucorvus leadbeateri is* a Vulnerable bird species of the eastern part of southern Africa, as it has declined significantly outside protected areas in South Africa and Zimbabwe. Major factors contributing to this include competition for space with increasing human population, loss of large hollow tree trunks used for nesting, eating of poisoned baits and snaring (Chiweshe, 2007). In the Limpopo Province, the Venda people often perceive Southern Ground Hornbill as a bringer or signifier of death/destruction/loss/deprivation (Theron *et, al*. 2013). More specifically, it is believed that seeing or encountering this bird in the wild, or having it enter or approach a village or homestead signifies impending disaster, which most often was believed to involve the death of someone known to the individual, or the damage and destruction of personal property. These beliefs are particularly prevalent in South Africa.

In many other African cultures, lightning and drought are often perceived to be a manifestation of witchcraft or punishment from their ancestors. For these cultures, the Southern Ground Hornbill is perceived as a protective influence, against evil spirits, lightning and drought. In the case of evil spirits, this 'protection' does not refer to physical protection, but rather to the creation of a strong personality that would be able to withstand the attacks of such evil spirits. To harness the protective powers believed to be contained in the Southern Ground Hornbill, parts are typically removed from a bird that was either specifically killed for this purpose or found dead in the surrounding areas. The practices to protect oneself or one's property (e.g. homestead, crops and other belongings) against lightning involve mixing various parts of the Southern Ground Hornbill (e.g. feathers and feet) with plant parts and animal fat, and smearing this mixture on various parts of the homestead (Coetzee, 2014).

Crested guineafowl (*Guttera pucherani)*

The Zulu name for a guineafowl is *impangele*, which means "the one who is in a hurry". The word *impangele* comes from the verb *phangela*, which means to wake up in the morning and go to work. The Zulu people in KwaZulu-Natal perceive the guineafowl as a bird that is symbolizes human effort at survival. This is a very sacred bird among all people throughout Africa. It is a bird of protection. People believe that the guineafowl is gifted with protective powers by the gods, that the guineafowl will protect your village's chickens against chicken disease (Mutwa, transcribed text).

Cultural beliefs and practices related to snakes

Southern African pythons are important snakes in most African cultures, used by most traditional healers as a way to communicate with ancestors or as a way of getting strength to heal people (SANBI, 2018). Tsonga people believe that ancestors live in underground villages, and that they can appear in the human community in the form of snakes. In the Venda culture the appearance of a python near the homestead signifies a serious misfortune, and the snake is not supposed to be killed but instead you are required to consult a traditional healer (Nengovhela, 2010). In the Xhosa culture the totem of *amaJola* clan is the brown mole snake locally known as *uMajola.* The mole snake is not venomous, it customarily visits the home when there's a new born child in the clan and when there is a new bride as a welcoming rite (Birama, 2005).

Certain traditional beliefs attached to reptiles tend to make a positive contribution to their conservation because revered species may be assured of conservation support from indigenous communities. Such species include chameleons, which are revered by Zulu-speaking people as representative of ancestors and *Lamprophis fuiginosus* (African house snake), which is revered by amaMpondomise (a Xhosa tribe) as a representative of ancestors. These species are expected to be respected and not harmed as it is feared that such action would anger the ancestors. (Simelane and Kerleyl, 2015)

Cultural beliefs about bees

Insects, especially bees, are very significant to the Xhosa and their culture. When there is a swarm of bees in the house, they believe it is the ancestors. In order to appease the ancestors and get rid of the bees, one has to make *umqombothi* (a beer made from maize, maize malt, sorghum malt, yeast and water) and sometimes slaughter an animal (sheep or goat) and communicate with the bee swarm (SANBI, 2014)

Examples of spiritually and culturally significant sites in South Africa

Special places in South Africa also have spiritual and cultural significance, including the Motouleng caves (meaning 'place of beating drums') located in the mountains of the eastern Free State and Lesotho, which have served as a spiritual gathering place of prayer for over 800 years. Thathe Vondo, Limpopo Province's most beautiful and majestic forest, is regarded as sacred by the local Venda people. Hogsback in the Eastern Cape is regarded as a place of spiritual upliftment, and Xhosa legend holds that the Hole in the Wall landmark at the mouth of the Mpako River is the gateway to the world of their ancestors. Even in urban areas, there are natural spaces popular for rituals and prayer (e.g. Lion's Head in Cape Town, Melville Koppies in Johannesburg).

Cultural and religious uses of water

There are a range of practices (for example baptism) that are performed by cultural and religious communities that involve the use of water from sources such as rivers, streams, dams and springs. Almost all Christian and African traditional churches in South Africa perform baptism ceremonies that involve the use of water. Freshwater sources such as rivers, streams, lakes and dams are preferred sites for baptism, but they also take place in the sea.

Lake Fundudzi

Lake Fundudzi is found in the northern part of South Africa in the Limpopo Province. (DWAF, 2013). Lake Fundudzi is South Africa's largest inland lake and situated along the Mutale River. Several beliefs are upheld about Lake Fundudzi. One of them is that it is inhibited by the god of fertility in the form of a python. It is also symbolic of the Vha-Venda ancestors and treated like a holy shrine. Deceased members of the tribe are first buried in the grave by the kraal, then after a number of years, their bones are exhumed, cremated and thrown into the lake. The lake therefore has become the final resting place for the ancestors.

The sacred Lake Fundudzi captured from a distance
© Emanuel Berger

A white crocodile is also believed to live in the lake. When Venda kings die their remains are placed in the lake and the white crocodile would cough up a stone, which the new king had to swallow. The ghosts of the ancestors of the Venda people are believed to reside beneath the surface of Lake Fundudzi and are guarded by this white crocodile (Anyumba & Nkuna, 2017).

Adjacent to Lake Fundudzi is the sacred forest of Thathe Vondo, where Venda kings were buried for untold generations. According to Anyumba and Nkuna (2017), Venda people were buried at home. However, after ten to fifteen years, their remains would be uncovered by family members and brought to the Sacred Forest. The family members would spend the night in the forest, using snuff to help them communicate with the ancestors, and leave the remains deep in the forest so that their loved one could join other ancestors there.

Motouleng Sacred Caves

The South Sotho communities perform ceremonies on sites such as religious sites including burial grounds, holy springs or wells and caves believing that the dead with their supernatural powers are believed to reside in and around these places, believing that God and the ancestral spirits dwell there.

The Motouleng Caves, meaning 'place of beating drums', are located in the mountains of the eastern Free State and Lesotho, between Clarens and Fouriesberg. The large cave was created in a limestone mountain by a rock fall, a small river and pools lie below the cave (Mensele, 2011). There is a fountain at the entrance of Motouleng called 'Sediba sa Bophelo', meaning 'The Fountain of Life' where people drop coins for good fortune. The cave is a 2 km hike from the nearest farm, which is located 15 km outside of Clarens. Locals go as they please but visitors are required to attend guided tours to ensure respect for the ancestors. Women are required to wear long skirts and cover themselves up out of respect

People who perform rituals in these caves include herbalists, diviners and traditional healers who all aim to treat disease and reduce misfortune. They also perform rituals to protect families, homesteads, cattle, and property (Mbithi, 1969). The rituals performed in this sacred location are regarded as important for the holistic wellbeing of an individual (Rites of Passage, 2010). The caves also function to mark the rite of passage for specific occasions including births, puberty, marriage, baptisms, and even funerals. The caves are also used to recognize harvesting times and commemorate unifying events as well as catastrophic events such as war and famine. These rituals are important as they help define the social makeup of the Basotho communities as they turn 'boys to men' and 'girls to women (Mensele, 2011) The areas are open for all people to see, however, some rituals are done in isolation and privacy as the Basotho community believes they require respect. Some of these rituals are profound, therefore people who do not understand the rituals or who are unable to show respect are not permitted to view as their actions or behaviours could anger the ancestors.

Isinuka, a Sulphur spring with supernatural healing powers Wild Coast, Eastern Cape

The Isinuka Sulphur Spring is located about 20 km west fo Port St Johns in the Wild Coast, on the way to Lusikisiki. The Wild Coast is located in the Eastern Cape Province of South Africa and is a popular site with dramatic coastlines, jagged cliffs, wild beaches, rolling hills and valleys. “Isinuka-which means ‘with a smell’ due to the sulphurous odour is treasured by both locals and city folk for its magical healing powers” (Majangaza, 2014). Isinuka drains into the Umzimvubu River, an important water body discharging into the Indian Ocean at Port St Johns. The well emits a powerful gas and because of this, the area is called “VICKS”. Visitors to Isinuka believe that by inhaling the gas their headaches and other body problems can be cured. (Faniran et al., 2001) “The locals take turns inhaling the gases as part of their regular treatment. The inhaling of gas is the most intriguing part of the treatment and it appears to be unique to Isinuka spring” (Jumbam, 2012). The main healing activities identified were: bathing in the spring water; fetching and drinking the saline healing water; fetching and smearing of faces and/or whole bodies with white or black clay; and inhaling gases oozing out of rock cracks (Jumbam, 2012). The local Mpondo people believe that it a sacred site and that the spring water has magical healing powers.

Hole in the wall in Coffee Bay Eastern Cape

The Hole-in-the-Wall © Peter Chadwick

Hole-in-the-Wall is one of the most imposing landmarks along the entire South African coastline. Standing at the mouth of the Mpako River, the cliff consists of dark-blue shales, mudstones and sandstones of the Ecca Group, dating back some 260 million years (Wild Coast, 2018). The local Bomvana people named the formation 'EsiKhaleni', or the Place of the Sound. Local legend has it that the river running through the Hole-in-the-Wall (Mpako River) once formed a landlocked lagoon as its access to the sea was blocked by a cliff. A beautiful girl lived in a village near the lagoon cut off from the sea by the mighty cliff. One day she was seen by one of the sea people, semi deities who look like humans but have supple wrists and ankles and flipper-like hands and feet who became overwhelmed by her beauty and tried to woo her. When the girl's father found out he forbade her to see her lover. So at high tide one night, the sea people came to the cliff and, with the help of a huge fish, rammed a hole through the centre of the cliff. As they swam into the lagoon they shouted and sang, causing the villagers to hide in fear. In the commotion the girl and her lover were reunited and disappeared into the sea. At certain times of the year, it is said, the music and singing of the sea people can be heard. Xhosa legend holds that this is the gateway to the world of their ancestors (Wild Coast, 2018).

Language and biodiversity in South Africa

In **language**, biodiversity plays an important role and is used in place names and sayings. In the Zululand region there is uMkhanyakude District Municipality, and the name comes from umkhanyakude trees (Fever tree; *Vachellia xanthophloea*) that are common in that area. There are a number of isiZulu sayings or proverbs that are derived from animals, e.g. 'ingwe idla ngamabala' (meaning 'a leopard gets what is due to it because of its spots' – i.e. each person lives off his/her talents); 'zimbiwe insele' (when something is plentiful and free, e.g. honey combs have been dug up by a honey badger and anyone can help themselves); and 'uzulelwa amanqe' ('vultures are circling over you' – warning someone of impending danger). Both Xhosa and Zulu cultures use the proverb 'indlovu ayisindwa umboko wayo' ('an elephant does not find its trunk too heavy' – relating to one's struggles in life). The isiXhosa names for months come from names of plants or flowers that grow or seasonal changes that happen at that time of year. They are:

- January – EyoMqungu (month of Tambuki Grass)
- February – EyoMdumba (month of swelling grain)
- March – EyoKwindla (month of first fruits)
- April – UTshazimpuzi (month of withering pumpkins)
- May – UCanzibe (month of Canopus)
- June – Isilimela (month of Pleiades)
- July – EyeKhala / EyeNtlaba (month of aloes)
- August – EyeThupha (month of buds)
- September – EyoMsintsi (month of coast coral tree)
- October – EyeDwarha (month of lilypad)
- November – EyeNkanga (month of small yellow daisies)
- December – EyoMnga (month of mimosa thorn tree and simba)

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11. BIODIVERSITY PROVIDES OPPORTUNITIES FOR CITIZEN SCIENCE

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Key messages

The NBA 2018 notes that investment in existing and future biodiversity monitoring programmes is essential to strengthen scientists' ability to detect and report on trends, plan accordingly and manage effectively. This is supported by Strategic Objective 6 of the National Biodiversity Strategy and Action Plan and the National Biodiversity Framework, which is: ***effective knowledge foundations, including indigenous knowledge and citizen science, support the management, conservation and sustainable use of biodiversity***. As there has been a decline in the resources allocated to some monitoring programmes, some of South Africa's key monitoring datasets are very old and are not being updated. Data collected from the regular monitoring of species, ecosystems, pressures, utilisation of natural resources (e.g. water abstraction, harvested species) and other aspects of ecological condition are crucial for use in species and ecosystem Red List assessments. Such monitoring also gives important feedback to researchers on where to expand monitoring

efforts. This monitoring is a huge task and can be assisted by citizen science platforms that allow people across the country to contribute to the effort. South Africa is recognised for its many citizen science programmes.

South African biodiversity and the role citizen science plays in conservation

South Africa is recognised as one of the megadiverse countries of the world. It is the only country that has three biodiversity hotspots within its boundaries (Myers et al, 2000). The key features of our biodiversity are the rich species diversity, wide range of ecosystems and the high level of endemism. These key features make South Africa one of the most unique and interesting countries in the world. This rich biological heritage is one of the key drivers of a thriving Citizen Scientist community in South Africa. Coupled with this, we are experiencing pressures on our biodiversity and these pressures have inspired South Africans to become involved in projects where they can learn more about their biodiversity and contribute to conserving and protecting it for current and future generations.

Our citizen science engagements have been further strengthened by key Non-Governmental Organisations (NGOs) that support the work of government to ensure the conservation of our biodiversity. Key partners in facilitating citizen science engagement in South Africa to mention a few, are NGO's like the Botanical Society of South Africa (BotSoc), the Wildlife and Environment Society of South Africa (WESSA), the Endangered Wildlife Trust (EWT), the World Wide Fund for Nature South Africa (WWF South Africa) and Birdlife South Africa.

But what is citizen science and who can become a citizen scientist? Citizen science is firstly a research technique that makes use of the public (e.g. citizens) to collect scientific information. This information can range from recording the first species to flower in spring to collecting water samples in a river to assess the water quality. More specifically a biodiversity **citizen scientist** is another way that people feel connected to South Africa's biodiversity and be enriched in their everyday lives. Citizen science can be conducted by crowd-sourcing and can also be a form of volunteering.

Citizen science has benefited enormously from recent technological advances, specifically the internet, digital cameras, geographical positioning systems (GPS), cell phones and artificial intelligence. Together these allow instantaneous capture and transmission of data for recording, sharing, identifing and discussing. There is a proliferation of applications (apps) and sites catering for these novel needs and opportunities, and the field will probably experience significant advancements in the next decade, as technology is ever changing.

The work of citizen scientists transcends geographic, taxonomic and ecosystem boundaries. There are more than 50 active projects in South Africa and several thousand citizen scientists contribute data to these projects. These datasets are used to gain a better understanding of biodiversity, including monitoring population trends, influencing conservation priorities and land-use decision making. Apart from learning about biodiversity one of the key motivations for citizen scientists to contribute their time and resources is the fact that they can actively be involved in conserving species and ecosystems. Being involved in citizen science projects also gives people an opportunity to engage with key researchers and scientists and this creates exceptionally useful interactions. These interactions bring benefits to research as well as developing the capacity of citizen scientists. Citizen scientists can become very proficient in their areas of interest. Some even become experts as

they participate in these projects and can provide valuable information as they are on the ground and know what is happening in real time. This also creates a sense of belonging and encourages people to take ownership of their natural heritage as South Africans.

The South African National Biodiversity Institute (SANBI) and various other institutions in the environmental sector have long recognised the value of citizen science and several projects and platforms have emerged to help channel the South African public's interest and passion for biodiversity conservation into providing vital assistance to biodiversity science. For example, species monitoring records collected by the public (in the field in their own time) and uploaded to platforms such as iNaturalist, Protea Atlas Project and the various virtual museums run by the Animal Demography Unit (ADU) are used by scientists to support various biodiversity monitoring projects as the data feeds into national databases of species distribution records. The DigiVol (including SAFARIS and Transcribe) system enables citizen scientists to contribute from the comfort of their own homes and digitise information from the many historical museum - and herbarium specimens, images (e.g. camera traps) and field notes archived in collections around the country. This digitising provides vital historical information about species distributions and field trips undertaken up to 300 years ago. Projects like the Southern African Bird Atlas Project (SABAP1 and 2), Southern African Butterfly Conservation Assessment (SABCA) and the Southern African Reptile Conservation Assessment (SARCA) documented species distributions and contributed to species conservation assessments.

Here we present a sample of the various citizen science projects running in South Africa and how these projects are contributing to mutual beneficiation of our national biodiversity heritage, by science and the people of South Africa.

Species and taxonomic group focussed projects in the terrestrial realm

Custodians of Rare and Endangered Wildflowers

The Custodians of Rare and Endangered Wildflowers (CREW) programme involves citizen scientists directly in field surveys and monitoring key sites for threatened plant species in priority parts of the South African landscape. CREW is jointly implemented by the Botanical Society of South Africa (BotSoc) and SANBI, and works with a range of conservation stakeholders throughout South Africa.

CREW was started in 2003 in the Fynbos region as a pilot project to engage citizen scientists in monitoring threatened plants. Due to the success of the programme it was expanded nationally and the programme now operates in seven of the nine provinces (Figure 22).

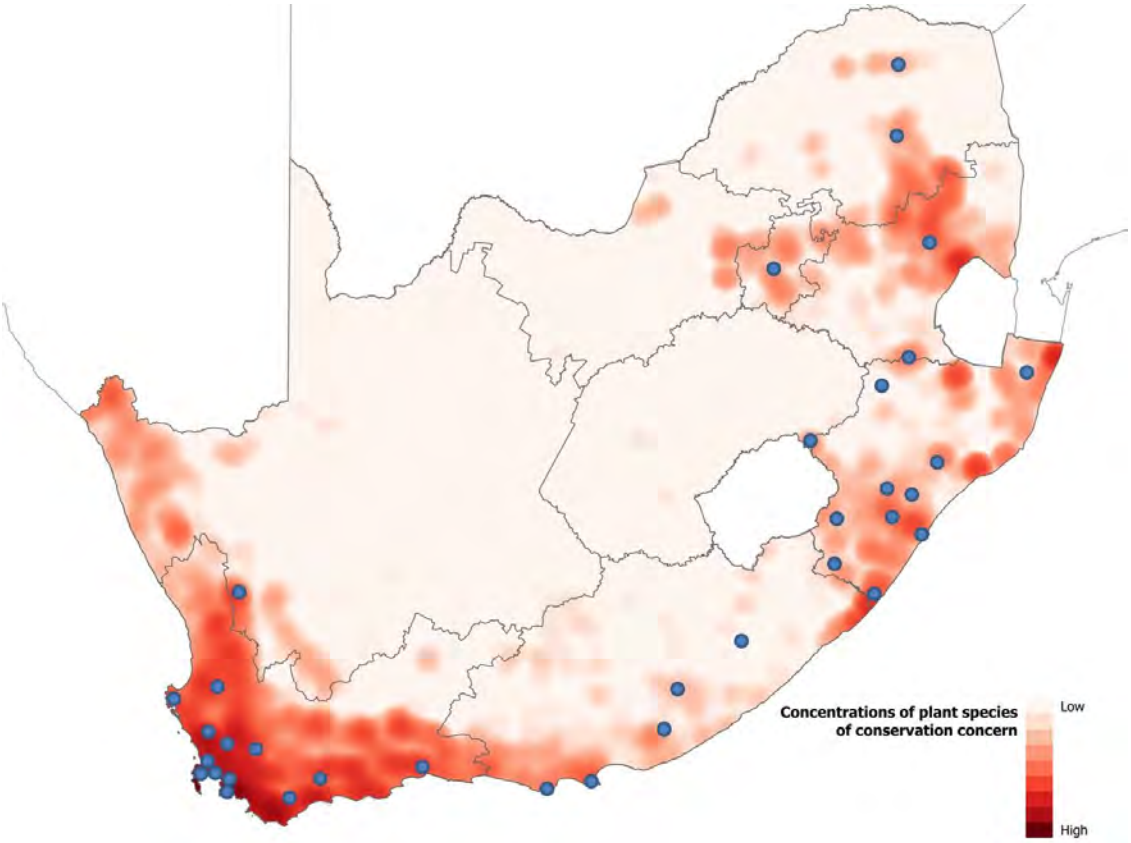


Figure 22. Distribution of CREW groups in relation to concentrations of threatened plants in South Africa.

South Africa has more than 22 000 plant species of which 60% are endemic and more than 2 800 threatened with extinction. It is thus imperative to strengthen the community of people working on conserving these species. The magnitude of the task of monitoring all of these species is far too great for just the professional botanists and scientists to deal with, so engaging and building a strong network of citizen scientists to support this process is essential to updating the conservation status of our plant species.

In addition, the value of this model is to build capacity in local people to conserve plants and connect with local conservation authorities to ensure the protection of key priority sites for conservation. CREW works with 35 volunteer groups across the country and more than 800 volunteers have been involved in the programme to date. Each group consists of a champion who co-ordinates local activities in their immediate area, supported by other volunteers. In addition, the project is fortunate in having a large network of amateur botanists who are passionate about the flora and contribute to CREW on an individual basis.

Besides the general enrichment and fulfilment of taking part in this project, citizen scientists are provided with educational benefits, such as skills for accurate data collection, critical thinking and scientifically informed decision-making. This increases scientific capacity, better informs decisions and improves social capital in South Africa, particularity pertaining to conserving our exquisite flora. This has allowed the network of citizen scientists to be active beyond just monitoring threatened species and they contribute to other activities such as collecting seeds of threatened species for the Millennium Seed Bank Partnership, recording presence of invasive alien plants and assisting in local municipal monitoring projects.

The CREW programme has been in operation for 15 years and our volunteers have made significant contributions to monitoring and conserving threatened and rare plant species. Over 1 500 sites across South Africa (Figure 23) have been surveyed, at which 8 973 species have been monitored including 2 120 taxa of conservation concern (Figure 24). This focussed collection of data is one of the key features and benefits of the CREW programme. Volunteers have contributed more than 178 000 hours by conducting field trips, collecting specimens, processing data and uploading pictures to online platforms such as iNaturalist.

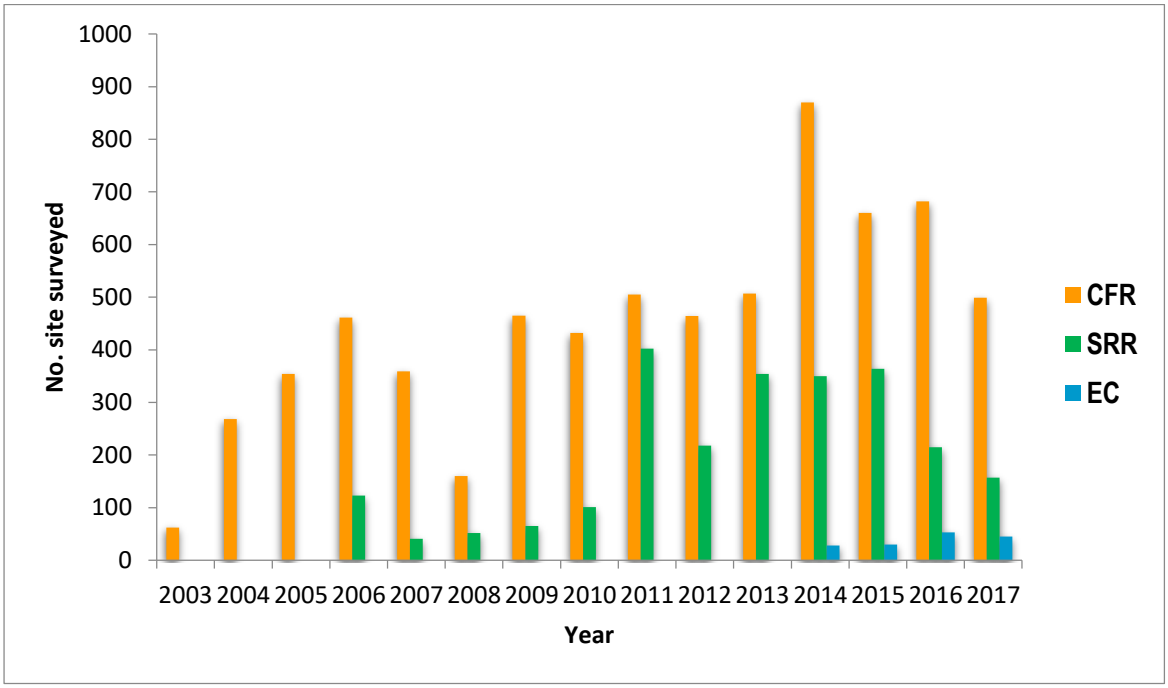


Figure 23. CREW sites visited per year per CREW node including the Cape Floristic Region (CFR), Summer Rainfall Region (SRR) and the Eastern Cape (EC).

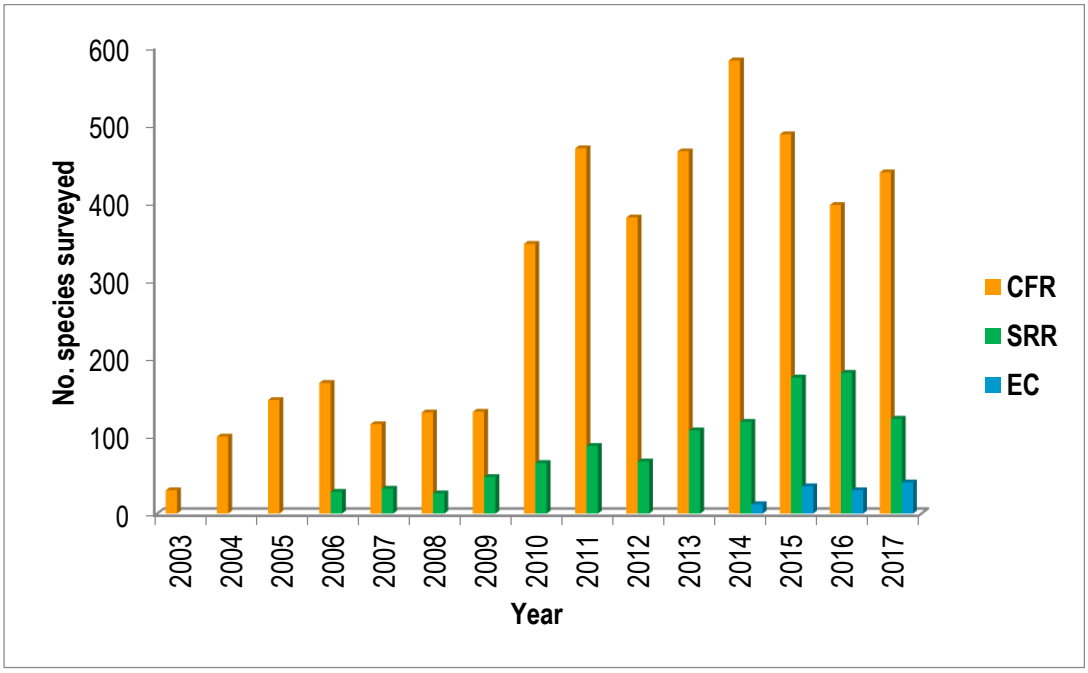
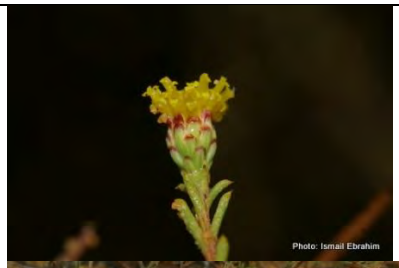


Figure 24. Number of taxa of conservation concern records per year per CREW node.

Discovering undescribed species

The CREW volunteers have been very successful in finding species new to science. As CREW volunteers gain experience and improve their plant identification skills, they are able to recognise unusual species or specimens, and notice plants and populations that they have not seen before in their areas. The volunteers use taxonomic keys and identification guides to recognise distinguishing plant features and can alert taxonomic experts to species that may not be known to science. CREW volunteers are in the field for most of the year so they are also able to see the full range of species through the different seasons and can notice interesting species that flower at odd times of the year. Since most botanists are active during the peak flowering season, they may miss species flowering in odd times. Thus, many new species found by CREW volunteers have been found outside of the peak flowering season. CREW volunteers also focus on finding all threatened plants, so they don't specialise in a specific plant group. Because they are searching for target threatened species, they need to focus on obscure or uncharismatic plant groups to collect monitoring data and in turn collect valuable taxonomic information for these plant groups. CREW groups collect priority plant material that are required for taxonomic studies by professional taxonomists. This focussed plant collecting has resulted in the discovery and mapping of many undescribed species with more than 35 new plant species being described to date with others still being formally described (Table 11).

Table 11. A few examples of new discoveries by CREW volunteers across the country

Psoralea vanberkelae - Berkels Fountainbush This species was discovered by Outramps CREW volunteer Nicky Van Berkel in the Robberg Conservation Corridor near Plettenberg Bay. The Outramps groups have been surveying the Southern Cape and documenting plant species for over 30 years, since the start of the Protea Atlas Project. This group has built up their plant expertise and have been a key stakeholder in numerous conservation projects in the Southern Cape and Little Karoo. This discovery was a great example of a partnership between taxonomists and citizen scientists. After being visited by Professor Charles Stirton (renowned Fabaceae (Pea family) specialist) and his student Abubakr Bello, who was doing phylogenetic studies on the genus *Psoralea*, the group was asked to assist with collecting specimens. This lead to the discovery of two new *Psoralea* species.	© Nicky van Berkel  
Marasmodes crewiana - Crews Autumn Aster *Marasmodes* is a genus in the Asteraceae family. When this genus was assessed by the Red list team in 2006 it was discovered that there was a dearth of information and all the species seemed highly threatened. In 2007, CREW launched the *Marasmodes* Day Botanical public holiday which coincides with National Freedom Day, 27 April. This annual event is dedicated to searching for new populations of *Marasmodes* species and monitoring existing populations. This initiative has yielded more than 30 new locality records and two undescribed species. In addition, the data collected by volunteers have been used to refine the distribution and resolve taxonomic issues within the genus. This mass effort led to the updating of these species Red List assessments and the recognition of the genus as the most threatened among plants in the country. ***Marasmodes crewiana* was named in honour of the CREW programme and its contribution to *Marasmodes* taxonomy**.	  © Ismail Ebrahim

Rediscovering species thought to be lost forever

CREW are focussed on finding populations of threatened plant species. When South Africa completed the first comprehensive Red List in 2009, a number of species where identified as Critically Endangered Possibly Extinct based on the IUCN Red List criteria because their population status could not be verified and no recent records have been found. These species formed the basis of the target species for the CREW volunteers and they assisted with searching for these populations. CREW citizen scientists were provided with historical distribution information and descriptions of the species and tasked to search for these species. CREW has rediscovered more than 30 species that were listed as Critically Endangered Possibly Extinct and two species that were listed as Extinct. This has been one of the most significant contributions that CREW volunteers have made to the programme as it allows us to accurately assess the conservation status of these species (Table 12).

Table 12. Rediscovery of species by CREW volunteers

Polhillia ignota *Polhillia ignota* was known from two historical records, last recorded in 1928. After conducting four targeted trips to try and find this species in one of the historical areas it occurred, it was unsuccessful. In 2016 on *Marasmodes* Day in the Eendekuil area a small population of *Polhillia ignota* was rediscovered. This was the first record of the species in 88 years. Since its rediscovery, we have found two more new populations of the species.	 © SANBI
Cuscuta gerrardii Historical records of this parasitic plant are extremely scarce and old. The last known collection was made by Rudatis in 1910 at a site that is completely transformed. Although not a targeted species, on an outing with visiting botanists in 2016, *Cuscuta gerrardii* was re-discovered in the Umtamvuna Nature Reserve in KwaZulu-Natal. Little is known about this species and it is being monitored for information on host plants.	 © Graham Grieve
Riocreuxia flanagannii var alexandrina This climbing plant was found by chance on a CREW outing to the Vernon Crookes Nature Reserve in 2015. It was first collected by Rudatis in 1911 and there were no records of subsequent collections prior to this re-discovery. Subsequently, several *Riocreuxia flanaganii* var *alexandrina* have been found at another locality in the area. Although initially only one plant was seen at Vernon Crookes, on a recent visit another very healthy plant was found, suggesting that there may be more in the reserve.	 © Suvarna Parbhoo

CREW engaging students

The majority of the citizen scientists involved in CREW are over the age of 65 and retired. To ensure continuity in the programme and to engage younger people; CREW works closely with key universities in South Africa. In addition, since plant conservation is a relatively scarce skill, the CREW

Programme has therefore introduced the CREW Human Capital Development project. The project is designed for 2nd or 3rd year Botany, Environmental Science, Horticulture and Nature Conservation students at higher education institutions across the country. CREW staff conduct a one-hour lecture covering topics of South Africa's biodiversity, the South African Plant Conservation Strategy, Red Listing, the CREW Programme, iSpot/iNaturalist and job opportunities within the plant conservation field. Further, some universities request a fieldtrip either to monitor a threatened species or to teach students some plant family characteristics.

The CREW summer-rainfall node works with the University of KwaZulu-Natal (Pietermaritzburg campus) and the Durban University of Technology. Over the years the node has extended the project to University of Zululand and Mangosuthu University of Technology. In 2016, CREW engaged with students from the University of the Witwatersrand, University of Pretoria and Tshwane University of Technology while the University of the Free State showed keen interest to host the CREW lecture in 2018. This engagement is increasing the number of students attending the CREW Gauteng and Midlands fieldtrips, in particular.

The CFR node continue to work with the University of the Western Cape (UWC), Cape Peninsula University of Technology (CPUT) and Stellenbosch University. In addition to conducting a lecture and fieldtrip, the CREW CFR node conducted a weekend skills development programme for UWC Honours students in 2017. This is aimed at sharing practical skills with students and showcasing available biodiversity tools. The Eastern Cape node has assisted Rhodes University Botany Department's bi-weekly practical sessions as well as helping the academic staff with a plant specimen collecting fieldtrip.

CREW contributes by raising plant awareness as well as creating a sense of ownership to the general public

Biodiversity underpins all ecosystem goods and services important for human wellbeing. This is especially the case for the rural livelihoods in the Eastern Cape. Some communities associate plants with grazing and medicine. In recent history plants were used to mark months of the year among the Xhosa community. The Eastern Cape Province is rich in indigenous knowledge as well as natural resources, making the province an ideal place to combine indigenous knowledge and richness in natural resources towards the conservation of plants. The CREW citizen science model applied in the EC focuses on reducing the pressures on natural resources, while encouraging users to be stewards of their natural heritage, by educating the community about the numerous threatened plants species occurring in their areas and identifying the pressures to these species.

The CREW Eastern Cape Node started in 2014 through the Groen Sebenza project. This opportunity created the platform for CREW to access deep rural parts of the Eastern Cape that would not have been possible without the Groen Sebenza model. Using this approach CREW monitored locally distributed species of conservation concern, highlighting the importance of areas surrounding villages, thus creating a sense of pride among the community members. Two villages were the focus during the Groen Sebenza project. These communities are subsistence resource harvesters and also make use of their lands for grazing and crop production. While these activities can be viewed as posing a huge threat to biodiversity, dependency on these resources also means that the community cannot afford to deplete them. Continuous engagements as well as shared learning is being undertaken to ensure habitat protection of threatened species in this area and to ensure sustainable relationships with these important communities.

CREW Eastern Cape recently formed a group in the Alpine Grassland region of the Eastern Cape; another part of the province, renowned for species-rich flora and a high level of endemism. Livestock grazing among other threats is the major cause of habitat degradation, across this region. Here CREW works in collaboration with pre-existing initiatives by local NGO's in the area i.e. Conservation South Africa and Environmental and Rural Solutions programmes. Plant collecting as well as basic plant Identification workshops have been conducted in the area and these have opened a "whole new world" of plants to the various stakeholders in this region, including community members. Field trips have also been done and species of conservation concern discovered.

CREW interaction with students, teaching them plant identification skills and mapping; in the field, as well as using specimen material and GIS techniques. © SANBI

CREW contributing to national ecosystem work

Although the focus of CREW is on threatened plant species, the data collected from CREW have the potential to improve our understanding of South African national ecosystems. SANBI is also the custodian of the National Vegetation Map and this map contains over 450 different types of terrestrial ecosystems, with a description of the communities and plant species for each. However, currently the map does not have comprehensive species lists for all ecosystems, and all known endemic species still have to be assigned to communities. Fortunately, CREW datasheets record species lists as well as an accurate locality. Therefore, CREW staff have begun working with the National Vegetation Map team to augment the incomplete species lists in the National Vegetation Map with CREW data.

Southern African Bird Atlas Project – SABAP

The second **Southern African Bird Atlas Project – (SABAP2),** a project run by the University of Cape Town, BirdLife South Africa and SANBI, is an important bird monitoring project in the region. It contributes to other conservation initiatives that depend on the results of the bird atlas. The data can be used to determine the conservation status of a species (e.g. species range information and how this is changing). The selection of sites and habitats critical to bird conservation are also influenced by these data. SABAP2 is the follow-up project to the SABAP1 that took place from 1987-1991. The second bird atlas project started in 2007 and plans to run indefinitely. The project aims to map the distribution and relative abundance of birds in southern Africa and the atlas area includes South Africa, Lesotho and Swaziland.

All field work for this project is done by more than **2 100** volunteers, known as citizen scientists - **they are making a huge contribution to the conservation of birds and their habitats**. The unit of data collection is the pentad, five minutes of latitude by five minutes of longitude, squares with sides of roughly 9 km. There are 17 339 pentads in the original atlas area of South Africa, Lesotho and Swaziland, and a further 10 600 in Namibia, 4 900 in Zimbabwe and 6 817 in Kenya.

At the end of June 2017, the SABAP2 database contained more than 189 000 checklists. The milestone of **10 million records** of bird distribution in the SABAP2 database was less than 300 000 records away. Nine million records was reached on 29 December 2016, eight months after reaching seven million on 22 August 2015, and 10 months after the six million record milestone. Rapidly capturing a million records in eight-month periods has become a norm for this project. More than 78% of pentads in the original SABAP2 atlas area (i.e. South Africa, Lesotho and Swaziland) have at least one checklist at this stage of the project. More than 36% of pentads have four or more lists.

The most pressing data collection needs are to get coverage as complete as possible, and to try to build a foundation of four checklists per pentad. On top of this foundation, the skyscraper of checklists can be built. Ideally, we would like checklists representing every month of the year. This information can be used by birders and scientist to enjoy and investigate biodiversity respectively.

Lepidopterists' Society of Africa – LepSoc

Monitoring invertebrates, specifically butterflies and moths, is the passion and of many volunteers involved with the Lepidopterists' Society of Africa.

The study of Lepidoptera (lepidopterology) has been a citizen scientist endeavour, from its beginnings, even in Europe and North America. Amateur lepidopterists in the 19th century amassed collections of butterflies from all over the world, and many of these specimens found their way to museums. In Southern Africa the development and progress of lepidopterology was well described by Ball (2012) and he acknowledges pioneers such as A. Janse and G. van Son (professional entomologists) as well as "citizen scientists" such as K.M. Pennington and C.G.C. Dickson.

The Lepidopterists' Society of Africa (LSA) was founded in 1983 and was a citizen science organisation from its inception, and aimed to encourage the scientific study and conservation of Lepidoptera (butterflies and moths). A landmark in conservation was the publication of the first Red List for butterflies in Africa by Henning and Henning (1989). Active conservation came of age with the launch of the Brenton Blue campaign in 1993, documented in Steenkamp and Stein (1999). This campaign gave all South Africans the inspiration to become "citizen scientists" and many contributed

to achieving the prevention of the extinction of this butterfly. Another achievement of citizen science was the publication of Pennington's Butterflies by Pringle *et al.* (1994), which gave a comprehensive account of all then known southern African butterflies. Publishing is an ongoing activity of LSA, with their flagship publication *Metamorphosis*, a peer-reviewed scientific journal (see below).

Edge and Mecenero (2015) summarised the progress of butterfly conservation up to 2015, most of which has been led and contributed to by "citizen scientists". The projects which have built this progress are briefly outlined below.

***Metamorphosis* (1983–)**

Metamorphosis is a publication of the LSA, which originated in 1983 to provide a platform for members to contribute articles of interest about Lepidoptera (butterflies and moths). It has grown over time into a fully-fledged, peer-reviewed scientific journal that publishes articles on any aspect of the study of African Lepidoptera. This supports the LSA's objective of furthering the knowledge of the diversity, taxonomy, habitats, distribution and life cycles of African Lepidoptera. This knowledge contributes to Lepidoptera conservation, which is one of the ultimate aims of the society. The contributors are not only accomplished international scientists, but also "**citizen scientists**" who are encouraged to embark upon the learning experience of scientific publishing and, in the long run, become accomplished scientists, as many of LSA's members have done.

From 2012 *Metamorphosis* became published online (ISSN 2307-5031), as well as a printed journal (ISSN 1018-6490). Each year a printed version is produced, containing all the articles published during the previous calendar year.

In 2015 *Metamorphosis* became an "Open Access" journal, in order to further raise LSA's international profile and prestige and members of LSA do not contribute to page charges encouraging all participants to contribute.

LepiBase/Lepidops (1995–)

LepiBase is an active database developed and owned by LSA containing species records from participating members as well as the SABCA data and in future the LepiMap, SALCA and BioGaps data (all projects described here). The purpose of this database is to build up a dataset with sufficient data to perform distribution and trend analyses of Lepidoptera species. The LepiBase dataset is designed to capture not only record location data but also other behavioral data with the purpose of offering students of Lepidoptera, environmentalists and conservationists a verifiable data set to assist in their efforts. The database was initiated in 1995 and has captured records since then. It has recently been expanded to include the SABCA database and is continuously being updated with new records. All parties are encouraged to participate and data submission is compulsory for permit compliance. Data usage is free for qualified contributors. At present the database contains well over **30 000 images of Afrotropical Lepidoptera** and the image base is continuously improved.

SABCA (2007 - 2012)

The Southern African Butterfly Conservation Assessment (SABCA) was established in 2007 as a partnership between LSA, the Animal Demography Unit of the University of Cape Town (ADU), and the SANBI. The aim was to gather all the available data on our butterflies' distribution and abundance, assisting SANBI in its mandate to report and monitor South Africa's biodiversity. The

project was co-funded by SANBI and the Norwegian Agency for Development Co-operation. LSA not only provided expertise but also contributed to funding by means of voluntary unpaid fieldwork and related services.

The geographical scope of the project was South Africa, Lesotho and Swaziland. All distribution data for this region from as many as possible of the known butterfly collections around the world were gathered into a single database. The project was extended beyond the LSA membership: a public Virtual Museum (VM) was established, harnessing the enthusiasm of a much larger group of "citizen scientists" and Butterfly Census Weeks were arranged.

From April 2007 to March 2011 nearly 350 000 records were gathered, of which nearly **18 000 came from the public via the VM** in the form of photographic records. Many new localities were found, and the conservation status of all of southern Africa's butterflies – the common as well as the threatened ones – was assessed using the rigorous IUCN Red Listing protocol. The final outcome of the project was the publication "Conservation Assessment of Butterflies of South Africa, Lesotho and Swaziland – Red List and Atlas" (Mecenero *et al.* 2013).

Outcomes of SABCA included:

- As a result of the heightened public awareness and interest in butterflies and moths, the VM component of SABCA has been continued as LepiMAP (see below), expanded to include moths, and covering the whole of Africa.

Greater scientific authority has been accorded to the conservation status of all of our butterflies, resulting in conservation bodies and development planners to incorporate Lepidoptera data into their planning units and priorities.

COREL (2011–)

During the SABCA project 61 taxa were identified as threatened in terms of the IUCN (2010) categories and criteria. Drawing inspiration from SANBI's successful Custodians of Rare and Endangered Wildflowers programme (CREW), LSA decided to launch a programme called COREL (Custodians of Rare and Endangered Lepidoptera), to promote and ensure the conservation of all butterflies and moths Red Listed as threatened in South Africa. This programme was adopted unanimously by the trustees of the Brenton Blue Trust, which is now funding the project. COREL initially focused on the Critically Endangered (CR) butterfly and moth taxa, of which there were originally 15, including the moth *Callioratis millari*. For each CR taxon LSA has identified one or more custodians who have agreed to take the primary responsibility for monitoring and preventing extinction of the taxon. The COREL programme has been expanded since the SALCA project to include also the Endangered and Data Deficient butterflies and moths, and now covers 58 taxa, of which 21 are CR.

Caterpillar Rearing Group (2012–)

The Caterpillar Rearing Group (CRG) is an LSA project, which combines the efforts of both expert lepidopterists and citizen scientists to discover the life histories of all Lepidoptera (moths and butterflies) occurring in Africa, particularly for previously unknown lepidopteran life histories. The world of Lepidoptera does not only consist of the flying adult moths and butterflies that we see on a daily basis. These flying wonders have gone through the magical process of metamorphosis, having transformed from crawling, and hungry caterpillars to the flying adult moths or butterflies we know

so well. Our current knowledge has yet to scrape the surface of this world, but the small glimpses we have seen have sparked the interest of lepidopterists far and wide. Tens of thousands of moth species and about 4 500 butterfly species occur in Africa. Relatively few of their life histories are known, and the amount still to be discovered is staggering. The concept is simple: find caterpillars in the wild and rear them through to adulthood, taking notes and photographs of the various life-stages, host-plants and other interesting behavioral phenomena. This information is contributing significantly not only to scientific knowledge, but also to the conservation of Lepidoptera on the African continent, and is being conducted by a large group of "citizen scientists". See Staude *et al.* (2016) for details. To date at least 1 800 species have been reared by 92 participants, with host plant information included.

LepiMAP (2012–)

LepiMAP is an African Lepidoptera citizen science mapping project, run jointly by the ADU and LSA. LepiMAP's long-term (and very ambitious) aim is to establish the distribution and conservation priorities of all butterflies and moths of Africa.

LepiMAP represents an excellent opportunity for citizen scientists to make their photography count for conservation. A huge database of photographs (with their locations) of butterflies and moths throughout Africa is being built. LepiMAP is a continuation of SABCA's VM, during which a database of over 300 000 records of butterfly distributions (mostly acquired from digitising and georeferencing collections) was built. LepiMAP continues to add to this database and to generate increasingly comprehensive distribution maps for all of Africa's Lepidoptera. These maps enable their conservation status to be monitored, and provide early warning of threats to various species.

SALCA (2015–2018)

The Southern African Lepidoptera Conservation Assessment (SALCA) is a project of the Brenton Blue Trust and LSA, with support from SANBI. Results of the SALCA project are feeding into the current National Biodiversity Assessment (NBA) being conducted by SANBI.

SALCA has re-evaluated the conservation status of all butterflies of conservation concern in the southern African region (154 taxa; including threatened and rare taxa). Additionally, seven new butterfly taxa recently observed in South Africa for the first time have also been assessed, as well as four Least Concern taxa with no recent observations. SALCA has also, for the first time, included basic analyses for the region's moths after creating a consolidated moth database of about 3 000 species. All the conservation assessments, based on IUCN Red Listing standards, have provided essential baseline information that is needed for conservation planning. This information has helped determine the current risk of extinction to our Lepidoptera. This information has contributed to assessing butterfly protection levels, calculating the Red List Index (for the very first time for South Africa); highlighting the main threats to these insects; identifying what conservation actions are urgently required to protect these threatened species; and giving input to SANBI's Critical Habitat Mapping project. LSA appointed 15 taxon authors, mostly citizen scientists for each taxon, who conducted field surveys for taxa identified by SALCA as of greatest conservation concern and in areas where there were knowledge gaps. The project also digitised some important collections, particularly for moths, and included verified butterfly photos submitted by the public via LepiMAP.

Karoo BioGaps (2016–2018)

This project was launched by SANBI in 2016 and has aimed to carry out surveys on 13 animal and plant taxon groups (including butterflies) at 50 sites spread across the Karoo. LSA's scope of work, all conducted by "citizen scientists" was to:

- Survey 30 compulsory and 20 optional sites; each site to be visited at least twice.
- Produce datasheets containing details of all records collected in the field.
- Total records of at least 500 butterfly new primary field presence or presence/absence records, fully digitised and able to upload into the Specify Database.
- Obtain at least 240 DNA samples of butterfly species suitable for barcoding.
- Submit progress reports on fieldwork undertaken.
- Identify any butterfly records from the Karoo region posted on iNaturalist and the ADU VM.
- Carry out at least 10 Red List assessments for butterflies (or checking and updating of current assessments).
- Publish a peer-reviewed scientific paper in a suitable journal.
- Compile 20 butterfly species pages to be submitted via SANBI's species page portal.

a)

b)

c)

d)

e)

a) Hazards of investigating oviposition sites of butterflies, b) *Chrysoritis dicksoni* female ovipositing by S Woodhall, c) *Orachrysops niobe* - Brenton Blue female - Justin Bode, d) Collecting data in the branches and e) Getting stuck in the Karoo. © LepSoc Africa

Cape Citizen Science Project - Citsci

Cape Citizen Science (Citsci) is a programme in the Western Cape Province that hosts multiple projects focused on plant health in the Greater Cape Floristic Region (GCFR). The programme is primarily research outcome oriented, but the organisers have also dedicated time to achieve educational outcomes. For example, the main aim of the pilot study was to reveal the diversity of a group of microscopic organisms that kill indigenous plant species, but the research was also used as a platform to raise awareness about microbes as the cause of disease and emphasize the connection of microbes to public health.

Cape Citizen Science in the field working with schools and rangers as well as botanical garden staff. © Cape Citizen Science

Most of the educational outcomes have been achieved through organized workshops for reserve rangers and botanical garden staff or through outdoor adventures with youth that involve sample collection. The programme also invited citizens to contribute to methods in the laboratory (lab). Providing the opportunity to visit the lab empowered a Grade-11 learner to make the critical decision to study microbiology at university. The workshops with garden staff and rangers added capacity for the early detection of new disease epidemics or insect pests. Collecting samples during these activities also added to the research outcomes, which demonstrates that citizen science programs can achieve research and educational outcomes simultaneously.

Engaging the public in research has many benefits. Cape Citizen Science was founded because researchers recognised that engaging the public could enhance monitoring for the early detection of novel invasions and plant disease epidemics. Citizens (including the public, environmental education groups, and state agency staff) have contributed to the programme through many methods such as submitting physical samples and reporting unhealthy plants online. Together, these citizens have contributed to reveal the microscopic biodiversity and advanced our knowledge about threats to the flora of the GCFR.

The primary objective of Cape Citizen Science is to provide opportunities for citizens to 'release their inner scientist' and contribute to research to conserve plant species in the GCFR. The programme intends to continue to host projects that promote plant health and reduce the effects of novel plant disease epidemics and insect invasions.

Iimbovane - Ants

Iimbovane Outreach Project (https://www0.sun.ac.za/Iimbovane/), is a science education project that is part of the DST-NRF Centre of Excellence for Invasion Biology, based at Stellenbosch University. Aptly named ("Iimbovane" means "ants" in isiXhosa), the project uses ants as a model

group to teach Grade 10 Life Sciences learners about biodiversity science and the scientific method. The aims of the project are to educate and raise the awareness levels of educators and their learners on the importance of biodiversity, and to create an appreciation and understanding of biodiversity science. This is achieved through curriculum-based lessons at participating schools, biodiversity workshops based at Stellenbosch University campus and surrounding areas, the taking part in science career expos as well as tailor-made outreach activities. Partnered with the Western Cape Education Department (WCED), Iimbovane currently has 17 actively participating schools throughout the Western Cape Province, as well as 10 additional schools where the project has been introduced. These schools are predominantly previously disadvantaged, rural schools, and were chosen in collaboration with the Western Cape Education Department, based on their location, to represent the diversity of landscapes and vegetation types within the province. In the past, Grade 10 learners collected ant data on their school grounds, which were coupled with data collected by the project, in reserves spread across the province. Iimbovane's focus has since developed into science outreach, with an expansion of outreach activities and collaborations, whilst maintaining the core of the project - the use of ants to educate learners about biodiversity and to support educators in delivering the curriculum. While participants in the project are no longer actively collecting data for scientific purposes, Iimbovane has developed into a new niche, a link between schools, nature reserves and universities.

Iimbovane in action, during school visits, each school is visited twice a year and includes a field work session, where learners are taught about survey designs and ants are collect on their school grounds. The second visit includes a session on classification and mini-microsphere and basic dichotomous keys are used to identify the ants that was collected. © Iimbovane

Iimbovane has contributed a decade of biodiversity data collected in Nature Reserves, National Parks, municipal land and school grounds across Western Cape. This database has contributed to four journal articles, which have advanced our understanding of ant diversity and change, as well as the ins-and-

outs of initiating a citizen science project in a resource poor country. These data have also been used in countless classroom lessons. Additionally, Cape Nature and SANParks received data collected in theirs reserves to use in protected area management. An important component of the Iimbovane project has been the creation and maintenance of an extremely valuable ant reference collection for the Western Cape and parts of the Northern Cape and KwaZulu-Natal.

Iimbovane attends the annual SciFest Africa in Grahamstown (Makhanda), where a workshop for youth between the ages from 8 to 18 are run and includes fun interactive session. © Iimbovane

Iimbovane has provided training and support for life sciences educators through workshops and the provision of scientific apparatus to supplement lessons, empowered thousands of high school learners through active participation in the research process, and holds many workshops annually that promote an appreciation and knowledge of biodiversity. Additionally, Iimbovane serves as a connection point for high school learners with tertiary education in science, particularly at Stellenbosch University. Through our workshops on campus, learners are exposed to university life, and are provided with information on various courses in the biological sciences, admission information and bursary options. One of Iimbovane's greatest achievements has been mentoring Iimbovane learners who later go on to study science at university level, and then came back and volunteered at Iimbovane workshops and outreach activities.

Citizen scientists are just as active on the coast and in the ocean as they are on land

South Africa's unique and diverse marine environment provides the perfect platform for a thriving citizen scientist community, allowing non-professional scientists to voluntarily participate in research activities to support scientific projects. Citizen scientists have increasingly been contributing to a range of South African marine projects, including the distribution mapping of various marine animal groups (Potts *et al.* in prep). The contributions from citizen scientists can be substantial and, in addition to providing crucial information for species red listing processes, can lead to the discovery of new species and bioprospecting opportunities. There are several atlassing projects in the ocean – including the National Sea Fish Atlas, EchinoMap, the Sea Slug Atlas and more.

SeaKeys

The SeaKeys Project was a large collaborative project (2013 - 2018) that aimed to collate and increase foundational marine biodiversity information and translate this information into products to support decision making and the development of new benefits for South African society. Citizen scientists contributed substantially to the outcomes of the project. Contributions via the platform iNaturalist provided more than 41 000 new marine biodiversity records. The National Fish Atlas was established under this project and provided >8 000 fish records from citizen scientists. Over the course of the project, 1 683 images were submitted to the Echinomap Virtual Museum and 118 species with distribution records have been identified from these submissions (some are still unidentified and probably represent new records). Some of the records submitted by citizen scientists also included new distribution and/or species records, including new starfish records added to our asteroidea fauna. Two citizen scientists contributed to many of the project's national species checklists.

A sample of monitoring in the inland aquatic realm

4WATER - Wise Wayz Water Care Programme

The Wise Wayz Water Care (WWWC) Programme is a community development initiative funded through corporate funding i.e. AECI Community Education and Development Trust (CEDT) and implemented by i4WATER, a Non-Profit Company. The aim of the programme is to address the socio-economic and environmental challenges along the lower Mbokodweni Catchment in KwaZulu-Natal, South Africa. This is achieved through skills development in the fields of science, natural resource management and business development. To achieve the desired outcomes of improving the health of the lower Mbokodweni catchment and that of its communities, it is imperative for the programme to focus holistically on issues that impact on the socio-economy and the natural environment in this catchment. The programme is based in the townships of Folweni and Ezimbokodweni areas of Durban, and has 120 participants/volunteers/citizen scientists (Figure 25).

These communities face issues such as poor waste management practices, poor sanitation, lack of environmental awareness, poverty, infestations of alien vegetation and a lack of skills within the community to address these issues. The WWWC Programme identified seven interventions to achieve its outcome and address these issues. One of the interventions is aquatic monitoring, which focuses on communities conducting monthly monitoring of the lower Mbokodweni Catchment using citizen science tools.

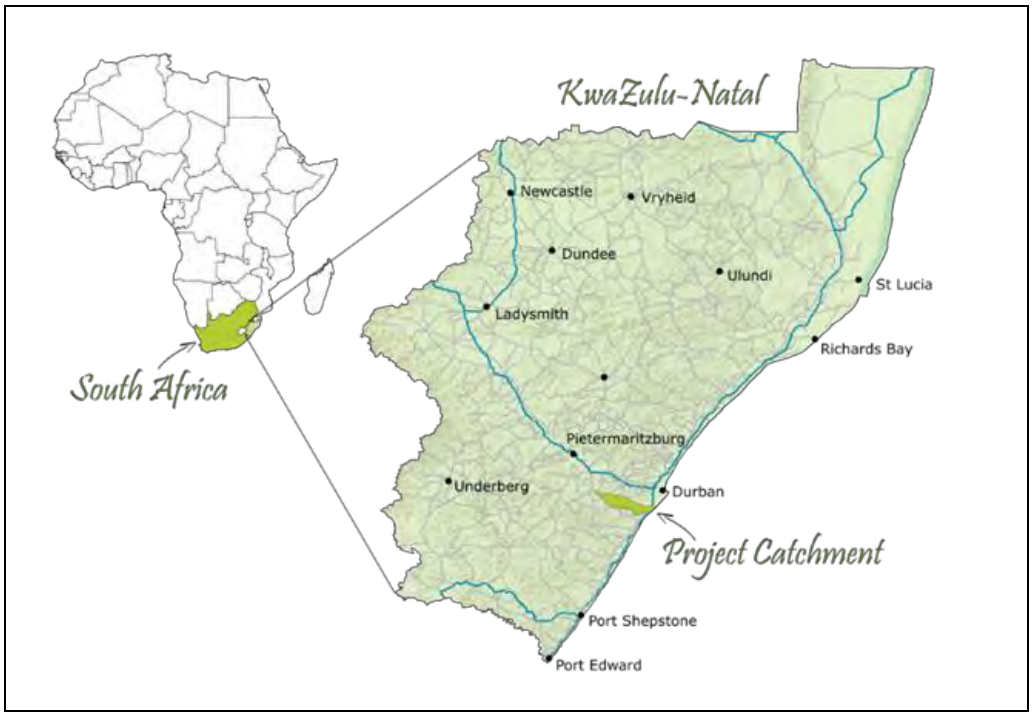


Figure 25. A map showing the location of Mbokodweni Catchment.

Community-based aquatic monitoring

The development of citizen science tools for aquatic monitoring through the Water Research Commission (WRC) K5/2350 project, was aimed at encouraging broad-based public participation and helping citizens to develop an understanding of their local aquatic ecosystems through the tangible action-taking process of co-managing their water resources (WRC K5/2350, 2014).

With regard to aquatic monitoring and citizen science, the WWWC community-based monitoring programme has a few objectives:

- To develop capacity, scientific skills and establish career opportunities for youth in historically disadvantaged communities, particularly in the field of science.
- For the community-based monitors to use the monitoring programme as a means to create peer-to-peer awareness, and educate their community about the catchment and its role, as well as the direct benefits the aquatic systems provide to the community.
- To identify pollution sources and take appropriate action to address the issues with eThekwini Municipality and the community, this inspires co-operative governance between the municipality and the community, and more effective management of the catchment.
- To use the data as a measure to monitor and evaluate the progress of the WWWC programme in improving the health of the catchment.

The aquatic monitoring programme consists of ten volunteers who have received a range of training; including the use of citizen science tools to monitor the health of the lower Mbokodweni Catchment. Twenty-two monitoring sites were identified along a 30 km stretch of the river (Figure 26).

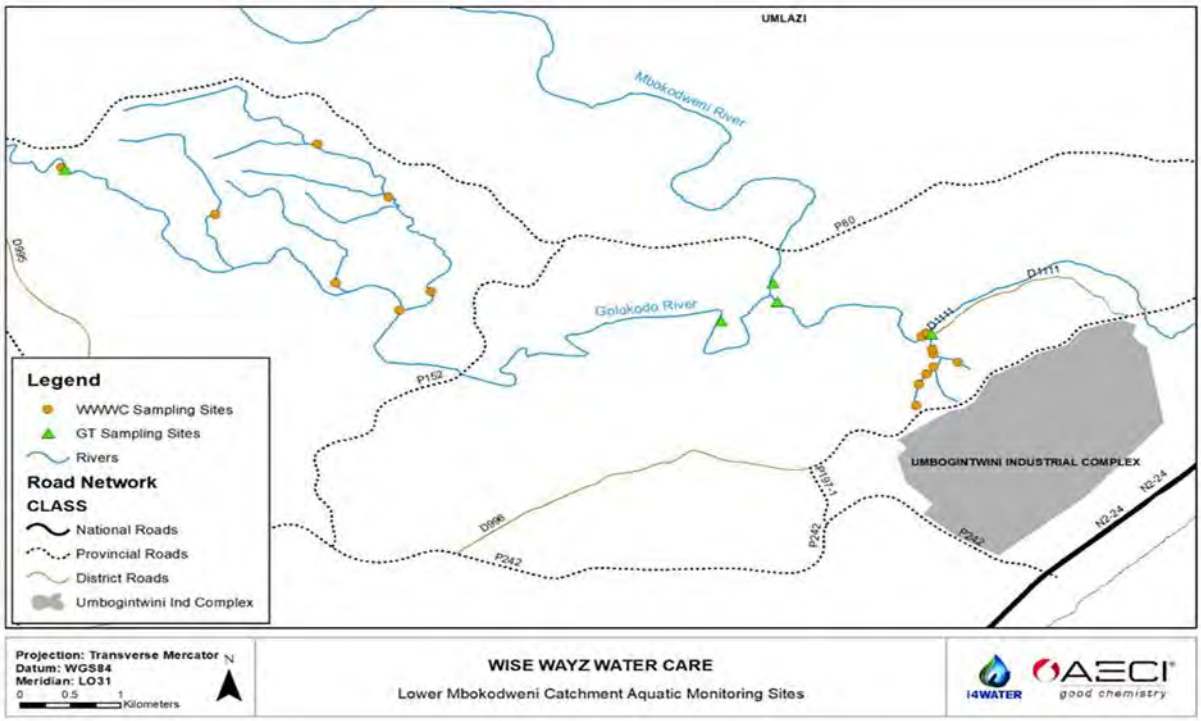


Figure 26. A map showing sites monitored by WWWC beneficiaries using citizen science tools.

Following extensive training and mentorship over a period of two years, the monitoring group is able to independently monitor the catchment on a monthly basis using citizen science tools developed by the WRC i.e. miniSASS for measuring river health, Velocity Plank to assess water level, flow fluctuations, Clarity Tube to determine the extent of suspended particles in the water, an *E. coli* swab,

developed by Expose Labs to measure the presence of *E. coli* colonies in the river. Recently, the programme has introduced citizen science tools to measure water chemistry components.

Major personal changes through citizen science Experience

The citizen science experience has given the volunteers a sense of responsibility to safeguard their natural environment. All participants have come to recognise that they are the custodians of their catchment and they have taken a responsible role in minimising the extent of pollution and preventing it where possible. This has provided the volunteers with a sense of being valuable members in their communities. Often when the monitoring teams are seen busy with their work, they are referred to as the "River Doctors" (Figure 27).

Bongekile Ngcongo assessing the condition of Mbokodweni River using miniSASS. © Ntswaki

Figure 27. miniSASS results for the lower Mbokodweni Catchment, uploaded onto the miniSASS website by WWWC's monitoring team.

The unique skills that the WWWC members bring to their local community has sparked an interest from local environmental experts such as SRK, JG Afrika, and Talbot and Talbot; who have subsequently provided more opportunities by inviting the teams to assist in some of their marine and aquatic assessments, some of these opportunities have led to income generation for the citizen scientists.


WWWC monitoring team working with Aquatic Ecologists from SRK consultants to assess the condition of springs in Ezimbokodweni area, South of Durban. © WWWC

Shifting the minds of local communities

Citizen science has served as a medium of communication among community members about environmental issues, particularly the aquatic ecosystem. These interactions have enriched the community with knowledge of their local catchment. This has further resulted in community members alerting the WWWC monitoring team in the event of sewer leaks and illegal waste disposal in the river system. Hence, sewer leaks are now attended to immediately.

A sudden and unexpected growth of *E. coli* colonies usually indicates sewer spillage or nappies disposed in the streams. In a case of a spilling manhole, the monitoring team will engage with the WWWC plumbing team to report the spilling manhole to eThekwini Municipality. In a case of nappies disposed in the river or streams, the monitoring team engages with the WWWC Community Education team to create awareness in areas adjacent to the affected sites. The engagement with the community also includes sharing of their results and that often sparks interesting discussions about environmental issues. This peer-to-peer awareness creation has seen a shift in the minds of community members as they start to understand and internalise the impacts of their actions.



The real face of citizen science – Community members bringing science and knowledge to their communities. © WWWC

The WWWC story demonstrates the value of empowering citizens through engaged participation in the field of science. The knowledge gained from using the tools has given the WWWC volunteers a sense of ownership and responsibility to continue their efforts in safe guarding their catchment area.

The results derived from the monitoring programme also serve as encouragement to the rest of the WWWC participants who are involved in other interventions; as results indicate that their efforts in removing waste and alien vegetation from the streams and creating awareness in the community are creating positive change and thus giving their catchment a chance to flourish and function as intended.

Projects focused on using technology to interact with citizen scientists

Images are a powerful form of data collection: they can tell stories about the past and present, and can be used in the future. This is well illustrated by the following projects: iNaturalist, iSpot, the SAFARIS and rePhotoSA. These projects take a very interesting approach to collecting data and making use of the new technologies available to collect data and interact with volunteers or citizen scientist.

iNaturalist

SANBI uses iNaturalist as its primary citizen science platform for observations. iNaturalist offers not only a repository for interesting observations, but also various other features, including:

- identification tools to make or get an identification,
- a discussion site for finding out more information from other observers and experts,
- a checklist manager for personal and site-based species lists,
- a project management tool for collecting, summarizing and reporting on projects – be they personal, local, national or international,
- and many other tools.

The primary use of iNaturalist is as a data repository, like several other citizen science sites in the region. Data require an observer, date, location and either a photograph or sound recording. It is thus a virtual museum, storing verifiable data. Additional data can be volunteered, and in the case of data contributed to specific projects, additional data can be collected and collated. Observers get feedback in terms of identifications, comments and queries, as well as summaries of their contributions. A smartphone application (app) streamlines data submission anywhere, anytime.

These data are available to scientists, environment assessors and project managers for uses as diverse as monitoring, detecting distribution range changes, Red List assessments, medicinal and other uses and behaviours. Specific projects monitor climate change, roadkill, new alien invaders, and population trends, providing data in real time to scientists and managers. Projects can be general such as SeaKeys – dealing with anything marine, to specific such as monitoring the rate of spread of the Harlequin Ladybeetle in southern Africa. Several scientific papers, including those describing new species, have been based on iNaturalist data.

SANBI initiated its citizen science online work using iSpot (run by the Open University) in 2011, but in early 2018 data were migrated to iNaturalist (run by California Academy of Sciences). To date some 3 200 observers have contributed 44 000 observations of 24 675 species in southern Africa, which have been confirmed by 2 800 identifiers around the world (Figure 28). The current rate of

observations is 130 000 per year (Figure 29). Currently, within iNaturalist, South Africa is positioned 5th in the world based on observations (after United States, Mexico, Canada and New Zealand), 3rd in the world based on species observed (after United States and Mexico), about 14th in terms of identifiers, about 18th in terms of observers and 8th in terms of web traffic. Southern Africa is set to become the 7th iNaturalist Network Community (with Canada, Colombia, Mexico, New Zealand, Portugal and United States).

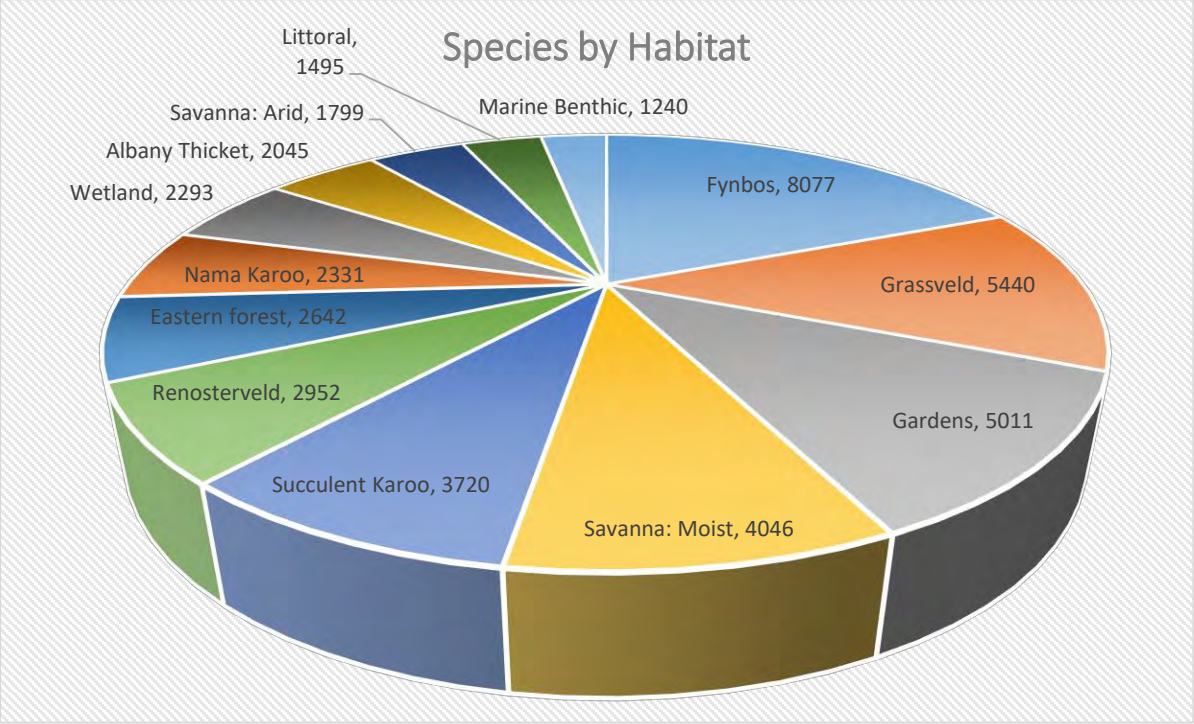


Figure 28. Number of species (plant, animal and mould) recorded for the major habitat types in southern Africa on iNaturalist (extracted December 2018)

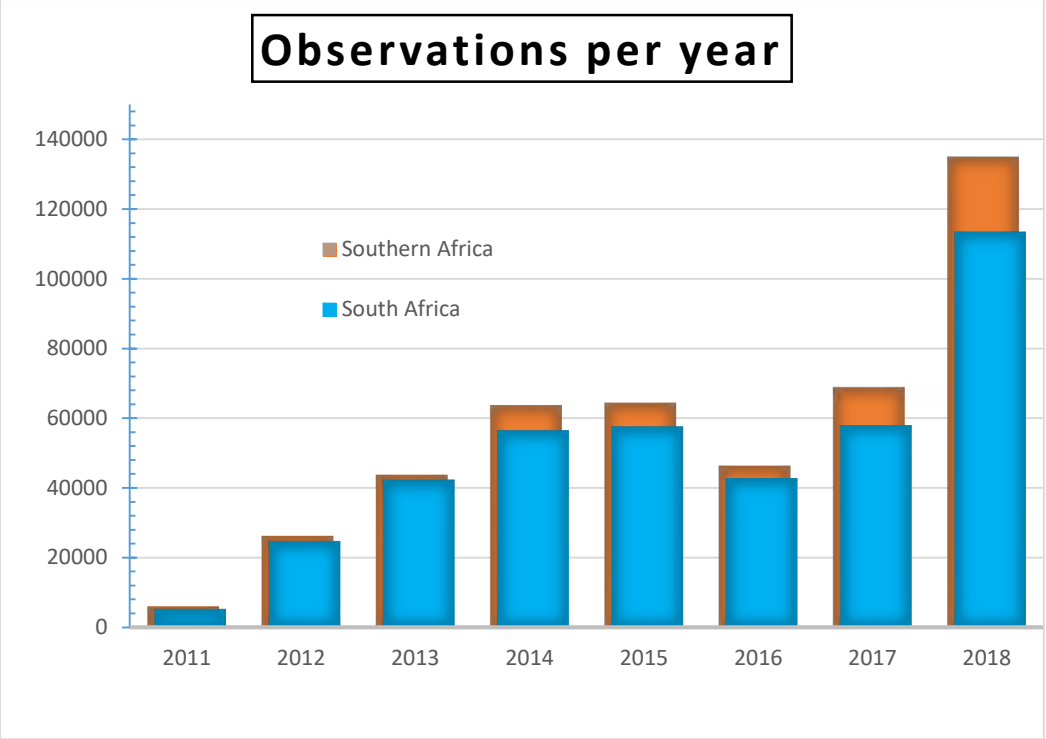
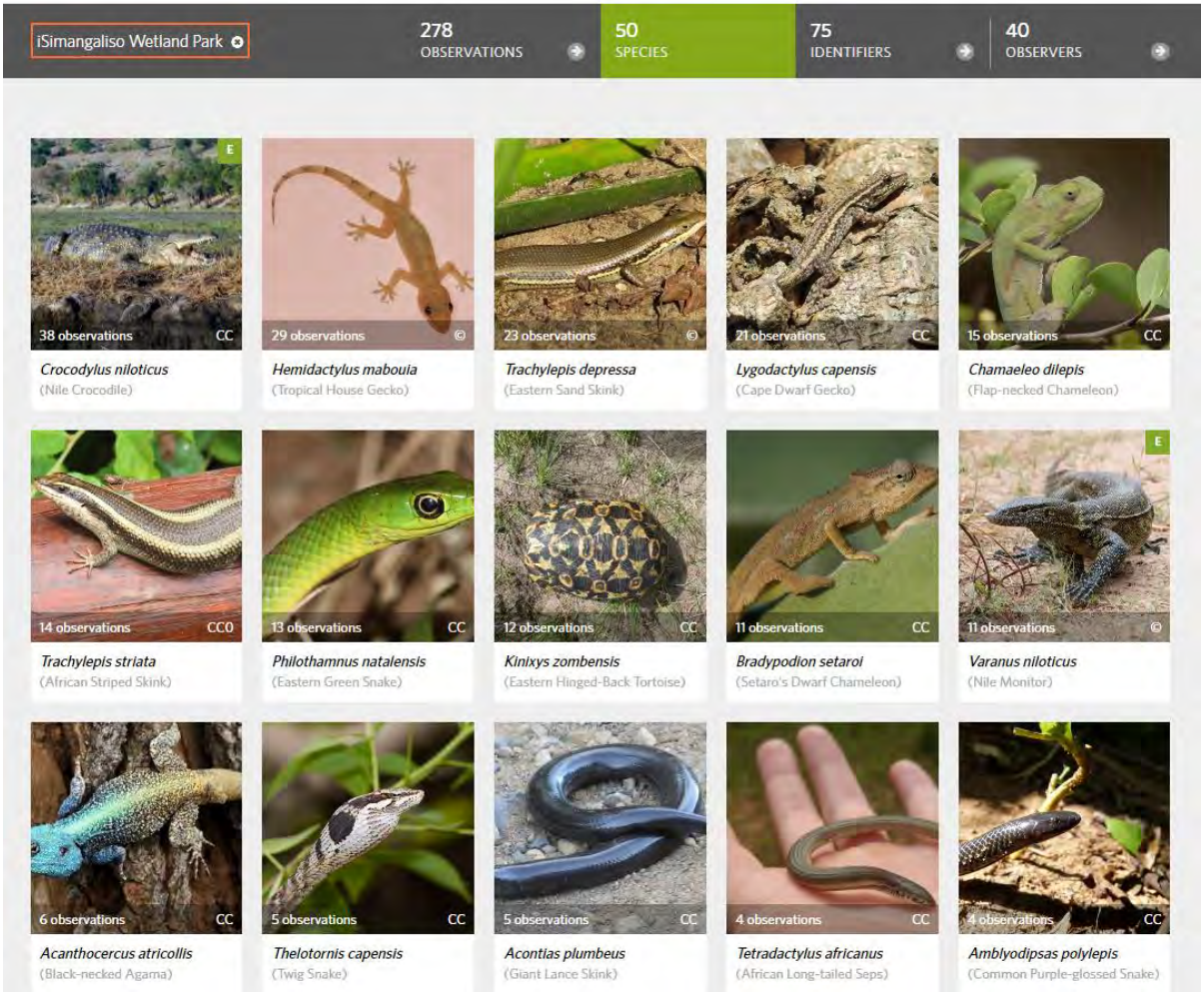


Figure 29. Contributions of observations to iNaturalist per year for South and southern Africa.

iNaturalist provides users with several ways of getting an identification. An artificial intelligence interface suggests the most likely identifications the moment a cursor is placed in the identification field. Matches with images are ranked by likelihood of being correct. An identotron allows the refinement of an existing identification by displaying related species previously recorded in the area. Both the taxon and the area can be broadened should no matches be obvious. And other users can suggest identifications and agree with previous identifications or post alternatives. For specialists and taxonomists, a curatorial tool manages the review process allowing rapid and efficient inspection of available observations. A “community identification” protocol manages conflicts with identification and interfaces with data for use by third parties.

Filters and Projects on iNaturalist allow the extraction of data based on taxa, places, users and other criteria. Thus it is possible to extract the Proteas in flower during the month of May in the Marakele National Park, or reptiles in iSimangaliso Wetland Park (example below).



The most commonly recorded species of reptile in the iSimangoliso Wetland Park, KwaZulu-Natal (extracted December 2018).

Any user can download the resultant data files for further analysis. However, precise locality data for sensitive species – those threatened by collecting or poaching on the IUCN Red List – are not available, and can be obtained only from the site managers. There are many existing projects on iNaturalist that users might want to participate in. Some merely collect observations, but others manage data. Here are some examples of projects on iNaturalist:

Cetacean Sightings

Cetaceans, such as whales and dolphins, are relatively understudied in S Africa.

National Botanical Gardens of southern Africa

SANBI's Conservation Gardens & Tourism Division manages a network of ten

NEMBA Alien Species (S Afr)

Collecting all the NEMBA Projects: The Department of Environmental Affairs (DEA) manages Invasive Alien

Harlequin Ladybeetles in southern Africa

To monitor and track the spread of this invasive throughout s Africa

Glass Encounters

Death by windows! Any instances of organisms killed or trapped by flying into glass, panes

VEGMAPhoto

The aim of this project is to collect representative photographs of vegetation types listed

Karoo BioGaps

To document fauna and flora in the Greater Karoo region Currently the Karoo is poorly surveyed

Undescribed Species & Taxa

To collect all those undescribed taxa that only get identified to genus, tribe or family.

Powerkill

Death by electrics: security fences, Wind Farms, Sun Farms, Powerlines and other Power facilities.

First & Last Records For Season

One Swallow makes a Summer. But lots of other plants and animals migrate or flower or

Used Medicinally

For observations depicting the use or misuse of organisms by the medicinal, muti, magical and marketing

Strandings

For Strandings along the southern African coast. Includes: beaching, cast ashore, high and dry

Habitats

To facilitate the documenting of s Afr habitats for observations to summarize the data.

Sea Coral Atlas

Sea Coral Atlas – mapping the distribution of our marine Coral species

Sea Slug Atlas

Southern African SeaSlugs are cool. There are over 75 species in False Bay and the Peninsula alone

Seaweed Atlas

The purpose of this project is: To record the distribution of seaweeds on the s African coastline

Sea Shell Atlas

Aim: Record distribution of shelled marine molluscs on the s African coast and continental shelf.

Sea Fish Atlas

The Sea Fish Atlas project is a SeaKeys initiative and aims to map where different fish are found

SeaKeys

SeaKeys is the first large collaborative project funded by the Foundational Biodiversity Information

Blue Community

A feature of this community is their exposure to predation from above and below

Nests & Nesting

Nests of any shape or size, even webs. Dens, scrapes, holes. Also Roosts

Roadkill

Animals killed on our roads. Data will be shared with other surveys of this problem.

Scats & Dung

Scats, droppings, pellets, dung: faeces of any animal, including middens and their derivatives.

Spoor & Signs

Spoor, tracks and signs of animals.

Skulls & Skeletons

Bones and remains of animals and plants.

Alien Biocontrol

To collate records of Biocontrol Agents used in controlling alien species

Champion Trees of South Africa

The Minister of Water Affairs and Forestry can declare certain tree species and individual trees

Projects also allow summaries and reports to be shared with participants. To participate in a project, join, by selecting “join”. If you cannot find a project to meet your needs, merely create one. You can allocate other users to help you curate and manage a project.

iNaturalist has contributed significantly to the following national initiatives:

SeaKeys was a collaborative project bringing in teams of marine scientists and interested citizens in documenting our marine environment. Some 102 users contributed 21 902 observations of 1 932 species during the five years that the project ran.

Karoo BioGaps documented the fauna and flora in the Greater Karoo region, which was poorly surveyed for biodiversity. Under BioGaps several bioblitzes were organised and over three years some 228 observers contributed 19 076 observations of 2 860 species. These data were used to model plant and animal community patterns in the karoo.

Redlist is the Custodian of Rare and Endangered Wildflowers (CREW) data collection form. It allows any observer to provide data suitable for revision of the South African Red List of Plants. Some 71 observers have provided 2 495 assessments for 1 254 species. There is also a more detailed online form.

Alien Early Detection & Rapid Response aims to highlight new alien species that are starting to invade South Africa. The hope is that invasions can be nipped in the bud, before expensive clearing programmes are needed. Some 29 users recorded 101 observations of 62 species, all of which were followed up with varied success by teams at SANBI, the City of Cape Town and Ithekweni Municipality. These data augmented their Spotter Network data. Over 430 users have also contributed 7 140 observations of 335 National Environmental Management: Biodiversity Act (NEMBA) alien species in South Africa, helping map the distributions of alien invasive species.

DigiVol – Southern African Friends and Researchers Indexing Specimens - SAFARIS

SAFARIS (**S**outhern **A**frican **F**riends **a**nd **R**esearchers **I**ndexing **S**pecimens) on DigiVol (previously the Volunteer Portal on Atlas of Living Australia, volunteer.ala.org.au) started in August 2013 and has had contributions from 73 of the 3 208 DigiVol volunteers. DigiVol hosts expeditions from the Australian museums and herbaria, and many institutions from outside Australia, including New York Botanical Gardens, Kew and Smithsonian Institute. Validation is always the bottleneck in transcriptions and those volunteers who give their time to review what other volunteers have transcribed are invaluable contributors to the citizen science effort.

SAFARIS has now completed 2 976 tasks, of which 2867 have been validated. This represents about 86 000 species-locality-time biodiversity records. Georeferencing is still needed for many records. These tasks are from nine collecting registers and 21 of the 44 field note books from the Acocks archive.

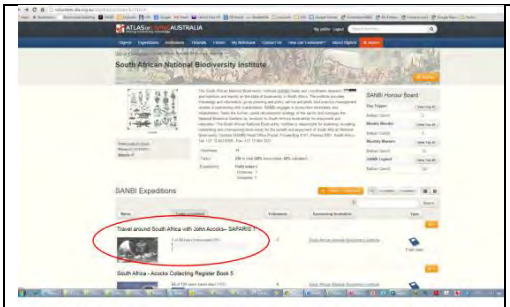
Transcribing and georeferencing enables a volunteer citizen scientist to enjoy virtual travels with early explorers and see some things as those early travellers saw them. It is a very fulfilling pastime, and makes a truly valuable contribution to understanding our biodiversity. A busy airline pilot can enjoy profitable use of time in hotels around the globe transcribing tasks rather than simply watching television. Contributors can enjoy this rewarding activity in which skills in biodiversity, geography, logic and interpretation can be learnt. Further doing deductive work to determine what the handwritten text

is or figuring out precisely where the collection or observation was made. It is a wonderful benefit to the citizen scientist as well as to exploration, conservation, sustainable use, appreciation and enjoyment of South Africa's exceptionally rich biodiversity.

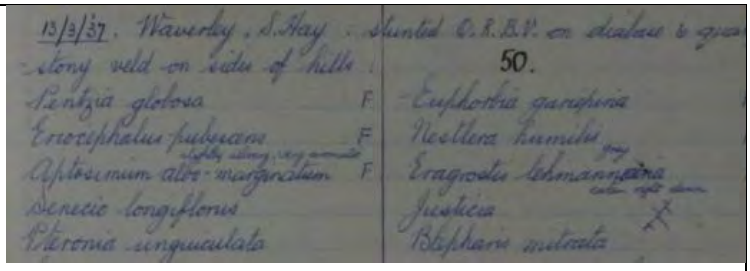
Volunteer experiences with SAFARIS from abroad: An unemployed volunteer from the Albury-Wodonga area in Australia, has transcribed 1 056 tasks for SAFARIS out of her 6 797 for DigiVol. She has validated 52 tasks, all for SAFARIS with a total DigiVol contribution of 6 849. This is a way that she contributes to society. While contributing, she developed skills that opened doors for her to work with historical documents in a library, all improving her employment prospects, and found that contributing at DigiVol was a positive learning experience and very interesting work.

A volunteer from Dalmeny in Australia is passionate about fungi. She gives a lot of time to transcribing on DigiVol and has transcribed 415 tasks of Acocks collecting registers and field notes out of her total of 78 536 DigiVol tasks, and validated 628 SAFARIS tasks out of a total of 150 343 DigiVol tasks with a total DigiVol contribution of 228 879 tasks. She was born a Galpin, suggesting that her love of nature is in her genes, and was touched when the curator of SAFARIS was able to alert her to the fact that she transcribed a species *Mosdenia phleoides* named for Galpin's farm Mosdene.

Another volunteer started a degree in botany and zoology, genetics, forest botany, but preferred to keep it as a hobby and did not complete the degree. He worked in purchasing and IT admin and has a love of nature, settling on a block of land near Burra, Australia, and enjoys volunteering his time as a useful activity on wet days. He has transcribed 492 SAFARIS tasks out of 2 308 tasks and validated 1 169 SAFARIS tasks giving a total DigiVol contribution of 3 477.



from the SANBI Institution page http://volunteer.ala.org.au/institution/index/5374124



Process of digitising using DigiVol.

rePhotoSA

rePhotoSA is the repeat photography project of southern African landscapes and is a joint initiative between the Plant Conservation Unit (PCU) and the Animal Demography Unit at the University of Cape Town (http://rePhotoSA.adu.org.za). It is a citizen science project, which means that the public are encouraged to find and take repeats of the historical photographs that have been uploaded to rePhotoSA. The PCU has scanned and digitised over 50 000 historical images, of which over 20 000 are landscape images (Scott *et al.* 2018). Currently, there are nearly 6 000 historical photographs on the website from photographers such as John Acocks, IB Pole Evans, Keith Cooper and Ulrich Nanni (Hulbert *et al.* 2019). Citizen scientists can search for historical images on the online database, download one or more historical photographs, and start the process of finding the exact location from where the original photograph was taken. Once repeated, the contributor is required to register with the project in order to submit the repeat. Downloadable guidelines for taking repeat photographs are available, as well as simple field datasheets to record metadata while in the field. We continuously find new ways in which to

encourage the public to get involved, such as through social media, popular articles, repeat photography workshops, and presentations at citizen science days and conferences. RePhotoSA builds on a decades-long research programme on long-term environmental change in southern Africa (Hoffman *et al.* 2018, Scott *et al.* 2018). The aim of rePhotoSA, therefore, is to build upon the wealth of environmental baseline data contained within mid-20th century historical photographs by involving citizen scientists through an online interactive database platform. From this information, we can better understand how and why landscapes are changing over time.

(Left) Photograph from a citizen repeat photography workshop held at Rondebosch Common on 23 June 2018; (Right) After a day in the field with citizen scientists up Signal Hill. © Samantha Venter.

Ground-based repeat photography has a long history in documenting landscape change. Due to growing concern over the rate and scale of climate and land-use change, the benefits of involving the public in data collection efforts is increasingly being realised. The potential contribution of citizen scientists to repeat photography research is significant, especially where there are numerous historical photographs and the locations are spread across large geographical areas. To date, **218 repeat photographs from across southern Africa** have been uploaded to the rePhotoSA website by 35 active citizen scientists (Figure 30). This number continues to grow as more citizen scientists become involved in the project. Many citizen scientists know their area of interest well and so local knowledge has benefitted the project in better understanding why some of the changes have occurred.

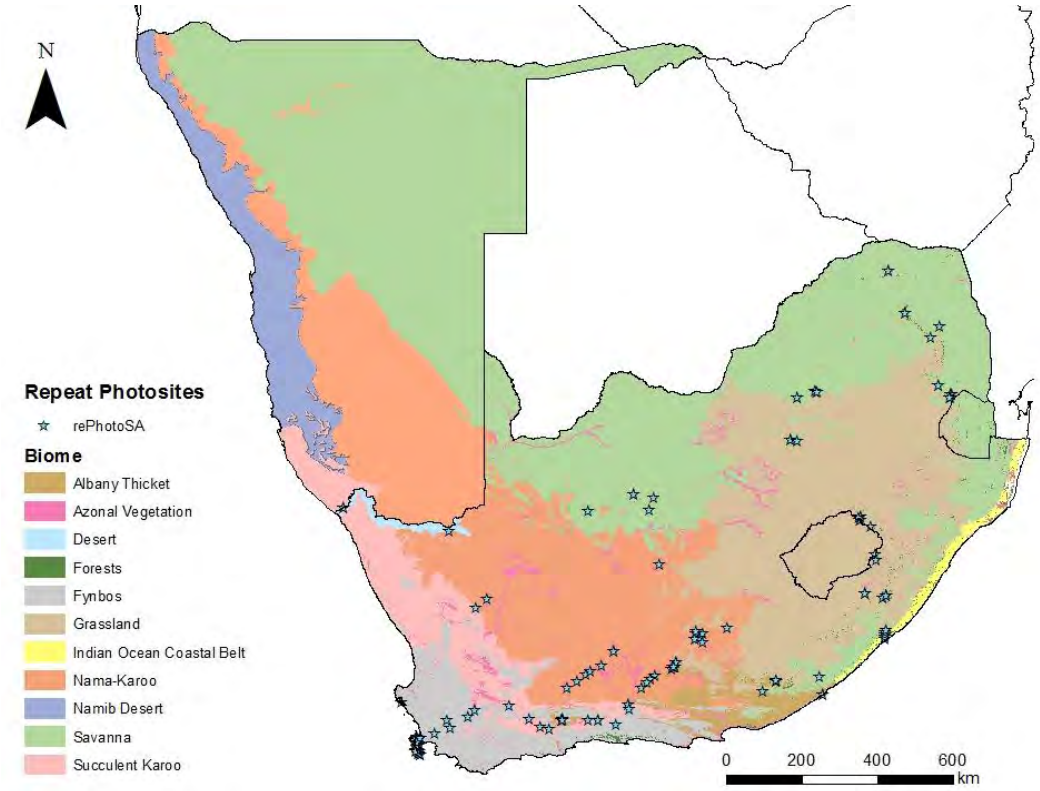


Figure 30. Map of southern Africa showing the major biomes and the location of repeats uploaded to rePhotoSA (stars)

An assessment, using 115 of the 218 repeat photographs, shows important changes in vegetation across southern Africa, such as an increase in grass cover in the Karoo (Figure 31), and a decrease of grass cover in the grasslands and a corresponding increase in woody vegetation (including alien vegetation). These changes in the Karoo and Grasslands are aligned with changes published in the literature (e.g. Masubelele *et al.* 2014, O'Connor *et al.* 2014) and so we can see how valuable rePhotoSA is as a long-term monitoring tool on vegetation and biodiversity changes in southern Africa. Evidence from the photographs received to date suggest that Fynbos has largely remained the same except for a slight increase in woody vegetation. With each repeat, we take another step forward towards understanding how and why the vegetation of southern Africa has changed or is changing.

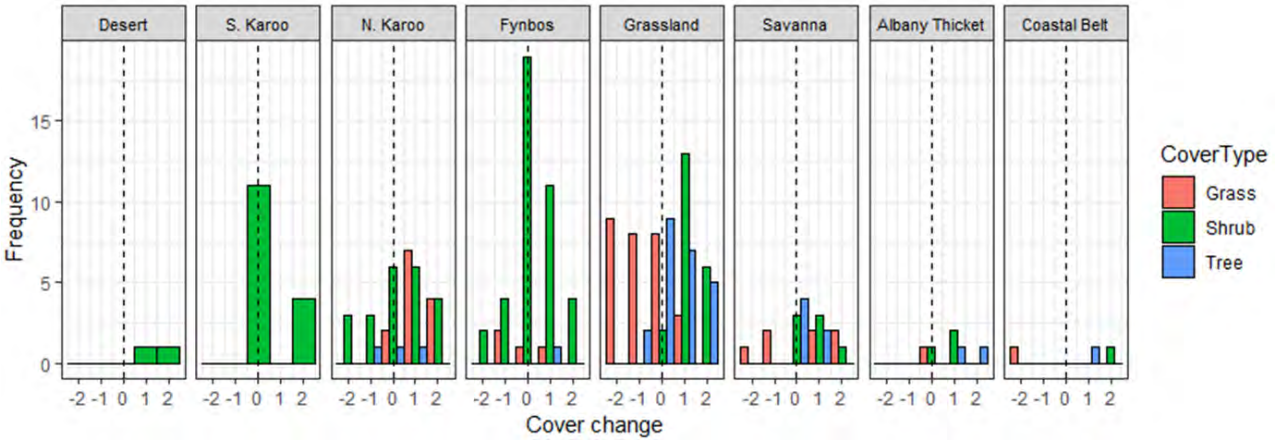


Figure 31. Change in vegetation cover in the biomes of South Africa where 0 represents no change, 1 represents a positive or negative change between 5 and 25%, and 2 represents a positive or negative change of >25%. Results are included for the Desert (n=2), Succulent Karoo (n=8), Nama-Karoo (n=22), Fynbos (n=41), Grassland (n=28), Savanna (n=9), Albany Thicket (n=4) and Indian Ocean Coastal Belt (n=1) biomes.

Changes in the Karoo and Grassland biomes are illustrated below with repeat photographs. Further examples of change can be seen at: http://rePhotoSA.adu.org.za/Examples.php.

Historical photograph #3706 of Erin Farm in the Eastern Cape (QDS 3125CA) taken by John Acocks on 6 May 1971 and its repeat taken by citizen scientist Justin du Toit on 8 April 2016. Both images were taken after a prolonged drought. There is a distinct change in vegetation due to a reduction in stocking numbers and an increase in rainfall. Image credit of the original: Acocks, John Phillip Harison © SANBI [1971] and licensed under Creative Commons licence CC-BY.

Historical photograph #22 of "East Griqualand near Kokstad. Mt Currie." in the Eastern Cape province (QDS 3029CB) taken by IB Pole Evans in 1918 and its repeat taken 100 years later by citizen scientist Zander Venter on 7 January 2018. Note increase in indigenous woody vegetation (predominantly *Leucosidea sericea*). Image credit of the original: Pole Evans, Illtyd Buller © SANBI [1918] and licensed under Creative Commons licence CC-BY.

Many of the participants get involved because they are **excited** by the **challenge of trying to locate the exact site of the original photographs** and the fact that the project gets them outdoors into nature. Many have equated the project to going on a treasure hunt or to geocaching. Although many citizen scientists upload photographs from their home town, some actively plan repeat photography tours where they travel across the country taking repeats for the project. Some have said that since starting with the project, they view landscapes in a different light when the original is compared with the repeat, especially when the original photograph was taken 100 years or more ago. One citizen scientist said that as a newcomer to South Africa, rePhotoSA has provided a wonderful opportunity to learn about the Cape and its people. Another added that although from Cape Town, it has encouraged him to explore the Cape and surroundings more, from the peaks to the coastlines, and has provided opportunities to visit places that are often restricted to the public. In addition, both added that it is a great activity to do with friends and is a great way to meet people but most importantly they have fallen in love with the project and will continue with it well into the future.

South African citizen science today and tomorrow

The value of citizen science in South Africa has been known for a long time; however, its true value has only recently been realised with the expansion of technology and the need for data to support policy decision making. To ensure that we build on this foundation, we need to ensure that:

1. That funding for these projects are sustained with financial support from the various organisations such as SANBI and other government departments as well as NGO networks. These projects contribute to understanding biodiversity at a much greater extent than only academic contributions; and there are direct benefits to the participants as citizens can contribute to the conservation of our biodiversity.
2. There is limited funding to support research and other conservation initiatives; therefore, these types of projects are critical to sustain the ability for South Africa to monitor and report on the state of biodiversity.
3. Many of these projects are possible only through the hard work and dedication of individual people and groups, hence we need to ensure that their contributions are acknowledged and rewarded by making use of the data and giving feedback on where and how they are contributing to conserving biodiversity.
4. Currently many of these projects are spatially restricted, and are mostly operating in highly populated areas such as urban areas. Thus, where possible, efforts should be made to expand into rural communities. Some projects have already started work in rural communities and shows promise for future opportunities where indigenous value systems and practices can contribute to biodiversity monitoring and reporting.
5. It's the responsibility of all South Africans to protect our biodiversity as we have an entire floral kingdom within our borders, many endemic species and three biodiversity hotspots to take care of. Citizen science is a great tool to take up this responsibility.
6. In South Africa we have a well-established culture of citizens contributing to science and biodiversity monitoring. This culture needs to be transferred to younger South Africans as well as previously disadvantaged groups that have not been as active in this field, also to include and encourage participation of people from a range of backgrounds to engender a sense of ownership of the amazing and unique biodiversity this country has to offer.
7. There is a need to increase the use of technology to make citizen science more appealing and accessible to the general public of South Africa. This will also increase the efficiency and data flow of these projects.
8. Innovation is needed to address our current biodiversity challenges and citizen science offers a platform where people can get involved, and provide creative solutions.

The South African National Biodiversity Institute intends in future to play a coordination role of all citizen science project across the country. A citizen science working group have been established in 2018 and aims to:

1. Ensure SANBI has an overarching strategy that addresses Citizen Science project that provide biodiversity monitoring that links directly to SANBI Biodiversity Monitoring Framework.
2. Ensure that citizen science projects contribute to decision making, via processing data generated by citizen science projects through species and ecosystem assessments, into products that can be used by decision makers.

3. Guide and identify the needs in the biodiversity sector, where citizen scientists can contribute much needed monitoring data.
4. Lead the use of new technologies to collect biodiversity data, making it easier for participation in citizen science for all citizens.
5. Actively address the demographic bias of participants in citizen science projects across the country and strongly encourage the contribution of rural African citizens in monitoring projects.

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