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3 Environmental Challenges to Meeting Sustainable Development Goals in Southern Africa

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Abstract

There is an inextricable link between ecosystem integrity and the potential for achieving sustainable development goals (SDG). This chapter highlights key ecosystem threats and their drivers within the southern African regional context to emphasize the role of earth system science in supporting the achievement of regional sustainable development goals. It describes how some major anthropogenic threats have unfolded in terrestrial, aquatic and marine ecosystems of the region. Earth system science is increasingly contributing to understanding how globally driven climate and environmental changes threaten these ecosystems, and in turn how these impact people's livelihoods. Long-term changes in rainfall variability, concomitant disruption of hydrological balances, impacts on ocean chemistry, together with more immediate impacts on the frequency and magnitude of extreme climate events are some of the critical global change drivers. While terrestrial ecosystems are already faced with encroachment by novel species, characterized by the proliferation of both invasive alien and endemic woody species, freshwater and marine ecosystems appear more immediately threatened by more local impacts, such as the accumulation of contaminants. Overall, predicted climate and environmental changes are projected to hamper

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development trajectories and poverty reduction efforts, and possibly exacerbate adverse impacts on human livelihoods.

3.1 Introduction

Southern Africa's terrestrial, freshwater and marine ecosystems are highly diverse, unique in their biodiversity as described in Chap. 2 and of great regional significance to human livelihoods locally and regionally (IPBES 2019). This region also plays a role in global environmental sustainability, for example, through feedbacks via the carbon cycle, and therefore has global socioeconomic importance (Darwall et al. 2009; Davis-Reddy et al. 2017). Building an understanding of the trends in impacts and their effects in this region is of importance from the local to global level. Fundamental and applied science in this region, as conducted under the SPACES program, addresses information needs to support key environmental policy efforts, and in particular, the Sustainable Development Goals. The protection of life under water and on land remains one of the key strategic imperatives for most countries in the southern African region as expressed by SDG 14 (Life below water) and SDG 15 (Life on land), respectively.

SDG 14 seeks to conserve and sustainably use the oceans, seas and marine resources for sustainable development. SDG 15 focuses on protecting, restoring and promoting sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halting and reversing land degradation and reducing biodiversity loss. Despite the critical role ecosystems play to sustain livelihoods and life on earth, these systems are increasingly threatened by the growing human population through habitat destruction or degradation, overharvesting and pollution (i.e., air, water and land) (Darwall et al. 2009; Galvani et al. 2016). These threats are superimposed on climate change and the associated extreme events (Dudgeon et al. 2006; IPCC 2007a, 2007b). For terrestrial ecosystem, climate change-related hazards include droughts, floods, heat waves and wildfires, occurring at a global scale, while for marine ecosystem of concern is ocean chemistry modification and sea-level rise which comes at a risk of coastal ecological infrastructure erosion (Darwall et al. 2009; McBean and Ajibade 2009; Kusangaya et al. 2014; Galvani et al. 2016). These risks are highlighted in SDG 13, focused on action to combat climate change and its impacts as well as to build resilience in responding to climate-related hazards and natural disasters. In southern Africa, these three SDG efforts (13, 14 and 15) are thus linked and mutually supportive.

This chapter considers how selected threats to terrestrial, freshwater and marine ecosystems may impede progress in attaining targets associated with these three SDGs. The chapter provides illustrative cases on the local relevance of these SDGs in some of the southern African countries (land areas south of 17° S) and discusses these briefly using empirical evidence on how ecosystems have been and are being modified, and the drivers behind these trends.

The chapter proposes that climate change and anthropogenic activities are the major long-term drivers threatening ecosystem function and the persistence of biodiversity in this region. A vast body of literature has documented the impacts of climate change on people's livelihoods (IPCC 2012) and illustrates how human-induced changes are creating conditions for unsustainable rapid changes in ecosystems despite some evidence for natural adaptive responses via biological evolution. Adverse trends include the worldwide deterioration of biodiversity, ecosystem functioning and ecosystem services (IPBES 2019). It is anticipated that climate and environmental change will hamper poverty reduction, or even exacerbate poverty in some if not all of its dimensions (IPBES 2019).

3.2 Ecosystems and Sustainable Development Goals Nexus

The year 2015 witnessed the convergence of world leaders adopting 17 Sustainable Development Goals (SDGs) that aim to "free humanity from poverty, secure a healthy planet for future generations, and build peaceful, inclusive societies as a foundation for ensuring lives of dignity for all" (Fig. 3.1, UN 2016). These goals are supported by 169 targets with over 200 indicators. All SDGs interact with one another, but since they are not by design an integrated set of global priorities and objectives (e.g., Nilsson et al. 2016), their interactions are complex and not always mutually supportive (Fonseca et al. 2020). The International Council for Science (ICS) explored the nature of interlinkages between the SDGs determining to what extent they reinforce or conflict with each other and found that SDG 2 (zero hunger), SDG 3 (good health and wellbeing), SDG 7 (affordable and clean energy), SDG 14 (life below water) and SDG 15 (life on land) were found to be the most synergistic with other goals (Griggs et al. 2017). This chapter focuses on some examples of how the "earth system science-focused" SDG14 and 15, whose scope covers issues of water and land-based systems respectively, provide a context for fundamental and applied science addressing the main ecosystem types covered in this book and the approaches through which these may be productively interrogated, i.e., terrestrial, aquatic ecosystems and ocean ecosystems and their inherent services. Southern African terrestrial biota has been classified variously into biomes and their marine biota into ecologically similar regions (see Chap. 2). In this chapter, we provide indicative examples of specific threats in the context of these ecological units.

Southern African ecosystems are found predominantly across tropical and subtropical climates, but with significant regions that fall within temperate, arid and hyperarid climate zones and even including an appreciably sized Mediterranean-type climatic zone in its southwestern reaches (Chap. 2, Midgley and Bond 2015). The subcontinent and its adjacent marine waters host a diversity of ecosystems, most of which are still relatively intact with reference to their preanthropogenic biodiversity (Chap. 2, Scholes and Biggs 2005). The evolutionary legacy of this region remains largely preserved, with unique elements of fauna and flora relatively well represented in an extensive conservation-based spatial network (Pio et al. 2014). This globally valuable resource represents a complex history of evolution,

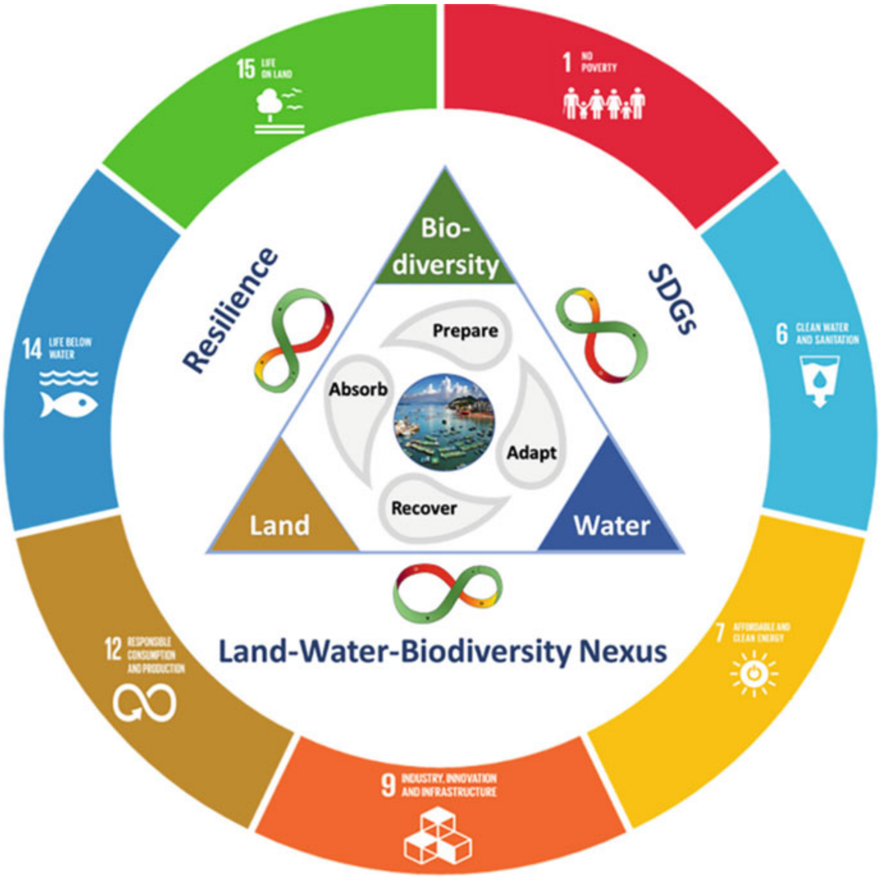

Fig. 3.1 The interaction between the SDGs, the land–water–biodiversity nexus and resilience (UN 2016)

for example, with arid and semiarid biomes retaining evidence of both ancient and recent diversification of desert groups (Klak et al. 2004), and fire-dependent C4 grasses that appear to have diversified extensively in association with changes in atmospheric CO_2 and climatic conditions (Spriggs et al. 2014). Freshwater biodiversity on land is also exceptional, with cichlids being an outstanding example (Zahradníčková et al. 2016). The southern African region is characterized by freshwater biomes including rivers such as the Zambezi, Orange River and Okavango Delta which coexist with azonal wetland ecosystems to support the associated biodiversity compositions. Along the coastal regions of southern Africa, marine biodiversity shows exceptional richness, also largely intact and with an expanding conservation effort showing some successes (Griffiths et al. 2000; Sowman et al. 2011). Biodiversity thus represents an extremely useful metric by which the successful achievement of goals in the nexus between SDGs 14 and 15, and sustainable development policy, can be assessed.

3.3 Drivers of Change, Typical Threats and SDG Implications

Southern African ecosystems are locally and regionally under threat from a range of climatic and nonclimatic drivers. While climate change trends and their impacts are already being detected in the region, local and direct impacts due to human use of ecosystems and biodiversity are well-known and extensive and represent critical short and medium-term pressures. These include land-use change due to deforestation and agricultural development, urbanization, environmental degradation (including freshwater quality and soil condition), illegal poaching, the informal and commercial overutilization of wild resources and invasions by alien species (IPCC 2021).

Terrestrial freshwater ecosystems are locally threatened by impacts such as canalization, inappropriate afforestation, deforestation and abstraction of water for agricultural, industrial and domestic activities (Meybeck 2003; Vörösmarty et al. 2004; Milly et al. 2008; Rahel and Olden 2008) that result in pollution and contamination of aquatic environments (Bashir et al. 2020). Marine systems are impacted largely by overharvesting and somewhat by pollution (Chaps. 2 and 8). Table 3.1 provides classic examples of ecosystem threats in the region.

Historical impacts over the past two centuries have mainly been due to land-use change and in the overutilization of ecosystems and wild species. Land-use change and climate change have been identified to be major drivers underlying the potential loss of biodiversity in southern Africa (MA 2005). While the region is one of the highly biodiverse regions of the world (WCMC 2000), biodiversity loss is a key concern given the impact on ecosystem functioning (Biggs et al. 2008). For example, Scholes and Biggs (2005) observed a 16% decline in wild species populations relative to the precolonial era, with a 95% confidence range of ±7%. These analyses averaged population sizes of the remaining plant and vertebrate groups in the major terrestrial biomes of southern Africa including the following countries (results brackets): Botswana (0.89), Lesotho (0.69), Mozambique (0.89), Namibia (0.91), South Africa (0.80), Swaziland (0.72) and Zimbabwe (0.76).

3.4 Natural Habitat Loss, Transformation and Degradation

3.4.1 Anthropogenic Land-Use Change

3.4.1.1 Transformation for Croplands and Commercial Timber Plantations

Population growth and economic growth are major drivers of land-use change, which in turn drive changes in the quantity and flow characteristics of water in lakes and river systems. In South Africa, a recent study showed 0.12% natural

Table 3.1 Select examples of studies of terrestrial and aquatic ecosystems threats within the Southern Africa context

Threats to ecosystems	Type of change to ecosystems	Ecosystem type	Country of the study	Case studies/Evidence
Climate change threats				
Droughts	Destruction of wetland ecosystem services. For example, the habitat and breeding areas of endangered crane bird species were perceived to be dwindling, affecting their reproduction.	Savanna	Zimbabwe	Severe 1968, 1973, 1982, 2004 1991/1992 season and 2012 seasons (Nangombe 2015)
Floods	More intense rainfall will cause soil capping, flash flooding, erosion and poor recharge.	Savanna Grasslands	Mozambique, Malawi, Zimbabwe	Cyclone Idai, 2019 and Tropical Storm Anna 2022.
Heat waves and Wildfires	Clearing of natural vegetation, destruction of natural habitats for wild species	Forests and Grasslands	South Africa	Western Cape, Central Karoo.
Terrestrial ecosystem threats: Anthropogenic land-use change				
Policy implementation	For example, Agrarian reform			
Deforestation	For example, impacts on biodiversity, impacts on ecosystem services, desertification	Forests and Woodlands	Southern Africa	In southern Africa, both the forests and woodlands cover 40% of the region and about 25,000 to 50,000 km^2 being cleared yearly at a rate exceeding regrowth (Scholes and Biggs 2004).
Bush encroachment	Increase of invasive or alien species outcompeting native plant species (e.g., *Seriphium plumosum* and *Acacia mearnsii*). Abandoned rainfed agriculture in rural areas are now hotspots for bush encroachment (e.g., Acacia species)	Grassland, Savanna	South Africa, Namibia	Invasive and alien plant species are reducing grazing resources in Southern Africa. While abandoned rainfed farms are hotspots for bush encroachment (Cho and Ramoelo 2019).

Alien invasive species on land	Abandoned land, degraded environment through overgrazing and high frequency, and inappropriate fire.	Grassland	Southern African savanna	*Lantana camara* invasion in Matabeleland South Province of Zimbabwe (Ncube et al. 2020).
Biodiversity loss on land	Clearing of natural vegetation for agriculture and human settlement development	All	Africa, SA	IPBES Africa Assessment report (Skowno et al. 2021)
Freshwater and marine ecosystem threats				
Flow alteration	Flow alteration in rivers and wetlands due to extraction of water, building of dams, interbasin transfers, urbanization, planting of higher water use crops (e.g., plantation forests, sugarcane), and climate change, resulting in changes in aquatic habitat availability.	Freshwater	Southern Africa	Impact of: • Extraction of water and building dams (Döll et al. 2009). • Snaddon et al. (1998). • Plantation forests in South Africa (Scott et al. 2000). • Climate change across Southern Africa (Kusangaya et al. 2014; Banze et al. 2018).
Overharvesting of aquatic species	Decline in aquatic species.	Freshwater + Marine	South Africa	
Sea-level rise	Rising sea levels and (periodically) low river discharges are expected to increase freshwater salinity and soil salinity in coastal areas due to saltwater intrusion from the seaside.	Marine	Namibia	Boyer and Hampton (2001) observed a major decrease in Namibian sardine population and many other resources, which was associated with wide-scale advection of low-oxygen water into the northern Benguela from the Angola Dome in 1994, and the subsequent Benguela Niño of 1995.

(continued)

Table 3.1 (continued)

Threats to ecosystems	Type of change to ecosystems	Ecosystem type	Country of the study	Case studies/Evidence
Pollution	Pollution due to acid mine drainage, agricultural runoff, industrial effluent or poor management of sewage infrastructure.	Freshwater	South Africa	McCarthy (2011) described the impact of gold and coal mining on acid mine drainage in the Vaal River catchment. Oberholster et al. (2021) found that water quality in the Loskop Dam is degraded due to discharge from overloaded wastewater treatment plants and acid mine drainage, with levels of numerous chemical variables exceeding local and international guidelines NBA.
Biodiversity loss in aquatic systems	High variability of rainfall and droughts create diverse freshwater ecosystems. For example, inland wetlands are classified into 135 distinct types, while 222 distinct types were classified from rivers.	Freshwater	South Africa	

habitat were lost between 1990 and 2014 and accelerated to 0.24% between 2014 and 2018 (Skowno et al. 2021). The major drivers of natural habitat loss were settlement, agricultural and plantation forestry expansions (Skowno et al. 2021). The expansion of agriculture to feed a growing and developing population impacts water availability through the introduction of livestock, irrigation, with some rainfed crops and forest plantations having higher rates of transpiration and interception than the native vegetation (Jewitt 2006). In southern Africa, forests and woodlands cover 40% of the region and about 25,000 to 50,000 km^2 being cleared yearly at a rate exceeding regrowth (Scholes and Biggs 2004). Between 2001 and 2019, South Africa lost about 1.42 million hectares of tree cover, though most of this was from plantation forests, with only 11.9 Kha of indigenous forest loss. Forest loss in Mozambique was 3.8 Mha and 224 Kha in Zimbabwe over this same period (GFW 2022).

Wetlands are frequently drained to facilitate the planting of crops or other uses of land, thus significantly altering the hydrological characteristics of these unique environments (Vörösmarty et al. 2004; Darwall et al. 2009). The bidirectional interactions between the pursuit of food goals (SDG 2) and land and ecosystems (SDG 15) are nuanced and asymmetrical. For example, while land and its ecosystems clearly sustain food systems (with mostly positive interactions), food production often generates important land-related trade-offs which can have both positive and negative interactions (Pham-Truffert et al. 2020).

3.4.1.2 Transformation for Infrastructure (e.g., Hydropower, Dams and Urbanization)

The development of water resources infrastructure, such as dams, canals, wastewater treatment works and interbasin transfers, is necessary to sustain growing populations and economies. Perhaps, the greatest threat to imperiled freshwater species exists in the form of massive hydropower development projects currently underway in much of the developing world (Dudgeon 1999, 2000). This infrastructure results in the regulation of flows in streams and rivers, and the alteration of aquatic habitats (Meybeck 2003; Rolls et al. 2012). Environmental needs are often not prioritized, leading to overallocation of water resources (Poff et al. 2003). These problems are mitigated to some extent by the introduction of environmental flow requirements.

Urbanization results in the development of impervious areas and accompanying storm water infrastructure which rapidly discharges rainwater into streams and rivers, thus altering flow regimes (Walsh et al. 2005). Impervious areas and rapid discharge of water also hinder groundwater recharge, leading to less sustained base flows in river systems (Rolls et al. 2012). Overabstraction of groundwater, whether in urban areas or for agricultural use, also results in reduced base flows (Mccallum et al. 2013).

3.4.1.3 Policy Implementation Including Agrarian Reform

Land reform is a significant process throughout southern Africa that is unfolding rapidly with significant implications for food security (SDG6) but also manifold impacts relevant to SDG 15. The evolution of land reform programs and rangeland policy evolves over time in countries such as Zimbabwe and South Africa. Sibanda and Dube (2015) assessed the aftermath of land reform in Zimbabwe and found significant changes in land use and land cover between 2000 and 2010 with an increase in agricultural areas and a decrease in woodlands, specifically in newly resettled areas. In the same study, tree species diversity was found to be higher in unsettled areas relative to the post-redistribution resettled areas.

3.4.2 Woody Plant Proliferation

The direct effects of land-use change have also been coupled with climate and atmospheric CO_2 changes that appear to have increased rates of bush encroachment and the proliferation of invasive alien species (Chaps. 14, 15 and 16; Sibanda and Dube 2015). Over time, there has been an increase in woody plant cover across the terrestrial systems of Southern Africa causing a challenge in meeting the sustainable development goals. This proliferation in woody cover is both by bush encroachment and a rapid expansion of alien invasion plant species. The extent of woody proliferation in southern Africa is widespread as seen in Fig. 3.2, where Venter et al. (2018) showed a net greening in all southern African countries except for Madagascar where deforestation is extensive.

Driven by a combination of land use (overgrazing, fire suppression), climatic change regimes and rise in CO_2, bush encroachment is one of the most complex degradation phenomena in southern Africa (Bond et al. 2003; Kgope et al. 2010; Bond and Midgley 2012; Rohde and Hoffman 2012) and is discussed in greater detail in Chap. 15. It is defined as the directional increase in the cover of indigenous woody species in savanna and the invasion of the formerly grassland

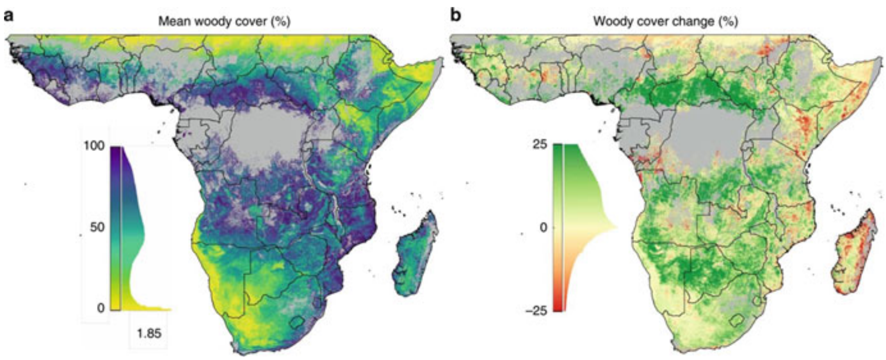

Fig. 3.2 (Venter et al. 2018): Woody plant cover dynamics over sub-Saharan Africa. Satellite observations of 30 years of fractional woody plant cover (**a**) reveal a dominant increasing trend (derived from the slope of the linear trend line between 1986 and 2016) (**b**). Histograms alongside color scales indicate data distributions. Gray areas were masked from the analysis and represent urban surfaces, wetland, cropland and forest (areas >40% cover by trees >5 m). Maps were constructed in Google Earth Engine (Figure and caption taken from Venter et al. (2018)

biome (O'Connor et al. 2014). The largely documented encroacher species in southern Africa are mostly nitrogen fixing legumes such as *Vachellia* and *Senegalia* (formerly *Acacia*) species, *Dichrostachys cinerea* and *Colophospermum mopane*, as well as nonlegumes (among others) such *as Terminalia sericea* and *Seriphium plumosum* (Stevens et al. 2017; Graham et al. 2020; Shikangalah and Mapani 2020; Lewis et al. 2021). Moreover, bush encroachment in South Africa and Namibia is estimated to be 10–20 and 26–30 million hectares, respectively (Bester 1999; Kraaij and Ward 2006; Daryanto et al. 2013; Eldridge et al. 2013). As much as bush encroachment comes with benefits such as the provisioning of woody fuels and woody material for multipurposes as well as the regulation of CO_2 through carbon sequestration, its impact on loss of biodiversity, water and grazing capacity leading to major reductions in meat, milk and other animal products is something to be not overlooked (Tallis and Kareiva 2007; Wigley et al. 2009; Trede and Patt 2015).

3.4.3 Alien Invasive Species

Alien invasive species (AIS) are any nonnative species introduced by humans into the new environment deliberately or nondeliberately. In this chapter, we focus on alien invasive plants AIPs such as aquatic weeds, arable weeds and woody weeds among other AIS such as viruses, fungi, insects and animals (Eschen et al. 2021). The main reasons for the introduction of invasive alien plants are to increase ecosystem services through rehabilitation, agroforestry and some as ornamental plants (e.g., *Lantana camara*) while others get introduced by accident (e.g., *Chromolaena odorata*) (Shackleton et al. 2019). *Prosopis,* one of the most widespread invasive species in southern Africa, was introduced into countries such as South Africa, Namibia and Botswana to provide ecosystem services including fuel wood and fodder. Similarly, the invasive Acacia species in Madagascar and South Africa have been introduced to provide timber, pulp for paper, bark for tannins and fuel wood (de Neergaard et al. 2005; Kull et al. 2007). *Opuntia ficus-indica* in South Africa is mainly used as fodder and food source (Henderson 2007; Shackleton et al. 2011).

As with many alien species around the world, these introduced IAPs become problematic by outcompeting the native species, spreading quickly (due to lack of biocontrol agents) and negatively affecting ecosystem services and livelihoods (van Wilgen et al. 2018; Shackleton et al. 2019). IAPs such as *Prosopis*, *Chromolaena* and *Lantana* have been documented to have severe impacts on the terrestrial system by reducing grazing capacity, biodiversity and moisture availability in these dry systems (Shackleton et al. 2014; Shackleton et al. 2019; Byabasaija et al. 2020; Kashe et al. 2020). *Prosopis,* which has long tap root that can utilize deep water sources, has spread rapidly in dry systems forming impenetrable thorny thickets that hinder maneuverability and injure animals (Hussain et al. 2020). IAPs in grasslands and Fynbos biomes have detrimental effects on stream flow due to high transpiration and hence reduce the country's mean annual runoff (Enright 2000). Le Maitre et al. (2016) estimated an annual water loss of 1444 million m^3 in South Africa largely by invasive *Acacias* (*Acacia mearnsii, A. dealbata* and *A. decurrens*) (34%) followed by *Pinus* species (19.3%) and *Eucalyptus* species (15.8%) among others.

Economical loses associated with invasive species in South Africa are estimated at US$1400 million in water resources, US$14 million y^{-1} for tourism and recreational and about US$ 52 ha^{-1} in pollination services (Pejchar and Mooney 2009; Nampala 2020). The increased biomass of the invasive species also increases the intensity of wildfires, which increases the damage from fire and the ability to control the fires. These negative effects, therefore, undermine the efforts to meet the Sustainable Development Goals (SDGs)-. Many programs have been put in place to eradicate invasive species before they become more widespread (Nampala 2020). Using biocontrol, such as *Dactylopius opuntiae* and *Opuntia ficus-indica,* in South Africa is now regarded as stable and desirable for food and fodder (Shackleton et al. 2011; Brown et al. 1985; Zimmermann and Moran 1991). The three phases of control that are effective are initial control (e.g., using biocontrol), follow-up (controlling seedlings, root suckers and regrowth) and maintenance (sustaining low and decreasing IAP numbers with annual control) (Martens et al. 2021).

3.5 Threats to Freshwater and Marine Ecosystem

Many aquatic species and ecosystems face an uncertain future. As human populations continue to expand their influence into the Earth's aquatic frontiers, conservation biologists are increasingly concerned about the implications for aquatic systems. In addition to the ongoing persistence of historically important threats facing aquatic environments, new stressors, including emerging diseases, the increasing taxonomic scope and ecological influence of invasive species, new industries and the accelerating trajectory of climate change, have the potential to radically alter the biological composition and ecological functioning of aquatic systems. More specifically, these alterations may manifest themselves in changes in aquatic biodiversity, individual life history patterns, communities, species distribution and range, and the extinction of vulnerable species (Dallas and Rivers-Moore 2014).

3.5.1 Overharvesting of Aquatic Species

Overharvesting of aquatic food sources is a major driver of the region's freshwater and marine ecosystem degradation, with the rich fish diversity of the region a significant target of increasingly effective extractive harvesting efforts mainly in the ocean. One of the most significant results has been the so-called "fishing-down" process illustrated by a historical decline in mean body size of the main harvested resources (Chaps. 11 and 25).

3.5.2 Coastal Impacts

Coastal regions will experience degradation from sea-level rise (SLR) combined with storm swells. Coral reefs will experience bleaching attributed to warmer oceans. Rising sea levels and (periodically) low river discharges are expected to increase soil salinity in coastal areas due to salt-water intrusion from the seaside. Boyer and Hampton (2001) observed a major decrease in Namibian sardine population and many other resources, which was associated with wide-scale advection of low-oxygen water into the northern Benguela from the Angola Dome in 1994 and the subsequent Benguela Niño of 1995. Some South African sea bird species have moved farther south over recent decades, partly due to climate change, though land-use change may also have contributed to this migration (Hockey and Midgley 2009; Hockey et al. 2011). It is considered that South African seabirds could be a valuable signal for climate change, particularly given the changes induced on prey species related to changes in physical oceanography. However deeper understanding of the ecology is needed so as to separate the influences of climate parameters from other environmental drivers (Crawford and Altwegg 2009).

3.5.3 Pollution

Aquatic ecosystems are the ultimate sinks for contaminants in the landscape (Bashir et al. 2020). Water pollution is the outcome of human activities such as urbanization, industrialization, mining and agriculture (Chap. 27). Excess pesticides and fertilizers, and sewage from residential and industrial areas, ultimately find their way to the aquatic environment, leading to eutrophication of freshwater ecosystems. Most of the great lakes of Southern Africa are in danger, with the extinction of as many as 200 fish species being recorded in Lake Victoria (Ryan 2020). The Vaal River catchment in South Africa is a hotspot for pollution due to acid mine drainage (McCarthy 2011), agricultural runoff and sewage leaks resulting from poor maintenance of infrastructure. Higher water temperatures, increased precipitation intensity and longer periods of low flows under climate change are expected to aggravate many forms of water pollution. These may include sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution (Bates et al. 2008).

Although marine systems are generally larger and less constrained than riverine habitats, the industrialization of offshore waters through oil and gas platforms in some areas has been on a remarkable scale, while the increasing oil spills have posed a huge threat to ecosystems. A case in point is the devastation of the Mauritius oil spill with an estimated 1000 tons of oil leaking into the Indian Ocean, severely contaminating Mauritius's shoreline and lagoons (Shaama et al. 2020).

3.6 Climate Change, a Threat to Biodiversity and Ecosystem Functioning

Global climate change is likely to lead to significant changes across the southern African biomes, and seasonal rainfall will have implication on the ecosystems services they provide through the alteration of existing habitats, organism extinctions, water scarcity, and biodiversity and vegetation loss (Chaps. 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23). Southern Africa is anticipated to become hotter and dryer and discussed in detail in (Chaps. 6 and 7).

Extreme weather events together with anthropogenic activities might threaten the sustainability of Southern African ecosystem affecting species distribution through shifting habitat, changing the migration patterns, geographic range, emerging alien species and changing organisms' seasonal activity by altering life cycles of many terrestrial and marine species (Chaps. 14 and 26; UNEP 2012).

Projected increases in the likelihood of floods suggest a possibility of changes to the flow regimes in rivers (Dudgeon et al. 2006). Groundwater, which is critical to maintaining "low flows" and aquatic habitats during the drier periods, is likely to be impacted by changes in recharge rates due to increases in floods and droughts. Changes in flow regimes may affect channel geomorphology, longitudinal and lateral connectivity, aquatic habitat and biotic composition. Systematic quantification of loss and damage to ecological and coastal infrastructure around the riverbanks and coastal regions in Southern Africa could significantly inform estimation of adaptation needs and hence bolster attainment of SDG 15.

Regardless of which Shared Socioeconomic Pathway is used for predicting climate futures, current best estimates are that the southern Africa regions are likely to experience increased drought relative to 1850–1900 (IPCC 2021). Hydrological impacts from increased drought include reduced stream flow, resulting in degreased water storage in dams (Forzieri et al. 2014; Trambauer et al. 2014), long-term declines in rainfall (Rahman et al. 2015; Kruger and Nxumalo 2017), increased evaporation from water bodies and increased plant transpiration (Meybeck 2003). The reductions in stream flow and storage will be accompanied by climatically induced increases in the demand for water in environments such as agriculture (especially in terms of irrigation) and, to a lesser extent, power generation (Brown et al. 2013).

The Southern African region is considered to be water stressed, with South Africa and Namibia being the worst affected. In South Africa, more than half of the country's water management areas are in deficit (Alcamo and Henrichs 2002). Southern Africa has also been identified as a region characterized by a relatively high degree of flow alteration caused by the construction of dams (Döll et al. 2009). A review of studies on the impacts of climate change on stream flow found that reductions are projected for many basins in southern Africa including the Zambezi, Pungwe, Limpopo, Thukela, Okavango, Ruvhuma, Orange, Gwayi, Odzi and Sebakwe (Kusangaya et al. 2014). Given these patterns and the growing populations and economies in the region, the ability of aquatic ecosystems to provide ecosystem services is considered under threat. A challenge to the management of water in the region is the transboundary nature of many of the river basins, with 12 such basins existing across the Southern African Development Community countries (Kusangaya et al. 2014).

In the southern African region, drought occurred simultaneously with heat waves and the combined contributes to crop losses (Engelbrecht and Scholes 2021), stresses on regional water supplies and to widespread livestock mortality (Sivakumar 2007). In addition, reduced rainfall and increased drought frequency could result in a reduction in forage quality and quantity, hence affecting the dynamics and ecosystem function for wildlife and the vegetation (Nangombe 2015).

Heat waves are defined as warm extreme temperature events or excessively hot weather (Nairn and Fawcett 2013) that have socioeconomic and ecological impacts. Extreme temperatures are a threat to development in Southern Africa. The region experiences increased frequency of fires due to drastic increases in heat waves events (Engelbrecht et al. 2015; Garland et al. 2015; Mbokodo et al. 2020). Garland et al. (2015) reported warming over southern African region using the Conformal Cubic Atmospheric Model (CCAM) forced with the A2 emission scenario. Their model results suggested that extreme apparent temperature days in Africa are projected to increase in the future climate. This was in accord with Engelbrecht et al. (2015) who also projected substantial increases in the annual number of heat waves days over southern Africa. Moreover, a case study by Mbokodo et al. (2020) projected that there will be an increase in the number of hot extreme events in the most parts of the interior of South Africa throughout the year 2070–2099, while the number of cold events is decreasing. As a developing region (southern Africa), the substantial changes in the number of extreme temperature and heat wave events are a threat to a number of sectors including ecosystems, agriculture, water resources, energy demand and human health (Zuo et al. 2015).

For tropical and subtropical biomes, studies suggest that large landscapes in sub-Saharan Africa are prone to relatively fast shifts in vegetation structure and biodiversity due, in part, to shifts in fire regimes (Chap. 14, Lehmann et al. 2011; Bond and Midgley 2012; Moncrieff et al. 2014).

Foden et al. (2007) conducted a study on the distribution of *Aloe dichotoma* and observed changes in species distributions based on ~100-year (1904–2002) observational records. This study provides evidence that the range of a Namib Desert tree is shifting poleward, with extinction along trailing edge exceeding colonization along leading edge. Similar impacts are anticipated for countless other species.

Decision by African policy makers and stakeholders toward the attainment of SDG 15 goals must consider making urgent choices relating to trade-offs between biodiversity, carbon sequestration capacity of biomes and their direct ecosystems service. Such a decision could benefit from mechanistic studies that consider important plant functional types, herbivory and climate feedbacks (Huntley et al.

2014). Investment in early warning systems could help curb some of the major losses on ecosystems, especially around ecosystems that host critically endangered species.

3.7 An Analysis of SDGs and Ecosystem Threats

Changes in the biophysical environment, including droughts, floods, water quantity and quality, and degrading ecosystems, are expected to affect opportunities for people to generate income thus altering the synergistic nature of the SDGs. Interactions between targets for SDG 14 and SDG 15 with other SDGs show that generally, there are more synergies between goals and targets than there are trade-offs. Cumulative impacts from direct and indirect (via climate change) human pressures on marine and coastal ecosystems are potentially large and require concerted action in attaining both SDG 14 and SDG 13 (Griggs et al. 2017). The pursuit of food (SDG 2) and energy (SDG 7) goals can cause significant trade-offs with other SDGs, especially water (SDG 6) and ecosystems (SDG 15) (Pham-Truffert et al. 2020). Examples of interactions between SDG 14 and SDG 15 with other SDGs are outlined in Table 3.2.

3.7.1 Policy Implications for Ecosystem Protection and Restoration

Implementation of the adaptation component of the global climate policy is intractably linked to progress the SDG 14 and 15. This chapter posits that adaptation to the impacts of climate change-induced threats, in the least and developing countries in Southern Africa would be constrained without improved access to global climate finance by both private and public institution actors. Adaptation support in a form of technologies and means of implementation, of the global climate policy, would therefore accelerate the two SDGs through: fast tracking of ecosystem restoration and rehabilitation, e.g., nature-based solutions, intensify "working for" projects; protection of coastal settlements, ecological infrastructure and other uses of natural or seminatural ecosystems and landscapes for the delivery of ecosystem services; implementation of climate risk informed land-use planning. Reversal of some of the loss and damage and climate-proofing of infrastructure for all sectors of development (e.g., through improved design of dams, flood drainage and water reservoirs); and tailoring of climate services informed by researchers, service providers and fellow users' communities should not be negotiable.

Table 3.2 Examples of interactions between SDG 14 and SDG 15 with other SDGs

Interactions between SDG 14 and other SDGs	Interactions between SDG 15 and other SDGs
Sustainable management of fisheries in terms of supporting food security. Globally, fisheries play an important role in food security (SDG 2). SDG 14 includes the target to end overfishing and illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plan to support restoring fish stocks in the shorted possible time and to produce the maximum sustainable yield as determined by their biological characteristics (WWF 2017). Water use (SDG 6) can impact the oceans, seas and marine resources referred to in Goal 14. Unregulated sewage disposals into these water bodies, as well as fossil-fuel mining and agricultural activities can have adverse impacts on the marine water resource, including the flora and fauna within it. Oceans and coastal ecosystems both affect and are affected by climate change, and this results in strong synergistic and bidirectional links between SDG 13 and SDG 14 (Griggs et al. 2017). An example of a synergy in achieving SDG 14 and SDG 13 is through conservation of coastal ecosystems acting as blue carbon sinks. A trade-off between SDG 13 and 14 is, for example, based on risks of coastal squeeze when trying to protect coasts from sea-level rise. Climate adaptation and coastal and marine protection measures need to be carefully managed to ensure that they do not conflict.	Life on land (SDG 15) is impacted by the availability and quality of water (SDG 6), as such, SDG 15 sets a two-fold target of protecting inland freshwater ecosystems and the services they provide, and to reduce the impact of invasive alien species on water ecosystems (WWF 2017). While land and its ecosystem services clearly sustain food systems (mostly positive interactions), food production often generates important land-related trade-offs (both positive and negative interactions) (Pham-Truffert et al. 2020). Agricultural intensification rarely leads to positive ecosystem impacts, for example, in some parts of sub-Saharan Africa, promoting food production can also constrain renewable-energy production (SDG 7) and terrestrial ecosystem protection (SDG 15) by competing for water and land (Nilsson et al. 2016). Agriculture's extensive land use also drives biodiversity loss (Lanz et al. 2018), as well as land degradation (Nowak and Schneider 2017). Conversely, limited land availability constrains agricultural production (Nilsson et al. 2016) An example of a positive interaction between SDG 7 and SDG 15 is that of renewable energy which can help decrease the role of firewood as an energy source in southern Africa, and so reduce the dangers of deforestation and help to protect habitats and ecosystems (WWF 2017)

3.8 Conclusion

There is an inextricable link between ecosystem function and the various SDG goals and targets. Invariably global climate change and the projected outlook threaten both the terrestrial and aquatic ecosystems impacting people's livelihoods. It is anticipated that climate and environmental change will hamper poverty reduction, or even exacerbate poverty in some or all of its dimensions. These changes, together with a shortage of adequate coping mechanisms and innovations to adapt to climate change, are to result in a surge in economic and social vulnerability of communities, particularly among the poor. While pollution could be regarded as a historical threat to aquatic biota, and thus outside the realm of a review focused on emerging threats, the scale of pollution impacts is accelerating in parallel with exponential human population growth and demographic population shifts to nearby surface water sources and coastal cities.

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