Coupled Earth System and Human Processes: An Introduction to SPACES and the Book

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Abstract

Ecosystems in southern Africa are threatened by numerous global change forces, with climate change being a major threat to the region. Many climate change impacts and environmental-based mitigation and adaptation options remain poorly researched in this globally important biodiversity hotspot. This book is

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a collection of chapters covering research undertaken in southern Africa by the German Federal Ministry of Education and Research's (BMBF) SPACES and SPACES II programs. SPACES II covered a wide range of global change-linked environmental issues ranging in scope from the impacts of ocean currents on global climate systems through to understanding how small-scale farmers may best adapt to the impacts of climate change. All the research has identified policy implications, and the book strives for a balance between presenting the detailed science underpinning the conclusions as well as providing clear and simple policy messages. To achieve this, many chapters in the book contextualize the issues through the provision of a mini-review and combine this with the latest science emulating out of the SPACES II program of research. The book therefore consolidated both past and the most current research findings in a way that will be of benefit to both academia and policy makers.

1.1 Introduction

This open-access Ecological Studies volume provides results and synthesis of key issues from the research program "Science Partnerships for the Adaptation to Complex Earth System Processes" (SPACES II), addressing the scientific, social and economic issues related to climate change impacts in southern Africa including terrestrial and marine ecosystems. It is written by 66 scientists from African nations together with 111 of their German and other European collaborators and summarizes, in 32 chapters, selected highlights from the latest research findings of SPACES II (2018–2022). These are of significant potential relevance for a better understanding of climate change impacts on marine and terrestrial ecosystems and may help to improve management options and guide environmental policy decisions. This is crucial considering projected African population increase in the context of very likely adverse impacts of climate change, including significant increases in aridity and warming, and the frequency of extreme weather events affecting both marine and terrestrial ecosystems and the human activities that depend upon them.

There is a particular value to such research in the southern African ecosystems, because their terrestrial ecosystems are among the last refugia in the world for their unique wildlife and rare plant diversity, and support a multiplicity of ecosystem services and human livelihoods. The oceans surrounding southern Africa furthermore comprise a critical bottleneck in the global thermohaline circulation, they act as a relatively poorly understood regulator of the global carbon balance, and they play an important role in sustaining marine biodiversity and the highly productive fisheries. These and other geographic advantages are further elucidated in Sect. 1.4, with reference to their coverage in relevant chapters.

In addition to key locational advantages for advancing research in global change science, southern Africa has a particular legacy of human scientific research capacity, some level of networking and extensive biophysical and social–ecological data

available that can provide the basis for effective scientific advancement. However, the region lacks somewhat with regard to modern harmonized monitoring infrastructures and the networking required for quantitative and region-specific multisector impact assessments and applied efforts, such as development of evidence-based adaptation options. Although the understanding of the region's climate drivers has increased extensively over the past few years, there remain large gaps in knowledge and predictive skills of potential and actual impacts on the diverse ecosystems of the region. The development of the SPACES II suite of projects was positioned to address these with awareness of the facilitative environment described above.

1.2 Long-Term Southern African–German Scientific Cooperation and Background to SPACES

The scientific cooperation between German scientific institutions and southern Africa is based on decades of successful collaborations.

Joint research on biodiversity under climate change was the focus of the research program "BIOdiversity Monitoring Transect Analysis in Africa - southern Africa" (BIOTA South 2000–2006). Objectives of the program (Hoffman et al. 2010; Jürgens et al. 2010; Schmiedel and Jürgens 2010) were:

- Scientific support for sustainable use and conservation of biodiversity in Africa.
- A continental observation network in Africa, contributing to GEOSS (Global Earth Observation System of Systems).
- A network for observing land degradation and for developing measures to combat desertification in Africa.
- A network for capacity development and rural development in Africa.

Investigations of Earth system processes and their interactions at different spatial and temporal scales were the focus of the "Inkaba ye Africa" program in southern Africa (de Wit and Horsfield 2006, 2007). Furthermore, Germany also contributed to international marine research programs such as the "Benguela Current Large Marine Ecosystem" (BCLME) and "Benguela Environment Fisheries Interaction and Training" (BENEFIT) (Hampton and Sweijd 2008). Other bilateral and multilateral projects in marine research such as "NAMIBGAS" (Eruptions of methane and hydrogen sulfide from shelf sediments off Namibia, 2004–2007) and "GENUS" (Geochemistry and Ecology of the Namibian Upwelling System, 2009–2015) have put the current cooperation activities on a broad basis.

The goal of SPACES is to deepen both the thematic and geographical expansion of the research expertise acquired so far. With new research topics and with additional partners, SPACES has made a lasting contribution to the corresponding national programs and initiatives in the region. The promotion of young researchers is an essential component of SPACES. In addition to workshops and summer schools, an education and training component is an integral part of the program. To this end, the BMBF supports a German Academic Exchange Service (DAAD)

scholarship program (master's and doctoral scholarships). In addition, training cruises for African students were offered on the German research vessels FS MERIAN, FS METEOR and FS SONNE.

Within its framework program "Research for Sustainable Development" (FONA), the German Federal Ministry of Education and Research (BMBF) funds research projects in key regions that are particularly affected by the impacts of climate change and to promote sustainable land-use and climate protection. The program was developed on the basis of multilateral discussions between Germany and South Africa in 2008, followed by two workshops in 2009 for a broad professional audience in Gobabeb and Henties Bay (Namibia) attended by scientists from Angola, Germany, Namibia and South Africa. The results of the workshop were then presented to potential partners in the South African and Namibian ministries and research institutions. The funding program "Science Partnerships for the Assessment of Complex Earth System Processes" (SPACES I) was initiated in 2012 under the FONA framework and followed by a second funding phase (SPACES II,) initiated in 2018 (PtJ 2021). Both SPACES I and SPACES II stemmed from national and international strategies and initiatives on global change and international partnerships. These include the German-South African Year of Science 2012, German Government's Africa Policy Guidelines of 2014, Strategy for the Internationalization of Science and Research (BMBF 2008), the BMBF's Africa Strategy (BMBF 2014a) and International Cooperation Action Plan of 2014 (BMBF 2014b), as well as the United Nations Sustainable Development Goals SDG13 "Urgent action to combat climate change and its impacts," SDG14 "Conserve and sustainably use the oceans, seas and marine resources for sustainable development," SDG15 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt biodiversity loss," and SDG17 "Strengthen the means of implementation and revitalize the global partnership for sustainable development." Furthermore, the joint research contributes to the international programs of the United Nations Framework Convention on Climate Change (UNFCCC), UN Convention on Biodiversity (UNCBD) and UN Convention to Combat Desertification (UNCCD).

The core aim of SPACES I and SPACES II was to initiate collaborative research projects that contribute to the formulation of science-based recommendations on Earth system management, to ensure the sustainable use and conservation of the ecosystem services of the region. Both stress the provision of approaches tailored to the needs of end users.

The research focus of SPACES I (2014–2017) was defined as interactions between the geosphere, atmosphere and ocean as well as those between land and ocean, and biosphere and atmosphere. The main research themes of SPACES, with focus on assessment, were:

1. Coastal current systems in southern Africa, and their influence on land–ocean–atmosphere interactions, biogeochemical cycles and resource availability.

2. Quantification of the fluxes of carbon, water, nutrients and pollutants in rivers, estuaries and desert areas in terms of transport and transformation mechanisms, and implications for biodiversity and related ecosystem services.
3. Determinants of large-scale landscape evolution, hydrological changes and land-use change in southern Africa.
4. Describing, monitoring and conserving biodiversity in the face of habitat loss, and modeling potential changes based on predicted environmental and societal change.
5. Development and application of measures to restore and rehabilitate ecosystems damaged by human activities and natural processes.
6. Marine and terrestrial repositories of past climate and ecosystem change and their relevance to land–ocean–climate interactions.
7. Investigating the formation and evolution of the ecosystem.

SPACES I funded ten collaborative three-year research projects:

- AGULHAS—Regional and Global Relevance;
- ARS AfricaE—Adaptive Resilience of Southern African Ecosystems;
- IDESSA—Decision Support System for Rangeland Management;
- GENUS—Geochemistry and ecology of the Namibian upwelling system;
- GEOARCHIVES—Signals of Climate and Landscape Changes;
- GSI—Groundwater/seawater interaction along the South African south coast);
- LLL—Limpopo Living Landscapes;
- RAiN—Regional Archives for Integrated investigations;
- OPTIMAS—Sustainable Management of Savannah Ecosystems;
- SACUS—Southwest African coastal upwelling system and Benguela Niños;

The intention of the SPACES II was not the direct continuation of previous projects, but rather the thematic deepening and geographical expansion of the research competence acquired so far. With new research topics and with additional partners, SPACES II will sustainably contribute to the corresponding national programs and initiatives in southern Africa in light of new international challenges. Further, projects operating infrastructures for monitoring key environmental variables and land surface processes were asked to develop a transfer concept for potential implementation and long-term usage by southern African collaborators and partners after project termination. Capacity building was considered as a major action to achieve this goal and to avoid leaving many of the activities as temporary endeavors without sustainable benefits for local stakeholders.

The research focus was defined as interactions between the geosphere, atmosphere and ocean as well as those between land and ocean, and biosphere and atmosphere; however, the scope was widened to include interactions between the anthroposphere, geosphere, hydrosphere, biosphere and atmosphere. Important themes for both, SPACES I and SPACES II were defined as soil erosion, drought, local and regional shifts in plant species composition, the interaction of climate

change and human impacts, such as land use and pollution, and changes in oceanic currents.

The second phase SPACES II (2018–2022) funded six terrestrial and three marine collaborative research projects (Table 1.1). The five main themes show the shift of focus from assessment to adaptations and include:

1. Seasonal and interannual variability and trends of coastal current systems, considering their influence on land–ocean–atmosphere interactions in southern Africa, and their implications for biogeochemical cycles and marine resources management,
2. The transport of carbon, water, nutrients and pollutants, considering their transformation mechanisms and dynamics in riverine, estuarine and coastal areas and in terms of their importance for population, biodiversity and ecosystem services,
3. The functioning of diverse landscapes in terms of sustainable land use, land-use change, carbon and water fluxes and their impacts on biodiversity, habitats and ecosystem services,
4. Management options for landscapes and their ecosystem components for societal resilience to environmental change,
5. Measures to restore and sustainably use degraded ecosystems for goals of resilience, adaptation and mitigation.

Networking and collaborations between research institutions were at the core of SPACES II. The program is carried out jointly with the South African Department of Science and Innovation (DSI) (at the start of the program, under its previous name Department of Science and Technology DST), and it is intended to contribute to the intensification of cooperation with the Ministry of Education at the Republic of Namibia. Premises of the cooperation are mutual added value through high-quality cooperation and focus on jointly defined areas, consideration of (country-)specific African and specifically German interests, partnership and ownership as well as continuity and reliability in the cooperation. Institutions of other neighboring sub-Saharan countries can be integrated into the projects accordingly.

1.3 SPACES II Training and Knowledge Exchange Program

In the long run, skills development through education and training is essential to economic development, security and stability in Africa, and BMBF sets the support of junior researchers and higher education as one of its central aims (BMBF 2008). As defined in the program call, all SPACES II projects were required to contribute to capacity development of the partnering institutions, promote young scientists, as well as facilitate scientific exchange and networking on thematic priority areas. Out of the ten target indicators that were set for the projects in the call, half were directly relevant to capacity development, namely (1) the number of jointly supervised student projects, (2) the development of joint training programs and utilization of research results in curriculum development, (3) training courses on intercultural

Table 1.1 Overview of the funded research projects in SPACES II (2018–2022) (PtJ 2021)

Acronym	Research project	Objectives	Study area
Landscapes in transition			
ASAP	Agroforestry in Southern Africa—new pathways of innovative land-use systems under a changing climate	Investigation of ecosystem services and environmental benefits of agroforestry systems (AFS) as an innovative, multipurpose land-use management practice in southern Africa.	Project partners in South Africa, Mozambique, Namibia, Zambia and Malawi
EMSAfrica	Ecosystem Management Support for Climate Change in Southern Africa	Dual impacts of climate change and land management in the savanna ecosystems of southern Africa. The interdisciplinary project aims to provide information to support decision-making concerning climate change adaptation and mitigation, and the sustainable management of ecosystems.	Three focal research areas are located along a precipitation gradient, from low to high precipitation in the summer rainfall area
ORYCS	Options for sustainable land-use adaptations in savanna systems	Impacts of wildlife-based land-use strategies in Namibian savannas on the feedbacks between wildlife movements and dynamics, vegetation and related ecosystem functions and services. Our study area is situated in the southwestern region of Etosha and includes communal conservancies, private game reserves and the Etosha National Park.	Semiarid Mopane savanna south-west of and including the western part of Etosha National Park, Namibia.
SALDi	South African Land Degradation Monitor	Development of a system for permanent observation for ecosystem changes and degradation based on satellite remote sensing. Improving procedures for assessing soil degradation with a focus on runoff-related soil erosion	Six study sites representing a major climate gradient from the semiarid winter-rainfall region in the southwest across the central semiarid year-round-rainfall region to the semihumid summer-rainfall region in the northeast.
SALLnet	South African Limpopo Landscapes Network	Functionality and resilience of multifunctional landscapes in southern Africa can be enhanced under climate change. The project focuses on three land-use types—rangelands, arable lands and orchards—that provide essential ecosystem services and are crucial for local livelihoods.	South African province of Limpopo

(continued)

Table 1.1 (continued)

Acronym	Research project	Objectives	Study area
Interaction land and sea			
TRACES	Tracing Human and Climate impacts in South Africa	Interdisciplinary investigations of the combined effects of climate change and anthropogenic impacts on aquatic and terrestrial ecosystems in eastern South Africa over the last 250 years. Existing data sets are completed by and compared with new information gained from estuary and terrestrial sediment archives.	I) Richards Bay with the catchments of the rivers Mhlathuze and Mfule and the Goedertrouw dam reservoir, II) Mkhuze swamps with the river catchments of Mkhuze and Pongola and the Pongolapoort dam reservoir, III) Olifants River catchment with the Loskop dam reservoir and two smaller reservoirs in the upstream.
Marine and coastal research			
BANINO	Benguela Niños: Physical processes and long-term variability	Improving the prediction of climate variability and impacts of climate change relevant for upwelling variability and its consequences for biological productivity.	South-East Atlantic Ocean encompassing the area off Angola, Namibia and South Africa
CASISAC	Changes in the Agulhas System and its Impact on Southern African Coasts	Changes in the oceanic conditions and regional sea level around southern Africa are explored through global ocean and coupled climate modeling. The highly variable Agulhas Current System is subject to changes in the hydrography and circulation in response to atmospheric variability and anthropogenic trends.	Agulhas current along the south African coastline
TRAFFIC	Trophic Transfer Efficiency in the Benguela Current	Fundamental research on the processes of the subsystems nBUS and sBUS (Benguela upwelling system) and their responses to climate change.	Benguela upwelling system off south-West Africa

competence; (4) capacity development of scientific personnel and (5) long-term development of joint German-African research and education capacity.

In line with these aims, capacity development in SPACES II was largely based on the following, BMBF-funded core activities:

1. Student fellowship program funded by the BMBF via the "Capacity Building and Development" (CaBuDe) scheme of the DAAD;
2. Short-term exchange grants for scientific visits under the CaBuDe;
3. Short courses and workshops in specialist research skills, as well as training on research vessels;

Capacity building for scientists and practitioners in general and specifically the training of early-career researchers were central aims of the SPACES II program. The integrated training program aimed at linking the capacities of the southern African and German research communities as well as strengthening the competencies in the key areas of SPACES II. These key competencies included for example various modeling approaches, ecosystem assessments, greenhouse gas measurements, generating earth observation products and field surveying methods. Some courses also focused on transferable skills, such as intercultural communication. Training formats ranged from summer/winter schools and workshops to joint conference sessions, tutorials and online materials.

Although the Covid-19 pandemic caused major disturbances to the program in terms of travel and meeting bans starting from early 2020, 11 courses and trainings were successfully completed by the beginning of the year 2022.

1.4 SPACES II Synthesis

This Ecological Studies volume summarizes new information and novel research approaches in the terrestrial and marine realms, and attempts where possible to integrate across these areas, especially with respect to their responses to global change phenomena. Although structured around projects of the SPACES II program, key chapters aim to give a coherent state-of-the-art summary of the dynamics of both ocean and terrestrial ecosystems as they are impacted by global change phenomena, by drawing on and synthesizing the deep legacy information and published work available for the region, including from the original 'Science Partnerships for the Assessment of Complex Earth System Processes' (SPACES I 2014–2017). It covers both the current and emerging understandings of the global change drivers of ecosystem dynamics, potential management options and an understanding of how future scenarios may be altered through policy and management interventions. Differing intensities of human use are considered where feasible, including levels of land management ranging from crop agriculture and agroforestry systems, through pasture and rangeland systems to natural vegetation as found in conservation areas for the terrestrial environment, and extractive industries in the oceanic realm. Common themes such as the drivers of net primary production and the dynamics

of carbon fluxes are explored for both the terrestrial and as well as marine systems, highlighting both commonalities and particular differences between these different systems. In the marine realm, content ranges from fundamental biophysical aspects through to social–ecological issues such as food security and sustainability.

The book is divided into five main sections, with each section comprising a number of individual parts: (1) a policy relevant introduction to the region, (2) a discussion of the policy implications of large-scale earth system processes impacting on the region, (3) management and adaptation considerations, (4) monitoring options and (5) a synthesis with overall recommendations. In line with accepted practice in Intergovernmental Panel on Climate Change (IPCC) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments, the information aims to be policy relevant, not policy prescriptive. The tone of the book, while adhering to scientific writing rigor, aims to provide understandable information to an audience of policy makers, and those involved in the science–policy interface, who might not be domain specialists, but wish to understand the importance of the issues to guide policy and management interventions.

Climate variability and change is a central theme and is considered on its own (Chaps. 5, 6 and 7), or as it interacts with the terrestrial or marine realms (see Fig. 1.1). Where feasible, the interplay between components of all three realms that were the focus of specific research questions and activities is highlighted in chapters (Fig. 1.1). For example, in the marine section, the physical processes affecting currents and upwellings form the basis for considering impacts on and risks to ecological processes (Chaps. 8 and 9), and how these may translate to production and fisheries (Chaps. 2, 11 and 25). In the terrestrial environment, research ranges from the ecological processes impacted by climate change in the terrestrial system

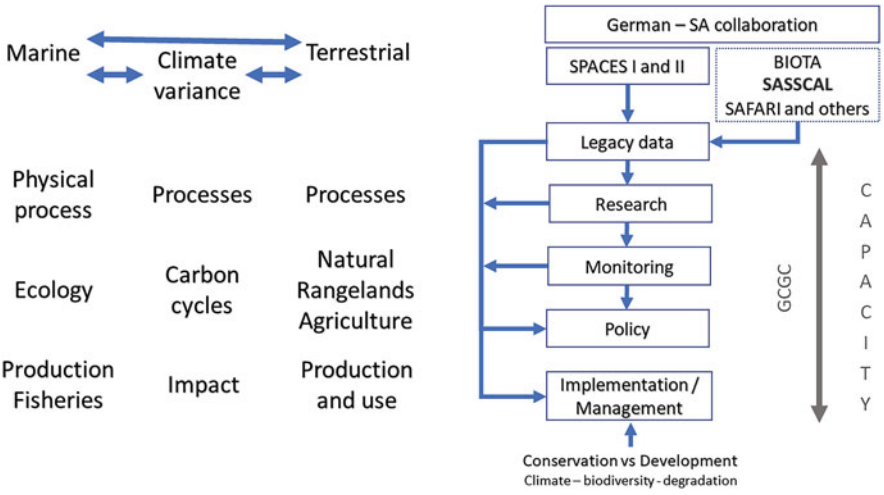

Fig. 1.1 Graphical abstract and conceptual overview of the book topics covered. GCGC = Global Change Grand Challenge

(Chaps. 14, 15, 16 and 17) to management and adaptation options for land uses ranging from natural systems (Chaps. 16 and 18) through extensively managed rangeland (Chaps. 16 and 19) systems and finally to intensively managed crop agricultural systems (Chaps. 20, 21, 22 and 23). Broader and integrative chapters consider physical processes driving the region's climate (Chaps. 8, 9 and 10), the region's role in regulating the global carbon balance (Chaps. 2 and 25) and feedbacks between climate and ecosystem productivity (Chaps. 2, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28 and 29).

1.5 Geographic Advantages for Global Change Research in Southern Africa

From an ecoregion and biodiversity perspective, southern Africa is globally unique, especially considering the high levels of endemism in both the terrestrial and marine ecosystems. Not only does the region have unique biodiversity including the plant diversity of the entire Cape Floristic Kingdom, but in addition it has extensive diversity of both terrestrial and marine habitats and biomes. A background to the southern African region, its unique ecosystems, the current threats to ecosystems as well as the macro-economics of the region is provided in the first four background chapters (Chaps. 2, 3 and 4).

Biomes in the southern African region are under increasing pressure, both from direct human activities and from the more indirect impacts of climate change (Chap. 3). Land transformation (Chap. 13), particularly for crop agriculture and plantations of exotic timber species has destroyed vast areas of natural habitat and spatially isolated areas of remaining natural habitat. Overharvesting, be it overfishing (Chaps. 2 and 25), overgrazing (Chaps. 15, 16, 17, 18 and 19), select use of individual natural species or deforestation, has degraded both the marine and terrestrial environment. A further major problem impacting on most ecosystems, but of particular concern to the Cape Floristic Region, is the extent of alien invasive organisms that have naturalized within natural habitats (Chap. 3). These organisms can displace indigenous biodiversity through direct competition for space, but also through altering the structural nature of the habitat or the disturbance regimes such as fire. Although these direct anthropomorphic threats are severe, it is the interplay between these and climate change that poses increased risk. For instance, agricultural fields may prevent plant and animal migration that would be required for the indigenous organisms to adapt to climate change impacts (Chaps. 2 and 3).

Climate change clearly poses a substantive threat to the unique biodiversity of the southern African subregion (Chaps. 2, 3 and 14). For instance a slight southward shift, possibly of as little as a few 10s of km, of the mid-latitude cyclones could have devastating impacts on the winter rainfall western cape region (Chaps. 6 and 7). Being at the tip of Africa, the region is impacted by numerous ocean currents that effectively meet. Global warming is anticipated to alter these currents, and this will have poorly understood impacts on local climate (Chap. 8). Equally, changes in the upwelling dynamics of the Benguela system could devastate the fishing industries

along the west coast of South Africa, Namibia and Angola (Chaps. 9 and 11). Overall, climate change, including impacts from atmospheric CO_2 concentrations, may well cause entire biomes to shift in their spatial distribution (Chap. 14), adding additional pressures to, in some instances, already poorly conserved and vulnerable biodiversity (Chaps. 2 and 3). Similarly, climate induced changes to the movement of ocean currents and impacts from changed dissolved CO_2 concentrations, could cause major shifts to the marine biota (Chaps. 2, 8, 9 and 25).

From a research perspective, the region has a long history of well-maintained and well-documented research activities and data, as well as an extensive research infrastructure within the region, making it an ideal location for undertaking ongoing global change research within a developing world context (Chaps. 2 and 32). Germany, in particular, has had a long history of biodiversity and ecological research in Namibia and South Africa that has developed long-term and strong collaboration between German and southern African research institutes. Most chapters in this book are joint endeavors including both southern African and German research partners.

The southern African region is a globally important, but currently under-researched component of the global carbon cycles. The vast savanna and grassland regions of southern Africa represent a huge carbon store, much to this as soil organic carbon (Chaps. 2, 15–17). Anthropogenic impacts such as land cover change (Chap. 29), erosion (Chap. 13) and deforestation cause a large amount of terrestrial organic carbon to be emitted into the atmosphere as CO_2. However, these environments also represent potential carbon sinks, and through management may be important areas for global change mitigation (Chaps. 11, 17 and 30). Long-term trends in terrestrial carbon fluxes both from land cover change and from climate change, remain poorly understood, the direction of change in many instances not being certain (Chaps. 2, 12, 17, 24 and 30). While the terrestrial carbon fluxes are significant, they are dwarfed by the marine fluxes. The Benguela current upwellings along the west coast of South Africa, Namibia and Angola represents one of the highest primary production regions globally, though the long-term fate of this sequestered carbon is still poorly understood (Chaps. 2 and 25).

From a socioeconomic perspective, southern Africa is a developing region, with the development concerns and trajectory of southern Africa differing significantly from those of Europe. Wide-scale poverty, high population growth rates and major problems of unemployment, mean that national policies tend to favor short-term growth opportunities over environmental concerns. This leads to tensions between sustainability and the needs for short-term development opportunities. As such, this creates unique sets of development and environmental challenges that differ substantially from those of high-income countries (Chaps. 3 and 4). Identifying sustainable terrestrial land-use options and opportunities given both the developmental and climate change realities creates major policy challenges (Chaps. 16, 18–23).

1.5.1 Climate Change

The second part of the book is devoted to the large-scale biophysical processes and drivers impacting the climate in the subregion. This is introduced through descriptions of the past (Chap. 5), current (Chap. 6) and projected future climates (Chap. 7). In addition, it covers an emerging understanding of the impacts of southern ocean currents (Chaps. 8 and 9) as well as land–atmosphere feedbacks on climate (Chap. 10).

Southern Africa has unique sets of climate challenges. There is substantive evidence that the interior of the subcontinent is warming at a rate above the global norm with heat waves, droughts and severe storms all likely to become more common (Chaps. 6 and 7). In addition, the latest future prediction largely agrees that the already predominantly arid region is likely to become dryer in addition to becoming hotter (Chaps. 6 and 7). Implications of climate change suggest that major negative impacts to both natural and agricultural land-use systems are almost certain. Given the wide dependency of the region on natural resources, nature-based tourism and agricultural production, the implications for the region are severe, and adaptation will be paramount (Chaps. 3, 4, 15, 16, 17, 18, 19, 20, 21, 22 and 23). The marine environment is not immune to climate change, with major impacts on the fisheries industry being likely, and possibly already being felt (Chaps. 2, 8, 9, 11 and 25).

Understanding past climate is important for both understanding the conditions under which current biodiversity evolved, as well as understanding how biodiversity may respond to future climates. Detailed measures of past climate are also critically important for calibrating future climate models (Chaps. 5, 12 and 28).

The current climate plays an important role in determining current biodiversity patterns (Chap. 2). A feature of the current climate is the extent of interannual variability (Fig. 1.2). This is especially apparent regarding precipitation and periods of both droughts and above normal rainfall are normal (Chap. 6). Although there is a clear link between El Nino events and drought, this linkage is both complex and not absolute. Equally, La Nina events favor periods of high rainfall, but with only a weak correlation between the strength of the La Nina and rain (Chap. 6). Clearly, many other factors are also involved in determining local precipitation patterns, and understanding these drivers is critical for current and future climate predictions. In this regard, the roles of ocean currents and the possible ways they may change due to climate change are critical (Chaps. 8 and 9). In addition, land-use change on the terrestrial environment could have feedbacks into the predominantly convective precipitation patterns and this is explored in (Chap. 10).

The book provides an up-to-date overview of the current understanding of climate and its drivers in southern Africa. It starts by reviewing climate over the last millennium and the availability of long-term climate surrogates that can be used to calibrate climate models (Chap. 5). It then discusses current climate with a specific focus on the hydrological factors and the drivers of interannual variance (Chap. 6). This is followed by a consideration of future climate projections for the region, a

Fig. 1.2 The profound impacts of climate variance are illustrated in these repeat photos from Boesmanskop 2011 (grassy) and 2016 (no grass). This shows the transition from a wet period (early 2010s) to a period of summer droughts (mid to late 2010s). Photos J du Toit

factor important to most chapters within the book (Chap. 7). The two following chapters consider the roles of currents and upwellings in the climate system (Chaps. 8 and 9). The final chapter in this section considers the feedback between terrestrial land use, and specifically deforestation, and the climate system (Chap. 10).

1.5.2 Carbon Dynamics

Carbon dynamics, an important component of the global understanding of impacts and feedbacks of climate change, is a theme that runs through many of the SPACES II programs and book chapters pick up on this in all sections.

The southern African environment plays an important, but poorly understood role in global carbon dynamics. It is both a potential source and sink of carbon depending on a combination of climate change futures, management options and ecosystem responses. African savanna, because of its vast extent, is recognized as both an important carbon pool and representing a potentially important carbon sink (Chaps. 2 and 15). More arid environments, such as the Nama-Karoo biome, have smaller carbon stocks, but their carbon dynamics are very poorly understood (Chap. 17). Supporting carbon flux monitoring within the savanna has been an important component of the SPACES I and II programs (Chaps. 17 and 30).

Carbon dynamics in the marine environment of southern Africa are poorly understood, despite the west coast of southern Africa being an important upwelling system with exceptionally high net primary production. Understanding the fate of this biomass in terms of the role it plays as a major carbon sink is of global importance (Chap. 2 and 25).

1.6 Science in Support of Ecosystem Management

Part III of the book (Chaps. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 24 and 25) focuses on science in support of ecosystem management. This section is focused on the policy relevant science to assist in the management of the southern African marine, freshwater and terrestrial ecosystems. It is grouped into four partly overlapping themes with each then developed through a number of interlinked chapters. Within the themes, chapters move from a general description of the sector and the threats that global change is placing on the sector to more focused discussions on potential policy and management interventions. The themes range from the marine and freshwater systems, through general terrestrial consideration, to rangelands and finally agricultural and agroforestry considerations. This represents a transition from management of relatively natural systems through partly transformed rangeland systems to fully transformed and intensely managed agricultural systems.

Human actions are having profound impacts on the natural ecosystems. Overfishing and natural variability have fundamentally changed and reduced fish stocks from the production rich west coast of southern Africa. Understanding these changes

and how climate change will impact on these already vulnerable resources is considered in (Chaps. 2, 11 and 25) (Fig. 1.3). To understand how these systems will change requires both an understanding of the drivers of upwell systems (Chaps. 8 and 9) as well as understanding the trophic ecology of the marine production system (Chaps. 2 and 25). This will have important implications for the management of the west coast fisheries industry, as well as potentially changing the so-called CO_2 pump and the degree to which this system sequesters carbon (Chap. 25). At the biome level, climate change may result in a shift in the spatial distribution of terrestrial biomes, favoring some and restricting others. These potential changes are explored in (Chap. 14).

Humans live on land and within the southern African region, and most human activity is related to the terrestrial landscape. The terrestrial landscape is also subdivided into areas with different levels of direct use and management. Understanding probable global change impacts on the terrestrial environment is therefore critical for its long-term sustainable management. Despite having been identified as an issue over a century ago, land degradation and more especially soil erosion, remains an important management consideration and this is instigated in (Chap. 13).

The predominant use of the natural or seminatural habitats of southern Africa is as rangeland, i.e., land used to support either or both livestock or indigenous game management. An overview of the savanna rangeland and its current threats is given in Chap. 15, and responses of savanna rangeland to drought are investigated in (Chap. 16). One strategy advocated for dealing with the management of arid savanna areas is to use these areas for wildlife management rather than livestock. This switch from livestock to wildlife has been observed to have taken place over the past few decades and a case study from the Etosha region of Namibia is investigated in (Chap. 18). Rates of primary production and how this may change given climate change are critical concerns for understanding climate change impacts. Long-term carbon flux measurements in the region are scarce, though there have been measurements in the savanna dating back to about the year 2000. Measurements in the vast Nama Karoo areas are fewer and this is explored in (Chap. 17).

Livestock management remains a key use of rangeland throughout the region and is of especial importance to Bantu tribes as in addition to the financial aspects, there are strong cultural aspects to livestock. The communal tenure of many traditional areas adds great complexity to achieving sustainable livestock management (Chap. 17). A feature of the savanna landscape is the long winter dry periods during which time grazing becomes scarce, especially during drought periods. Chapter 19 considers dealing with the feed gaps in such systems.

Although livestock management is important across most of the subregion, in areas with sufficient rain to support cropping, agriculture field crops become important as a livelihood strategy. Climate change is expected to have negative impacts on cropping due to general decline in precipitation over much of the region and longer and more frequent droughts. Chapter 20 provides an overview of the agricultural land-use systems of the region and the agricultural challenges that are being faced. The challenges are the development of integrated cultural landscapes, providing food security, ecosystem services and saving biodiversity.

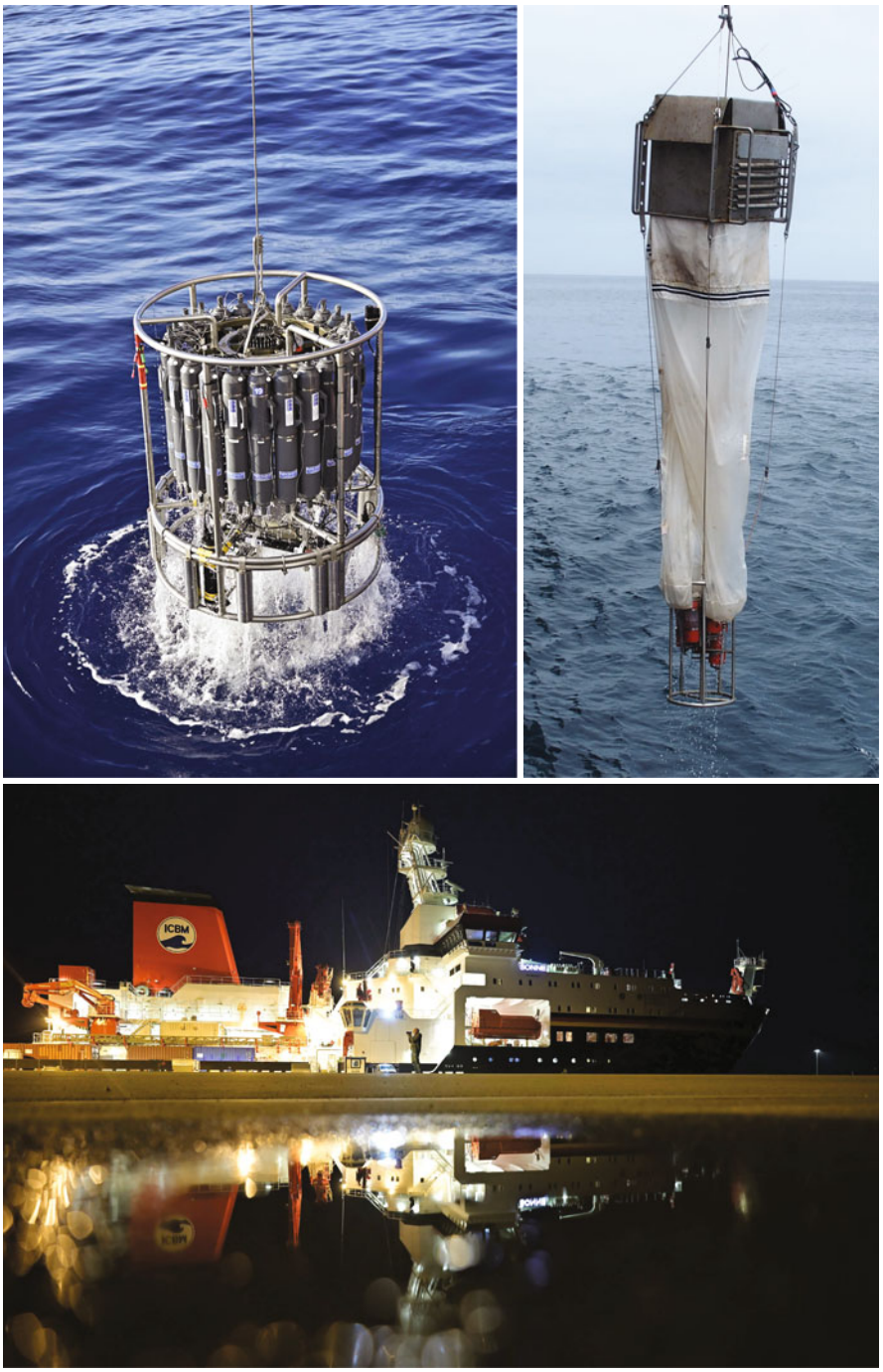

Fig. 1.3 An important component of the spaces program was the extensive use of ship-based programs to sample biotic and abiotic component of the marine environment. Photos Zankl (1,3) and AF Sell (2)

In this context, agroforestry and other sustainable agricultural technologies are identified as potential adaptation opportunities (Chaps. 21 and 23). Chapter 22 considers macadamia, a crop growing in importance for both small-scale and large-scale farmers as a case study for impacts of climate change. In Chap. 23, overarching technology improvements and innovative strategies for small-scale farmers land management are considered.

1.7 Monitoring

Part IV of the book considers a number of emerging tools and processes for improved monitoring and modeling of the southern African environment (Chaps. 24, 25, 26, 27, 28, 29 and 30).

As discussed above, southern Africa has extensive legacy data that makes ongoing research in the region easier. However, maintaining and expanding monitoring networks is critical given the rapid changes that are being observed due to global change forces. New and cost-effective monitoring tools are also constantly emerging and evolving. Chapters 24 and 29 consider the emergence of new capability from remotely sensed products, while Chap. 30 considers South Africa's network of field-based data monitoring stations.

Marine monitoring for a better understanding of the primary productivity and carbon balances in the west coast upwelling systems is discussed in (Chap. 25), while (Chap. 26) considers the modeling of net primary production (NPP) in the terrestrial environment using both satellite-based and -modeled approaches.

The sediments in wetlands, estuaries and other coastal areas can provide long-term historical data based on pollutants and biological material that has been deposited. This can be interpreted both to know the state of the current environment (Chap. 27) and to reconstruct histories of based land cover (Chap. 28).

Chapter 29 considers how observational data can be used in support of policy, and Chap. 30 discusses research infrastructures for long-term environmental observation with a focus on greenhouse gas measurements.

1.8 Synthesis and Outlook

Section 1.5 of the book is a short synthesis of results. It contains results for a small study that reviewed lessons from north-south collaboration projects (Chap. 31). Overarching messages emerging from the research studies as well as suggestions for the future are given in Chap. 32.

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