Chapter 1
Biological Invasions in South Africa: An Overview

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Abstract South Africa has much to offer as a location for the study of biological invasions. It is an ecologically diverse country comprised of nine distinct terrestrial biomes, four recognised marine ecoregions, and two sub-Antarctic Islands. The country has a rich and chequered socio-political history, and a similarly varied history of species introductions. There has been a long tradition of large-scale conservation in the country, and efforts to manage and regulate invasions began in the nineteenth century, with some notable successes, but many setbacks. With the advent of democracy in the early 1990s, South Africa established large alien species control programmes to meet the dual demands of poverty alleviation and conservation, and has since pioneered regulatory approaches to address invasions. In terms of research, South Africa has played an important role in the development of invasion science globally. It continues to have one of the most active communities anywhere in the world, with strengths in theoretical and applied invasion science, and world-leading expertise in specific sub-disciplines (e.g. the classical biological control of invasive plants).

In this introductory chapter to the book "Biological Invasions in South Africa", we highlight key events that have affected biological invasions, their management, and the research conducted over the past two centuries. In so doing, we build on earlier reviews—from a national situational review of the state of knowledge in

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1986, culminating most recently with a comprehensive report on the status of biological invasions and their management at a national level in 2018.

Our book comprises 31 chapters (including this one), divided into seven parts that examine where we have come from, where we are, how we got here, why the issue is important, what we are doing about it, what we have learnt, and where we may be headed.

The book lists over 1400 alien species that have established outside of captivity or cultivation. These species cost the country at least US$1 billion per year (~ZAR 15 billion), and threaten South Africa's unique biodiversity. The introduction and spread of alien species, the impacts that they have had, the benefits that they have brought, and the attempts to manage them have provided many opportunities for research. Documenting what we have learned from this unplanned experiment is a primary goal of this book. We hope this book will allow readers to better understand biological invasions in South Africa, and thereby assist them in responding to the challenge of addressing the problem.

1.1 Why South Africa Is an Interesting Place for Biological Invasions?

South Africa has a rich and varied biodiversity, and a long history of alien species introductions that took place within the context of a complex socio-political environment. South Africa also has a long history of conservation management, as well as a history of regulating and managing biological invasions. Research specifically on biological invasions goes back at least five decades. In this section we review these factors, and argue that, as a result of them, South Africa is a particularly interesting place to study the phenomenon of biological invasions (Fig. 1.1).

1.1.1 A Rich and Varied Biodiversity

South Africa, covering only 0.8% of the earth's terrestrial area, is one of the planet's 18 "megadiverse countries", defined by Conservation International as nations that harbour the majority of Earth's species and high numbers of endemic species. It is home to 23,420 described terrestrial plant species (~6% of the global total; Willis 2017), ~60,000 terrestrial and freshwater invertebrate species (~1% of the global total), 3107 vertebrate species (~6.5% of the global total), 12,000 coastal marine species (~15% of the global total; Le Roux 2002; Griffiths et al. 2010), and ~1.8% of the world's described soil species (Janion-Scheepers et al. 2016)]. 60% of South Africa's terrestrial plants and 70% of its terrestrial and freshwater invertebrates are endemic (Le Roux 2002).

This diversity is partly due to the wide variety of environmental conditions (Wilson et al. 2020a, Chap. 13) that have resulted in continental South Africa's nine terrestrial biomes, ranging from desert to rainforest (Mucina and Rutherford 2006; Fig. 1.2). There are also four recognised marine ecoregions in South Africa

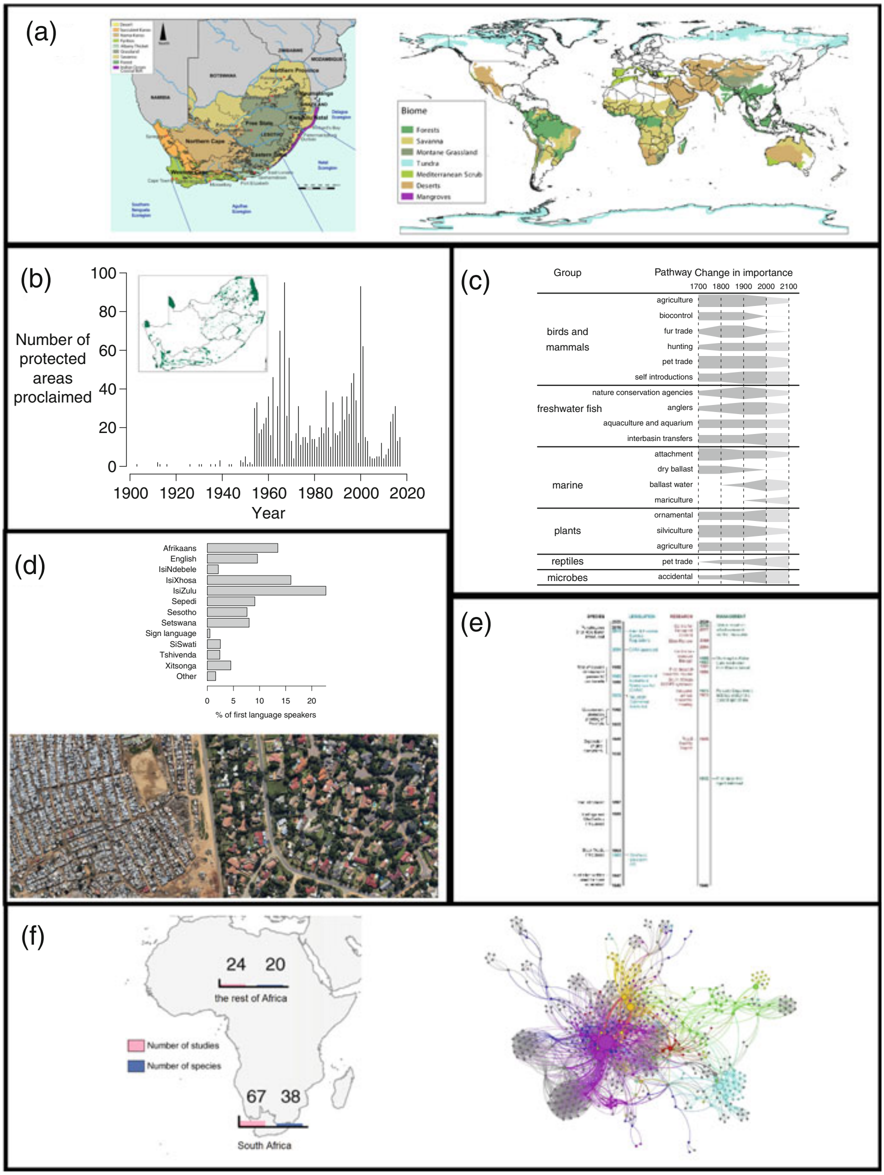

Fig. 1.1 South Africa is a particularly interesting placed to study invasions as it has a rich and varied: (**a**) biodiversity; (**b**) history of biodiversity conservation; (**c**) history of introductions; (**d**) socio-political history; as well as (**e**) a long history of management; and (**f**) a strong research tradition in invasion science. Sources: (**a**) is based on Figs. 1.2 and 1.3. (**b**) the map is courtesy of L. C. Foxcroft and the bar chart drawn by the authors based on data in UNEP-WCMC (2019); (**c**) is redrawn with permission from Richardson et al. (2011b); (**d**) the bar chart shows the proportion of different first language speakers in South Africa (Statistics South Africa 2012), and the photograph is of Kya Sands and Blousbosrand in Gauteng and is from a 2018 Google Earth image; (**e**) Fig. 1.4; (**f**) the relative research output of South Africa vs. the rest of Africa is from Pyšek et al. (2008), and the network diagram is from Abrahams et al. (2019) highlighting the high level of inter-connectedness of invasive scientists in the country (each point is an author funded by Working for Water, with the size of point relative to productivity, and connections indicating co-authorship)

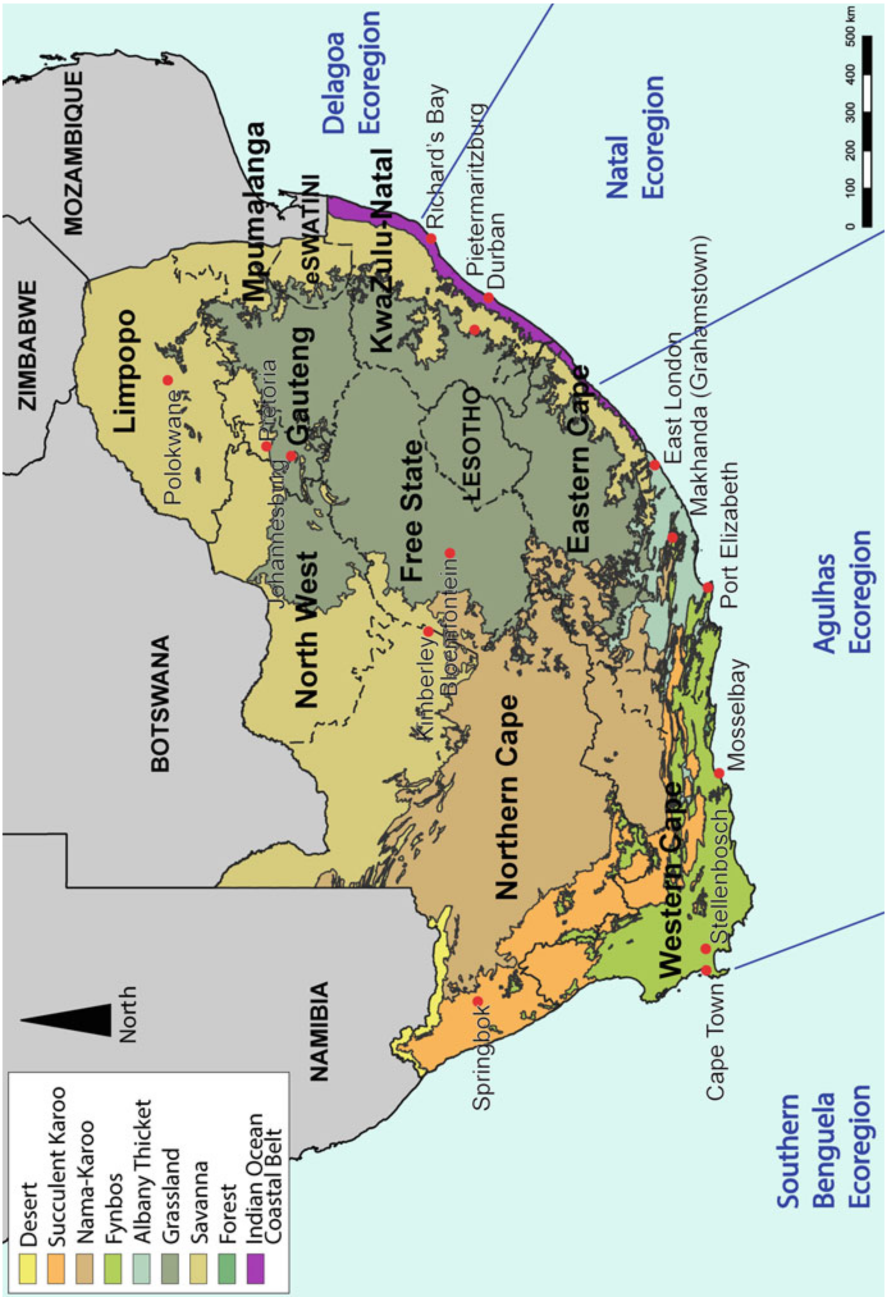

Fig. 1.2 South African terrestrial biomes (shaded); provinces and neighbouring countries (provincial and international boundaries indicated by dashed and solid lines respectively); and marine ecoregions. Some towns and cities mentioned in the text are also indicated

(Fig. 1.2), and marine species are drawn from three major biogeographic zones (Indo-Pacific, Atlantic and Antarctic). Well-known marine ecosystems range from cold-water kelp forests to tropical coral reefs. There are several marine islands close to the shore of South Africa, and biological invasions and their management on these inshore islands are dealt with in Chaps. 9 and 22 (Robinson et al. 2020; Davies et al. 2020). South Africa's southernmost territory, the Prince Edward Islands (Marion Island and Prince Edward Island) lie ~2000 km south-east of Cape Town in the Southern Ocean. The native biota, invasive alien species, and the management of biological invasions on these islands are discussed in Chap. 8 (Greve et al. 2020). The status of freshwater invasions are discussed in Chap. 6 (Weyl et al. 2020). Given this diversity, it is unsurprising that large areas of the planet have climatic and environmental analogues to South Africa (Fig. 1.3; see also Richardson and Thuiller 2007).

1.1.2 A Rich and Varied History of Biodiversity Conservation

The first protected areas in Africa were established in South Africa in the 1890s, initially for "game" protection. The Sabi Game Reserve in the (then) Transvaal Republic was proclaimed in 1895, and together with the Shingwedzi Game Reserve (proclaimed in 1903) went on to become South Africa's first National Park (Kruger National Park, proclaimed in 1926) (Greyling and Huntley 1984). A different philosophy was followed by the Department of Forestry, who sought to protect water and forest resources rather than game. The Department of Forestry was responsible for the early establishment of protected areas in mountain water catchments (e.g. the Langeberg in 1896 and the Cederberg in 1897), coastal areas (e.g. Walker Bay in 1895), and indigenous forest areas (Knysna forests in 1894; Greyling and Huntley 1984). Today, terrestrial protected areas cover 8.85% of the country (Fig. 1.1b), while marine protected areas have recently been increased to ~5% of the ocean around the coastline, an area in excess of 50,000 km^2.

1.1.3 A Rich and Varied History of Introductions

South Africa is believed to be the place where the complex behaviours typical of modern humans first appeared (Marean et al. 2014). These peoples inhabited coastal areas about 110 thousand years ago, and interacted closely with native plants and animals in small hunter-gatherer communities (Marean et al. 2014; Marean 2016). Their descendants are believed to be the Khoisan people who were widespread in South Africa prior to the arrival of migrating peoples (Marean et al. 2014). The Khoisan continue to inhabit parts of South Africa and southern Namibia today.

South Africa has a rich social history formed by immigration predominantly from Africa, Europe, and Asia. From about 200 AD, Bantu-speaking people from central and eastern Africa migrated into South Africa. They brought with them livestock and

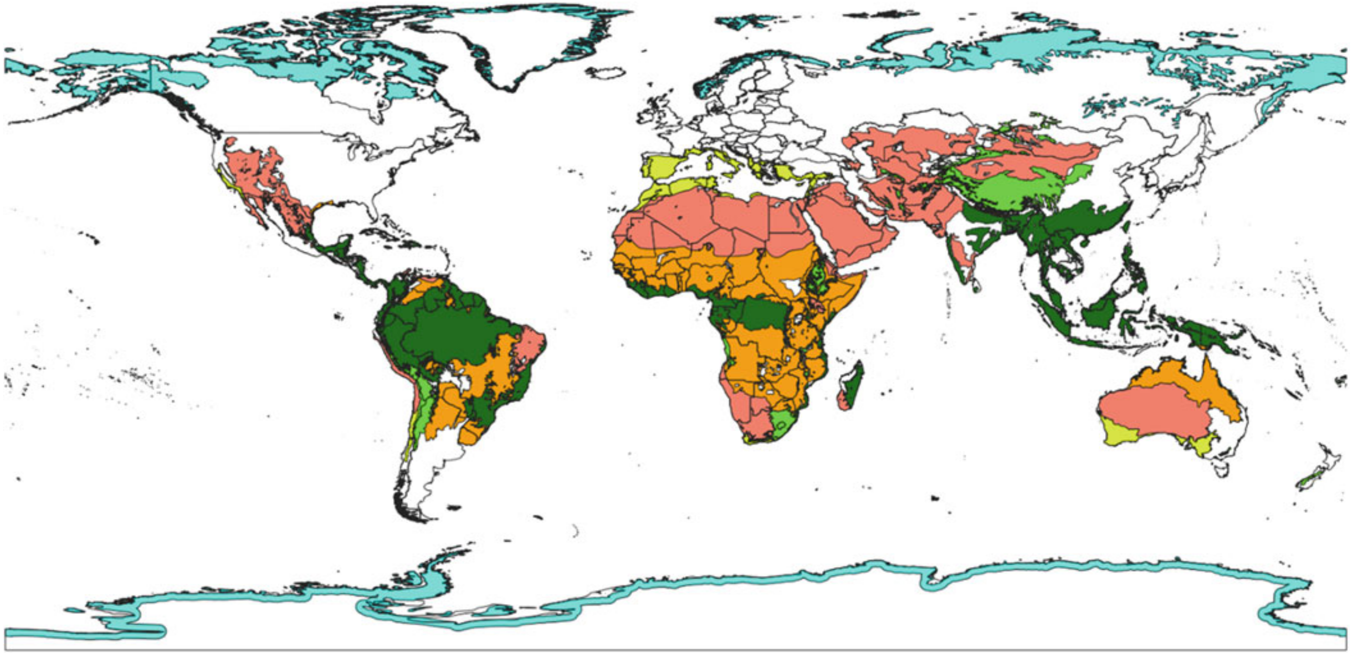

Fig. 1.3 Of the 14 terrestrial ecoregions of the world as defined by Olson et al. (2001), South Africa (including the Prince Edward Islands) has seven. Here the global extent of these seven biomes is shown to emphasise how much of the world is represented in South Africa, giving rise to the expression “a world in one country”. Note a separate analysis has also shown that a significant proportion of the world has a climate similar to South Africa (Richardson and Thuiller 2007). In particular, while South-East Australia is a different ecoregion, it has a very similar climate to much of South Africa and has donated and received many invasive species to and from South Africa

plants. Prior to the arrival of European settlers, the South African coastline was likely visited by boats from different seafaring trading nations, including Phoenicians, Egyptians, Greeks, Arabs, Chinese and Indians. Infrequent visitors, such as the Portuguese maritime explorer Bartolomeu Dias, built structures on land (*padrãos*, circa 1490), and their visits almost certainly facilitated unintended invasions of vermin. Their ships also carried dry ballast, and with it organisms from their ports of origin.

The first permanent European settlement was in 1652, when the Dutch established a presence in what is now Cape Town. Even then, invasive species were recognised as a problem, and European settlers were sometimes mindful of not introducing some species because they might have become problematic. For example, the first Dutch administrator at the Cape, Jan van Riebeeck, deliberately avoided introducing European Rabbits, *Oryctolagus cuniculus*, to the mainland, and passed this advice onto his successor (Measey et al. 2020a, Chap. 5, Sect. 5.2). Nevertheless, the early years of colonisation saw many deliberate introductions of both plants and animals that later became and remain major invasive species (and ironically rabbits seem incapable of naturalising).

Under Dutch rule, slaves were brought from South East Asia (the Dutch East Indies in particular) in the latter half of the seventeenth century, and there were various waves of immigration from Europe (in part to escape religious intolerance). The British took over from the Dutch as colonisers in 1806. Under British colonial rule, over 150,000 indentured labourers from India arrived in Natal from 1860 to 1911 (when the system of indentured labour was stopped). Other colonisers came from all over the globe as traders, miners, and for various opportunities (some of which were temporary). These diverse groups of people have introduced, deliberately and accidentally, species from all taxonomic groups to South Africa in various complex waves of introductions (Fig. 1.1c). Alien species have been vital to feed, clothe, nurture, employ, and enrich the growing human population, but some alien species have spread and in some instances caused undesirable environmental and socio-economic impacts.

From the mid-nineteenth century onwards, people deliberately introduced and promoted a wide range of alien species to South Africa, for a range of purposes, and many went on to become prominent invaders (Fig. 1.4). In 1847, active and widespread planting of Australian *Acacia* species (wattles) as a means of stabilising dunes along the coast began. Plantings continued to the 1940s, and the large areas planted resulted in substantial invasions (Shaughnessy 1986). In 1864, *Acacia mearnsii* (Black Wattle) was introduced and planted to produce tannins from bark (Stubbings and Schönau 1983). Black wattles have subsequently become one of the most widespread invasive alien trees in South Africa (Nel et al. 2004). In 1889, Cecil John Rhodes introduced Fallow Deer (*Dama dama*), Grey Squirrels (*Sciurus carolinensis*), Chaffinches (*Fringilla coelebs*) and Common Starlings (*Sturnus vulgaris*) to the Cape (Measey et al. 2020a, Chap. 5, Sect. 5.2). Common Starlings subsequently became one of the most widespread invasive birds in South Africa (Measey et al. 2020a, Chap. 5, Box 5.1; Picker and Griffiths 2011). Rainbow Trout (*Onchorhynchus mykiss*) were introduced to South Africa in 1897 (Weyl et al. 2020,

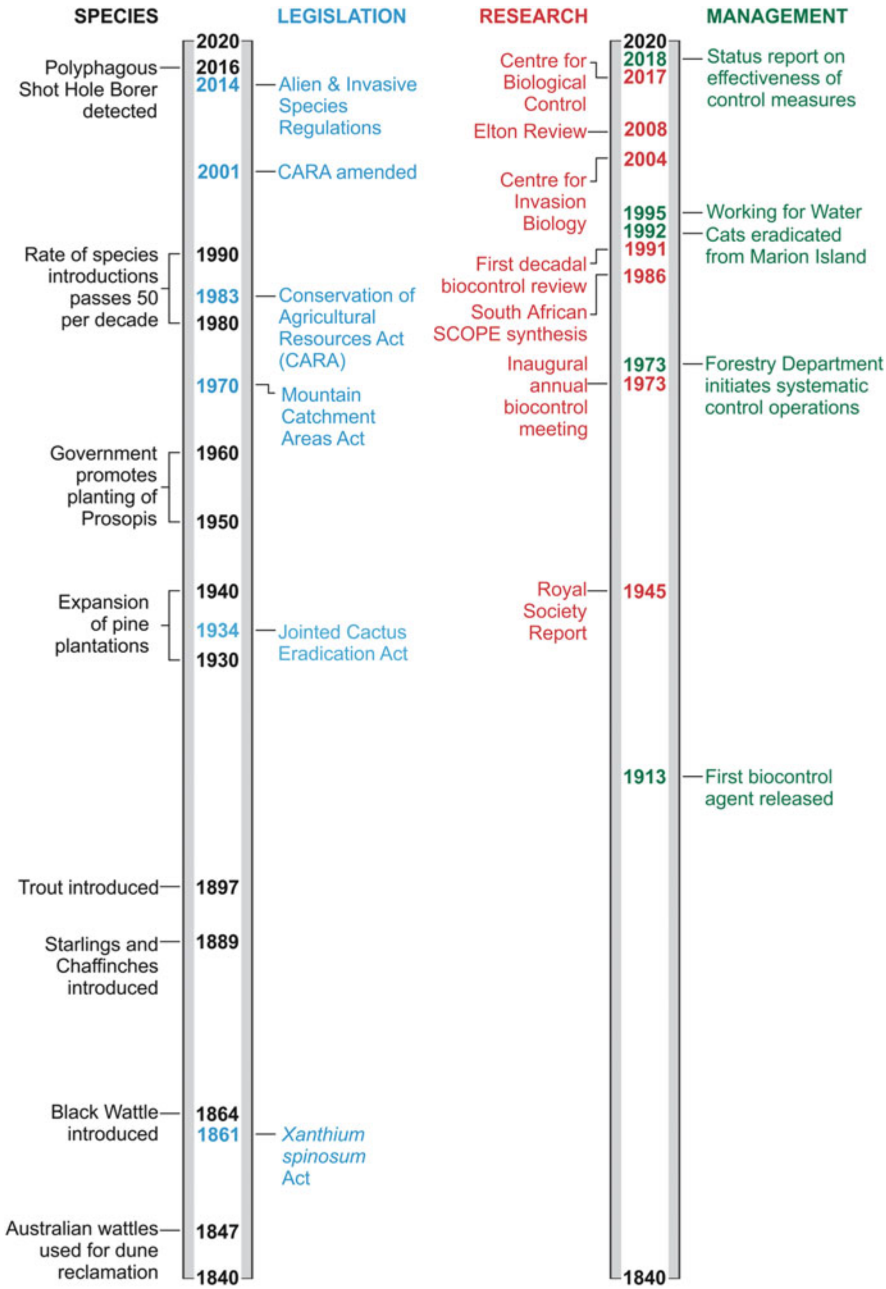

Fig. 1.4 Timeline of selected milestones in the history of biological invasions and invasion science in South Africa over the past two centuries with respect to the introduction of alien species, and the country's responses in terms of legislation, research and management

Chap. 6, Sect. 6.2), and hatcheries were established at Jonkershoek (Western Cape) and Boschfontein (KwaZulu-Natal) to breed and distribute trout for recreational fishing. The establishment of hatcheries facilitated stocking of angling species such as Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*M. dolomieu*), Common Carp (*Cyprinus carpio*), Brown Trout (*Salmo trutta*) and *O. mykiss*, initially by government agencies and later by angling societies and private individuals. These fish have subsequently become invasive, and their management is complicated and sometimes highly contentious because of differences in how people view the benefits they provide and the negative impacts they cause (Woodford et al. 2016; Ellender et al. 2014; Zengeya et al. 2017). While certain pines (*Pinus* species) were introduced as early as 1690, it was not until the 1930s that extensive planting in formal plantations began, to grow a viable forest industry. Pines subsequently become invasive, particularly in the Fynbos Biome (van Wilgen and Richardson 2014). In the 1950s, farmers were actively encouraged by government, through subsidies and extension programmes, to plant *Prosopis* trees on their farms to provide for shade and fodder (Wise et al. 2012). These trees are now the most serious invaders of arid landscapes in South Africa. These few examples of early deliberate introductions and propagation were typical of our history until relatively recently. Currently, almost 1500 alien species are known to have established in South Africa, many of which have become invasive (see Sect. 1.3). The rate at which new taxa are recorded as introduced and established has been increasing over the past decades, and by the 1980s over 50 new species were recorded as established per decade, rising to 70 recently (van Wilgen and Wilson 2018). Of the invasive species that were assessed by experts, 107 have either severe or major negative impacts: 80 of these are plants, 11 terrestrial invertebrates, eight mammals, seven freshwater fish species, and one marine invertebrate (van Wilgen and Wilson 2018). Data on how invasions have changed over time are not available for most taxa, but, based on the Southern African Plant Invaders Atlas (SAPIA), it is clear that both the number and extent of plant invasions has increased markedly in recent years [as of May 2016, SAPIA had records for 773 alien plant taxa, an increase of 172 since 2006; and between 2000 and 2016, the number of quarter degree grid cells occupied by alien plants has increased by ~50% (Henderson and Wilson, 2017)]. While many early introductions were deliberate, accidental introductions are becoming more common (Fig. 1.1c; Faulkner et al. 2020, Chap. 12). One recent and potentially very damaging example is the Polyphagous Shot Hole Borer (*Euwallacea fornicatus*), an ambrosia beetle native to Asia, that together with its fungal symbiont *Fusarium euwallaceae* poses substantial threats to both native and alien trees in South Africa (Paap et al. 2018; Potgieter et al. 2020, Chap. 11, Box 11.3).

Particular features of South Africa's biomes and biota have resulted in a demand for particular alien species, thereby shaping introduction pathways (Richardson et al. 2003; Faulkner et al. 2020, Chap. 12). For example, the paucity of native trees suitable for timber production resulted in major efforts to introduce trees from many other parts of the world. Although such introductions created much-needed ecosystem services to support growing human populations, they also sowed the seeds, literally and figuratively, for rampant invasions decades or centuries later. No other country has had such a deluge of alien tree species, and South Africa can surely claim the title of "tree invasion capital of the world" (Richardson et al. 2020b, Chap. 3). But there is also a demand for South African species from other parts of the world, as discussed by Pyšek et al. (2020), Chap. 26; and Measey et al. (2020b), Chap. 27. Many South African grasses, which evolved adaptations to deal with frequent fires and intense pressure from a diverse fauna of large mammals, have been disseminated across the planet to create or supplement pastures and rangelands for growing populations of domestic livestock (Driscoll et al. 2014). Many of these grass species have become aggressive invaders with the capacity to transform ecosystems (Visser et al. 2016; Linder et al. 2018).

1.1.4 A Rich and Varied Socio-political History

South Africa also has a unique socio-political landscape—the legacy of waves of colonisation and migration, and decades of enforced separation of races during the apartheid era. South Africa has eleven official languages (ten of which originated in the country), and a range of other native languages spoken by the Khoisan. None of these languages is spoken by more than a quarter of the population as a home language (Fig. 1.1d), just one measure of the social diversity. There also has been, and remains, a high degree of inequality between different segments of South African society, often resulting in very different perceptions regarding the relative value of, or harm done by, particular invasive species. As we were finalising this chapter, in May 2019, the cover story of *Time* proclaimed South Africa "The world's most unequal country" (Baker 2019; see also Fig. 1.1d). Sharp gradients between affluence and abject poverty in many parts of the country pose major socio-political and environmental challenges. The rich tapestry of biodiversity, a long history of species introductions and invasions, and the complex social issues have created a unique natural laboratory in which to study perceptions relating to benefits and negative impacts due to alien species across diverse gradients (e.g. Kull et al. 2011 for Australian *Acacia* species).

1.1.5 A Long History of Managing and Regulating Biological Invasions

For more than a century, considerable effort has gone into managing and regulating invasive species in South Africa (Fig. 1.4), with varying degrees of success. This has meant that the management of invasions has been relatively well studied, because efforts to manage invasive species in natural areas began earlier than in most other parts of the world. Where invasive species are clearly harmful, there has been general agreement that they should be controlled, but in several cases the situation has not been clear-cut. Species introduced for commercial or amenity value, (e.g. trees for commercial forestry and freshwater fish for recreational angling) that have become invasive have led to vociferous disagreement as to how they should be managed (van Wilgen and Richardson 2014; Woodford et al. 2016).

South Africa's attempts at regulation began in 1861 with the passing of an Act requiring the control of the invasive Bur Weed (*Xanthium spinosum*). Many similar acts followed (Richardson et al. 2003; Lukey and Hall 2020, Chap. 18), usually with a focus on a particular species, or set of species, and holding landowners responsible for controlling the species concerned (Lukey and Hall 2020, Chap. 18).

Active management of biological invasions in South Africa arguably began in 1913 with the release of the Cochineal Insect (*Dactylopius ceylonicus*) to control Drooping Prickly Pear (*Opuntia monacantha*). This was the first release of a biological control agent in South Africa (Moran et al. 2013). The later release of biological control agents against *Opuntia ficus-indica* (Mission Prickly Pear) led to spectacular success, and biological control of invasive alien plants was to become an effective method for reducing populations of several important invasive plants.

In 1934, the Jointed Cactus Eradication Act (Act 52 of 1934) was promulgated. This Act marked a change in the legislative approach (facilitating a more state-coordinated, programmatic and integrated approach), and it was followed by a largely successful suite of management interventions, including biological control and mechanical clearing (Moran and Annecke 1979).

Despite the early biological control successes against invasive *Opuntia* species in the 1920s and 1930s, by 1945 people were becoming concerned about other invasive alien species, particularly in the Western Cape. These concerns were addressed, *inter alia*, in a publication of the Royal Society of South Africa on the preservation of the vegetation of the Fynbos Biome (Wicht 1945). It was the first scientific report to consider the management of invasive species in South Africa, and noted that invasive tree species were "*one of the greatest, if not the greatest, threats*" to the conservation of vegetation in the Fynbos Biome. Concerns about invasive plants continued to grow, mainly in the Fynbos Biome (Anon. 1959; Stirton 1978). In 1970, the Mountain Catchment Areas Act (Act 63 of 1970) was published. This Act authorised, within 5 km of the boundary of a proclaimed mountain catchment area, "*the destruction of vegetation which is, in the opinion of the Minister, intruding vegetation*" (the term "intruding vegetation" referred to invasions by alien plants). The Mountain Catchment Areas Act thus empowered the Minister not only to clear invasive species from formally protected areas, but also to extend these control operations to 5 km beyond the boundaries of proclaimed areas. In the 1970s, the Department of Forestry, backed by the Mountain Catchment Areas Act, embarked on very ambitious projects to clear invasive plants from mountain catchment areas in the Fynbos Biome. These co-ordinated alien plant clearing projects in mountain catchment areas in the Western Cape were the first concerted, long-term alien plant control operations at a provincial scale (Wicht and Kruger 1973; Fenn 1980). Invasive species have also been actively managed in the Kruger National Park since the 1950s (Foxcroft and Freitag-Ronaldson 2007), and the Department of Forestry and its successors have implemented large-scale alien plant control operations since the 1970s (Wicht and Kruger 1973).

In 1983, the publication of the Conservation of Agricultural Resources Act (Act 43 of 1983) instituted the regulation of 47 invasive alien plant species that required compulsory control. This was subsequently increased to 198 species in 2001 (Lukey and Hall 2020, Chap. 18, Sect. 18.6). These species were listed in three categories: (1) invasive species of no value; (2) recognised invasive species that also have commercial value; and (3) recognised invasive species that have ornamental, but no commercial value.

With respect to invasive animals, a long-term campaign to eradicate feral Domestic Cats (*Felis catus*) from Marion Island began in 1973, was declared a success in 1992 (Bester et al. 2002; Greve et al. 2020). This was the first large-scale eradication in South Africa, and the second overall (Wilson et al. 2013).

South Africa became a constitutional democracy in 1994, and ratified the Convention on Biological Diversity (CBD) in 1995. Article 8 (h) of the CBD requires each Contracting Party to, as far as is possible and as appropriate, "*prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species*". This commitment was strengthened when South Africa adopted a new constitution in 1996 that enshrined the right to an environment protected from degradation. Section 24(b) of the Constitution guarantees the right to have the environment protected for the benefit of future generations through reasonable legislative and other measures that prevent "*ecological degradation, promote conservation, and secure ecologically sustainable development*".

In 1995, the Working for Water programme was launched (van Wilgen and Wannenburgh 2016). This programme had the dual purpose of protecting a vital resource (water) from reduction due to invasive plants, while at the same time providing employment and developmental opportunities to disadvantaged people in rural areas. It went on to become the largest environmental programme on the African continent. Working for Water has substantially broadened the scope and extent of alien species management projects in South Africa, and these are reviewed in van Wilgen et al. (2020a), Chap. 21, and Davies et al. (2020), Chap. 22.

In 2014, the then Department of Environmental Affairs published the Alien & Invasive Species (A&IS) regulations, which essentially replaced the regulations under the Conservation of Agricultural Resources Act (Box 1.1), and broadened the scope and coverage by addressing all invasive alien taxa (not just plants). The A&IS regulations listed 559 taxa that would require compulsory control. In 2018, the national report on the status of biological invasions was produced under the auspices of the A&IS regulations (van Wilgen and Wilson 2018; Box 1.2).

Box 1.1 South Africa's Alien & Invasive Species Regulations

South Africa is one of the few countries that has regulations in place on biological invasions, and many parts of the regulations are highly innovative. In many places throughout this book, reference is made to these regulations, and here we provide a brief overview as background.

The Alien & Invasive Species Regulations were published in 2014 in terms of the National Environmental Management: Biodiversity Act (NEM:BA; Act 10 of 2004). These regulations place restrictions on the use of listed alien species and regulate how they are to be managed. In addition, the regulations prescribe the process to be followed if a new alien species is to be imported into the country, and list species that are prohibited from importation. The intent of the regulations is to: reduce the risk of importing alien species that could become invasive and harmful; reduce the number of alien species becoming invasive; limit the extent of invasions; and reduce the impacts caused by these invasions—while recognising that society should continue to benefit from alien species.

Currently, 559 invasive taxa are listed in terms of the regulations in different categories:

- Category 1a species are those targeted for national eradication.
- Category 1b species must be controlled as part of a national management programme, and cannot be traded or otherwise allowed to spread.
- Category 2 species are the same as category 1b species, except that permits can be issued for their usage (e.g. invasive tree species can still be used in commercial forestry providing a permit is issued that specifies where they may be grown and that permit holders "*must ensure that the specimens of the species do not spread outside of the land or the area specified in the permit*").
- Category 3 are listed invasive species that can be kept without permits, although they may not be traded or further propagated, and must be controlled if they occur in protected areas or riparian zones. In essence, this is for species that are being phased out—e.g., feature trees can be kept (as it is too costly and unpopular to remove them), but they may not be replaced.

In terms of the regulations, permits are required for the import of alien species, and these will only be granted if a risk analysis is conducted and the results deemed by the government to be acceptable (see Kumschick et al. 2020). However, 560 taxa have been listed as prohibited, i.e. an import permit will not be considered for these species.

(continued)

Box 1.1 (continued)

The regulations, amongst other things, also require the development and adoption of management plans by organs of state; the development of a register of state-funded research projects and results; and the production of a national status report (Box 1.2).

Box 1.2 The First Status Report on Biological Invasions in South Africa

In terms of South African legislation (regulations under the National Environmental Management: Biodiversity Act, Act 10 of 2004), the South African National Biodiversity Institute (SANBI) has to submit a report on the status of biological invasions, and the effectiveness of control measures and regulations, to the Minister of Environmental Affairs every 3 years. The first report was released in October 2018 (van Wilgen and Wilson 2018).

The report was compiled by a team from SANBI, in collaboration with the Centre for Invasion Biology at Stellenbosch University, involving 37 contributors from 14 organisations. It is the first report globally that provides an assessment of the status of all aspects of biological invasions at a national level. It covers *pathways* of introduction and spread, the extent, abundance and impact of individual *species*, and the richness and abundance of invasive species in particular *sites*, and their collective impact on those sites. In addition, the report assesses the effectiveness of *control measures*, and the effectiveness of *regulations* on the control of alien species.

In order to report on these aspects, the team developed a set of indicators for assessing status at a national level (Wilson et al. 2018). The framework of indicators is intended to facilitate the inclusion of biological invasions in environmental reporting at national and international levels.

Key high-level findings included that approximately seven new alien species have recently been recorded as establishing annually at a national level; that over 100 species were already having major impacts; that 1.4% of the country was experiencing major impacts; and that management success levels were around 5.5%. The level of confidence in these estimates was low, however, because the data on which they were based were scattered and incomplete (figure below).

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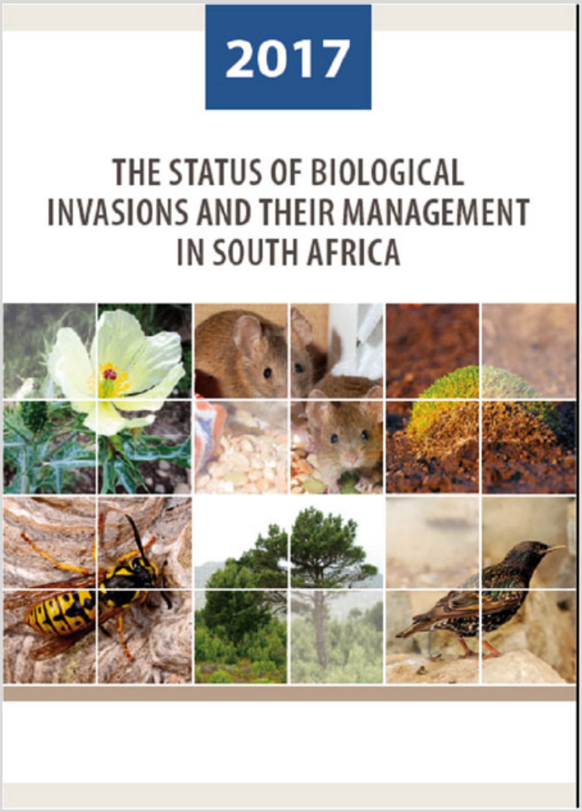
Box 1.2 (continued)



Much of the information collated in this book came from that compiled in South Africa's first national-level assessment of the status of biological invasions and their management and an accompanying special issue of a journal (Wilson et al. 2017)

1.1.6 A Strong Research Tradition in Invasion Science

South Africa is one of the leading countries in terms of research on biological invasions globally, and contributes well over half of the research on the topic in Africa (Pyšek et al. 2008; Fig. 1.1f), with a strong collaborative network of researchers (Abrahams et al. 2019; Fig. 1.1f). An active research interest in biological invasions in South Africa dates back over 100 years, and this book builds, on information contained in several previous reviews of the field (Fig. 1.4). The most important of these are discussed briefly here.

Biological control of invasive plants was arguably the first research-based activity focused on biological invasions (Moran et al. 2013). In 1973, the biological control research community held its inaugural meeting that ultimately was to be repeated annually, and is ongoing. It has recently broadened to encompass all aspects of biological invasions (Moran et al. 2013; Wilson et al. 2017). The biological control research community has also, since 1991, produced a succession of comprehensive reviews, at roughly 10-year intervals, of South African biological control projects against individual invasive plant species or taxa (Hoffmann 1991; Olckers and Hill 1999; Moran et al. 2011). The 2011 review included a catalogue of all species considered, and papers on regulations and risk assessment, on mapping, and on cost: benefit analyses.

Research on biological invasions gained momentum in the 1980s when South Africa participated in the international SCOPE programme on biological invasions. South Africa's contribution to the SCOPE project (Macdonald et al. 1986) was also the first comprehensive review of the field at a national level, and it included historical aspects, accounts of invasion in terrestrial biomes and offshore islands, current ecological understanding, impacts, and management. The SCOPE project on biological invasions concluded with a global synthesis in 1989 (Drake et al. 1989), in which South African authors provided chapters on invasive plant pathogens, aquatic plants, Mediterranean-climate regions, and protected areas.

In 1998, the Forestry and Agricultural Biotechnology Institute (FABI) was established at Pretoria University. Research at FABI, *inter alia*, considers the pathogens and pests associated with native trees and woody hosts, many of which are invasive. The achievements of FABI are summarised in Steenkamp and Wingfield (2013), and Wingfield (2018).

In 2003, the Working for Water programme convened an interdisciplinary meeting to address the ecology, economics, management and social impacts of biological invasions (Macdonald 2004). Papers describing these topics were subsequently published in a special issue of a local journal (van Wilgen 2004), and the meeting provided one of the first opportunities for researchers from varied backgrounds (including ecology, economics, engineering, hydrology and social sciences) to collectively consider the issue of biological invasions.

In 2004, the DST-NRF Centre of Excellence for Invasion Biology (C·I·B) was launched. This initiative provided access to significant funding for research into all aspects of biological invasions at a national scale (van Wilgen et al. 2014), and participants in the Centre's programmes have subsequently made substantial inputs into the field in South Africa and beyond (Richardson et al. 2020a, Chap. 30). For example, in 2008 the Centre convened an international conference to review the field of invasion ecology, held in Stellenbosch, South Africa (Richardson 2011). The conference marked the 50th anniversary of the publication of Charles Elton's seminal book on the ecology of invasions (Elton 1958). As noted in the foreword to the book produced out of the proceedings, the meeting stood out "*as a guidepost and a significant turning point for an entire field*" (Mooney 2011). In 2008, the Centre's researchers also produced a special issue of a local journal that reviewed riparian vegetation management in landscapes invaded by alien plants in South Africa (Esler et al. 2008).

In 2017, the Centre for Biological Control (CBC) was established at Rhodes University. The Centre builds on existing research collaborations and seeks to sustainably control environmental and agricultural pests for the protection of ecosystems and the societies that depend on them, and to ensure that the maximum benefits of biological control are realised through excellence in research, implementation and community engagement (van Wilgen 2020, Chap. 2).

Finally, in anticipation of the legal requirement to prepare a status report on biological invasions in South Africa in 2017 (Box 1.2), the C·I·B and the South African National Biodiversity Institute convened a 3-day symposium (at the 43rd National Symposium on Biological Invasions) to assemble information that could be used in the status report. It was the first meeting to consider the full spectrum of issues pertaining to the research and management of biological invasions across all taxa. This culminated in a special issue of a local journal (Wilson et al. 2017) in which the status of introduction pathways, the status of taxa (plants and animals) and their impacts, and the effectiveness of management were reviewed.

1.2 How Many Alien Species Are There in South Africa?

It is important to have an accurate picture of how many alien species have established in the country, to know their status (*sensu* Richardson et al. 2011a; Blackburn et al. 2011; Wilson et al. 2018), and to understand where they occur. Such knowledge is necessary to underpin effective regulation, to prioritise species for management, and to monitor their status. Lists are dynamic, subject to regular change, and can differ greatly between curators. For example, Picker and Griffiths (2017) documented that South Africa had 41 naturalised alien vertebrate species that had their origins outside the geopolitical borders of the country. Van Wilgen and Wilson (2018) included all alien vertebrate species, and so had a much higher number (283), although they also provided a number of naturalised species as 45; and in this book, Measey et al. (2020a) lists 30 terrestrial vertebrate species in Chap. 5, and Weyl et al. 2020 lists 21 fish species in Chap. 6 (i.e. 51 naturalised alien vertebrate species). These differences are partly attributable to differences in definitions. In this book, we follow the scheme of Blackburn et al. (2011), and apply the definitions of Richardson et al. (2011a). In brief, alien species are those that have been moved over a natural geographic barrier, naturalised species are alien species that have self-sustaining populations outside of captivity or cultivation over several life-cycles, and invasive species are naturalised species that have dispersed and formed new populations a considerable distance from the initial point of introduction. In large countries such as South Africa which have many biomes and a diversity of climates, species can be both native and alien within the borders of the same country. These species have been called “domestic exotics” (Guo and Ricklefs 2010), or “extra-limital species” (Foxcroft et al. 2017). Because they are shown as native species in local guidebooks, they are sometimes ignored or not given the same level of attention as species from other countries or regions. The number of species for different taxonomic groups or habitats covered in this book are listed in Table 1.1;

Table 1.1 Numbers of naturalised or invasive alien species listed in this book. The totals for each chapter include both naturalised and invasive species, except for the offshore Prince Edward Islands, where only invasive species are included

Chapter	Coverage	Number of naturalised or invasive species
Richardson et al. (2020b), Chap. 3	Terrestrial plants	759
Hill et al. (2020b), Chap. 4	Freshwater aquatic plants	19
Measey et al. (2020a), Chap. 5	Terrestrial vertebrates	30
Weyl et al. (2020), Chap. 6	Freshwater fauna	77
Janion-Scheepers and Griffiths (2020), Chap. 7	Terrestrial invertebrates	466
Greve et al. (2020), Chap. 8	Plants on offshore islands	17 (one of which is native to South Africa, and four are also invasive on continental South Africa)
Greve et al. (2020), Chap. 8	Fauna on offshore islands	18 (two of which are native to South Africa, and 11 are also invasive on continental South Africa)
Robinson et al. (2020), Chap. 9	Coastal marine species	56
Total (for South Africa)	*All taxa*	*1422*

the total for South Africa stands at 1422 alien species that are naturalised or invasive in the country.

1.3 Estimating the Cost of Invasions to South Africa

Biological invasions have economic consequences because they can substantially reduce the flow of ecosystem services from invaded areas. According to one estimate, the cost of invasive species amounts to more than US$300 billion per year in the United States, British Isles, Australia, Europe, South Africa, India and Brazil alone (Pimentel 2011). Preventing these losses, or restoring the flow of services by removing the alien species concerned, also has a cost because the control measures have to be paid for. Ideally, these parameters should be known, and the decision to initiate control measures should take these into account by assessing what the return on investment from control would be; in other words, control should ideally be undertaken only where the estimated value of avoided or restored costs exceeds the estimated cost of control.

Understanding the magnitude of impacts of invasive species would be a first step towards estimating their costs. However, impacts have in most cases been poorly quantified, and it is necessary to make assumptions when extrapolating to larger spatial scales. Several South African studies have followed this approach. An early South African example is provided by Higgins et al. (1997), who estimated that ecosystem services arising from a hypothetical 4 km^2 area of mountain fynbos would be worth US$3 million with no management of invasive species, compared to US $50 million with effective alien plant management. Other studies followed (see Le Maitre et al. 2011 for the most recent comprehensive review), but it was the prediction that alien plant invasions would lead to substantial reductions in water runoff from catchment areas (Le Maitre et al. 1996) that provided the economic motivation to initiate large-scale alien plant control operations (van Wilgen and Wannenburgh 2016). At the time, it was estimated that more water could be delivered, at a lower unit cost, by integrating alien plant control with the maintenance of water supply infrastructure, than without control (van Wilgen et al. 1996). While further studies that quantified the economic impact of invasive species on ecosystem services and returns on investment from control were subsequently undertaken, they were all either focussed on a relatively small area (e.g. Hosking and du Preez 2004 for selected project sites), or on a single species [e.g. De Wit et al. 2001 for Black Wattle (*Acacia mearnsii*); McConnachie et al. 2003 for Red Water Fern (*Azolla filiculoides*); and Wise et al. 2012 for Mesquite (*Prosopis* species)].

In 2010, De Lange and van Wilgen (2010) attempted a national-scale estimation of the economic losses due to invasive alien plants, with a focus on the value of water resources, rangeland productivity, and biodiversity. These ecosystem services were chosen because data were available to make the estimates possible. Their study suggested that the value of annual losses of water resources amounted to US$773 million per year, and that the loss of livestock production from invaded natural rangelands amounted to US$45 million annually. The losses due to reductions in biodiversity were conservatively estimated to be US$57 million per year. All of these were predicted to grow as invasive species continue to spread, and as more species become invasive. This remains the only study to provide economic estimates at a national scale.

The full amount spent by South Africa on the control of alien species is not known, but it amounts to at least ZAR 2 billion (US$142 million) each year, this being the amount currently spent by the national government's Department of Environment, Forestry, and Fisheries (i.e. the Working for Water programme). This is about 16% of the current estimate of costs (US$875 million per year). Both are underestimates, as not all expenditure or impacts are accounted for. Rates of return have yet to be estimated for this investment. A number of factors would need to be taken into account here, including the current rate of spread of invasions, the area that would be occupied if these species were allowed to invade all available habitat, and the effectiveness of the control measures in reversing (or at least slowing) the ongoing rate of spread. Indications are that the returns on investment could well be positive, but that achieving a positive return would require increases in management efficiency, and a focus on priority areas (van Wilgen et al. 2016).

While a few studies have attempted to estimate the returns on investment from manual and chemical clearing of alien plants, most have had to be based on assumptions, or have looked at relatively small areas, so the level of confidence in the estimates is often low. The returns on biological control have been summarised by van Wilgen and De Lange (2011). Their review suggests that biological control programmes against invasive plants have been extremely economically beneficial, delivering benefit:cost ratios of between 8:1 and 3726:1 at a national scale. Further details of the costs of invasions, and the returns on investment from control are to be found in Chaps. 15, 16, 21, and 22 (Le Maitre et al. 2020; van Wilgen 2020; van Wilgen et al. 2020a; Davies et al. 2020).

1.4 Scope and Arrangement of This Book

In planning this book, we set out to compile an encyclopaedic reference to biological invasions and their management in South Africa, with the aim of providing information that can help current and future generations to deal more effectively with invasions. The intended audience thus includes academics, post-graduate students, policy makers, and conservationists.

The book is composed of 31 chapters (including this one) that are divided into seven parts. The 104 contributing authors include academics, policy makers, conservationists, managers, and post-graduate students—representing a diverse range of expertise on biological invasion in South Africa and beyond.

Part I (Chaps. 1 and 2) provides a broad overview of biological invasions in South Africa, to set the scene for the material that follows (van Wilgen et al. 2020a, this chapter), and gives a selective account of some of the South African researchers and research initiatives in this field over the past 130 years (van Wilgen 2020, Chap. 2). It is evident that South Africa has made a disproportionate contribution to the developing field of invasion science, arising from a small, well-connected, and highly collaborative research community.

Part II (Chaps. 3–11) deals with the current situation. The first chapters focus on specific taxa—terrestrial plants (Richardson et al. 2020b), aquatic plants (Hill et al. 2020a), terrestrial vertebrates (Measey et al. 2020a), terrestrial invertebrates (Janion-Scheepers and Griffiths 2020), and pathogens that affect mammals, including humans (van Helden et al. 2020). The ecology of diseases, such as those covered by van Helden et al. (2020), has not yet been integrated within the invasion science agenda in South Africa. It is hoped that the inclusion of this chapter will stimulate further work to explore the links between disease ecology and invasion science (cf. Ogden et al. 2019). The remaining chapters focus on specific areas that are invaded—freshwater ecosystems (Weyl et al. 2020), coastal marine ecosystems (Robinson et al. 2020), offshore sub-Antarctic islands (Greve et al. 2020), and urban settings (Potgieter et al. 2020). Most invasive alien species in South Africa are plants (Table 1.1), and these are consequently best understood. Invertebrates are also important, but are less well documented. Other groups (e.g. birds, reptiles and amphibians) have markedly fewer invasive species, and our understanding of marine and microbial species is still very limited.

Part III (Chaps. 12–14) details the underlying factors influencing invasions—how species arrived in South Africa, and how they were dispersed once they got here (Faulkner et al. 2020); the environmental factors, including geomorphology, soils, climate, extreme events (specifically droughts and floods), fire, and land uses that influence the success of alien species (Wilson et al. 2020a); and the role of symbiotic interactions in affecting biological invasions in South Africa (Le Roux et al. 2020). Many early introductions were deliberate, but accidental introductions are increasing in importance. The high diversity of alien plants that have established is in part due to the wide range of environmental conditions across the country, but successful establishment can be limited by fire and aridity. Biotic interactions also play a role, with examples documented of parasitism and mutualism and how these relate to various ecological and evolutionary hypotheses aimed at explaining invasions. But it is clear there is much scope for further research.

Part IV (Chaps. 15–17) addresses why invasive species are important in the South African context, dealing with water resources (Le Maitre et al. 2020), rangeland productivity (O'Connor and van Wilgen 2020), and biodiversity (Zengeya et al. 2020). As in the rest of the world, the impacts of invasive species have not been adequately documented, but enough research has been done to examine particular aspects. Invasive trees and shrubs are estimated to be reducing the national mean annual runoff by almost 3%, and reductions in some key catchments are much higher. The productivity of rangelands has been reduced by about 1%, but this will almost certainly increase as aggressive invasive plants spread. Formal assessments of the impact of individual alien species on biodiversity have only recently been initiated, but red-listing processes suggest that alien species constitute a significant extinction risk for several native species of fish, amphibians and plants.

Part V (Chaps. 18–25) covers aspects of the management of invasions in South Africa. The first traces the development of policy from the first legislation passed in 1861 to the current day (Lukey and Hall 2020). The next charts progress with the development of a system of preventative measures and risk assessments (Kumschick et al. 2020). The following chapters focus on control and rehabilitation—biological control of invasive plants (Hill et al. 2020b), mechanical and chemical control of alien plants (van Wilgen et al. 2020a), ecosystem restoration (Holmes et al. 2020), and alien animal control (Davies et al. 2020) (note: the management of aquatic plants and alien species on offshore islands are covered in Part II, together with the status of those invasions). Finally, the human dimensions affecting alien species control projects are addressed in terms of the evidence for how people cause invasions, how they conceptualise them, what effects invasive species have on people, and how people respond to them (Shackleton et al. 2020, Chap. 24). Chapter 25 covers education, training and capacity-building (Byrne et al. 2020). Currently, South Africa has strong legislation that supports management, but the capacity to enforce it is low. There has been good progress towards gaining control of invasions in some areas, but invasions continue to increase at a national scale. A notable exception is those plant species that have been brought under effective biological control. Perceptions of biological invasions are poorly understood across much of society, and increased education and outreach is needed to address this.

Part VI (Chaps. 26–30) explore additional aspects relevant to biological invasions. We have included two chapters that list plant (Pyšek et al. 2020, Chap. 26) and animal species (Measey et al. 2020b, Chap. 27) that are native to South Africa and that have become established in other parts of the world. The next chapter addresses the issue of the two-way flow of information between researchers and managers of biological invasions in South Africa, with emphasis on barriers to flow as well as the mechanisms that have been set up to improve information flow (Foxcroft et al. 2020, Chap. 28). The next chapter reports on a study based on over 2000 South African research papers that sought to document the impacts of global change drivers on biodiversity and ecosystem services (van Wilgen et al. 2020b, Chap. 29). The drivers included biological invasions, climate change, overharvesting, habitat change, pollution, and atmospheric CO_2. The intent was to gauge the relative research effort directed towards understanding the impact of biological invasions on biodiversity and the utility of terrestrial, freshwater and marine ecosystems respectively, compared to other drivers of global change. Interestingly, the long-cited statement that invasive species pose the second-largest threat to biodiversity conservation is reflected in South African research effort, but the relative research effort into drivers of change differs between realms, with habitat change, pollution and overharvesting being the most important in terrestrial, freshwater, and marine/estuarine ecosystems, respectively. The achievements of the Centre for Invasion Biology in advancing the science of biological invasions is the subject of a third chapter (Richardson et al. 2020b, Chap. 30).

In *Part VII*, we conclude with an evaluation of possible futures (Wilson et al. 2020b, Chap. 31). How are the actions that we take over the next five and next fifty years likely to affect the issue of biological invasions 200–2000 years from now? This chapter concludes that, in part based on the insights from this book, there are some actions that we as South Africans can take so that the next generation can decide what they want their future to be.

1.5 Conclusions

South Africa is a highly diverse country. This has created opportunities for invasions, but also increases the onus on us to try to manage the impacts that they cause. The problem of invasions seems daunting, but in tracking what we know now we can chart a course to a future we desire. The science and practice of biological invasions has come a long way over the past two centuries in South Africa, but much remains to be done. Control operations are struggling to keep pace with the increasing number and extent of invasive species, and conflicts of interest or differences in perceptions complicate management. We hope this book will provide the foundation for improved management of biological invasions in the future.

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