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A National Strategy for Dealing with Biological Invasions in South Africa






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A National Strategy for Dealing with Biological Invasions in South Africa



Minister Edna Molewa (back) and Deputy Minister Rejoice Mabudafhasi (front), whose leadership has made the accomplishments of the Working for Water programme and the bio-security focus possible. They are sitting at a "Chess Table" – a multi-purpose table for schools, within which chess boards are incorporated. The idea came from the President's calling for chess to be used in schools as part of cognitive development of Learners. The Chess Table is made from invasive alien wood cleared through the Eco-Furniture Programme, thus contributing to the control of invasive species and creating jobs for previously unemployed people.

CONTENTS

1.	**INTRODUCTION**	**1**
1.1.	The problem of biological invasions in South Africa	1
1.2.	Historic approaches to the management of invasive alien species in South Africa	4
1.3.	Current strategic imperatives	7
1.4.	A proposed framework for managing biological invasions	8
1.5.	Objectives of South Africa's National Strategy on Biological Invasions	13
1.6.	Sources	13
2.	**INTEGRATION**	**14**
2.1.	Introduction	14
	2.1.1. The need for integration	14
	2.1.2. Interventions to be integrated	14
	2.1.3. The question of scale	16
	2.1.4. Broad principles of effective management	16
2.2.	Past and current prioritization exercises in South Africa	17
2.3.	Relative emphasis of current interventions	19
2.4.	Constraints to effective integration	19
2.5.	A possible framework for optimizing effectiveness	29
3.	**LEGISLATIVE AND REGULATORY ENVIRONMENT**	**31**
3.1.	Introduction	31
3.2.	Existing international and domestic laws	31
3.3.	Current shortcomings and problems	39
	3.3.1. Fragmented legal mandates	39
	3.3.2. Inadequate capacity to enforce legal obligations	39
	3.3.3. The absence of coordinating mechanism	39
3.4.	Proposed broad guidelines to develop effective legislation	40
3.5.	Key actions	42
3.6.	Sources	45
4.	**PRE- AND AT-BORDER MANAGEMENT**	**46**
4.1.	General principles	46
4.2.	History of introductions to South Africa	46
4.3.	Current pre- and at-border management	47
4.4.	Challenges for pre- and at-border management	50
4.5.	Key actions	52
4.6.	Sources	53
5.	**POST- BORDER RISK MANAGEMENT**	**54**
5.1.	General principles	54
5.2.	History of post-border risk management in South Africa	56
5.3.	Current post-border risk management	57
5.4.	Key actions	58
5.5.	Sources	59

6.	**MANAGING ESTABLISHED SPECIES**	**60**
6.1.	Introduction	60
6.2.	Current situation in South Africa	60
6.2.1.	General	60
6.2.2.	The use of laws and regulations	60
6.2.3.	Existing invasive alien plant control projects	61
6.2.4.	Biological control	62
6.2.5.	Existing freshwater fish control projects	63
6.2.6.	Existing invertebrate control projects	63
6.2.7.	Leveraging benefits	63
6.2.8.	Monitoring and evaluation	64
6.3.	Key actions	64
6.4.	Sources	64
6.5.	Plants	65
6.5.1.	Established alien plant invasions in South Africa	65
6.5.2.	Current management of established populations of invasive alien plants	65
6.5.3.	Elements of alien plant control programmes	73
6.5.4.	Strategic approaches adopted	78
6.5.5.	Work on privately-owned land	78
6.5.6.	Key actions	79
6.5.7.	Sources	79
6.6.	Vertebrate animals	80
6.6.1.	Established vertebrate animal invasions in South Africa	80
6.6.2.	Impacts of invasive alien animals in South Africa	81
6.6.3.	Current management of established vertebrate animal invasions in South Africa	87
6.6.4.	Features of proposed management	89
6.6.5.	Key actions	90
6.6.6.	Sources	90
6.7.	Invertebrate animals	91
6.7.1.	Invertebrate animals as invasive species in terrestrial and freshwater ecosystems	91
6.7.2.	Impacts of invasive alien invertebrates in South Africa	91
6.7.3.	Current management of established vertebrate animal invasions in South Africa	96
6.7.4.	Key actions	99
6.7.5.	Sources	99
6.8.	Microbial organisms	100
6.8.1.	Introduction	100
6.8.2.	Key areas affected by microbial invasions	105
6.8.3.	Management of microbial invasions	106
6.8.4.	Key actions	106
6.8.5.	Sources	106
6.9.	Marine organisms	107
6.9.1.	Marine invasions in South Africa	107
6.9.2.	Impacts and risks	109
6.9.3.	Current management efforts	111
6.9.4.	Invasions on marine islands	112
6.9.5.	Key actions	113
6.9.6.	Sources	113

7.	**INFORMATION MANAGEMENT**	**114**
7.1.	Broad principles for the management of established species	114
7.2.	Current situation in South Africa	114
	7.2.1. Lists of alien species	114
	7.2.2. Permits	114
	7.2.3. Management plans	120
	7.2.4. Distribution	120
	7.2.5. Current proposals for information management	121
7.3.	Information Gaps	121
	7.3.1. Prevention	122
	7.3.2. Eradication	122
	7.3.3. Containment and impact reduction	122
7.4.	Key actions and targets	122
7.5.	Sources	124
8	**CAPACITY BUILDING**	**125**
8.1	Current capacity to manage invasive alien species in South Africa	125
	8.1.1 Background	125
	8.1.2 What capacity is there for invasive species management?	125
8.2	Current capacity to train people	129
8.3	Key actions	129
8.4	Sources	130
9.	**RESEARCH**	**131**
9.1.	Background	131
9.2.	Goals of research to support biological invasions	131
9.3.	Existing relevant research capacity in South Africa	132
9.4.	Research needs	133
9.5.	Key actions	134
9.6.	Sources	135
10.	**RAISING AWARENESS**	**136**
10.1	Current levels of awareness in South Africa	136
10.2	Approaches to awareness-raising in South Africa	136
10.3	Key actions	138
11.	**FUNDING THE STRATEGY**	**139**
11.1	Introduction	139
11.2	Historic funding and achievements	139
11.3	Drivers of funding growth	141
11.4	Current budget allocations and demands	141
11.5	Potential future options for improving funding	143
11.6	Key actions	148
12.	**INDICATORS**	**149**
13.	**REFERENCES**	**152**

FOREWORD

Biological invasions pose enormous threats to South Africa's ecosystems and the services that they deliver to our people. Thousands of alien species have been introduced to the country over the past 350 years, and hundreds of them have become invasive. These invasive alien species can seriously diminish the ability of ecosystems to deliver many services. They reduce water supplies, increase erosion, exacerbate wildfires, degrade valuable rangelands, threaten the health of people and livestock, reduce productivity in agriculture, and impact negatively on our remarkable biodiversity. The economic damage caused by these invasions has been estimated at billions of Rands per year, and is set to grow as invasive species spread, and as more species are introduced and become invasive.

There is a clear need to reduce the risk of introducing more invasive species to the country, as well as to contain those already here, and to reduce their impacts. Managing invasive species is complex, and will require a clear strategy to guide policy and management in the future. South Africa has a long history of managing invasive species, and is also the leading African country in terms of research into the problem. The Working for Water programme, initiated by South Africa's first democratically-elected government almost 20 years ago, is internationally-renowned for its innovative approaches that combine alien plant control with poverty relief, employment and development opportunities. The strategy presented here builds of these strengths, and seeks to increase efficiencies, encourage collaborative governance, and optimise the benefits that will arise from more effective management of the problem.

This strategy provides a comprehensive overview of biological invasions and their management in South Africa. It addresses all aspects of the problem, including the introduction, spread and control of plants, animals and microbial organisms in terrestrial, freshwater and marine ecosystems. It also considers vitally important aspects, such as the need for effective laws and regulations, and the imperatives to build management capacity, increase understanding through research and monitoring, raise awareness of the problem, and equitably distribute the costs of management. This is particularly acute in terms of environmental bio-security, and enhancing the emphasis on components such as early detection of emerging invasives, and biological control.

Although the Department of Environmental Affairs has a pivotal role to play in the implementation of this strategy, biological invasions have serious implications for the mandates of other government departments, including Agriculture, Forestry and Fisheries; Water Affairs; Health; Rural Development and Land Reform; Cooperative Governance; Trade and Industry; and, all nine provinces through their responsibilities with regard to managing the environment. The strategy therefore recognises, and seeks to promote, collaborative governance amongst the different spheres of government. This is particularly important for eliminating duplication, increasing efficiency, and ensuring that all priority aspects are effectively catered for. It is thus a truly national strategy that strives to protect the natural capital of the country, in the interests of achieving and sustaining the goals of the National Development Plan.

Our thanks to all those who have worked so hard to produce this Strategy. There is always more refinement required in strategies, owing to the dynamic nature of what is being addressed, but this is an excellent framework to guide and within which to plan the detail of our work.

Dr Guy Preston
Deputy Director-General: Environmental Programmes
Department of Environmental Affairs

GLOSSARY OF TERMS

Alien species (synonyms: adventive, exotic, foreign, introduced, non-indigenous, non-native)	Species whose presence in a region is attributable to human actions that enabled them to overcome fundamental biogeographical barriers (i.e., human-mediated extra-range dispersal).
At-border interventions	A component of an overall strategy for dealing with biological invasions that focuses on intercepting alien species at the border (i.e. after they have been transported to the target region but before they have gained entry or have become established).
Biological invasions	The phenomenon of, and suite of processes involved in determining: (1) the transport of organisms, through human activity (intentionally or accidentally, via introduction pathways) to areas outside the potential range of those organisms as defined by their natural dispersal mechanisms and biogeographical barriers; and (2) the fate of such organisms in their new ranges, including their ability to survive, establish, reproduce, disperse, spread, proliferate, interact with resident biota, and exert influence in many ways on and in invaded ecosystems.
Biofouling	The accumulation of microorganisms, plants, algae, or animals on surfaces (e.g. on the hulls of ships); in the context of this strategy, biofouling is an important means of transport of organisms to new regions and for dissemination of alien organisms within regions.
Biosecurity	The process of managing the risks posed by organisms to the economy, environment and human health through exclusion (the prevention of initial introduction of a species), mitigation, adaptation, control, and eradication. In the context of this Strategy it refers only to the risks posed by alien species.
Conflict species (also "conflict-generating species")	In the context of this strategy, these are invasive alien species that both useful (e.g. having commercial or other value) and harmful (e.g. causing undesirable impacts). Management of such species invokes conflict and demands compromises and trade-offs.
Containment	Actions taken with the aim of reducing the spread of invasive species, e.g. by preventing incursions into new areas, and extirpating any species that are found outside a defined area or beyond a defined line.
DNA barcoding	An international initiative that began in 2003 with the idea of developing a standardized method for species identification through the comparative analysis of short DNA sequences.
Eradication	The removal of an entire population of an alien species within a designated management unit where re-colonization is unlikely to occur (cf. extirpation).

Established alien species	Those species that are present and reproducing outside their native range, and whose extent of distribution and invasiveness makes eradication practically impossible.
Extirpation	The removal of an entire population of an alien species from a designated management unit where the presence of other populations close by means that re-colonization is likely (cf. eradication).
Extra-limital species	Species that have part of their native range in a given country, but whose presence in another part of the same country is attributable to human actions that enabled the species to overcome fundamental biogeographical barriers. The need for a definition for extra-limital species arises because biogeographical barriers for species often do not match political boundaries (i.e. a species can be both alien and native in the same county). From an ecological standpoint, such species are similar to other alien or invasive alien species, but the notion of indigenous species being "alien" gives rise to political and practical challenges.
Horizon scanning	The systematic search for incipient trends, opportunities and risks that may affect the probability of achieving management goals and objectives.
Invasion debt	The notion that that even if introductions cease (and/or other drivers of invasion are reduced), new invasions will continue to emerge and already-invasive species will continue to spread and cause potentially greater impacts, since large numbers of alien species are already present, many of them in a lag phase (see Box 1.3).
Invasive species	Alien species that sustain self-replacing populations over several life cycles, produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction, and have the potential to spread over long distances.
Microbes	Organisms whose mode of dissemination is microscopic (i.e. not visible to the naked eye). These include organisms as diverse as viruses, bacteria, fungi, algae, and many other microbes from lesser known eukaryote kingdoms.
Naturalized species	Alien species that sustain self-replacing populations for several life cycles without direct intervention by people, or despite human intervention. Naturalised species are not necessarily invasive, that is they have not (yet) spread any significant distance.
Pathways (also invasion pathways)	The combined processes that result in, or drive, the introduction of alien species from one geographical location to another. Examples of pathways are shipping and commercial forestry based on alien trees. Pathways may be classified as "high risk" where strong evidence exists that they are associated with the introduction or dissemination of species with a high risk of becoming invasive. See also "Vectors".
Post-border interventions	A component of an overall biosecurity strategy for dealing with biological invasions that focuses on approaches for managing species following their arrival in a new region.

Pre-border interventions	A component of an overall biosecurity strategy for dealing with biological invasions that focuses on assessing the potential for invasion in a region before species are transported to the region and reducing the likelihood of such species arriving via potential pathways.
Risk assessment	The estimation of the quantitative or qualitative value of risk (the likelihood of an event occurring within a specified time frame and the consequences if it occurs); see Box 4.1.
Species	A fundamental category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding.
Taxa	The plural of taxon (see below)
Taxon	A taxonomic category or group of living organisms, such as a phylum, order, family, genus, species or sub-species.
Vector	A mechanism responsible for the transport of species to new areas where they did not previously occur. A "pathway" (for example shipping) could have several vectors associated with it (for example in cargo, in passenger luggage, on passengers or crew themselves, in ballast water, or attached to the hull).
Watch list	In the context of this Strategy, a list of alien species that are not yet invasive but which are considered to pose a high risk of becoming invasive (see Table 7.2).
Weed biological control (WBC)	The use of imported plant-feeding or plant-damaging organisms ('natural enemies', also called WBC agents) to suppress problematic plants.
Working for Water	A government-funded poverty-relief initiative, founded in 1995 to manage invasive alien plants (mainly trees and shrubs) in catchment areas to reduce impacts on water resources. The programme is currently one of several "Natural Resources Management" subdivisions of the South African Department of Environmental Affairs.

ACRONYMS AND ABBREVIATIONS

CARA	Conservation of Agricultural Resources Act
CBD	Convention on Biological Diversity
CIB	Centre for Invasion Biology (also C•I•B)
COP	Convention of Parties
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DDT	Dichlorodiphenyltrichloroethane
DEA	Department of Environmental Affairs
DNA	Deoxyribonucleic acid
DST	Department of Science and Technology
EIA	Environmental Impact Assessment
EPPO	European and Mediterranean Plant Protection Organization
EPWP	Extended Public Works Programme
ESSP	Environmental Sector Skills Plan
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FET	Further Education and Training
GISP	Global Invasive Species Programme
HCDS	Human Capital Development Sector
HPAI	High Pathogenicity Avian Influenza
IAS	Invasive Alien Species
ISP	Invasive Species Programme
IUCN	International Union for the Conservation of Nature
KPI	Key Performance Indicator
MoA	Memorandum of Agreement
NBDRES	National Biodiversity Research Development and Evidence Strategy
NDP	National Development Plan
NEM:BA	National Environmental Management: Biodiversity Act
NEM:PA	National Environmental Management: Protected Areas Act
NEMA	National Environmental Management Act
NPPOZA	South Africa's National Plant Protection Organisation
NRF	National Research Foundation
OECD	Organization for Economic Co-operation and Development
OIE	World Organisation for Animal Health (The Office International des Epizooties was formed in 1924. In May 2003 the Office became the World Organisation for Animal Health but kept its historical acronym OIE).
PPP	Public-Private Partnership
PPRI	Plant Protection Research Institute

R&D	Research and Development
SADC	Southern African Development Community
SAIAB	South African Institute for Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SANBI ISP	South African National Biodiversity Institute, Invasive Species Programme
SANParks	South African National Parks
SAP	Scientific Advisory Panel
SAPIA	South African Plant Invaders Atlas
SARS	South African Revenue Service
SASRI	South African Sugarcane Research Institute
SCOPE	Scientific Committee on Problems in the Environment
SMART	Specific, Measureable, Assignable, Realistic and Time-bound.
SUSPECT	Species Under Surveillance for Potential Eradication or Containment Targeting
TNPA	Transnet National Ports Authority
UKZN	University of KwaZulu/Natal
UN	United Nations
UNEP	United Nations Environmental Programme
WBC	Weed Biological Control
WfW	Working for Water
WONS	Weeds of National Significance
WRC	Water Research Commission
WTO	World Trade Organization

EXECUTIVE SUMMARY

INTRODUCTION

This document provides a Strategy for managing biological invasions in South Africa, at a national scale and over a time horizon of ten years. It constitutes a national-level plan for the cost-effective achievement of specific objectives in an environment of uncertainty.

The costs of biological invasions are substantial. Invasive alien plants are estimated to cause billions of rands of damage through water-related losses, grazing losses, and decreases in biodiversity and ecosystem service delivery. Alien invertebrates require ongoing control that costs hundreds of millions of rands annually, in order to protect agricultural crops, livestock and human health. These examples indicate the seriousness of the problem, but are limited to estimates of the impacts of some alien species on some aspects of the economy. If all aspects were to be included, the current costs would be orders of magnitude more. Although more work must be done to quantify the costs, it is clear that the current spending on the problem (~ R1 billion annually) is a small fraction of the cost of the problem.

The Strategy is designed to help to achieve the goals of South Africa's National Development Plan. It recognises that natural capital and properly-functioning ecosystems are crucial for a sustainable environment that will underpin the achievement of the goals of the National Development Plan. Biological Invasions will erode natural capital, and must be managed to prevent or reduce impacts.

The Strategy considers the management of alien species at four stages of invasion: initial introduction, establishment, expansion and dominance; and considers three different strategic approaches to management: focussing on species, areas, or pathways of introduction and movement. This four-by-three framework provides a structure for much of the Strategy, but there are also several cross-cutting issues that need to be addressed.

This Strategy aims to facilitate the achievement of 11 complimentary sub-objectives:

1. To promote co-ordination and collaboration across all affected sectors.
2. To establish an effective legislative and regulatory environment.
3. To prevent the introduction of species that pose a substantial invasion risk.
4. To eradicate introduced species where possible and desirable.
5. To reduce the rate of spread of invasions and reduce the impacts of existing invasions.
6. To manage and provide access to information.
7. To develop adequate management and research capacity.
8. To foster research and development to improve management and decision-making.
9. To raise awareness of the problem.
10. To provide adequate financial resources for management.
11. To ensure effective monitoring and evaluation.

REQUIRED INTERVENTIONS AND THEIR INTEGRATION

In South Africa, the focus of efforts to date has been on established invasions of alien plant species, and on reducing the risk of introducing pathogens or pests of importance to human health and agriculture. This needs to be strengthened, inter alia, by addressing other (non-plant) groups, and by improving bio-security operations pre-, at- and post-border.

This Strategy identifies 19 high-level interventions that are needed to achieve the objectives listed above.

The effectiveness of various interventions is compared by examining the ratio of costs to benefits. By directing funding to more effective interventions, and by improving the efficiency with which interventions are implemented, it would be possible to change both the size of the benefits derived, and their effectiveness. But, in reality, several real-world constraints influence the degree to which such implementation would be possible. Overcoming these constraints, over time, is a key feature of the Strategy.

The broad principles that need to be applied to all management operations include planning to succeed; setting specific, measurable, assignable, realistic and time-bound (SMART) goals; ensuring that all essential aspects of management are catered for; co-ordinating activities to achieve maximum benefits; practicing adaptive management; involving qualified ecologists; engaging society and raising awareness; and, leveraging benefits.

LEGISLATIVE AND REGULATORY ENVIRONMENT

Statutory tools that address biological invasions in South Africa are currently fragmented, with responsibilities allocated institutionally rather than on an ecological basis. The absence of legislation that focuses on the management of biological invasions has been a large constraint to the ability of the government to effectively deal with invasions. This is currently being addressed through the promulgation of regulations under the National Environmental Management: Biodiversity Act.

Key actions:

- Continue with the implementation of existing legislation and regulations, while exploring the potential for a comprehensive Invasive Alien Species Act.
- Establish an Alien and Invasive Species Co-ordinating Forum.
- Repeal Provincial legislation relating to the regulation of invasive alien species, in line with national legislation.

PRE- AND AT-BORDER MANAGEMENT

One of the most effective ways to deal with the risk of biological invasions is to stop them before they happen, either by preventing high-risk species from entering the country ("pre-border" interventions), or by intercepting them at the border ("at-border" interventions). However, most effort in combatting biological invasions in South Africa to date has been reactive ("post-border" interventions).

The current approach to pre- and at-border management is largely based on species risk assessments, which are currently managed by the Department of Agriculture, Forestry and Fisheries (DAFF) through quarantine services and pre-border risk assessments for all species imported into South Africa. Screening is also done by DAFF, with the aim of reducing the rate at which new commercially important pests and pathogens arrive in the country. Less effort is placed on managing areas or pathways, although proposals are in place to manage ballast water more effectively.

The Bio-security Directorate of the Department of Environmental Affairs is mandated to address pre- and at-border management with a view to protecting the environment from high-risk alien species. Given that the DEA's activities in this field have to start from scratch, it will be necessary to align with, and build upon, the existing capacities, standards and protocols within DAFF. The development of interventions aimed at improving pre- and at-border management will therefore have to be based on an incremental approach.

Pre- and at-border management faces significant challenges. These include defining responsibility for biological invasions, knowing which species are already in the country, managing illegal deliberate imports, understanding trade patterns, managing long

land borders, and ensuring inter- and intra-governmental co-operation.

Key actions include:

- That a joint cross-governmental inspectorate at borders should be developed, with a clear identity, purpose, and lines of responsibility to facilitate the implementation of biosecurity measures.
- That the Department of Environmental Affairs should establish a joint inspectorate at O.R. Tambo International Airport, and expand this capacity incrementally to other airports, harbours and border posts.
- That a standard risk protocol will be developed to assess and manage all risk.
- That permits should be required for all new deliberate introductions.
- That high-risk pathways should be identified and a strategy developed for each.
- That work at an international level should be undertaken to ensure that the risk of invasions is reduced before species reach South Africa, and equally that South Africa should not export potentially invasive species.

POST-BORDER RISK MANAGEMENT

Many introduced alien species are only now starting to invade. For every widespread invasive species, there are probably three alien species that are already in the country that have only recently been recorded as spreading, with many more that will in future become problematic invaders. This "invasion debt" represents a massive threat to South Africa, but also provides an opportunity to manage the situation pro-actively.

Internationally, eradication has been shown to be highly cost-effective. It requires dedicated and focussed effort, but little money relative to reactive management. It is also important to detect new invasions and evaluate these in the context of any utilisation. High-risk pathways should be managed appropriately to reduce the number of species that they spread and the abundance of each species, and in some cases particularly risky activities should be prohibited.

Key actions include:

- That an emergency response strategy for dealing with newly-detected invasions in South Africa should be formulated, with capability and plans in place to allow for the rapid implementation of emergency interventions.
- That eradication plans for key target species should be drawn up and implemented.
- That key sites for historic and future naturalisations should be monitored.
- That specific targeted surveys, involving taxonomic experts on each group, should be conducted to detect invasions, particularly for poorly-studied groups or in localities that have been under-sampled.

MANAGING ESTABLISHED SPECIES

Established invasive alien species are defined as those species that are present and reproducing outside their native range, and whose extent of distribution and invasiveness makes eradication impossible. These species need to be contained as far as possible by preventing or slowing further spread. Management should also attempt to reduce or mitigate impacts.

The invasive alien plant control projects funded by Working for Water lie at the heart of current efforts to control established invasive species in South Africa today. Alien plant control operations focus on the creation of employment and on the control of invasive alien species. This strategy has allowed the programme to secure substantial funding, which in turn has been used to incubate and grow a wide range of control and other environmental projects.

Projects to utilize biomass of invading alien plants will be implemented in parallel with the control operations. These projects are a major strategic intervention that will further spread the benefits of alien plant control programs, and

that will enable a far greater proportion of the problem to be addressed nationally.

Key actions include:

- That guidelines for management plans should be developed within the next year.
- That management plans should be drawn up for priority ecosystems and species over the following two years.

Management of established plant invasions

Thousands of alien plant species have been introduced into South Africa, and many of these have become invasive. Of these, 198 species have been listed under the Conservation of Agricultural Resources Act as declared weeds, while the proposed national list of invasive alien species under the National Environmental Management: Biodiversity Act currently includes 381 invasive alien plant species that would require management.

Limited studies have indicated substantial impacts associated with invasive alien plants. These plants currently reduce surface water runoff by more than 3,000 million m^3 annually, but this could be more than eight times greater if the plants were to occupy the full extent of their potential range. The implications of this in a water-scarce country are simply unaffordable, and indeed gave its name to the Working for Water programme. Reductions in grazing capacity are currently just over 1%, but could increase to 71% should invasive alien plants occupy their full potential range. While the errors in these estimates could be large, the predicted impacts are so big as to suggest that, even with significant over-estimates, there is cause for serious concern. For example, even if the levels of impact are even just one-quarter of those predicted, they would result in a significant and unaffordable loss of benefits.

Current management programs are having positive effects by reducing established weed populations, but they are only reaching a relatively small proportion of the estimated invaded area.

Biological control of invasive alien plants has brought significant benefits in the form of enhanced control. Biological control is an attractive management option because: (i) it is relatively cheap and very safe compared with the costs and risks associated with herbicide development and deployment; (ii) it can be successfully integrated with other management practices; and (iii) it is self-sustaining. It is clear that greater investment is needed here.

In some cases, alien plant species (as with other taxa) can both bring benefits, and cause harm if they become invasive, leading to conflict. Plantation forestry trees provide a good example of such conflict species. Thorough economic assessments of these problems are needed to inform policy in this regard.

Key actions include:

- That control operations should be prioritized to address invasions in key ecosystems. Such priority areas should receive preferential funding as far as possible, taking existing commitments into account.
- That funding and capacity for planning, monitoring and evaluation should be strengthened, and that all priority projects should have management plans with clear targets to be achieved within defined timeframes.
- That transparent, participatory, expert assessments of need to be carried out for pines and mesquite trees, so that policies regarding their future management can be based on the best available information.

Management of established vertebrate invasions

Freshwater fish are the most problematic of the alien vertebrate species that invade terrestrial and freshwater habitats. Currently, 18 species of alien freshwater fish have established self-sustaining populations in South Africa. A smaller number of mammal and bird species are problematic, while proportionately fewer almost no reptiles or amphibians species are currently known to be problematic invaders.

Freshwater fish populations can be managed through a combination of piscicide control and manual removal. However, the most important strategy would be to identify areas where alien fish populations would be tolerated (to accommodate the demand for aquaculture and sport fishing), while protecting key biodiversity areas by locally eradicating alien fish, and with a strong emphasis on preventing their introduction where they are not yet present. Most active management of other vertebrate groups is aimed at eradication rather than at control of established populations, where possible and appropriate.

Key actions include:

- That South African rivers should be surveyed for alien fishes, to identify areas that are at high risk of invasion or where eradication of alien species is an urgent requirement. Where appropriate and possible, local eradication projects should be implemented.
- That tools should be developed to guide decisions about stocking permits.
- That management plans that differentiate between areas earmarked for conservation, and for economic benefits should be developed for conflict species.

Management of established invertebrate invasions

Invertebrates are a very large and important group of animals, with millions of species. The taxonomy of invertebrate species is poorly understood, although thousands of alien invertebrate species are known to have been introduced.

Many alien invertebrate species are major pests, causing substantial damage in agriculture, forestry, animal husbandry and human health, in addition to impacts on biological diversity. About one third of the more than 600 serious agricultural pests are known to be alien species. The cost of control runs into billions of rands annually. The impacts of alien invertebrate species on commercial crops, livestock, foodstuffs, wood, paper and textiles are generally well-studied, but impacts on natural ecosystems have been poorly studied.

Different agricultural and environmental situations require different approaches and management strategies. To address these needs, various specialized research institutes, focussed on particular agricultural commodities or health issues, have been established in South Africa. They have developed innovative management approaches including the development of pesticides, biological control, sterile insect techniques and mating disruption. Many of these interventions are effective, although the effectiveness of specific pesticides is limited, as invertebrates usually evolve resistance over time.

Key actions include:

- That the management of invertebrate species should focus on preventing new introductions.
- That the onus for improving the control of established populations of commercially-important species should lie with the established commodity-focused research institutes, where there is an economic imperative for funding and action.

Management of microbial organisms

Microbes are organisms whose mode of dissemination is microscopic, and they include organisms as diverse as viruses, bacteria, fungi, algae and many other microbes from lesser-known eukaryote kingdoms.

Microbes are found everywhere and on everything, and are entering the country on a daily basis through a wide variety of means. They are poorly known and their identification requires taxonomic specialists at a scale that is difficult to contemplate. Microbes also evolve much faster than higher organisms and can adapt and change rapidly, and for by far the majority of microbes it is not known whether they are alien or indigenous.

Microbial organisms impact significantly on human and animal health, plant health,

biological diversity and ecosystem health. Currently, interventions to reduce these impacts are left up to the affected stakeholder. Typically, microbes affecting human and animal health are treated under 'sanitary' principles, and those affecting plant health are treated under 'phytosanitary' principles. However, this approach excludes many potential environmental impacts.

Key actions include:

- That a public database of all the role players in the field should be built and maintained.
- That a task team should be formed to evaluate the current management strategies and the efficiency of communication between all the different role-players.

Management of established marine invasions

About 125 species of alien marine organisms are known to have established naturalized or invasive populations in South Africa. The entire rocky intertidal zone along much of the west coast is now heavily transformed by alien species (mussels and barnacles), while the south coast is moderately transformed and the east coast remains largely unaffected.

Most marine invasive alien species are relatively inconspicuous, with the majority currently restricted to sheltered harbours and estuaries. As a result, few South African marine introductions have known significant ecological or economic impacts, although most remain un-studied.

In comparison to terrestrial and freshwater alien and invasive species, the management of marine alien and invasive species in South Africa is in its infancy. Although a number of species were detected some years ago, there are currently no active marine invasive management programs in place. However, there are rigorous bio-security measures in place in terms of South Africa's offshore islands, implemented through the Department of Environmental Affairs' Oceans and Coast branch.

Key actions include:

- That national control plans should be developed for listed species.
- That biological control methods for marine invasive alien species should be reviewed, and that a pilot a program should be initiated to target selected species.

INFORMATION MANAGEMENT

Good information is essential for the development of appropriate policies, for the prioritization of management actions, and for monitoring and evaluating management efforts and their outcomes.

There has been substantial effort to develop lists of alien species, distribution maps and atlases in South Africa, with records of permits, and some spatial information on the management costs associated with invasive alien plants also available. However, there is no comprehensive alien species list, and current information tends to be scattered and patchy, with significant taxonomic and spatial gaps. Much of the information that does exist was designed to serve a purpose other than informing and supporting the management of biological invasions.

It will therefore be necessary to integrate, improve and standardise information management, and to develop a system that will allow users to integrate and interrogate existing information in a way that will effectively support policy development and management.

Key actions include:

- That a survey of potential users should be conducted to determine information needs.
- That minimum standards for data collection and storage should be developed.
- That programs to collect data to fill gaps where possible and desirable should be initiated.

- That a single data portal that can collate and link to all data on biological invasions should be established, with appropriate data sharing agreements in place.
- That a web-based interface should be designed and implemented to enable public access to information.

CAPACITY-BUILDING

Managing biological invasions requires expertise in numerous disciplines, but there are capacity constraints at all levels of management in South Africa. Focussed efforts are needed to improve capacity.

Invasive alien plant control efforts grew rapidly following the establishment of the Working for Water programme in 1995. The programme initially drew on existing experience from other Departments, notably from Provincial Conservation Agencies, South African National Parks, the South African National Biodiversity Institute, the Council for Scientific and Industrial Research, and the Agricultural Research Council, as well as from the private and Government forestry sector, and from tertiary institutions. The goals of achieving transformation and promoting development were built around this core of experienced capacity.

Several small but successful capacity-building initiatives have already been launched, but more are needed. In addition, comprehensive and strategic programs are required to formally train people, who should then be employed to provide the necessary capacity.

Key actions include:

- That a 2-3 year diploma course in the management of biological invasions should be created, and that students should be recruited and financed to undergo this course.
- That qualified graduates from this program should be employed.
- That the capacity to conduct research into biological control solutions should be doubled over the next decade.
- That capacity in critical but poorly-resourced areas (e.g. risk assessment and the taxonomy of under-studied groups) should be developed.

RESEARCH

South Africa has a long history of research on invasive species. The country has contributed to major international programs, including the two programs on biological invasions under the auspices of the Scientific Committee on Problems of the Environment (SCOPE) and Global Invasive Species Programme (GISP). South Africa has by far the most active research programs on invasions of any African country, and produces at least two-thirds of the invasion-related publications from the continent.

The Natural Resource Management Programmes of the Department of Environmental Affairs, of which the Working for Water is part, has formalized links with several research organizations. These research organizations will provide support that requires expert knowledge, or the use of complex technology, to the DEA, in the interests of achieving the goals of this Strategy.

Several issues require urgent attention. These include the need to understand the returns on investment that are gained from different interventions, many of them innovative. To understand the returns on investment, more research will be needed on the impacts of invasive species. Steps also need to be taken to correct the imbalance between research into invasive alien plants versus the other invasive alien taxa. Finally, there is a real and urgent need to address the lack of alignment between researchers and managers.

Key actions include:

- That a research strategy should be developed.
- That the Scientific Advisory Panel established to assist the DEA in areas that require expert input, and to provide guidance on research funding and targets, be strengthened.

- That the commissioning of research should be pro-active, and directed towards relevant questions within an agreed set of research priorities.

AWARENESS-RAISING

The successful implementation of this Strategy will require support from a wide range of stakeholders, as well as the broad public. It is therefore necessary to ensure that they should be well-informed.

Advocacy is a key element of this Strategy. Individuals, organizations, and businesses in the private and public sectors all drive the introduction and spread of alien species in the country, and it is vital to ensure that people should be aware (1) of the risks associated with any activity involving biological invasions, and (2) of the legal requirements that regulate the ownership, cultivation, trade and transport in or of alien species. Direct communication with key stakeholders is required.

Attempts to address awareness-raising in the past have included partnership programmes with green industries (notably the nursery industry), the establishment of invasive species forums, and the development of a National Invasive Species Website.

Key actions include:

- Identify key stakeholder groupings, and disseminate information as needed.
- Establish an Invasive Species Forum Outreach Programme that would be able to set up, support and sustain invasive species forums.
- Institute a National Invasive Species Week, assigned to a national public - private joint venture organization.
- Develop communications toolkits.

SCHEMES FOR FINANCING THE MANAGEMENT OF BIOLOGICAL INVASIONS

Since its inception, Working for Water has followed a strategy of combining alien plant control operations with the need to alleviate poverty by utilizing the employment opportunities associated with labour-intensive control work. This basic strategy, combined with a demonstrable ability to employ large numbers of people and to disburse the available funds, has been the prime reason that the programme has been able to secure substantially more funding than would otherwise have been made available, and to grow.

Funding available for the management of biological invasions within Department of Environmental Affairs amounts to 1.22 billion rands for the 2014/15 financial year. A projected additional R500 million may be available from other Government sources. Investments by the private sector could also potentially improve the funding situation. The amount available is nonetheless insufficient to meet the projected needs to fund the Strategy (around R5 billion annually), and re-alignments of activities will be needed to ensure the best possible returns on investment.

Several options exist to improve the funding situation, and these will need to be explored over the next years. They include investing in more efficient management interventions (changing what is done); reducing inefficiency in management (changing how things are done); eliminating duplication of effort; and sharing the cost burden.

Key actions include:

- That a rigorous re-alignment of the five-year projected budget be undertaken, based on estimated returns on investment, within the constraints imposed of existing commitments.
- That the investments of various Government Departments be re-aligned to eliminate duplication.
- That efficiencies be improved by examining and re-aligning the current mix of interventions, and by taking steps to improve the efficiency of implementation and to increase the quantum of benefits.
- That a program be developed to pursue the alternative funding options. This would include the development of

legislation to enable the generation of revenue from different users.

INDICATORS

High-level indicators are provided to monitor implementation and track progress of the national Strategy for dealing with biological invasions in South Africa. The indicators are aligned with the objectives of the Strategy. The responsibility for ensuring that regular assessments are carried out should lie with the Department of Environmental Affairs, and could be delegated as a standing item on the agenda of the Scientific Advisory Panel.

Key action:

- Agreement should be reached on high-level indicators, and a baseline should be established for each of the indicators as soon as possible.

1. INTRODUCTION

1.1. The problem of biological invasions in South Africa

The invasion of ecosystems by alien species is a growing problem worldwide. Until the late 19th century, mountains, large rivers, deserts and oceans provided formidable barriers to the movement and migration of species. Isolated parts of the world had distinct communities of plants and animals. However, the situation has changed dramatically over the past 100 years. Today, the redistribution of species to support agriculture, forestry, horticulture and recreation supplies a continuous pool of species from which invasive aliens are recruited. Invasive alien species are also a by-product of accidental introductions, and include disease organisms, weeds and insect pests. The opportunities for accidental introductions have grown dramatically with the rapid expansion in global travel and trade. The problem is exacerbated by human-mediated disturbance, and changes in the world's climate and biogeochemical cycling, which make ecosystems more susceptible to invasion by alien species. As a result, natural ecosystems as well as those influenced or dominated by humans are under siege from a growing number of destructive invasive alien species that erode natural capital, compromise ecosystem stability and threaten economic productivity (Box 1.1).

South Africa has been particularly badly affected, and the country is home to a large and growing number of invasive alien species. Reasons for this include the long history of colonial occupation (dating back 360 years), and the many and varied ecosystems all of which currently harbour populations of well-established invasive alien species.

Plants are the most noticeable group of invasive alien species in South Africa, occupying large parts of the country. Almost 9000 alien plant species have been introduced to South Africa, of which 381 have been listed as invasive in draft legislation, though there are others that are also invasive. In addition to alien plants, thousands of alien invertebrate species have been introduced into South Africa's terrestrial and freshwater environments. However, poor understanding of their taxonomy means that it is not possible to accurately estimate the number species involved. Nonetheless, about one third of over 600 species of insects that have been recorded as serious pests on cultivated plants, or in natural pastures, are alien species. Thousands of other alien invertebrate species have naturalised in South Africa, but have not yet been noted as serious pests. Alien terrestrial and freshwater vertebrate species in South Africa include a few mammal and bird species, but 18 species of alien freshwater fishes are the most problematic group. In addition to species that are alien to South Africa, 27 South African freshwater fish species have been introduced into waters outside of their indigenous range (extra-limital species), causing severe impacts in the recipient environments. The presence of alien species in marine environments has not been studied in any detail to date. The first paper specifically listing introduced marine species only appeared in 1992 and listed just 15 species. This number has since risen to 86 confirmed and a further 39 suspected or 'cryptogenic' species. This number is certainly an underestimate. Microbial organisms (or "microbes") pose particular challenges in the context of biological invasions, as they are enormously diverse, poorly known, found everywhere, and difficult to detect. Microbes are defined as organisms whose mode of dissemination is microscopic (i.e. not visible to the naked eye), and include viruses, bacteria, fungi, algae, and many other organisms from lesser known eukaryote kingdoms. Microbes are typically only studied when they cause disease to humans, animals and plants, but can have potentially catastrophic impacts on natural ecosystem biodiversity and the environment.

The costs associated with biological invasions are substantial. Estimates of these costs for South Africa have only been made for plants, and then only for a limited range of ecosystem services (mainly surface water runoff, livestock carrying capacity and biodiversity). At a national scale, the estimated value of annual water-related losses in 2008 was approximately R8 billion, and the annual value of grazing lost as

a result of invasions was R450 million. The annual losses due to decreases in biodiversity and ecosystem service delivery (other than water or grazing) were conservatively estimated at R570 million per year. This amounts to an estimated total annual cost of invasive alien plant-related losses of over R9 billion. Smaller-scale studies have revealed potential impacts in other ways. For example, famine weed (*Parthenium hysterophorus*) is an introduced alien herb which impacts on stock and crop production. It is also a serious threat to environmental and human health as a result of its ability to produce chemicals that cause severe dermatitis, allergy and toxicity in animals and humans (with corresponding reductions in quality of life and productivity). Famine weed is highly toxic to domestic animals, and if eaten, the meat becomes tainted and this causes direct economic losses. Crop losses also come about primarily through allelopathic effects and direct competition with crops. Famine weed is currently spreading vigorously through the KwaZulu/Natal province, where serious economic and health impacts are to be expected.

The above examples indicate the seriousness of the problem, but the information is limited to estimates of the impacts of some species on some aspects of the economy. Clearly, if all species and aspects were to be included, the estimates of the current costs of invasive alien species would grow. In addition, new species will continue to arrive, many species that are already here will become invasive (known as "invasion debt", Box 1.2), established invasive alien species populations will continue to grow in the absence of effective control measures, and in each case the economic impacts will expand (Figure 1.1). Given the magnitude of the problem, and the potential for it to increase, it is imperative that South Africa should develop an effective and realistic strategy to address the problem.

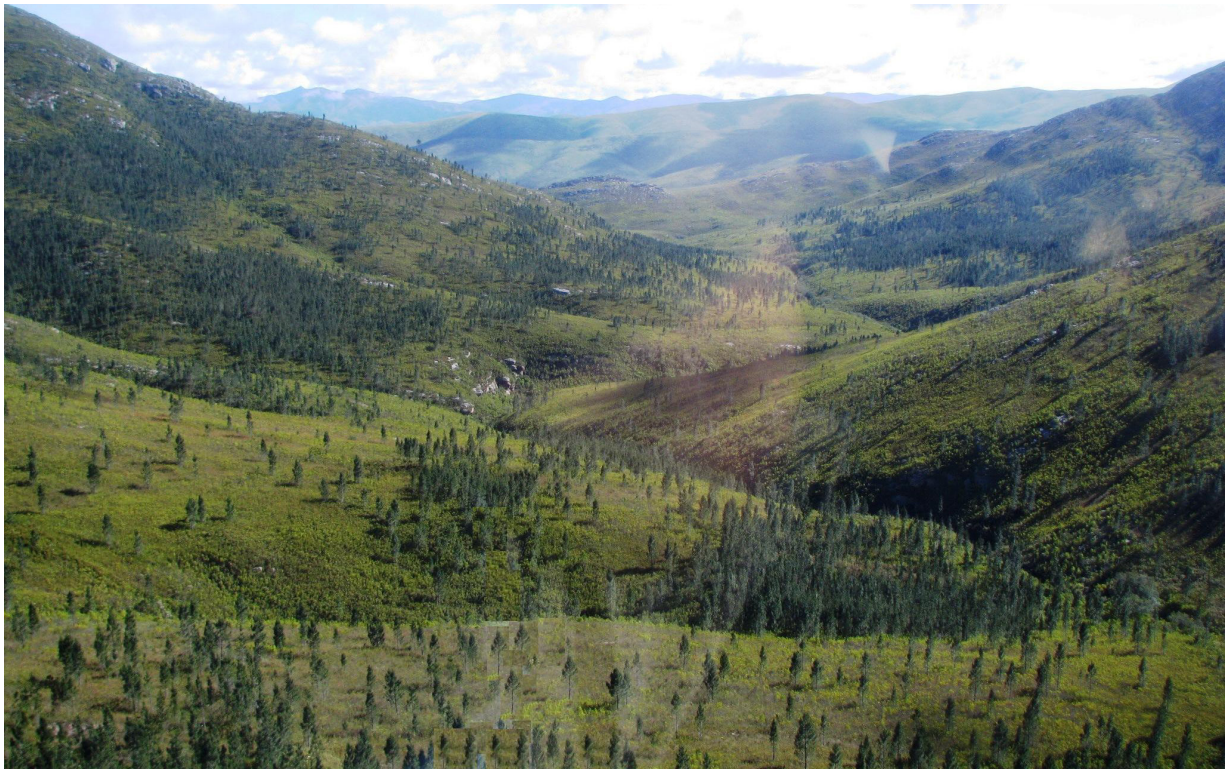


Figure 1.1. Invasive alien pine trees invading the remote parts of the Tsitsikamma mountains in the Eastern Cape Province. Unless these invasions are brought under control, the entire area will become covered in invasive pines, impacting severely on water resources and biodiversity, increasing fire hazard, and causing extensive erosion in the catchments.

Box 1.1. Examples of devastating invasive alien species

Invasive alien species, including plants, animals and pathogens, have had devastating impacts on the ecology and economies of countries around the world. Below is a selection of examples from a range of organisms that illustrate this point. Unless the problem is effectively managed, examples such as these will become much more common, with dire consequences.

Water Hyacinth (*Eichhornia crassipes*), a South American aquatic weed introduced widely into Africa, has blocked waterways limiting boat traffic, access to safe water and fishing. Water hyacinth also blocks sunlight and oxygen, dramatically altering biological diversity in aquatic ecosystems.

The Sweet Prickly Pear (*Opuntiaficus-indica*) was introduced to South Africa from South America 300 years ago. By the 1930s this cactus had invaded one million hectares of land in the Eastern Cape and Karoo, rendering land unproductive with ruinous effects on farming communities. The invasions were later significantly reduced by the introduction of biological control.

The Nile Perch (*Lates niloticus*) was introduced to Lake Victoria, Africa in 1954, where it caused the extinction of more than 200 endemic fish species, leading to far-reaching impacts that have been devastating for the environment as well as for communities that depend on the lake.

Rinderpest (a *Morbillivirus*) is believed to have originated in Asia, later spreading through the transport of cattle. Introduced into southern Africa in the 1890s, it killed 80 to 90% of all cattle in the region, as well as a very large proportion of the wildlife, with catastrophic ecological and economic consequences.

The introduction of rabbits (*Oryctolaguscuniculus*) to Australia from Europe in the 19th century had disasterous effects on that country. Rabbits have been the most significant known factor in indigenous species loss in Australia, and are also responsible for serious erosion problems that have been devastating to the land.

The cane toad (*Rhinella marina*), a poisonous amphibian native to South America, was introduced to Australia in 1935 with serious consequences for the environment, including the depletion of native species that die eating cane toads; the poisoning of pets and humans; depletion of native fauna preyed on by cane toads; and reduced prey populations for native insectivores, such as skinks.

The Brown Tree Snake (*Boigairregularis*) is infamous for its near complete extermination of Guam's native forest birds.

Caulerpa Seaweed (*Caulerpataxifolia*) has spread throughout the northern Mediterranean where it is a serious threat to the native marine flora and fauna.

The Asian long-horned beetle (*Anoplophoraglabripennis*) was accidentally introduced into the United States in 1996, and is now one of the most destructive non-native insects in the United States; it and other wood-boring pests cause an estimated $3.5 billion in annual damages.

Source of information in this Box:

Lowe S. et al. (2004) 100 of the World's Worst Invasive Alien Species: A selection from the Global Invasive Species Database. Invasive Species Specialist Group, Species Survival Commission of the World Conservation Union (IUCN), 12pp. Updated and reprinted version.

Box 1.2. Invasion debt

Invasion debt is a concept that posits that even if introductions to a region cease, problems associated with invasions will continue to increase. New invasions will emerge as already-introduced alien species become naturalised and then invasive, already-invasive species will continue to spread, and the impacts from all invasions will increase in magnitude. This is because there are often significant delays between introduction, naturalization, invasion, and the manifestation of major impacts.

Experience across the world has demonstrated that alien species normally do not become invasive immediately on introduction to a new environment. It takes time for the population to build up, and invasions may only start, or be noticed, years or decades after a species has been extensively spread and propagated by people. While this can be simply due to a low number of individuals being introduced, in many cases there is something actively limiting an invasion the so-called "lag phase". Such species eventually become invasive for various reasons: a change in climate or disturbance regime; selection or adaptation allowing species to acclimatize and become dominant in their new surroundings; or the arrival of a suitable pollinator or seed disperser. Whatever the case, several decades may pass before an introduced species begins to invade. And most invasive species may well take centuries to reach all suitable areas in their new range.

The consequences of invasion debt are large. South Africa is home to thousands of alien species that are either only just becoming invasive, or have not yet done so. It can thus confidently be predicted that, even if measures to prevent further introductions are perfect, the costs of invasions will increase over the coming decades. A consequence of invasion debt is that some species that currently benefit some sectors of society will in future have significant negative impacts often on the broader society. This can and does create conflicts of interest between the state and particular interest groups. Invasion debt clearly needs to be taken into account in a national Strategy for dealing with invasions, highlighting the need to manage pro-actively and consider all stages of invasions.

Source of information in this Box:

Essl F., et al. (2011). Socioeconomic legacy yields an invasion debt. Proceedings of the National Academy of Science 108, 203–207.

1.2. Historic approaches to the management of invasive alien species in South Africa

South Africa has a long history of addressing biological invasions, especially alien plant invasions. Mechanical control efforts aimed at clearing invasive alien plants began in the first half of the 20th century, but were initially at best uncoordinated and erratic, and did little to stem the spread of invasive alien plants. Although few efforts were adequately documented, evidence shows that poor understanding of the ecology of invasive species, as well as a lack of follow-through control after alien plant removal, led to much wasted effort and money until the late 1970s. In the 1970s and 1980s, coordinated control programmes were introduced in the fynbos regions of the country. These programmes were aimed largely at clearing watersheds of invasive pines, hakeas and wattles, and they involved mapping invasive plants, and scheduling mechanical clearing in conjunction with prescribed burning. These carefully-planned operations had the desired effect of making considerable progress towards achieving clearing targets. However, these coordinated clearing programmes declined drastically in the late 1980s for a combination of reasons. As a result, programmes to control invasive alien plants fell behind, and many cleared areas were re-invaded.

Biological control for invasive alien plants was developed in parallel with implementation of mechanical clearing, but not necessarily in an explicitly collaborative or coordinated way. The first biological control agents were released in 1913 against the invasive cactus *Opuntiamonocantha*. Since then 270 species of

organisms have been considered as potential biological control agents, including insects (87%), mites (2%) and pathogens (11%). Of the 270 potential biological control agents that have been considered in South Africa, 106 were tested and released and 75 have become established on 48 species of invasive alien plants. Of the weed species in South Africa on which agents have become successfully established, 23% have been completely controlled (i.e. no other control measures have been needed) and 38% are under substantial biological control (i.e. other control measures may be intermittently or routinely needed, but less effort or expenditure is required than would have been the case in the absence of biological control). In most cases these benefits have been sustained for decades and will continue to accrue into the future.

South Africa's first democratically-elected government revived the invasive alien plant control efforts in 1995, with the establishment of the Working for Water programme. This followed the presentation of arguments that: (i) invasive alien plants were a large and growing national problem; (ii) these invasions were specifically a serious threat to water resources; and (iii) that these problems could be addressed by creating important employment opportunities for poor people in underdeveloped rural areas. The Working for Water programme was housed within the Department of Water Affairs for its first 15 years, with a major focus on controlling invasive alien plants linked to a reduction in water resources. The programme grew rapidly from a budget of R25 million (initially secured as a once-off grant from the Reconstruction and Development Programme by Professor Kader Asmal, the then Minister of Water Affairs and Forestry) , and currently operates in all nine provinces on a budget of R1.05 billion in 2012/13, and employs almost 40 000 people. The programme moved to the Department of Environmental Affairs in the 2011/12 financial year, where its mandate was formally broadened to address all invasive species and all ecosystems, and with the addition of a responsibility for biosecurity.

In line with the new mandate, efforts have been stepped up to address at least some prominent animal invasions. Projects have been implemented in the Western Cape to remove invasive freshwater fish (smallmouth bass, *Micropterus dolomieu*) from selected river stretches, and to restore the native fish species that had been displaced by the alien fish (Box 6.6.1). A concerted campaign was made to eradicate Himalayan tahrs (*Hemitragusjemlahicus*) from the Table Mountain National Park, a World Heritage Site, and to eradicate populations of house crows (*Corvus splendens*) from Cape Town, Durban and Richard's Bay; while programmes to control feral pigs (*Sus scrofa*), guttural toads (*Amietophrynusgutturalis*), mallards (*Anasplatyrhynchos*) and various wasp species (e.g. *Vespulagermanica*) have been launched.

In 2008, a unit (now called the Invasive Species Programme; ISP) was established within the South African National Biodiversity Institute as an implementing agent of Working for Water to (1) detect and document new invasions, (2) provide reliable and transparent post-border risk assessments and (3) provide the cross-institutional co-ordination needed to implement national eradication plans successfully. As of the end of 2012, the ISP had an annual budget of R36 million, employed 33 people working across all nine provinces, supported 10 post-graduate students, and hosted 35 interns. The unit has worked towards full risk assessments for 39 plant taxa and has developed eradication plans for seven species; the unit is now helping to implement these plans.

A milestone toward addressing the capacity problem for managing biological invasions in South Africa was the establishment of the Centre for Invasion Biology in 2004. It was one of the six initial "Centres of Excellence" created by South Africa's Department of Science and Technology in all fields of science. The establishment of the C·I·B points to the recognition of biological invasions as a major challenge to the South African environment. The formation of the CIB provides a platform and critical mass for further research on key issues relating to the management of invasive species. In its first decade, the C·I·B produced more than 700 publications in peer-reviewed journals, supported over 200 graduate students and post-doctoral associates, and provided high-level input to policy formulation.

Recent assessments have identified both strengths and weaknesses in the current approaches to controlling invasive alien plants in South Africa. Some invasive alien plant species are being brought under control through an effective combination of labour-intensive mechanical control combined with long-term, sustainable biological control. For example, *Hakea* species appear to have declined because of historic (pre-1995) mechanical clearing, ongoing clearing by Working for Water, and biological control (Box 1.3). Some Australian *Acacia* species, among the worst invasive species in South Africa, have been reduced in extent and vigour. In particular, a gall-forming fly recently released on black wattle (*Acacia mearnsii*) has virtually stopped pod production in some areas, offering encouraging prospects for gaining control through a combination of mechanical clearing and seed reduction through biological control. However, despite high levels of funding, current control operations aimed at invasive alien plants have only reached a relatively small proportion of the estimated invaded areas, so that many species continue to spread despite considerable control effort.

Box 1.3. The combined impact of sustained mechanical and biological control on invasive alien *Hakea* shrubs in South Africa

The control of invasive alien plants often involves the integration two or more approaches, including mechanical clearing, the application of herbicides, burning, and biological control. The effect of such an integrated approach over four decades has been demonstrated in the control of invasive *Hakea* species in South Africa. Invasive *Hakea* shrubs are widespread across an area of approximately 800 x 200 km, occurring in rugged, inaccessible and fire-prone mountain areas. *Hakea* is a serotinous species, and produces copious amounts of seed that are wind-dispersed after fires. The management approach has included extensive felling (to kill adult plants) and burning (to kill seedlings), augmented by the release of biological control agents that attack the seeds of the plant. A recent assessment suggested that the overall distribution of the species was reduced by 64 %, from 531 229 to 191 094 ha between 1979 and 2001, and concluded that initial programs of mechanical clearing were responsible for reducing the density and extent of infestations, while biological control was largely responsible for the failure of the species to re-colonize cleared sites, or to spread to new areas following unplanned wildfires.



Box Figure 1.3.1. Extensive mechanical operations to clear invasive *Hakea* shrubs were carried out in the Western Cape in the 1970s by the Department of Forestry (left). Biological control (in this case by the fungus *Colletotrichumacutatum* which causes die-back) has assisted to hold on to some of the gains made by mechanical clearing (right).

***Source of information in this Box**: Esler, KJ et al. (2010). A landscape-scale assessment of the long-term integrated control of an invasive shrub in South Africa. Biological Invasions 12, 211 - 218.*

In terms of reducing the risk of introducing new invasive species, the Department of Agriculture, Forestry and Fisheries has monitored commercial agricultural products for pests and pathogens, and has provided diagnostic services for interceptions and risk assessments that are required for other imports. However, the monitoring has to date largely been focussed on economic commodities, and only classical biological control agents have been subject to an in-depth risk analysis.

1.3. Current strategic imperatives

South Africa's development pathway will be guided by the National Development Plan (NDP, see Box 1.4). The NDP has a focus on economic growth, social development and service delivery, and makes little direct reference to environmental issues. Given the projected growth in the impacts of invasive alien species on vital natural resources (which are essential for achieving the goals of the NDP), strategic interventions to reduce erosion of the country's natural capital by invasive species are crucial.

South Africa's National Biodiversity Strategy and Action Plan, published in 2005, recognised biological invasions as one of several important pressures on biodiversity conservation and sustainability across the landscape and seascape, and called for the establishment of a multi-agency national programme to deal with the full suite of impacts posed by invasive species in both terrestrial and marine environments. South Africa's National Biodiversity Assessment, published in 2011, noted that South Africa had responded significantly to the challenge of invasive alien species, but that most effort had been invested in managing invasive species that have already become a problem. It noted that, increasingly, countries around the world are recognising the value of a hierarchical approach to dealing with invasive species, with a strong focus on preventing the entry of new high-risk alien species and eradicating those that are at an early stage of establishment. The return on investment of public funds would much higher for prevention and eradication than for containment and management of established invasive species. It also noted that, for invasive species that are so widespread that they cannot be contained, it would be important to take an asset-based approach to management, restoring and protecting *specific* highly-valued ecological assets. Finally, it noted that draft regulations in terms of the National Environmental Management: Biodiversity Act would provide support to management, but that South Africa would benefit from a national Strategy for invasive alien species, in addition to the regulations, to guide and support the effective implementation of legislation.

In order to deal with biological invasions effectively, a comprehensive and strategic approach is thus required, given the problem's magnitude and complexity. This document provides such a Strategy; it constitutes a national-level plan for the achievement of specific objectives in an environment of uncertainty.

Box 1.4. The National Development Plan

The National Development Plan (NDP), accepted by the South African parliament in 2012, is a strategic plan for the country. It outlines the key drivers of poverty and inequality and provides a framework for the elimination of poverty and reduction of inequality by 2030. The plan provides a roadmap for the realization of these goals by directing the energies of its people, growing an inclusive economy, building capabilities, enhancing the capacity of the state, and promoting leadership and partnerships throughout society.

The NDP offers a long-term perspective in defining desired destinations and identifies the roles of different sectors of society in reaching the stated goals. As a long-term strategic plan, it serves four broad objectives:

- Providing overarching goals to be reached by 2030.
- Building consensus on key obstacles to achieving these goals.
- Providing a shared long-term strategic framework within which more detailed planning can take place to advance the long-term goals set out in the NDP.
- Creating a basis for making choices about how best to use limited resources.

The NDP aims to ensure that all South Africans attain a decent standard of living, the core elements of which are identified as:

- Housing, water, electricity and sanitation
- Safe and reliable public transport
- Quality education and skills development
- Safety and security
- Quality health care
- Social protection
- Employment
- Recreation and leisure
- Clean environment
- Adequate nutrition

Economists typically recognise five kinds of capital: financial, natural, produced, human, and social. All are stocks that have the capacity to produce flows of economically desirable outputs. The maintenance of all five kinds of capital is essential for the sustainability of economic development. The protection of natural capital is not explicitly addressed in the NDP, but is fundamental for achieving the aims of the NDP, listed above. Invasive species pose a rapidly growing threat to biodiversity and ecosystem functioning, to food and water security, to economic income from nature-based tourism, and to human health. It is therefore essential that the damaging effects of invasive alien species are seen as a national priority.

1.4. A proposed framework for managing biological invasions

At the sixth Convention of Parties (COP) to the Convention on Biological Diversity (CBD), member states to the Convention agreed to a set of guiding principles with regard to the management of invasive alien species (COP 6 Decision VI/23). Principle 2 of these guiding principles calls for a "hierarchical approach", based on four clear stages of invasion. The approach would require (1) that priority to be given to preventing the introduction of invasive alien species; (2) if a potentially invasive species has been introduced, it should be eradicated if possible and desirable; (3) in the event that eradication is not

feasible or resources are not available for its eradication, containment measures should be implemented; and (4) long-term mitigation measures should be implemented where species have become widespread and dominant.

The management of each of the four stages of invasion can include three broad approaches. These would be (1) species-based approaches, with the focus on a single species at a particular stage of invasion; (2) area-based approaches, with a focus on an ecosystem (e.g. a catchment, a river reach, or a protected area) that is at a particular stage of invasion; and (3) pathway-based approaches, with a focus on the movement, from one area to another, of species at a given stage of invasion. This gives rise to a "four by three" approach scheme (Figure 1.2).

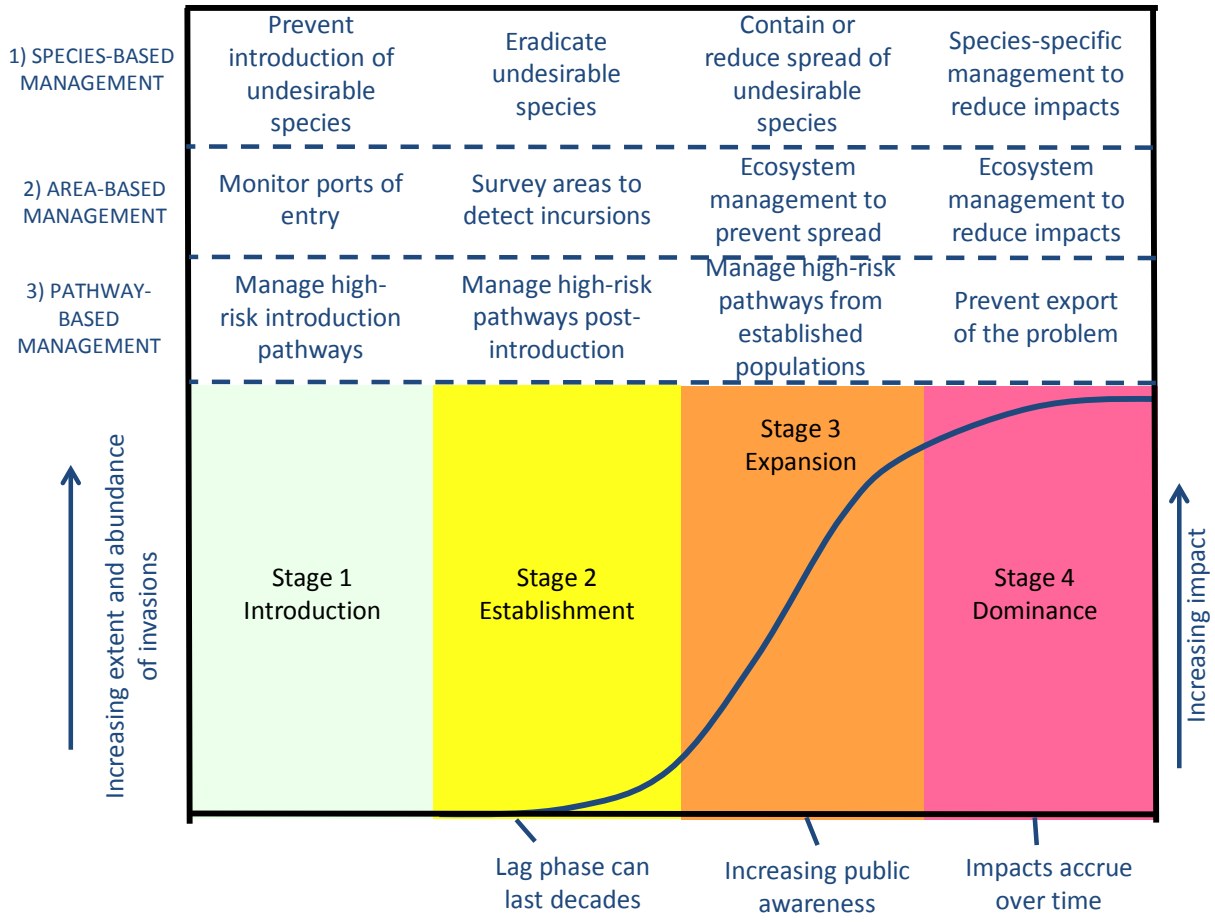


Figure 1.2. A "four by three" framework for the management of biological invasions. There are four stages of invasion, dependent on the extent and abundance of the species concerned (pre-introduction; initial incursion; expansion; and dominance), and three broad types of management responses that would focus either on managing single species (a species-based approach), or managing priority areas invaded by one or more species (an area-based approach), or managing the pathways that are responsible for the spread of invasive species (a pathway-based approach).

As invasions progress from one stage to the next, the goals of management become increasingly expensive to achieve, but there is more certainty as to the nature and scale of any negative impacts. Depending on the circumstances, the approach to managing biological invasions at each stage can be either species, area or pathway-based, or a combination of all or any of these. It would however be important to consider an appropriate mix of approaches, rather than a single approach, to ensure that key actions are not overlooked.

Species-based approaches focus on preventing the introduction of, eradicating, containing or controlling particular species. In some cases, a focus on species (as opposed to areas) is essential. For example, risk assessments are often species-specific, and the development of biological control methods should be based on the release of host-specific biological control agents that would attack only the target invasive alien species. In addition, eradication attempts are aimed at particular species, and not at suites of different species in the same area. For regulatory purposes, permits may be issued for particular species, and so on.

Area-based approaches would have a focus on ecosystems invaded by several alien species. Where several invasive alien species co-occur, it does not make sense to manage only one or some of those species, as the remaining species could simply replace those whose density and impact have been reduced. This approach would be appropriate when it becomes necessary to protect a priority area from invasion, or to reduce the impacts of invasion in a priority area, so as to protect the ecological integrity of the area concerned.

Pathway-based approaches would focus on reducing the risks of transporting invasive alien species to new areas. In invasion ecology, the term “dispersal pathways” is used broadly, and refers to the combination of processes and opportunities that result in the movement of alien species from one place to another. Pathway-specific management approaches have a focus on identifying “vectors” (that is, the actual mechanism by which species are able to arrive). For example, introduction via ocean-going ships would be a pathway, with several possible vectors (introduction in ballast water, in cargo containers, by clinging to the hull of the ship, or arriving in the luggage of passengers).

The features of some of the important interventions associated with different approaches to management at different stages of invasion are illustrated in Table 1.1.

Table 1.1. Examples of important interventionsand goals associated with four stages of invasion and three broad approaches to the management of biological invasions.

Management approach	Stage of invasion			
	Introduction (requiring pre- and at-border management)	Establishment (requiring post-border risk management and eradication)	Spread (requiring incursion response management, and containment)	Dominance (requiring ongoing maintenance management to reduce impacts)
Species-based management	Pre-border risk assessment for intentional introductions, so that proposed introductions of alien species can either be refused or permitted and regulated where necessary. (e.g. permits for importing potential biofuels)	After a species has been introduced, an assessment of the risks poses in the context where it is present or has established is required to provide a basis for a decision on whether to try to regulate the species or not. Where a species is deemed to pose a high risk of invasion, eradication can be attempted where feasible. (e.g. this will include the assessment and monitoring of alien mammals in captivity for invasive potential AND/OR detecting, assessing and eradicating any populations established in the wild)	When a species is known to pose a high risk of having negative impacts, has a restricted but expanding distribution, but cannot be eradicated, then steps need to be taken to contain the spread of the species. A containment area can be defined with barrier zones intensively managed to prevent spread (e.g. creating a barrier for an insect pest)	Where species dominate large areas, control operations can be designed and carried out to reduce the impacts. Such control operations would be based on an understanding of the ecology of the species concerned. (e.g. developing integrated strategy for controlling an invasive tree that might include biological control, mechanical control, and restoration)
Area-based management	Carry out surveillance at ports of entry to identify and pick up new introductions. (e.g. setting up insect traps	Following a principle of early detection and rapid response, areas should be regularly surveyed to detect incursions by alien species not previously known to be present in those areas. When such species are detected attempts	Appropriate suites of integrated alien species control programmes should be developed and implemented in selected priority areas. The goal would be to locally eradicate, reduce the density of, or	An integrated alien species control programme should be developed and implemented in a given area to restore, as far as possible, key ecosystem services and functioning, or to reduce the

Management approach	Stage of invasion			
	Introduction (requiring pre- and at-border management)	Establishment (requiring post-border risk management and eradication)	Spread (requiring incursion response management, and containment)	Dominance (requiring ongoing maintenance management to reduce impacts)
	at container ports)	should be made to eradicate them. (e.g. monitoring arboreta for signs of naturalisation)	halt or retard the spread of invasive alien species whose populations are small but expanding. (e.g. use high-altitude teams to remove alien species from exposed slopes to prevent these contributing to fast spread)	impacts on invasion by multiple species. (e.g. managing invasive organisms on water-ways to reduce the risk of flood damage)
Pathway-based management	Identify and monitor vectors that could carry invasive species into the country, so that high-risk practices can be prohibited, or managed and regulated. (e.g. the regulation of ballast water in shipping)	Monitor the pathways that species are moved around the country post-introduction, including looking at possible vectors that would take species from points of entry to final destinations. Manage high-risk pathways appropriately. (e.g. follow supply chain of imported timber)	Identify the pathways responsible for the spread of alien species from source populations, so that high-risk practices can be prohibited, or managed and regulated. (e.g. develop best-practice for moving fodder around the country from areas known to be invaded)	Take steps to prevent the export of the problem to new areas, for example internationally.

1.5. Objectives of South Africa's National Strategy on Biological Invasions

The overarching objective of this Strategy is to minimise the risks posed, and reduce the negative impacts caused, by invasive alien species in South Africa. There are four complementary sub-objectives:

1. *Prevent the introduction of new species that pose a risk of becoming invasive:* The risk of introducing new alien species with the potential to become invasive and to do damage needs to be reduced as far as possible (addressed in Chapter 4);
2. *Eradicate introduced species where possible and desirable:* Any alien species with the potential to become invasive and to do significant damage needs to be detected as soon as possible, and such detection followed by rapid and appropriate action (addressed in Chapter 5);
3. *Reduce the rate of spread of invasions:* The spread of established invasive alien species needs to be contained as far as possible (addressed in Chapter 6); and
4. *Reduce the impacts of existing invasions:* the impacts reduced as far as possible, with a focus on high priority areas (addressed in Chapter 6).

In addition to the main sub-objectives, seven cross-cutting objectives also need to be achieved, so that the overarching objective can be achieved. These are:

1. *Establish an effective legislative and regulatory environment*: Existing laws and regulations need to be rationalised, important gaps need to be filled, and effective enforcement will be necessary (addressed in Chapter 3);
2. *Develop adequate management capacity*: Effective management of biological invasions will require the training of a critical mass of suitably-qualified personnel (addressed in Chapter 8);
3. *Develop adequate research capacity*: Effective management should be based on sound science, and adequate research capacity is needed to generate the necessary scientific understanding (addressed in Chapters 8 and 9);
4. *Ensure cross-sectoral co-ordination and collaboration*: The effective implementation of this Strategy will require effective collaboration between various government departments, and between government and the private sector (addressed in Chapters 2, 3 and 11);
5. *Raise awareness*: The support of society at large is a prerequisite for the success of the Strategy (addressed in Chapter 10);
6. *Ensure effective monitoring and evaluation*: Managing invasive alien species effectively will require the setting of achievable goals, and monitoring the degree to which goals are met; this in turn will require the development of robust indicators (based on research) and the establishment of information databases (addressed in Chapters 7 and 12); and
7. *Provide adequate resources*: The successful implementation of this Strategy will require adequate funding from sustainable sources (addressed in Chapter 11).

1.6. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 28, 35, 62, 117, 120, 131, 169, 179, 192.

2. INTEGRATION

2.1. Introduction

2.1.1. The need for integration

A wide range of issues need to be addressed to manage biological invasions effectively (see 2.1.2 below). This chapter describes major national-level interventions that will be integrated to achieve the goals of the Strategy. Not all of these interventions are being implemented right now, and up to now South Africa's approach to managing biological invasions has arguably had a skewed focus on (1) managing established alien plants and invertebrate pests, but with a miniscule focus on other taxa such as birds and fish; and (2) reducing the risks of importing unwanted pathogens or pests of relevance to agriculture and human health. Some interventions will deliver bigger returns on investment than others, and this needs to be considered in a reconfiguration of current actions. This Strategy therefore seeks to reconfigure and integrate the range of interventions, so as to improve efficiency, recognising that this will have to be phased in over time, taking real-world constraints into account.

2.1.2. Interventions to be integrated

The "four by three" framework for the management of biological invasions (Figure 1.1) can be used to define a broad set of interventions that need to be considered (Table 2.1). In addition, it is necessary to consider cross-cutting elements that relate to all stages of invasion and to monitor and evaluate progress with regard to achieving the goals of this Strategy. Table 2.1 provides examples of high-level interventions, but more details of these and related approaches are expanded on in the chapters that follow.

Table 2.1. High-level interventions, taken in this Strategy as necessary for achieving the goals of managing biological invasions. These interventions will be integrated and optimised at a national level. The interventions are classified according to the stage of invasion, and the broad types of management (see Figure 1.1). See Table 2.2 for a discussion of how these interventions should be implemented.

Goal of management	Species-related interventions	Area-related interventions	Pathway-related interventions
Prevent the introduction of high-risk species (Stage 1).	Joint inspectorate at borders.	Joint inspectorate at borders.	Joint inspectorate at borders. Identify high-risk pathways and develop a strategy for each.
Eradicate undesirable introduced species (Stage 2).	Emergency response strategy and capability in place. Eradication of target species.	Emergency response strategy and capability in place. Monitor key sites for historic and future naturalisations.	Emergency response strategy and capability in place.

Goal of management	Species-related interventions	Area-related interventions	Pathway-related interventions
Contain the spread of established species, and control widespread species to reduce impact (Stages 3 and 4).	Prioritize species. Develop management plans. Implement management plans. Monitor outcomes of implementation, and evaluate.	Prioritize areas. Develop management plans. Implement management plans. Monitor outcomes of implementation, and evaluate.	Identify high-risk pathways and develop a strategy for each pathway.
Regulate behaviour (All stages).	Develop appropriate legislation. Enforce legislation.		
Practice collaborative governance (All stages).	Collaborative governance.		
Manage information (All stages).	Manage species-related information.	Manage area-related information.	Manage pathway-related information.
Build capacity (All stages).[1]	Full-time and in-service training in risk assessment, taxonomy, and species recognition, and risk assessments.	Full-time and in-service training in applied ecological management.	Full-time and in-service training in the management and regulation of travel and transport-related pathways, including interacting with stakeholders.
Improve understanding (All stages).[2]	Research into the ecology and control of selected species.	Research into ecosystem management at a range of scales.	Research into the introduction and within-country dispersal of alien species.
Raise awareness (All stages).	Raise awareness relating to invasive alien species.	Raise awareness relating to areas.	Raise awareness relating to pathways.
Monitor progress with the Strategy (All stages).	Develop and monitor indicators of the introduction, spread and control of alien species.	Develop and monitor indicators of area affected by invasions, and area covered by approved management plans.	Develop and monitor indicators of pathways and vectors under active management.

[1] Capacity will also need to be built for many cross-cutting activities as well as activities aimed specifically at addressing species, areas or pathways.

[2] Research will also be required for many cross-cutting processes, in addition to research aimed specifically at improving understanding about species, areas and pathways.

2.1.3. The question of scale

While this Strategy has a focus on the national scale, integration is needed at a range of spatial scales, from national, to provincial or biome, to catchment, to municipality or protected area, and within individual projects. Similarly, this Strategy has a time scale that spans the next five to ten years, but funding is usually allocated according to budget cycles (typically three years) and adjusted annually in annual plans of operation, while much longer time-scales need to be considered to achieve other goals.

2.1.4. Broad principles of effective management

To achieve effective management of biological invasions, several broad principles will be used to guide management. These include:

- *Plan to succeed*. Sufficient funds will, as far as possible, be allocated to the highest-priority projects first, to ensure that they are adequately resourced. The realities of existing commitments, and an imperative to create employment in impoverished rural areas, will also be taken into account.
- *Set SMART goals*: management will be guided by goals that are SMART, that is Specific (the nature and level of the performance required must be clearly identified); Measureable (the indicators chosen must be meaningful, easily understood and measurable); Assignable (who will carry out the actions?); Realistic (what can realistically be achieved, given the available resources?); and Time-bound (the timeframe for the achievement of goals must be clear).
- *Cover the essentials*. Insofar as possible, adequate funding and resources will be provided to effectively cater for all aspects of management, including planning, implementation, and monitoring and evaluation.
- *Co-ordinate activities*. Management will strive to co-ordinate and integrate all activities in an area to achieve maximum beneficial effect.
- *Be flexible*. The outcomes of management interventions will be monitored regularly, and progress towards planned goals will be evaluated. Where progress falls short of planned targets, action will be taken to correct the shortfalls. Where targets are demonstrably not achievable, the goals of the plans will be re-assessed. An adaptive approach to management, which requires that plans should be as flexible as possible to accommodate unforeseen setbacks or unplanned events, will be adopted.
- *Use the best available understanding*. This Strategy recognises the importance of using the best available science to guide management, including the appropriate involvement of ecologists with an understanding of the ecology of the target species and of ecosystem responses.
- *Raise awareness and influence behaviour*. For invasive alien species control operations to succeed, society at large must support the projects. This requires comprehensive awareness-raising initiatives, as well as the use of incentives, disincentives and advocacy to influence and guide behaviour.
- *Leverage benefits*. The establishment of alien species control operations in rural areas brings opportunities to leverage benefits, for example through the creation of employment and the utilization of harvested material. This will be a major focus of the Strategy, given the substantial multiple benefits that will be generated using such approaches.

2.2. Past and current prioritization exercises in South Africa

Because funding and management capacity are limiting, it is necessary to prioritize interventions to achieve the greatest possible returns on investment. There have been few formal exercises to prioritize interventions aimed at the management of biological invasions in South Africa, and those that have been carried out have been restricted to plant species in terrestrial and freshwater environments (species-based approaches, Box 2.1), and terrestrial ecosystems (area-based approaches, Box 2.2) at a range of scales. There has been no prioritization of other groups of alien species. In addition, no attempts have been made to prioritize interventions relating to pathways of introduction and spread of invasive alien species, nor has there been any attempt to make a benefit-cost analysis of the suite of management actions being taken in South Africa. The management of ballast water is an exception, as it has been identified as a priority pathway in terms of species introductions in the marine environment, and has resulted in the compilation of draft legislation to manage ballast water.

Box 2.1. Species-based prioritization

Several exercises have prioritized invasive alien plant species in South Africa. These exercises recognised that management programmes must target well-established invaders, but must also give appropriate attention to emerging problems (see Table 6.5.1. for the most prominent plant species). The first study (in 2003) attempted to prioritize 61 invasive alien plant species that were known to be problematic. The project identified seventeen criteria, grouped into five "modules" that assessed invasiveness, spatial distribution and density, potential impact, potential for control, and conflicts of interest. A subsequent study in 2004 proposed protocols to objectively derive lists of invasive alien plants in South Africa, using available quantitative data and expert knowledge. 'Major invaders' were recognised as those invasive alien species that are well-established, and which already had a substantial impact on natural and semi-natural ecosystems. 'Emerging invaders' currently have less influence, but have attributes and potentially suitable habitat that could result in increased range and consequences in the next few decades. This exercise recognised 117 major invasive alien plant species in South Africa, and 84 emerging invaders, and these were prioritized according to range (widespread or localised) and abundance (abundant, common or scarce). Although these exercises generally produce similar lists of priority species, there is no formal national agreement on priorities that is comparable to the Australian system of "Weeds of National Significance".

The issue of "emerging" invaders is important (see Box 1.1). A study in 2007 examined the potential of 28 alien plant species, currently restricted in distribution, and concluded that almost 80% of the remaining natural environment in southern Africa was vulnerable to invasion by at least one of these "emerging" species, 50% by six or more and 24% by 16 or more species. This underscores the importance of a focus on containment, in line with the adage that "a stitch in time saves nine".

Sources of information in this Box:

Mgidi, T.N. et al. (2007). Alien plant invasions—incorporating emerging invaders in regional prioritization: A pragmatic approach for Southern Africa. Journal of Environmental Management 84, 173–187

Nel, J. L. et al., (2004) A proposed classification of alien plant species in South Africa: towards prioritizing species and areas for management action. South African Journal of Science, 100, 53-64.

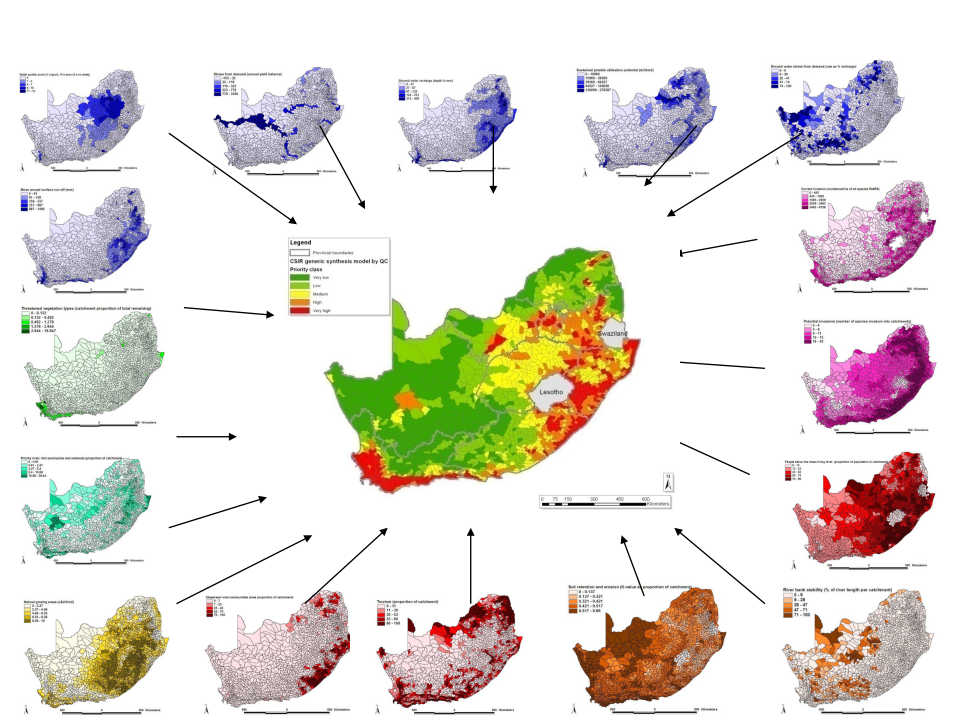
Robertson, M.P. et al. (2003). A proposed prioritization system for the management of invasive alien plants in South Africa. South African Journal of Science 99, 1 – 7.

Weeds of National Significance (WONS). Information on the Australian system of WONS can be found at http://www.weeds.org.au/natsig.htm

Box 2.2. Area-based prioritization

Invasive alien plant control operations in South Africa were scaled up dramatically in 1995. Projects were initiated based on (1) the presence of management capacity, which was found, for example, in national and provincial conservation organizations, larger municipalities, and water boards; (2) a focus on alien plants with high water use, mainly trees in catchments and along rivers; and (3) the imperative to create employment in impoverished rural areas. Attempts to prioritize areas for the management of alien plants have taken place since then, with the goal of more accurately identifying priorities for intervention.

Between 2008 and 2012, the Working for Water programme commissioned a series of prioritization exercises, aimed at identifying those areas where invasive alien plant control was most needed, and where such control would bring the largest returns on investment. These prioritization exercises were carried out at three scales. At the highest level, South Africa's ten terrestrial biomes (the [moist and arid] savanna, grassland, Nama karoo, fynbos, succulent karoo, Albany thicket, Indian Ocean coastal belt, desert and forest biomes) were considered. At the next level, priorities within primary catchments within each biome were analysed, and this was followed at the lowest level by the prioritization of quaternary catchments within primary catchments. In 2012, all the criteria that had been identified in a series of prioritization exercises were pooled to develop a "generic" prioritization model. This model identified 19 criteria that were judged to be the most important and consistently-used, and used these to derive an overall, national-scale map of priorities (Box Figure 2.1).



Box Figure 2.1. A prioritization of South Africa in terms of areas of importance for the control of invasive alien plants. Smaller maps show input datasets that were used to determine priorities. These included water yield and quality, groundwater recharge, terrestrial and aquatic biodiversity, natural resource utilization and ecosystem services, the distribution of invasive alien plants, and the presence of poverty.

From these exercises, three broad areas appear to be the highest priority: (1) the fynbos areas of the Western and Eastern Cape provinces; (2) the eastern parts of the country (KwaZulu-Natal and parts of the Eastern Cape), from the Drakensberg catchments to the sea: and (3) the Highveld areas of the Free State, Gauteng and Mpumalanga provinces.

These prioritization exercises have not yet had a great influence on the re-direction of funding to priority quaternary catchments in practice. Almost all of Working for Water's projects were initiated prior to 2004 when prioritization exercises began. The re-direction of funding, should it be needed, would have to take several additional issues into account. These include the need to complete projects already initiated prior to prioritization, and to honour contractual commitments; capacity constraints; and the need to cater for poverty alleviation goals that were not explicitly considered in prioritization exercises. The prioritization exercises used only certain criteria (e.g. they had a focus on ecological criteria, but paid less attention to social and political criteria). Future prioritisation processes will therefore be broadened to more explicitly include social, political, ecological and economic criteria. These could include, for example, levels of poverty and household income; and the degree to which local communities are dependent on ecosystems for water, grazing, fuel and building materials.

Sources of information for this Box:

Forsyth, G.G. et al. (2012). The prioritisation of invasive alien plant control projects using a multi-criteria decision model informed by stakeholder input and spatial data. Journal of Environmental Management 103, 51 – 57.

Le Maitre, D.C., Forsyth, G.G. and O'Farrell, P. (2012). Development of generic species- and area-based prioritization models for use by Working for Water in prioritizing alien plant control operations in South Africa. Report number CSIR/NRE/ECO/ER/2012/0028/B, CSIR, Stellenbosch.

van Wilgen, B.W., Nel, J.L. and Rouget, M. (2007). Invasive alien plants and South African rivers: A proposed approach to the prioritization of control operations. Freshwater Biology 52, 711 – 723.

2.3. Relative emphasis of current interventions

In order to address the problem of biological invasions in a comprehensive manner, it would be necessary to include all of the broad interventions listed in Table 2.1, across all taxa. However, historic approaches by DEA have focussed on only a few interventions. The budget for the management of biological invasions by the Natural Resources Management Programme of the DEA amounts to R1.22 billion (2014/15 financial year). The majority of these funds (78%) are to be spent on managing invasive alien plant species, almost all of which are in the dominant stage of invasion (stage 4 in Figure 1.2). This includes funding for biological control, high altitude teams, mechanical clearing by the Working for Water programme, the rehabilitation of wattle jungles ("Working for Forests"), and the control of aquatic weeds. A further 7% has been set aside for value-added industries such as eco-furniture factories. Biosecurity operations by the DEA will be scaled up in the coming year, in collaboration with the Department of Agriculture, Forestry and Fisheries, and 4% of the funds have been set aside for this purpose. It should be noted that DAFF (which administers the Agricultural Pests Act, and the Animal Diseases Act, see Table 3.1) also carries out interventions relating to preventing the introduction of undesirable species. The overall annual budgets for these activities run into hundreds of millions of rands (for example R273 million for Inspection and Quarantine Services; and R489 million for plant production and health, annually), a large proportion of which is dedicated to the management of biological invasions. The remainder of the DEA funds will be utilized for overhead costs (7%) and operations support, planning and capacity-building (4%). It is clear, therefore, that efforts need to be strengthened in some areas.

2.4. Constraints to effective integration

This Strategy identifies 19 high-level interventions that are needed to achieve the objectives as set out in Chapter 1. These interventions were identified by stakeholders as an effective and necessary means of achieving the stated objectives. In an ideal world, these interventions would be implemented in line with best practice, but in reality several real-world constraints influence the degree to which such implementation would be possible. The interventions and their implementation in an ideal world are

summarised in Table 2.2, along with constraints and an indication of the chapters where the recommended approaches to overcoming these constraints are presented.



Figure 2.1. Efforts that are to be initiated by the Department of Environmental Affairs to further reduce the risk of introducing unwanted species (such as the more widespread use of sniffer dogs at airports) will need to be co-ordinated and aligned with the existing efforts of the Department of Agriculture, Forestry and Fisheries.

Table 2.2. Priority interventions required at a national level for dealing with biological invasions at different stages. A brief description of the ideal implementation of the intervention is provided, along with real-world constraints to implementation.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
A. Introduction of new alien species (Stage 1)	1. Joint inspectorate at borders	a. A unit that can work across national government departments, based at border posts, working with provincial and municipal governments to ensure permitting compliance. b. Introduction risks are identified and used by a co-ordinated team with access to dedicated resources. c. Taxonomic experts and technological support are available to ensure compliance to permits and monitor risks.	1. Different departments are mandated to deal with different aspects, and co-operative governance is difficult to achieve. 2. There are a variety of relevant legal instruments. 3. There are insufficient taxonomic experts to do the necessary work, while some technologies (e.g. DNA barcoding) need to be developed further so that evidence will stand up in court. 4. There is reluctance in some cases to make the contents of permits publicly available, as permit-holders feel they may lose competitive advantage.	See recommendations in Chapter 4.
	2. Identify high-risk pathways and develop a strategy for each	a. For each pathway, the various vectors are identified and a co-ordinator can act as a link between the stakeholders involved in the pathway and the taxonomists and researchers identifying risks.	1. Pathways can often be best managed at points of departure, but this requires managing processes outside of South Africa's borders.	See recommendations in Chapter 4.
	3. Increase capacity for risk assessment.	b. Science-based assessment of risks posed by currently listed species. c. There is sufficient capacity to carry out the necessary environmental risk analyses.	2. Understanding is limited, and adequate protocols for risks assessments are not in place. 3. In cases where permits for species are granted, compliance with permit conditions is difficult to monitor.	See recommendations in Chapter 4.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
B. Initial establishment of alien species (Stage 2)	1. Emergency response strategy and capability in place.	a. Newly-arrived species are readily detected. b. Response teams are able to act immediately and effectively with appropriate legal powers and the support of stakeholders. c. Appropriate management plans and decisions are already in place to guide emergency responses.	1. It is difficult to maintain management capacity on stand-by for unforeseen events. Officials with existing responsibilities would have to be used, and this may be difficult if they have many responsibilities. 2. It is difficult to estimate the impact of events that do not happen, and to plan for the unforeseen (there is little prior effective experience in this work in South Africa to date)	See recommendations in Chapter 5.
	2. Eradication of target species	a. All populations of species targeted for eradication are identified and appropriately delimited. b. All individuals and their seeds or propagules are eradicated. c. All individuals are in accessible areas.	1. Individuals might be in areas that are difficult to access, or there may be conflicts (e.g. ornamental species on privately-owned land). 2. Seeds or propagules are persistent in the environment. 3. Species can still have positive population growth below the detection threshold. 4. Need to ensure continuity of high-quality management despite turnover in personnel and variation in performance.	See recommendations in Chapter 5.
	3. Monitor key sites for historic and future naturalisations.	a. Instances of naturalisation are picked up before eradication ceases to be a cost-effective option.	1. There may be uncertainty regarding the location of high-risk sites. 2. There are many high-risk sites, often as a result of haphazard introductions.	See recommendations in Chapter 6.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
C. Expansion of alien species, reaching dominance (Stages 3 and 4).	1. Prioritise species.	a. The criteria to guide prioritization would be universally agreed upon. b. Sufficient capacity to undertake prioritisation would exist.	1. Alien species control programs often have multiple objectives, including the need to protect ecosystem services, conserve biodiversity, and to create employment opportunities. These diverse objectives require the development of different sets of criteria, and trade-offs are required, affecting the efficiency with which competing objectives can be accommodated. 2. Some invasive alien species also bring benefits (such as trees in forestry, or trout in rivers), and there is disagreement over the relative value of these costs and benefits. This leads to conflict, and an inability to agree on criteria for prioritization. 3. The information and expertise needed to conduct prioritization exercises is inadequate.	See recommendations in Chapter 6.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
	2. Prioritise areas.	a. The criteria to guide prioritization would be universally agreed upon. b. Sufficient capacity to undertake prioritisation would exist.	1. As with species, the objectives for the sustainable use of land parcels can differ. These include conversion of the land to crop production, extensive utilization as rangelands, for harvested products from natural vegetation, or retention in a natural condition as catchment or conservation areas. 2. Government priorities for the expenditure of funds in poverty nodes may not coincide with the priority areas for the protection of ecosystems. These dissimilar objectives generate different sets of criteria, and trade-offs are required, affecting the efficiency with which diverse objectives can be achieved. 3. The information and expertise needed to conduct prioritization exercises is inadequate.	See recommendations in Chapter 6.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
	3. Develop management plans.	a. All projects would have management plans with Specific, Measureable, Assignable, Realistic, Time-based (SMART) goals (see 2.4). b. Management plans would cater for flexible management that will allow adjustments to be made for unforeseen events. c. The most cost-effective, integrated combination of methods would be used when drawing up plans. These should include the appropriate use of control methods (mechanical, chemical and biological); value-addition through the use of material generated by control programs where appropriate; and guidelines for finding an appropriate mix of government and private-sector investment.	1. The skill, capacity and experience necessary to draw up management plans for all projects are inadequate to meet the needs. 2. Many private-sector landowners cannot afford the costs that would be needed to bring invasive species under control.	See recommendations in Chapter 6.
	4. Implement management plans.	a. Multiple-year management plans with SMART goals should be implemented professionally.	1. The capacity to implement multiple-year plans is inadequate, resulting in a focus on annual plans of operation. 2. The ability to implement multiple-year plans is constrained by multiple agencies that need to manage separate aspects of the problem, on separate land parcels, in the same planning domain. 3. Government is often seen as the agency that caused the problem (for example by encouraging the planting of alien trees, or the introduction of alien fish), making it difficult to transfer the responsibility for control to private land owners.	See recommendations in Chapter 6.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
	5. Monitor outcomes of implementation, and evaluate	a. There should be regular monitoring of progress towards SMART goals, evaluation of trends, and adjustments to plans where necessary. b. Both outputs (for example areas cleared) and outcomes (for example increases in water yield) should be monitored.	1. The capacity to monitor the progress of multiple-year plans is inadequate, and these interventions are typically overlooked. 2. Poorly-framed goals inhibit effective monitoring and evaluation. 3. Outcomes are difficult to monitor, as they take longer to manifest themselves and are affected by multiple interventions besides the control of invasive species.	See recommendations in Chapter 6.
D. All stages (cross-cutting interventions).	1. Develop appropriate legislation.	a. Society reaches consensus and there is policy harmonisation; policy and legislation are realistic and practical. b. Clear, effective and appropriate penalties are in place.	1. There are currently too many different legal instruments and legislation is fragmented; in places there are overlapping or conflicting responsibilities. The law is thus confusing, and key aspects of managing the problem are not adequately catered for.	See recommendations in Chapter 3.
	2. Enforce appropriate legislation.	a. There is sufficient capacity to enforce legislation.	1. Capacity is often lacking.	See recommendations in Chapter 3.
	3. Practice collaborative governance.	a. Government departments work together to achieve the goals of the Strategy.	1. Different government departments have different mandates that may be overlapping, potentially leading to disputes regarding responsibilities. The different goals of individual departments give rise to different criteria regarding the management of biological invasions, leading to disparate priorities.	See recommendations in Chapter 3.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
	4. Information management	a. Baseline information is available to inform policy development and management decisions. b. An information management system is in place to draw baseline information from a range of sources. This system would contain a user interface designed to provide data-driven outputs that would meet user needs.	1. Baseline information is patchy and scattered. Some databases contain data of poor quality, due to a lack of adequate quality control. 2. Much of the information exists in databases that were designed for purposes other than the management of biological invasions. 3. No overarching information management system is in place.	See recommendations in Chapter 7.
	5. Build capacity.	a. Tertiary training institutions would have courses in place that would train people to implement all necessary interventions across a spectrum of prevention, containment, control, and law enforcement. b. A set of bursaries would be in place to attract suitable students. c. Implementing agencies would encourage and reward in-service training. d. Implementing agencies would have the capacity to employ recently-qualified people.	1. Tertiary training institutions do not have courses in place. 2. Implementing agencies do not have capacity to absorb recently-qualified people.	See recommendations in Chapter 8.

Stage	Intervention	Implementation in an ideal world	Real-world constraints	Recommended approach to improve effectiveness
	6. Research	a. Researchers and practitioners work closely together to agree on and clearly articulate research priorities. b. Funding is available to address these priorities. c. A network of stable, permanent, well-funded research institutes is in place, working on all aspects and stages of invasions. d. Adequate provision is made for technology transfer.	1. There is no agreement on research priorities. 2. Research funding is obtained from a variety of sources, often on an *ad-hoc* basis. 3. Research organizations and implementing departments operate separately, with different performance measures driving their behaviour.	See recommendations in Chapter 9.
	7. Raise awareness	a. There would be a clear understanding of the levels of awareness regarding biological invasions among key stakeholders. This would allow for the design of effective awareness-raising interventions. b. There would be sufficient capacity to design and implement awareness-raising projects.	1. Levels of awareness varies between stakeholders. Many stakeholders are confused because of contradictory messages, or because they hold different value systems. Many key stakeholders can be identified, but their level of understanding of biological invasions is not known. All of this makes it difficult to design effective interventions. 2. Human capacity and funding are limited.	See recommendations in Chapter 10.
	8. Monitoring and evaluation of the National Strategy	a. Indicators are developed and data is available to assess progress against indicators.	1. Data to assess indicators may not be available. 2. Capacity to conduct regular assessments may be limiting.	See recommendations in Chapter 12.

2.5. A possible framework for optimizing effectiveness

The various interventions listed in Table 2.2 can be compared to each other in terms of effectiveness by examining the ratio of costs to benefits generated by each intervention. This can be done by comparing the monetary cost of the interventions against the socio-ecological benefits that they provide. The benefit indicator is therefore non-monetary and is comparable to the Human Development Index of the Word Bank. The Human Development Index is based on three measures (income levels, literacy and life expectancy). They are neither monetary nor do they use the same metric or unit. They therefore need to be converted to indices that can then be weighed and ranked. In the same way, in this Strategy, the benefits arising from a given intervention are compared in terms of an index derived from four measures – the number of species affected by the intervention, the likelihood of success of the intervention, the number of people affected by the implementation of the intervention, and the time needed to generate the benefits. The relative effectiveness (the benefit indicator divided by the cost indicator), and the relative size of the benefits associated with each intervention are depicted in Figure 2.1. The height of the bars indicate the effectiveness and the width of the bars the relative quantum of benefits that are derived from each intervention. In this analysis, the interventions of pro-active planning, and of emergency responses, are very effective (high vertical bars), even though the benefits are relatively small (narrow horizontal bars). On the other hand, labour-intensive manual clearing, as currently practiced, is less effective, but delivers many more benefits. This way of examining relative effectiveness to benefits is akin to the way in which marginal abatement cost curves are conceived, where different technology options are compared with respect to the cost of removing a ton of carbon dioxide with the amount (total tonnage) such technology can remove. From a decision-making perspective this is a helpful way to derive relatively quick and strategic answers when compared to the more traditional cost-benefit analysis in which both costs and benefits are converted to monetary values. This approach is especially useful when comparing interventions that have diverse characteristics, each with different benefit streams and different levels of effectiveness. Some interventions are very effective, even though the benefits are relatively small, while others, as currently practiced, are not very effective, but deliver more benefits. This implies that a one-size-fits-all strategy covering all interventions would be inappropriate. Effective interventions should be well-resourced and, as far as possible, fully funded, while at the same time the efficiencies of other methods should be improved. In so doing it would be possible to change both the size of the benefits derived, and the effectiveness across the entire spectrum of interventions. This is discussed further in Chapter 11.

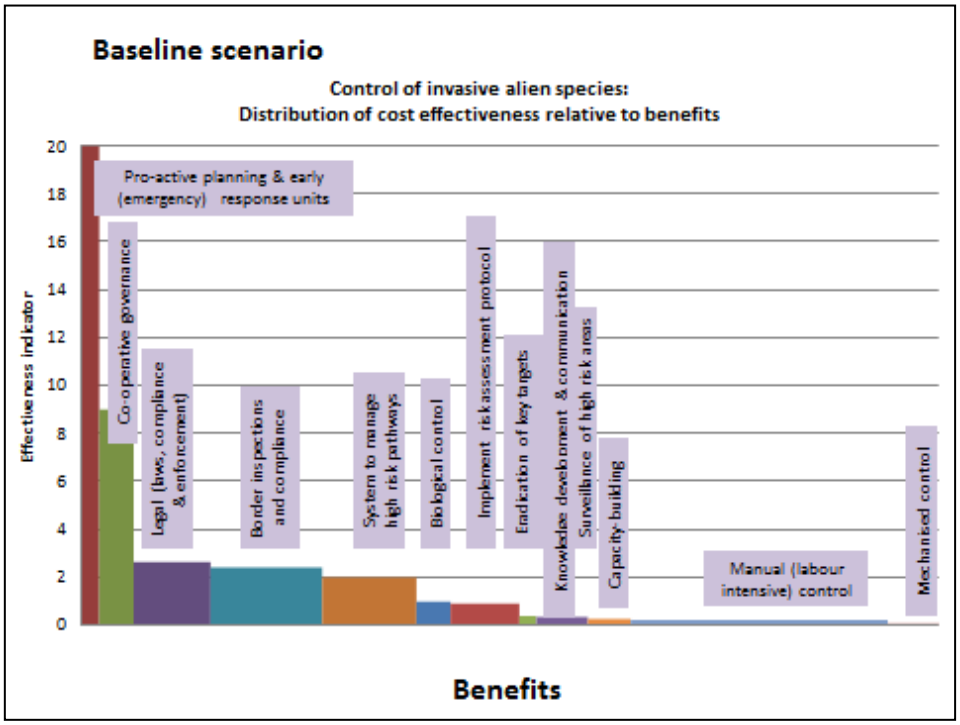


Figure 2.2. Relative effectiveness (given by the height of the bar) compared to the relative size of the benefits (given by the width of the bar) of various invasive species management interventions, as estimated for current practice (a baseline or business-as-usual scenario). Note, given the way in which the effectiveness indicator is calculated, values of less than 1 do not imply costs are greater than benefits.

3. LEGISLATIVE AND REGULATORY ENVIRONMENT

3.1. Introduction

The creation and enforcement of effective regulatory measures is an essential component of managing all aspects of biological invasions. In South Africa, the management of biological invasions is affected by many legal instruments that have been enacted over many decades; most of these were not intended to deal primarily or comprehensively with biological invasions. This chapter contains a high-level review of the existing situation and identifies current short-comings. It then outlines the interventions that will be needed to revise and rationalise the legislative and regulatory environment, in parallel with the more effective implementation of existing legislation. The Strategy also explores the potential for drafting a law that would focus on all aspects of the management of biological invasions.

3.2. Existing international and domestic laws

South Africa is signatory to several international conventions relating to biodiversity (Table 3.1). Since biological invasions are a pervasive threat to biodiversity, these conventions have implications for how biological invasions should be managed. The most important of these conventions is the Convention on Biodiversity, which requires signatory countries to manage invasive alien species. The International Plant Protection Convention also requires that signatory countries meet requirements designed to reduce the risks of plant diseases either leaving or entering the country. From a marine perspective, the UN Convention on the Law of the Sea obliges parties to prevent, reduce and control the intentional or accidental introduction of species, alien or new, to the marine environment where they may have significant harmful effects. The International Convention for the Control and Management of Ship's Ballast Water and Sediments imposes obligations to prevent, minimise and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ship's ballast water and sediments.

South Africa is obliged under international law to enact domestic legislation that gives effect to the obligations imposed under conventions to which it is signatory. It has passed some laws (Table 3.1), but these laws have evolved in a piecemeal manner, without comprehensive consideration of the drivers and mediators of biological invasions, so there is no effective legislative framework for controlling biological invasions. For example, under the CARA a set of regulations that govern the management of certain (listed) invasive alien plant species was passed. Until recently this was the major legislative instrument used to direct the control of invasive alien plants. Despite the initial intent of the CARA (which was to control weeds that had negative impacts on agriculture), the species listed include plants that impact primarily on untransformed ecosystems. The NEM:BA is set to implement regulations that cover all invasive alien species. These regulations are out for public comment, and it is anticipated that they will be promulgated in April 2014.

The absence of a comprehensive legal framework for managing biological invasions is also exacerbated by the fact that no single government department has the sole mandate for the control of biological invasions.

Table 3.1 summarises the existing situation in South Africa. It lists the international laws to which South Africa is party and which have a bearing on the control of biological invasions, and then summarises the domestic measures enacted to give effect to these International Law obligations or otherwise to control biological invasions.

Table 3.1. Legal instruments that directly affect the management of biological invasions in South Africa.

International Law Obligations

Legal Instrument	Purpose	Obligations regarding biological invasions
Convention on Biodiversity (International legally binding treaty—UN and UNEP)	The primary purposes of this convention are the conservation and sustainable use of biodiversity and the equitable sharing of benefits arising from genetic resources. However, it also regulates invasive alien species.	Article 8 (h) requires each Contracting Party to, as far as possible and as appropriate, to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" Article 19 requires each contracting party to take legislative, administrative or policy measures to provide for effective participation in the convention.
Convention on International Trade in Endangered Species of Wild Fauna and Flora (Multilateral treaty—UNEP)	Aims to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species in the wild, and it accords varying degrees of protection to more than 34,000 species of animals and plants.	Party states are required to put in place structures for permits and certificates regulating export and import of listed species, as well we other obligatory measures to be taken by parties. This will only be relevant to biological invasions if the regulated species that is both listed and known to be invasive or potentially invasive.
World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (Multilateral agreement – WTO)	Sets out the basic rules that countries should put in place to ensure that food is safe for consumers, and to prevent the spread of pests or diseases among animals and plants.	It allows countries to set their own standards, but also requires that regulations must be based on science. They should be applied only to the extent necessary to protect human, animal or plant life or health. And they should not arbitrarily or unjustifiably discriminate between countries where identical or similar conditions prevail. These sanitary and phytosanitary standards/measures can take many forms, such as requiring products to come from a disease-free area, inspection of products, specific treatment or processing of products, setting of allowable maximum levels of pesticide residues or permitted use of only certain additives in food.
World Organisation for Animal Health (Multilateral agreement - OIE)	Strives to improve transparency and international collaboration in the control of serious epizootic animal diseases that may be introduced through international trade in animals and animal products, while at the same time preventing countries from setting up unjustified	Requires Member Countries to submit information on the relevant animal disease situation – including on zoonoses present on their territory - in the most timely and transparent way.

Legal Instrument	Purpose	Obligations regarding biological invasions
	sanitary barriers to inhibit trade.	
International Plant Protection Convention (Multilateral treaty—FAO)	Aims to secure coordinated, effective action to prevent and to control the introduction and spread of pests of plants and plant products. Provides for supplementary agreements applicable to specific regions, pests or diseases, specific plants and plant products, and international transportation methods.	Requires a single, national government authority to be in charge of specific responsibilities regarding phytosanitary controls. In South Africa, this is the Department of Agriculture, Forestry and Fisheries (see Agricultural Pests Act)
International Health Regulations (International law—WHO)	Encourages countries to work together to save lives and livelihoods endangered by the spread of diseases and other health risks	States must prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks
Convention on the Law of the Sea (Convention of the UN)	Provides a comprehensive regime for the regulation of the world's oceans and seas, establishing rules governing all uses of the oceans and their resources.	Part XII includes both general provisions on the protection of the marine environment and more specific provisions on the management of invasive alien species. Article 196 provides that "States shall take all measures necessary to prevent, reduce and control … the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto".
The Ballast Water Management Convention (International Maritime Organization)	Sets out general rights and responsibilities in relation to the management of ballast water.	Article 2 (General Obligations), states that parties accept to undertake comprehensive actions in order to prevent, reduce and if possible eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments. Specific matters encapsulated in an Annex (e.g. the application and exceptions to the Convention, treatment standards, Ballast Water Management Plans, recording requirements, and designation of special areas with differing requirements). Article 4, paragraph 2 provides that parties must develop national policies, strategies or programs for ballast water management.

Legal Instrument	Purpose	Obligations regarding biological invasions
Convention on the Control of Harmful Anti-fouling Systems on Ships (International Maritime Organization)	The Convention prohibits the use of harmful organotins in anti-fouling paints used on ships and establishes a mechanism to prevent the potential future use of other harmful substances in anti-fouling systems.	There are no specific requirements for managing biological invasions, but hull-fouling is a major source of invasive species.

Domestic Legislation

Legal Instrument	Purpose	Obligations regarding biological invasions
Constitution of the Republic of South Africa Act, 1996) (Supreme law of South Africa)	The Constitution is a binding framework that governs all legislation, as well as the conduct of government and citizens	Section 24(b) 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". This requires a balance between biological and economic imperatives where they are in tension, for example, conflict species such as pines. This right imposes a binding obligation on both the State and third parties (section 8).
Conservation of Agricultural Resources Act (Act 43 of 1983) and regulations made under it (Department of Agriculture, Forestry and Fisheries)	Provides for control over the utilization of agricultural resources in the Republic of South Africa.	Regulation 15 (Government Notice R1048 in Government Gazette 9238 of 25 May 1984) governs the management of listed invasive alien plants in three categories (Category 1 plants, declared weeds; Category 2 plants, declared invaders that have commercial value; and Category 3 plants, declared invaders that have ornamental value). Obligations regarding their management and control (and in the case of Category 1 plants, a prohibition on them) arises in the case of each category.

Legal Instrument	Purpose	Obligations regarding biological invasions
National Environmental Management Act (Act 107 of 1998)	Provides for co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state.	Provides principles to guide all environmental management, including that "pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied" Imposes a duty on everyone who causes degradation of the environment to take reasonable measures to prevent that from occurring, even where that degradation is authorised by law (for example, by a permit).
National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (Department of Environmental Affairs)	Provides for the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act, 1998; the protection of species and ecosystems that warrant national protection; the sustainable use of indigenous biological resources; the fair and equitable sharing of benefits arising from bioprospecting involving indigenous biological resources; and the establishment and functions of a South African National Biodiversity Institute.	Chapter 5 of the Act sets the framework for regulating alien and invasive species. Although these sections have been in place since 2004, detailed regulations for the implementation have been in various draft forms until 19 July 2013, when regulations to govern the management of alien and invasive species were published in the Government Gazette on the 19 July 2013 (No. R. 506). The regulations are to take effect "on a date to be determined by the Minister". These regulations however, did not regulate invasive species as comprehensively as desired due to limitations in the Act. The Act has since been amended and a revised, more comprehensive set of regulations was published for public comment under GN 37320 on 12 February 2014.
National Environmental Management: Protected Areas Act (Act 57 of 2003) (Department of Environmental Affairs)	Provides for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes; and for the management of those areas in accordance with national norms and standards.	Section 41 of this Act prescribes that each protected area should have a management plan. The purpose is to "ensure the protection, conservation and management of the protected area". While the Act does not mention biological invasions, management prescriptions for invasive alien species typically form part of protected area management plans, as they are necessary to ensure conservation.

Legal Instrument	Purpose	Obligations regarding biological invasions
National Environmental Management Laws Amendment Act (Act 14 of 2013) and National Environmental Management Laws Second Amendment Act (Act 30 of 2013)	Amends the Environmental Management Acts to address problems with the earlier drafts.	Among other things, defines the powers of the Minister to act as the Competent Authority (to clarify where this takes precedence over the provinces); addresses regulatory gaps in the permit system; and to facilitate the implementation of self-regulation.
National Veld and Forest Fire Act (Act 101 of 1998) (Department of Agriculture, Forestry and Fisheries)	This act reformed the law governing the management of veld and forest fires. It provides for the establishment of Fire Protection Associations, the implementation of a National Fire Danger Rating System, and other aspects of fire management.	There is no specific mechanism, but fire management has implications for the control of invasive alien plants (for example, in some cases, the use of high-intensity burns that may be necessary to clear invasive alien plants would be prohibited under this Act).
Agricultural Pests Act (Act 36 of 1983) (Department of Agriculture, Forestry, and Fisheries)	Provides for measures to prevent and control the importation of agricultural and forestry pests, and to provide measures for their national control and matters connected therewith.	Permits are required to import "controlled goods" (controlled goods include any plant, pathogen, insect, exotic animal, growth medium, infectious thing, honey, beeswax or used apiary equipment). The Act also provides for preventing the spread of pests within the country by allowing for the control of movement of plants and plant products from one area to another. Its scope covers plants, plant products and their pathogens including biological control agents, insects and exotic animals as defined.
Animal Diseases Act (Act 35 of 1984) (Department of Agriculture, Forestry, and Fisheries)	Places a duty on government to ensure that animal diseases and parasites do not spread, and prescribes measures to improve the health of animals.	There are very strict measures for the import and export of animals. The main purpose is to prevent the spread of certain diseases across international borders. The Act makes provision for quarantine stations that should be set up where imported animals must be kept. The Act further provides that no animal may enter the country without a permit. The permit must first be obtained before the animal can be transported to South Africa and they can only enter the country in places as determined by the Customs and Excise Act (Act 91 of 1964).

Legal Instrument	Purpose	Obligations regarding biological invasions
Marine Living Resources Act (Act 18 of 1988) (Department of Environmental Affairs)	Provides for the conservation of the marine ecosystem, the long-term sustainable utilisation of marine living resources and the orderly access to exploitation, utilisation and protection of certain marine living resources.	Regulation 61 (1) (c) of the MLRA regulations requires that: "if imported species are being considered, the measures to be taken to avoid introduction of exotic commensals, parasites and pathogens, and measures to be taken to avoid establishment of introduced species in the wild, shall be stated. Regulation 68 states that "Except for indigenous wild fish caught in the Republic, no person shall release into South African waters any fish without the written permission of the Minister." "Fish'' includes any aquatic plant or animal whether piscine or not, and any mollusc, crustacean, coral, sponge, holothurian or other echinoderm, reptile and marine mammal, and includes their eggs, larvae and all juvenile stages, but does not include sea birds and seals.
Mountain Catchment Areas Act (Act 63 of 1970) (Delegated to provinces)	Provides for the conservation, use, management and control of land situated in mountain catchment areas	Authorises, 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".
Health Act (Act 61 of 2003) (Department of Health)	Provides for measures for the promotion of the health of the inhabitants of the Republic; to that end provides for the rendering of health services; defines the duties, powers and responsibilities of certain authorities which render health services in the Republic; and provides for the co-ordination of such health services.	Empowers the Minister to make regulations to institute measures at inland borders, ports and airports to prevent communicable diseases being introduced to or exported from the country.
International Health Regulations Act (Act 28 of 1974) (Department of Health)	To apply the International Health Regulations, adopted by the World Health Assembly, in the Republic, and to provide for incidental matters	The International Health Regulations cover the introduction of agents of infection or disease through the country's borders. It is implemented in the commercial ports by the Port Health Authority which has the power to inspect foreign and local vessels.
Maritime Draft Ballast Water Management Bill, 2013 (Department of Transport)	Provides for the treatment and management of ballast water.	Requires that ballast water be exchanged at sea prior to entering South African waters, to reduce the risk of introducing invasive alien species; the implementation of the International Convention for the Control and Management of Ship's Ballast Water and Sediment 2004, and matters related thereto.

Legal Instrument	Purpose	Obligations regarding biological invasions
National Ports Act (12 of 2005) (Department of Transport)	Provides for the establishment of the National Ports Authority and the Ports Regulator; provides for the administration of certain ports by the National Ports Authority; and provides for matters connected therewith.	The Port Rules gazetted in 2005 include a Rule on Ballast Water which stipulates that: "The master of a vessel and any other person to whom the Port Ballast Waste Management Plan applies, must comply with that plan." The Regulations and Port Rules Made under this Act do not regulate ballast water.
National Forests Act (84 of 1998) (Department of Agriculture, Forestry and Fisheries)	To promote the sustainable management and development of forests; to create the conditions necessary to restructure forestry in State forests; to provide special measures for the protection of certain forests and trees.	No specific mechanism, but plantation forestry using alien species, governed by this act, is a significant source of invasive species.
National Water Act (Act 36 of 1998) (National legislation—Department of Water Affairs)	Provides for fundamental reform of the law relating to water resources	Chapter 4, Part 4, allows the Minister, after public consultation, to regulate land-based activities which reduce stream flow, by declaring such activities to be stream flow reduction activities. Currently, plantation forestry is the only such activity recognised, and permits for plantations are recognised as demarcation permits for growing category 2 invasive alien plants under the CARA regulations.
Provincial Ordinances and Acts (Separate for each of the 9 Provinces)	Authority to implement some national acts, including the Environmental Conservation Act, the Mountain Catchment Areas Act and the Seashore Act, as well as aspects of the National Environmental Management Act had been delegated to the provincial authorities. In addition, many provinces have Nature Conservation Ordinances aimed at protecting indigenous flora and fauna, and some have Environmental Management Acts.	Most provinces manage nature reserves, where a component of that management is directed towards the control of invasive alien species. Most provinces also regulate the import into, or transport or release within the province, of non-indigenous species, but do not regulate the keeping or selling of such non-indigenous species.
Municipal By-laws	Municipalities may make by-laws over those matters which they have the right under the Constitution to administer. These include the provision of services, the promotion of social and economic development, the promotion of a safe and healthy environment and to deliver services in a manner which is environmentally sustainable.	Various

3.3. Current shortcomings and problems

3.3.1. Fragmented legal mandates

One of the main problems with the South African legal framework that regulates the management of biological invasions is that although the DEA has the mandate to deal with biological invasions, other government departments also has a responsibility within their respective functional areas.

Currently, the mandate of the DEA is primarily to conserve biodiversity, while the Department of Agriculture, Forestry and Fisheries is mandated to protect agricultural resources. The Department of Water Affairs has responsibility for protecting and regulating water resources (including stream flow reduction activities), and the provinces and municipalities each have their own Acts, ordinances and bylaws and, in some instances, (such as the Mountain Catchment Areas Act, 1970 (Act No.63 of 1970) and aspects of the NEMA administer national legislation. The activities that are regulated by the Department of Transport (all air, sea, road and rail travel) and the Department of Trade and Industry (Customs) are obviously relevant to the regulation of pathways, while the Department of Health is interested in species (including microbial diseases) that impact on human health. It is thus clear that statutory tools that address or impact on biological invasions are fragmented, with responsibilities allocated institutionally rather than on an ecological basis.

3.3.2. Inadequate capacity to enforce legal obligations

The absence of adequate capacity to administer and enforce the proposed regulations aimed at the management of biological invasions in South Africa is also a significant problem. A recent review of the capacity available to implement the proposed regulations on alien species under the National Environmental Management: Biodiversity Act found that, of 16 organs of state assessed, only five had human resources and budget allocations dedicated to the management of biological invasions. The review also found that, in respect of permitting, this capacity exists largely exclusively at a national level, with almost no capacity at the provincial level where many permits were to have been issued (the intention is that this function will now be carried out at a national, not provincial level). With some exceptions, most organs of state have not assessed their capacity to meet obligations imposed by the new proposed NEM:BA regulations and do not know what additional personnel and skills will be required to meet these obligations. However, even those that have completed such an assessment generally indicated that they require additional capacity and training in a variety of areas. The review concluded that the regulatory functions (in particular compliance monitoring and enforcement) were “seriously lacking in capacity”.

3.3.3. The absence of coordinating mechanism

Given that biological invasions will impact on the interests of several government departments in more than sphere of government, it will be vital to provide for a mechanism that will ensure effective collaboration between affected departments when addressing biological invasions, to avoid fragmented and ineffective interventions. No such co-ordinating mechanism or body has existed until recently. The management of biological invasions is a responsibility that is shared by various national Departments and beyond to all spheres of government, industry and the general public. The DEA has therefore put a National Bio-security Committee, comprised of decision-makers from the various government departments, in place. The committee is mandated with the management of

biological invasions to ensure synergy, co-operative governance and strategic partnership approaches in managing biological invasions.

The effective operation of such a body will enhance South Africa's bio-security system and strengthen the collaborative approach between the spheres of government mandated to address the country's broad range of biosecurity issues. This will involve, among other things, identifying national priorities that the various government departments will work on collaboratively to strengthen the national biosecurity system and setting out a process for identifying and reviewing national bio-security priorities. This will help to avoid unnecessary duplication of biosecurity activities and improve the efficient use of resources.

3.4. Proposed broad guidelines to develop effective legislation

The legislative regime regulating biological invasions in South Africa needs to be revised to give effect: (1) to the Constitutional imperative to protect the environment for future generations; and (2) to support policy requirements, including honouring international agreements, and in line with all aspects of the 4 x 3 framework (Figure 1.1). There is scope for innovative legislation to address such concerns within the framework of priorities as set out in the National Development Plan and other high-level government policies. The Strategy therefore explores the potential for drafting an Invasive Alien Species Act, which will cover all aspects of the management of biological invasions in a single statute.

The Strategy also advocates the ongoing use of existing legislation to promote the achievement of goals, to avoid having to wait for new legislation to come into being. There will therefore be an ongoing focus on the use of NEM:BA , mainly through the comprehensive set of regulations that are set to come into effect shortly.

The broad principles listed below should guide the development of any new statute or amendments to existing statutes and have been considered in the new draft regulations under NEM:BA.

1. Such legislation should recognise the National Development Plan and support its implementation.

2. Endorsement of any new or amended legislation or regulations should be sought from the Department of Environmental Affairs, Department of Agriculture, Forestry and Fisheries, Department of Water Affairs, Department of Transport, Department of Health, provincial governments and other key organs of state.

3. Given the magnitude and complexity of the problem of biological invasions, it is imperative that legal instruments should be practicable – sensible, enforceable, sufficiently supported, and capable of facilitating optimal outcomes.

4. Collaboration between government departments must be ensured by means of appropriate institutions, agreements and/or joint decision making mechanisms.

5. Lines of responsibility for the costs of biological invasions (Box 4.2) should be clearly defined and agreed, based on the "polluter pays" principle.

6. For alien species that are already within the country, the focus should be on those species where control would have the greatest chance of reducing projected impacts that would arise from invasion debt (see Box 1.2). Given the scale of the problems with existing invasions, there would be an imperative to focus on species that are known to be problematic, or are predicted to become problematic. Any other approach for dealing with the very large numbers of alien species within the country, especially for the lower-order taxa, would be unworkable.

7. The distribution and establishment of species that are indigenous to South Africa to areas outside of their known natural distribution ranges (extra-limital species) should be regulated only in those cases where they would cause serious problems in a manner similar to invasive alien species.

8. Explicit provision must be made for the managed importation, assessment, and distribution of alien species to be used as biological control agents.

9. The risks of accidental introductions of alien species should be reduced as far as possible by identifying the most likely pathways of introduction, and giving effect to legislation that would reduce these pathway-specific risks.

10. The process of deriving lists needs to be well-documented, transparent, science-based, and subject to public scrutiny, with specific opportunities for interested and affected parties to comment. In addition there needs to be a clear process for regularly updating the lists.

11. The new draft regulations under NEM:BA have placed species into different categories. It would be important to accommodate these categories (which were developed after wide consultation with experts and practitioners) in any future legislation. The categories are:

    - *Listed alien species in Category 1(a): Invasive species targeted for nation-wide eradication*. This category includes invasive species that would require strict control. Only species where effective control is possible (including by individuals) should be listed here.

    - *Listed alien species in Category 1(b): Invasive species requiring on-going control as part of a management plan*. The spread of alien species in this category must be contained, and in cases where effective control by individuals is generally not possible, an integrated programme (typically managed by a local, regional or national authority) would be necessary to bring them under control.

    - *Listed alien species in Category 2: Invasive species whose utilization would be subject to permit conditions, and whose spread would need to be controlled*. This category includes invasive species that have commercial or other perceived value.

    - *Listed alien species in Category 3: Invasive species that may be retained without a permit, but where propagation and trade are prohibited, and where spread must be contained.* This category includes invasive alien species that do not generate excessive harm. They would be permitted on a property, but for certain activities would not be permitted, e.g. further sale or planting not permitted. Zoological collections could be permitted to house species.

    - *Prohibited alien species.* This category includes alien species for which a permit will not be granted, and which may not be imported into the country. If a prohibited species were to be found in the country, it would automatically become a Category 1 (a) listed species.

    - *Exempted species*. This category includes alien species that were legally introduced into South Africa prior to the regulation of imports under the new (2014) draft regulations under NEM:BA. The import of exempted species would still be subject to phytosanitary controls.

12. Legislation should regulate the export of indigenous (South African) and non-indigenous species that pose a risk of becoming invasive elsewhere in the world.

13. Legislation should provide for the development of guidelines for drafting of management plans for prevention, eradication, containment and control operations, and the requirements for the implementation of these plans, monitoring of progress, and reporting on progress.

14. Current draft regulations under the NEM:BA call for the drafting of management plans for listed invasive alien species. The National Environmental Management: Protected Areas Act prescribes that protected areas should have management plans, and at least part of these protected area management plans would address invasive alien species. The latter would provide for ecosystem-based (rather than species-based) plans (see Figure 1.1), but only in protected areas. It would be desirable to expand legislation to cover management plans for identified priority ecosystems, part or all of which may be outside of protected areas.

15. Given that the capacity to issue permits and to monitor compliance will always be limiting, proposals have previously been made to formalise self-administration. These proposals have been for the establishment of accredited traders (people or organizations that trade responsibly in alien or extra-limital animals or plants). This would confer some form of competitive advantage on the holders of such status in a market where customers wish to have the assurance that the products purchased will not be harmful to the environment. In order to be accredited, traders would have to apply for registration, and would have to comply with certain conditions, including a requirement not to offer for sale, sell, propagate, donate, trade or in any other way distribute specimens of species listed in Categories 1a, 1b, 2 and 3. These proposals should be incorporated into formal legislation.

16. Since the direct provision for emergency powers is widely regarded as an essential component of the armoury to fight biological invasions, provision has been made in NEM:BA for emergency interventions. However, legislation must also cater for the provision of funds for rapid response to emerging problems.

17. Legislation should outline the responsibilities of landowners regarding the control of invasive alien plants on their land, and including the possibility that non-compliance could lead to the state doing the work at the expense of the land-owner.

18. Legislation should stipulate that those utilizing invasive alien species listed in Category 2 would require a permit, and permit holders should be accountable for propagule pollution. There must be a presumption that naturalised specimens of the permitted species that invade adjacent originated from the permitted source, unless the landowner can prove otherwise.

19. Legislation should consider the obligations of land owners when selling their land. Proposals have been put forward that the transfer of land from one owner to another should be subject to a certificate that invasive alien species have been adequately controlled.

20. While most current legislation targets species, it would be important for legislation to also address the regulation of pathways of dispersal (the Maritime Draft Ballast Water Management Bill is an example).

3.5. Key actions

In order to address the current shortcoming in the management of biological invasions due to the absence of a comprehensive set of controls for managing invasive alien species, and fragmented

institutional mandates to enforce these, the possibility of drafting a single law to manage species, affected areas, and pathways of introduction and invasion, at all four stages of the biological invasion process will be explored. A proposed outline of the legislation is provided in Box 3.1.

The support of all of the organs of state currently charged with administering laws that regulate biological invasions would be essential to the success of that legislation. Ideally a single department should have the mandate to manage biological invasions, but to the extent that this is not achieved, or that other organs of state would have concurrent jurisdiction over, for example, the permitting requirements of an activity that may result in a biological invasion, they should be required to make decisions jointly or at least in consultation with each other.

Legislation should impose duties on holders of invasive alien species and provide for a process by which species are listed, which process should include a risk assessment and a simple public participation process. The risk assessment process should then inform a permitting process governing the import, keeping and cultivating and export of invasive alien species, including in the marine context. Provision should also be made for area management and pathway control.

The legislation should also provide for directive and emergency powers, as well as general powers of enforcement.

Box 3.1. High-level Outline of Dedicated Invasive Alien Species Act

Objectives of Act

- To provide a comprehensive framework for the effective management of biological invasions.
- To uphold the constitutional obligation to protect the environment for future generations.
- To secure sustainable development by balancing the biodiversity and economic imperatives of introducing alien species.

1. DEFINITIONS

2. SCOPE AND APPLICATION OF THE ACT

2.1. Must bind all organs of state.

3. CATEGORIES OF INVASIVE ALIEN SPECIES

3.1. This section will specify the various categories of invasive alien species.

4. DECLARATION OF INVASIVE ALIEN SPECIES

4.1. This section will grant the Power to declare and categorise invasive alien species according to species and/or area.
4.2. Process to be followed when declaring and categorising invasive alien species:
4.2.1. Risk assessments and their minimum content;
4.2.2. Public participation process; and
4.2.3. Consultation with other organs of state potentially affected by declaration and/or categorisation;
4.3. Factors to be considered when declaring and categorising invasive alien species.

5. CONSEQUENCES OF CATEGORISATION

5.1. Specific obligations of holders or controllers of each category of invasive alien species.
5.2. Permitting requirements of specified categories of invasive alien species.

5.3. Obligations to prepare management plans for declared invasive alien species.
5.4. Transporting controls.

6. MANAGEMENT PLANS

6.1. The Act will specify the circumstances in which, and the parties that must, prepare management plans (if not only where declaration of invasive alien species as stipulated in 5.3 above) and what their minimum content must be.
6.2. Management plans could address species, or areas, or pathways of introduction that need to be managed.

7. CONFLICT SPECIES

7.1. Where a species has been declared or is proposed for declaration and classification as an invasive alien species, and an objection to that declaration is lodged on economic grounds, the competent authority may require the objector to:
7.1.1. Assess the full cost of introducing or cultivating the species to the terrestrial or marine environment
7.1.2. Assess the benefits, including socio-economic ones, to the applicant and those in the immediate vicinity of the proposed activity.

8. CO-ORDINATION OF ORGANS OF STATE

8.1. Where more than one organ of state has permitting powers in respect of activities that may involve the import, spread or control of invasive alien species the Act will:
8.1.1. Impose an obligation to consider applications jointly;
8.1.2. Grant the power to issue an integrated permit [if the other Act(s) under which permits must be granted allow that or separate permits concurrently;
8.1.3. Ensure conditions of any concurrently issued permits are not in conflict.

9. COMPLIANCE

9.1. The Act will grant directive powers to compel the recipient to
9.1.1. To take specific measures, to destroy something or;
9.1.2. to stop doing something, including assess the impacts of the activity (or failure to act) complained of
9.2. The Act will grant emergency powers in specified circumstances
9.3. The Act will grant step in powers where the recipient fails to comply with a directive or emergency directive
9.4. The Act will confer cost recovery provisions on the authority that exercised step in powers where the recipient of a directive failed to comply with the directive or emergency directive

10. ACCREDITATION SYSTEM

10.1. The Act will provide a degree of self-regulation of, for example, importers of plants, animals or fish that have been accredited
10.2. The circumstances in which accreditation may be achieved and the entities that will be certified to grant certification will be prescribed

11. TRANSFER OF LAND THAT IS THE SUBJECT OF A BIOLOGICAL INVASION

11.1. The Act will regulate the circumstances in which ownership of land that is the subject of a biological invasion may be transferred. [This provision will require careful thought regarding the extent of the invasion required before its application is triggered; whether there is a prohibition on transfer or if the transfer is subject to requirements such a management plan and of what that must consist].

12. POWERS OF ENFORCEMENT

12.1. Powers to enter, search, inspect, seize, sample and the like (If this is Act is declared to be a Specific Environmental Management Act ("SEMA"), which is recommended, then the enforcement provisions of NEMA will apply and enforcement provisions need not be dealt with here.

13. GENERAL POWERS

13.1. Regulation of research.
13.2. Reporting requirements.
13.3. Power to make norms and standards and circumstances in which these will apply.
13.4. Power to make regulations.
13.5. Power to support (advise, fund, provide staff) programmes and projects that combat biological invasions.
13.6. Power to direct conditions of import including measures to be taken at point of export.

14. OTHER MATTERS

14.1. Appeals (If this is Act is declared to be a SEMA then the Appeal provisions of NEMA will apply and need not be dealt with here.)
14.2. Offences and penalties
14.3. Transitional provisions

KEY ACTION	TARGET
Implement the draft regulations under NEM:BA	Draft regulations implemented
Promulgate and implement the Maritime Draft Ballast Water Management Bill.	Act promulgated and implemented
Establish an Alien and Invasive Species Co-ordinating Forum.	Co-ordinating Forum established and functioning at national and provincial levels.
Fully explore the potential for a comprehensive Invasive Alien Species Act, develop a White Paper, and if appropriate, promulgate legislation.	Report on potential for Act
	White Paper drafted
	Act promulgated and implemented
Withdraw provincial fish permits after two years, and continue to regulate extra-limital mammals through the Provinces for two years, until the issue of their regulation is resolved.	Regulation of alien freshwater fish and extra-limital mammals controlled at a national level under NEM:BA.
Repeal provincial legislation relating to invasive alien species	Provincial legislation repealed

3.6. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 18, 138, 156, 162.

4. PRE- AND AT-BORDER MANAGEMENT

4.1. General principles

One of the best ways to deal with the problem of biological invasions is to stop them before they happen, either by preventing high-risk species from entering the country ("pre-border" interventions), or by intercepting them at the border ("at-border" interventions). The adage "prevention is better than cure" is a guiding principle for most of the successful biosecurity schemes. Introductions can be accidental or deliberate, and deliberate introductions can be either legal or illegal – all need to be catered for. This Strategy takes account of the risks of deliberate and accidental introductions, against a background of considerable and growing pressure from entrepreneurs to approve the introduction of alien species. The Strategy also considers the question of accountability for the risks posed by alien species, and of liability if introduced species do become invasive.

The Biosecurity Directorate of the DEA is mandated to address pre- and at-border management with a view to protecting the environment from high-risk alien species. Historically, the biosecurity functions in South Africa were overseen by the DAFF. Given that the DEA's activities in this field have to start from scratch, it will be necessary to slot in with, and build on, the existing capacities, standards and protocols within DAFF. The development of interventions aimed at improving pre- and at-border management will therefore have to adopt an incremental approach.

This chapter examines the different types of introductions and the history of their management in South Africa, and outlines the intended interventions that will be necessary to reduce the risk of introductions of undesirable species, or to intercept accidental or illegal introductions.

4.2. History of introductions to South Africa

The pathways whereby species have been introduced to South Africa have been strongly shaped by changing socio-political forces (Figure 4.1). To date most introductions have come from outside of Africa, although it is expected that an increasing number of alien species will be introduced to South Africa from neighbouring countries.

For plants, many of the most widespread invaders were deliberately introduced and disseminated for forestry and horticulture. Many alien bird and mammal species were deliberately introduced for agricultural purposes, for the commercial fur trade, and as pets, with fewer species arriving accidentally. Introductions of alien birds and mammals for agriculture or other purposes have declined markedly, while introductions for the pet trade have remained important, and accidental introductions have increased. For these groups, the importance of these different pathways is expected to stay the same in the near future. By comparison, the legal and illegal trade in alien amphibians, arachnids, and reptiles has, as in other parts of the world, escalated dramatically in recent years. There have also been clear changes in the relative importance of known pathways for the introduction of alien freshwater fishes into open waters. Whereas introductions by nature conservation agencies to stock water bodies have ceased, many other pathways (e.g., introductions for angling and for the aquarium trade) have remained fairly constant, while introductions via inter-basin water transfers has increased substantially. For marine organisms, the most profound changes have come about as a result of a shift from the use of dry ballast to the use of seawater as ballast in ships. Very little is known about invertebrate and microbial

introductions, but it is clear that almost all of the problematic alien species in these groups in South Africa were introduced accidentally.

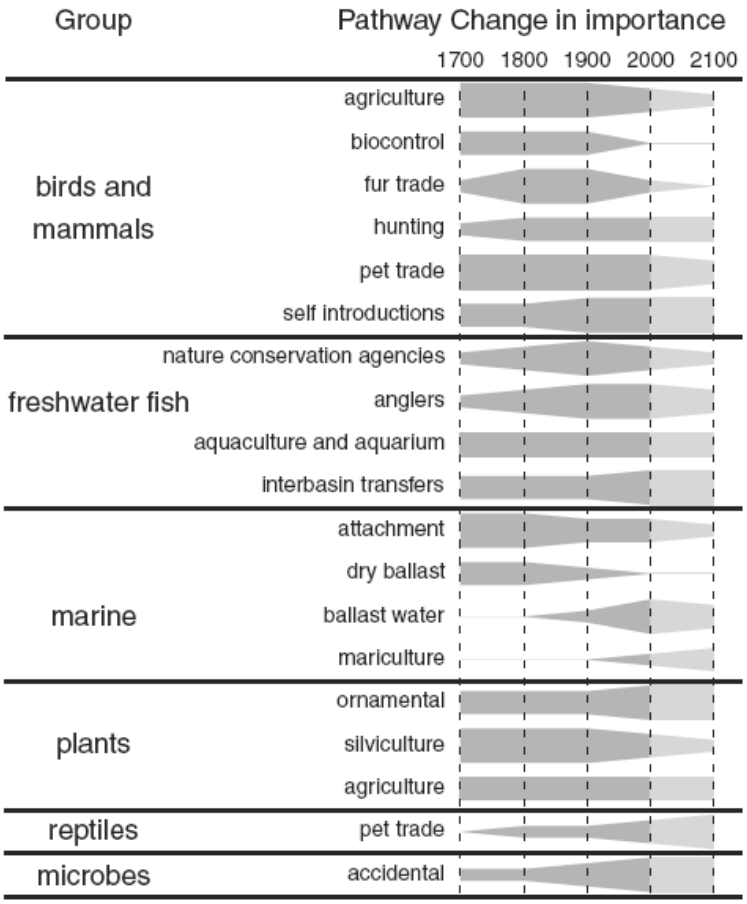


Figure 4.1. The pathways of introduction of selected groups of species to South Africa have varied through time for almost all groups. This highlights the need to consider future pathways rather than to base actions on historical trends.

4.3. Current pre- and at-border management

The approach to pre- and at-border management around the world is based on risk assessments (Box 4.1). In South Africa, the Plant Health Inspection Services, and Divisions of the Department of Agriculture, Forestry and Fisheries (DAFF) constitute South Africa's National Plant Protection Organisation (NPPOZA), which is mandated to prevent the entry, establishment and spread of invasive alien species associated with plants and plant products. The NPPOZA manages quarantine services and conducts pre-border risk assessments for all agricultural species imported into South Africa. These pre-border risk assessments have a focus both on minimising the risks of introducing pathogens or pests on imported species and on the risks of the species themselves becoming invasive. DAFF's mandate is for agricultural risks, and they have being assisting the DEA, as far as their capacity allows, in screening new species for introduction. However, this has not been sufficient to address all of the environmental risks associated with the introduction of new species. In general terms, the bar for accepting introductions has historically been set differently for different organisms introduced for different purposes. There are weaknesses with this approach. This Strategy will therefore encourage greater transparency and consistency regarding the

decisions and documenting of import requests; create systems to base the rigour with which each application is assessed on the risks posed; recommend standardisation of names (currently non-standard names are often used, which can confuse the assessment process); and develop systems to support the evaluation of permits at-border (a DNA-barcoding approach is being developed to address some of the taxonomic challenges to confirming that what is specified on a permit is actually what is being imported).

Box 4.1. Risk Assessment

Risk assessment involves identifying, analysing and evaluating the likelihood of an event happening, and the consequence if it does occur. As such risk assessments for biological invasions need to consider processes relating to transport, establishment, abundance, spread, and impact.

Deliberate legal introductions, e.g. plants for the horticultural trade or animals for pets, should require import permits based on species-specific risk assessments. Such risk assessments consider the likelihood that the species will escape captivity or cultivation, establish and spread, as well as the consequences of any such invasion (i.e. the impacts). However, in many cases, the probability that a species is likely to establish and spread would be sufficient to consider the species undesirable, mainly since predicting impact is difficult and context-dependent. Risk assessments are usually initiated when someone applies to import a species that is not yet in the country. These species-specific risk assessments need to be strict enough to minimise the possibility of introducing undesirable species, but they also need to strike a balance by not making it too onerous for importers to introduce alien species that would be beneficial.

Risk assessments for accidental or deliberate illegal introductions are typically not species-specific at the border. They focus on pathways and vectors, and assess the likelihood that alien species will be introduced via a pathway (e.g. shipping) or a specific vector (e.g. ballast water, or cargo containers), and the consequence in terms of new invasions.

Finally a separate risk assessment procedure is often needed for alien species already present and established (Chapter 5). In contrast to risk assessments for pre-border control, post-border risk assessments mainly focus on adverse effects of alien species and often include details about the management and landscape context of an introduced population. Such risk assessments can be used to prioritize management actions—species (or populations) with a high likelihood of becoming widespread and species (or populations) with a high potential impact if they are to become invasive should be prioritised. As for risk assessments of pathways, post-border risk assessments are often not triggered by applications, are carried out to inform policies, and are generally strategic in nature. However, the need for a post-border risk assessment might be triggered by an application to use a species more widely (e.g. to start growing a plant for biofuel production).

Importantly, all risk assessments needs to be transparent, accurate and consistent, but also flexible enough to allow the incorporation of new research findings. If a scoring approach is used, cut-off levels for accepting or rejecting species should be rigorously tested and updated regularly, adapted for new taxa and regions, and ideally explicitly linked to mathematical probabilities. Stakeholders should be consulted and informed of outcomes, with the process monitored and reviewed independently.

A sophisticated scheme for assessing deliberate introductions in South Africa has been developed for the release of biological control agents for use against invasive alien plants. Each permit application is put together by a dedicated research team who have investigated the risks over several years. These applications are assessed by an independent panel and sent for review to international experts. The requirements have been updated over the years in line with international best-practise, but at heart they require the applicant to demonstrate that there is a very low risk of damage to any crop species or native South African plants (and increasingly also to any other African plant species). This is achieved through a variety of structured pre-release experiments (e.g. no-choice feeding tests, choice feeding tests,

developmental trials) and native feeding range observations. Additional requirements include an assessment that the introduction has the potential to provide benefit (through reducing the impacts of invasive plant populations), and an estimate of whether indirect effects are likely, e.g. by changing food-web dynamics. Furthermore, biological control agents are tested in dedicated quarantine facilities. This minimises the risk of accidental escapes and allows the agents to be screened for parasites and diseases before release. The track record has been admirable, and frequent field surveys have not revealed any significant direct or indirect non-target effects. This has mirrored the experience elsewhere in the world—undesirable impacts have only occurred if the risks were not properly identified and assessed or were inappropriately evaluated and managed. However, biological control release permits have faced several major challenges. First the process of administering and reviewing permits has often been extremely slow, or has lacked informed input. This has been resolved recently with the setting up of a South African biological control review committee. Second, there have been calls for in-depth studies of potential direct and indirect risks associated with all applications. This is impractical and in effect leads to a closed door approach, i.e. no biological control agents can be introduced as it is impossible to identify and eliminate all risks. As such the current review system regarding permits for the introduction of classical biological control agents of weeds will be maintained and supported.

In contrast, as noted above, other introductions are not subject to any such rigour. Applications for introducing species for commercial purposes (e.g. horticultural plants or pets) are assessed largely on the basis of whether there is a record of invasiveness elsewhere in the world. It is not standard practise to even consider the potential for establishment (for example by using climate-matching techniques). By comparison, the rigorous approach adopted for biological control agents can cost millions of rands, and take up to eight years, before a release permit is granted. This Strategy seeks to redress that imbalance.

In some other countries (Australia, New Zealand and certain countries in Europe in particular) there are set procedures for assessing permit applications based on published risk assessment models. While these are not as rigorous as those developed for biological control, they are much more detailed than the current system in South Africa, where capacity still needs to be built. Such risk assessments, however, require trained capacity to support them.

To prevent accidental introductions, South Africa employs a limited number of both area and pathway-based approaches. The DAFF actively monitors sea-ports, airports and land borders. Sniffer dogs are also employed at airports but there are only a few specifically trained to detect agricultural material. Key cargo is monitored for specific pests (e.g. fruit fly) and animals are screened for pests and pathogens. There are also less formal mechanisms, e.g. if any vertebrates are found as stowaways on cargo at a port, local animal welfare agencies are asked to respond. Rules concerning land borders have fluctuated. Although rules are in place to regulate the movement of agricultural produce across borders, small amounts of agricultural produce have at various points been allowed through. However, given the lengths of the national borders and the focus on reducing the smuggling of high-value items (e.g. abalone and rhino horn) there is high potential for both accidental and illegal deliberate introduction of alien species. In comparison, airports in Australia and New Zealand have well-established quarantine services with intensive screening procedures. The main exception to this is South Africa's sub-Antarctic Islands. As part of the management plan to keep the Prince Edward Islands as pristine as possible, all vectors that might bring material onto the island have been assessed, and strict conditions are imposed on all visits to the island (including all visitors, and any equipment to be transferred).

Management of specific pathways or vectors has been similarly patchy. Agricultural imports are screened for pests and pathogens by a dedicated diagnostic service of the DAFF. Again the aim is reduce the rate with which new commercially important pests and pathogens arrive in the country. Beyond this there is little control. The main exception is the work (both pre-border and at-border) to prevent introductions via ballast water. Ongoing efforts to prepare for the pending Ballast Water Act, as well as the entry into force of the International Maritime Organisation's Ballast Water Management Convention, have targeted

port state control measures to increase controls on visiting foreign vessels. The Transnet National Ports Authority (TNPA) has included basic ballast water management measures in each of the commercial port environmental management plans. These function as voluntary requests for vessel compliance with the exchange of ballast water at sea, until such time as ship-board treatment technologies are readily available and required by national regulation. As South Africa does not have any commercial vessels registered under its flag, the Flag State Control components have not received much attention.

Various national departments and agencies are implicated in, and have been involved with ongoing activities on ballast water management. The Department of Transport and the South African Maritime Safety Authority have been advancing local capacity for testing of treatment technologies and supporting South African innovation and entrepreneurship in this sector. A land-based testing facility was developed in the Port of Cape Town to achieve certification for a South African treatment technology, now available for commercial installations.

The TNPA has been working with the various port community stakeholders to introduce a ban on the cleaning of ship's hulls in South African waters, to reduce the risk of introducing alien species. Although not currently enforced at all commercial ports in South Africa, the process is underway to expand the controls on ships. There has been some research focus on the role of international recreational vessels (e.g. yachts), and the possible mechanisms for consideration to reduce risks associated with this vector. International guidelines have been developed to assist countries in the regulation of bio-fouling by non-commercial vessels, however to date no formal process is underway in this regard.

Finally, it is necessary to consider the potential for exporting invasive species. South African exporters are responsible for ensuring that their goods are not contaminated by pests and pathogens. As South Africa is a signatory to the International Plant Protection Convention, there is a process of issuing phytosanitary certificates for exports of agricultural goods. If this process fails repeatedly then trade bans are imposed, causing significant impacts to producers and the economy (most recently the EU imposed a ban on the importation of citrus from South Africa due to citrus black spot). South African also has a moral responsibility to ensure that potential invasive species are not exported to neighbouring countries, and arguably an obligation to do so under the Convention on Biodiversity (Article 3). This is especially relevant to bordering countries and other African countries that do not yet have appropriate control measures.

4.4. Challenges for pre- and at-border management

There are a number of specific challenges to effective pre- and at-border management, listed below.

Defining responsibility for biological invasions: The introduction of an invasive alien species could have serious consequences, and the question arises as to who should be held responsible for ensuring that the risks are kept to a minimum, as well as who would be liable in the event of such an introduction (Box 4.2).

Box 4.2. Defining responsibility and liability for biological invasions

The manner in which alien species are introduced into a country can be used to define responsibilities if something goes wrong.

Applicants could be held liable if an organism that is deliberately released into the environment becomes invasive and causes undesirable impacts. Similarly, *importers* could be held liable if a deliberately imported species escapes and causes harm. Under the draft regulations of the National Environmental: Biodiversity Act (NEM:BA), any such introductions may only be made once a permit has been approved. The responsibility for the completion of a full detailed risk assessment should lie with the *applicant*. The Department of

Environmental Affairs (responsible for the implementation of the NEM:BA) requires an independent review of the application (again at the cost of the applicant), such that the risks are properly assessed and are deemed manageable in case of the issuing of a permit. It is worth noting that, to date, no-one in South Africa has ever been held responsible for the invasive nature of a species that was legally introduced.

Insurance companies are currently not in a position to accept applications for insuring against the risk of an introduced species becoming invasive, as they do not have the information necessary to make the actuarial assessments of costs. This raises the question of whether it would be appropriate to permit the introduction of species where an entrepreneur would make the profits, but society would bear the costs should the species become invasive. This is especially true in cases where the introduction could be regarded as frivolous, and where potential benefits would be far outweighed by the potential risk.

Exporters could be held responsible if parasites or pests are unintentionally introduced as contaminants in imported goods. In contrast, if the invasion is a result of a stowaway attached to or within a transport vector, then the *carrier* could be held liable. While it might be difficult to ascribe a particular invasion to a particular carrier, it would be possible to inspect and impose fines on carriers that have listed stowaways.

Finally *developers* should be responsible for any species that invade as a result of a new physical connection or corridor.

The most complicated situation ariseswhen alien species naturally disperse across political borders. The polluter pays principle should still apply, but it will often be difficult to hold liable those who introduced the species to a given bioregion in the first place. In practice assigning responsibility is problematic. It is difficult for exporters, carriers, and developers to ensure that unintentional introductions do not happen, in many cases it would require international law to hold responsible parties to account, and it is often difficult to enforce laws even if the liability is established and within a given jurisdiction. Given the delays in determining liability and tracing the original source, perhaps the only practical way will be to require that any such projects are suitably insured.

Sources of information used in this Box:

Hulme, P. E. et al. (2008) Grasping at the routes of biological invasions: a framework for integrating pathways into policy. Journal of Applied Ecology 45, 403-414.

Understanding which species are already in the country: Pre- and at-border control measures rely on accurate knowledge of what is already in the country, and whether any new introductions might affect species which are already in the country (e.g. by introducing new genotypes of a species that might be better adapted to climatic conditions). This is a challenge as the knowledge is incomplete.

Smuggling: The deliberate illegal introduction of species is a serious threat to South Africa's biosecurity.

Understanding trade patterns: the European Plant Protection Organisation has proposed several key items that need to be understood to manage pathways: 1) the strength of association between species and commodity/vector/corridor at point of export or import; 2) the volume of the commodity/vector/corridor imported; 3) the frequency of importation; 4) the species survivorship and population growth during transport/storage; 5) the suitability of environment for species establishment in the importing region; 6) the appropriateness of the time of year of importation for species establishment; 7) the ease of species detection within consignments/vectors/corridors; 8) the effectiveness of management measures e.g. fumigation, inspection regime; 9) how widely the commodity/vector is subsequently distributed in the importing region; and 10) the likelihood of transfer from the commodity/vector/corridor to a suitable habitat. The challenge for South Africa will be to collate these data and work out future risks.

Management of land borders: With neighbouring countries showing significant economic growth and becoming less reliant on South Africa for trade, a growing number of goods and species will be directly imported into these countries from other continents, potentially introducing invasive alien species. All government departments with a bio-security mandate therefore need to effectively participate in the inter-governmental co-operation that DAFF, through the NPPOZA, has with other SADC countries. In addition, the cross-border trade in species will be difficult to regulate and will be a major future challenge. Controlling the spread of species introduced to neighbouring countries often requires management more similar to containment than other border control measures.

Intra-governmental co-operation: The recently-formed Biosecurity Directorate of the Department of Environmental Affairs will focus on improving better co-ordination across the various South African government departments (see Key Actions in Section 3.5).

Preparing for the worst: In some cases prevention will fail. In such cases (or even if a species is not yet in the country), post-border measures (e.g. early detection) and the tools necessary to assess and implement eradication or containment should be developed in advance, with clear lines of responsibility for implementation, financing and report-back that include all stakeholders.

4.5. Key actions

There needs to be a significant expansion in general border control measures. Lessons learned from the experiences with the species-specific permitting of classical biological control agents; the area-specific control of sub-Antarctic islands; and the pathway-specific management of marine ballast water should be incorporated into general plans. As many of these proposals represent an imposition on trade, a key challenge will be to ensure that the responsibility for invasions is clearly defined and public support is maintained (see Box 4.2).

KEY ACTION	TARGET
Define and streamline responsibilities for at-border management	Cross-governmental agreement on biosecurity in place.
	Establish joint inspectorate at O.R. Tambo International Airport (the largest airport in the country), with a focus on passengers, cargo and mail.
	Expand joint inspectorates to other airports, harbours and border posts, incrementally, starting at the busiest of these points of entry.
Ensure appropriate and well-maintained physical infrastructure at borders to allow for inspections	Status assessment report with proposals for upgrading existing and build new facilities where necessary.
	Incremental improvement of physical infrastructure at border posts.
Develop a standard risk assessment protocol for all species importation applications. This protocol should be specifically developed and tested for South African conditions. This should be transparent, science-based with applications assessed based on a formal published procedure.	Standard risk assessment protocol in place.
Implement standard risk assessment protocol	All applications processed by individuals trained in assessing risk using the protocol

KEY ACTION	TARGET
Independent review committee to assess applications for releases of any new alien species into the environment (as for biocontrol releases).	Committee set up All applications reviewed according to best practice
Permitted introductions should be assessed for taxonomic identity (e.g. using a DNA barcoding technique),. If the material does not match the permitthen the consignment should not be allowed entry.	Taxonomic capacity and/or DNA-barcodes available to support the implementation of import permits
Develop general monitoring for introductions at ports of entry	Monitoring plans implemented for all ports of entry covering major groups
Identify, monitor, and manage high-risk vectors and pathways. Co-ordinate and use data on interceptions to develop risk profiles.	Assess all important vectors / pathways, and develop a management and monitoring plan for each
	Phase in management of high-risk pathways, starting at O.R. Tambo International Airport. Expand to at least one busy port (Durban), and one overland border post (Beit Bridge).
Identify species that need to be prioritised for specific monitoring activities	Develop a "watch list" (Table 7.2) Each species on watch list has a monitoring plan in place, and for particular priority species an emergency response plan is developed (Section 5.4)
Develop a regional governmental working group on biosecurity	Working group in place
Increase the assessment of export permits to include potential invasiveness of exported species	Protocol for issuing of phytosanitary or other appropriate certificates for export developed, and implementation in place
All applicants (for import permits), importers, exporters, carriers and developers should be required to demonstrate that they have suitable insurance to cover any costs that may be associated with the management of imported species that escape and become invasive.	Insurance scheme piloted and in place
Introduce regulatory measures to manage biofouling.	Best practice protocols are developed for removing organisms that foul the hulls of marine vessels, aircraft or vehicles.
Planning exercise to identify future risks	Horizon scanning exercise (see glossary of terms) required every 5 years

4.6. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 10, 42, 46, 81, 87, 94, 139.

5. POST- BORDER RISK MANAGEMENT

5.1. General principles

After a species has been introduced, there is the possibility that it can naturalise and become invasive. There are several strategic approaches for detecting new naturalisations or invasions (e.g. species-specific surveys, site-specific surveys, and random surveys). From an area perspective, the aim would be to detect incursions by alien species not previously known to be present in those areas, and extirpate them (this is not necessarily eradication as there might be a high chance of reinvasion). Finally, it would be important to monitor the secondary pathways that move species around the country post-introduction, including looking at possible vectors that would take species from points of entry to new areas. High-risk pathways should be managed appropriately to reduce the number of species that they spread and the abundance of each species, and in some cases particularly risky activities should be prohibited.

Following the detection of a new, potentially invasive species, the decision to prioritise resources and act against such a species needs to be based on an evaluation of invasion risk. As with pre-border risk assessments, there are a variety of tools available, but given the uncertainties inherent in the invasion process it has been suggested that risk assessments should become adaptive and pay close attention to the circumstances that may promote spread by a particular species (e.g. how changes in land use and disturbance patterns could affect population spread and growth rates).

Many introduced species initially have significant value for particular stakeholders while the costs associated with invasion only accumulate later (see Box 5.1.2). Therefore the net value of an introduced species can change substantially over time as it invades an ever-growing area. As such, post-border risk assessments should be carried out in consultation with relevant stakeholders. For example, New Zealand's National Pest Plant Accord is a cooperative agreement between the Nursery and Garden Industry Association, regional councils and government departments with biosecurity responsibilities, that identifies plants that pose a threat and that should not be sold, propagated or distributed.

Depending on the biology and administrative situation, eradicating new introductions before they become particularly problematic can be a feasible option (Box 5.1).

Box 5.1. Eradication as a viable management goal

Eradication literally means "pulling up by the root", but has a very specific meaning in natural resource management—the removal of every individual of a species from an area to which re-colonization is unlikely to occur. Throughout this Strategy, eradication is taken to mean the removal of every individual from the whole of continental South Africa. Where area is specified for removal of all individuals, but there are other populations close by, the term “local eradication” is sometimes used, but “extirpation” is preferred.

As a management goal, eradication is one of the few activities in the management of biological invasions that can have a permanent impact. There have been over 700 documented eradications of vertebrates from islands around the world, with many on-going projects. Other invasive taxa (e.g. invertebrates and plants) have also been successfully eradicated from islands and in some cases from countries and continents as well.

One example is the New World screwworm, *Cochliomyia hominivorax*, which lays eggs in wounds on mammals and causes major economic losses to cattle producers in infested areas. By releasing large numbers of

sterilised male flies, it is possible to halt the fly's population growth. Based on the successful application of this sterile insect technique, the screwworm was eradicated from the United States and Mexico in 1991 at a cost of ~USD 750 million (in 1991 values).

The most important eradication programme to date was the global effort to eradicate smallpox (declared a complete success in 1980). This programme was made possible by specific features of the biology of the disease, the unanimous international agreement in support of the goal of eradication, and the launch of a dedicated programme within the United Nation's World Health Organisation. The eradication of smallpox saves millions of lives every year.

A more recent example is the successful eradication of the marine Killer Alga *Caulerpa taxifolia* from southern California between 2000 and 2006. The eradication was started 17 days after the species was recorded and was carried out with strong local engagement through the Southern California *Caulerpa* Action Team. The management techniques used were based on international expertise supplemented by detailed experiments into detectability and control efficacy. This success occurred despite the failure of similar efforts in Europe, and the widespread scepticism regarding the chances of eradication from an international advisory panel.



The New World screwworm, *Cochliomyia hominivorax*



Variola virus that causes smallpox



The Killer Alga, *Caulerpa taxifolia*

Box Figure 5.1.1. Examples of species that have been successfully eradicated from parts of the world

The understanding of eradication has developed significantly in recent years as the number of successes has increased, and as lessons are learned from failed eradication attempts. There are five main features of successful eradications: (1) invasions (or new infections) are detected early, and there is little delay before action is taken; (2) sufficient resources are allocated from start to finish; (3) a person or agency has the authority to enforce cooperation; (4) enough research is conducted to identify when, where and how management will be most effective; and (5) the project has an energetic, optimistic, and persistent leader. Of these, the last is perhaps the most important—much of the successes in eradication are down to the people responsible for the project. If the person in charge of the eradication is not committed to it, acts slowly or over-cautiously, and does not adapt their approach in light of the data collected on the effectiveness of management, then projects tend to fail. As such it is vital to have skilled dedicated personnel who are committed to working in partnerships, can drive projects forward, and motivate people.

Sources of information in this Box:

Island Conservation, 2012. Database of Island Invasive Species Eradications. Hosted by the IUCN SSC Invasive Species Specialist Group, http://eradicationsdb.fos.auckland.ac.nz/

Myers, J. H., Savoie, A. and van Randen, E. (1998) Eradication and pest management. Annual Review of Entomology, 43, 471-491.

Simberloff, D. (2003) Eradication — preventing invasions at the outset. Weed Science, 51, 247-253.

5.2. History of post-border risk management in South Africa

Even with no new introductions, the number of biological invasions in South Africa will increase as already-introduced species naturalise and become invasive (Box 1.1). South Africa has ~9000 introduced plant taxa, of which 660 are naturalised, 381 have been included in invasive species legislation, and only 64 have been subjected to regular control. For all taxa only the widespread invaders have been managed post-border (in response to observed impacts rather than potential impacts); management is reactive rather than proactive; and there is a substantial invasion debt (see Box 1.2). Without large interventions, the number of invasive species, the extent of invaded land, and the societal costs due to adverse impacts will all increase substantially.

For commercial agricultural pests in South Africa there has been both area-specific monitoring (e.g. field inspectors employed to survey farms for pests) and species-specific monitoring (e.g. approximately R2 million per year was spent on detecting and controlling incursions of the fruit-fly *Bactrocera invadens* from neighbouring countries, though the species has recently been declared as established). But for other groups, most documented cases of naturalisation or invasion have come from a small number of interested scientists who have not been specifically employed to look at invasions. As a result, patterns in the records of naturalisation follow the activities of specific taxonomists, and large rises in the number of naturalised species recorded are often the result of a student project, a visiting expert, or a single specific survey under-taken. However, the naturalised plant flora is well known and documented due largely to the Southern African Plant Invader Atlas Project (SAPIA). SAPIA was founded on information collected during general roadside surveys for invasive alien plants and has grown to be the primary repository for new plant naturalisation records in the region. Data for other taxonomic groups are severely lacking.

Historically there has often been a significant gap between a species being detected and action being taken. Consequently it is not surprising that South Africa has a poor record of eradication, with only one documented example of a successful eradication programme in continental South Africa – against the Mediterranean snail (*Otala punctata*) in Cape Town (Figure 5.1). Some invasive species have also been eradicated from the Price Edward Islands. There have, however, been several plant eradication attempts. Intensive programmes were initiated in the early 1960s to remove camel thorn (*Alhagi camelorum*) from irrigation schemes. However, the systemic herbicides available at the time dealt poorly with the extensive underground root systems. Satansbos (*Solanum elaeagnifolium*) was first recorded in 1952, but legislation was only enacted in 1968 at which point an eradication programme was initiated. Despite some local successes, by 1972 the eradication campaign was cancelled with the total infested area having reached an estimated 14 500 ha. This failure was ascribed to inadequate biological knowledge; ineffective herbicides and application techniques; and a lack of co-operation from many farmers. The most extensive eradication campaign in South Africa was against jointed cactus (*Opuntia aurantiaca*). As early as 1892 it was highlighted as a potential eradication target, but eradication attempts only started much later. Despite legislative backing (e.g. the Jointed Cactus Eradication Act of 1934), thousands of labourers, and millions of rand spent on herbicides, apparently not a single farm was cleared. More recent efforts (since 1978) to eradicate another cactus (*Cylindropuntia fulgida*) have similarly failed, again probably because of a slow initial response, the lack of efficient follow-up, and ultimately inadequate funding. Attempts to eradicate alien vertebrate species from continental South Africa have not yet achieved full eradication. An attempt to eradicate the Himalayan tahr (*Hemitragus jemlahicus*) from Table Mountain (Cape Town) was initiated in 1973, but, despite concerted control efforts during 2004, the population remains. There have also been attempts to eradicate common crows (*Corvus splendens*) from Cape Town and Durban. In these cases, populations have been drastically reduced, but not yet eradicated.



Figure 5.1. The Mediterranean snail (*Otala punctata*) is the only invasive alien species to have been successfully eradicated from continental South Africa.

5.3. Current post-border risk management

The Biosecurity Directorate within the DEA provides funding to the South African National Biodiversity Institute's Invasive Species Programme (SANBI's ISP) to detect new invasions (coordinate surveillance for and manage records of new instances of naturalisation); provide post-border risk assessments (evaluating species in enough detail to make a decision as to whether regulation is required and, if so, in what form); and plan eradication (estimating the feasibility of eradicating species and either develop and implement an eradication plan or recommend a revision in listing). In assessing species for the feasibility of eradication, SANBI's ISP is also in a position to provide advice on a path of action that can be implemented rapidly in cases where eradication is not possible. In such cases, the goal would be to manage dispersal pathways and limit spread (see Chapter 6).

SANBI's ISP has grown steadily and by the end of 2013 had an annual budget of R36 million with a presence in all nine provinces. Detection efforts by SANBI's ISP to date have largely been based on revisiting historical records in SAPIA, but site-specific (e.g. historical arboreta) and species-specific surveys have been initiated. SANBI's ISP has a network of regional co-ordinators tasked with interacting with regional teams, and distributing information on all target species. However, more needs to be done to document the effort in building networks and the effectiveness of such communication.

The Biosecurity Directorate within the DEA runs a Nurseries Partnership Programme which, amongst other roles, aims to consult with the industry about proposed legislative changes as well as enhancing the level of awareness within the nursery industry and the general public of invasive alien plants, their potential impacts, and relevant current legislation (Chapter 10).

For marine invasions most of the commercial harbours have undergone comprehensive baseline surveys, or related *ad hoc* surveys conducted for research and management purposes. Several baseline surveys of commercial ports have been commissioned by the TNPA, although the resulting data may not be publically available in all cases. There also remain several priority areas, including some smaller harbours and marinas, which require comprehensive surveys to establish current biological conditions. Some initial level of standardization and training has been achieved however no national protocol or guideline has been adopted to ensure compatibility of output. Furthermore, there has been no strategic approach for design and implementation of surveys and monitoring programmes. As for terrestrial and freshwater

systems, a weakness in the local surveillance network is the lack of adequate taxonomic expertise to perform timely and accurate species-level identifications of samples from survey and monitoring activities. There is also no current centralized reporting mechanism to ensure appropriate authorities are aware of new species detected by the various stakeholders. Further to this, there is currently no response mechanism or plan to be followed to evaluate and respond to any potentially threatening marine and coastal incursions. This should be ameliorated in part by a recent project between SANBI and the International Oceans Institute to develop and implement a National Marine Invasive Species Monitoring Strategy for Port and Coastal Areas and develop an Emergency Response Plan for Marine Invasive Species.

5.4. Key actions

KEY ACTION	TARGET
Develop emergency control capacity to respond quickly to new invasions.	Within all management units explicit provision for Early Detection and Rapid Response is made that can rapidly call on a national emergency control fund.
	A National Monitoring Plan and Emergency Response System in place for marine invasions, to act as a model for other ecosystems
	Further Emergency Response Systems in place, based in marine system
	Emergency Response Agreements in place to facilitate action
Develop a process to record, verify and act upon observations from the general and professional public, so as to ensure observers feel valued and are more likely to submit records, thereby increasing the rates of detection.	Spotter networks established in each province for all taxa. Dedicated capacity in place to interact with on-line public identification tools (e.g. iSpot, see 7.2.4)
Develop a database of taxonomists (national and international) and facilitate agreements with taxonomists to improve the chances of rapid identifications.	Database and first agreements in place
Develop a database of DNA barcoding, with guidelines regarding access and use	Database and guidelines in place
Develop systems to identify unknown taxa more quickly to reduce reaction time	Samples submitted for identification should receive a preliminary identification within 20 working days
Develop standard processes to resolve issues of origin (native or introduced), so that control and legislation can be implemented timeously.	A protocol developed for determining the natural distribution range of species
Increase involvement of international expertise in further surveys, particularly focusing on poorly-surveyed organisms.	Support for five visits annually by international experts distributed over the seasons and for different taxonomic groups to detect introductions and new instances of naturalisation.
Assess and collate information sources on species that are already in the country, to identify records that need verification and to identify species that need further evaluation.	All recorded introduced species passed through an initial risk assessment framework and sites revisited where appropriate.
Identify sites where there is a high likelihood of naturalisation by high-risk species (e.g. ports in the case of marine species), so that monitoring can be targeted.	A National Invasion Monitoring Plan developed with specific goals and measurable indicators. To include once-off surveys of particular historical sites to determine the need for future monitoring.

KEY ACTION	TARGET
Include the potential for conflict in risk assessment protocols.	Potential for conflict included in risk assessment protocols (see 4.5).
Develop post-border emergency response plans for key species on watch list	30 species assessed with a post-border contingency plan for each
Eradicate key target species	Eradication plan developed and implemented against all species listed as eradication targets. Progress regularly monitored, and key management recommendations implemented. Specific resources dedicated for expected duration of the eradication attempt.

5.5. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 155, 192.

6. MANAGING ESTABLISHED SPECIES

6.1. Introduction

Established invasive alien species are defined as those species that are present and reproducing outside their native range, and whose extent of distribution and invasiveness makes eradication practically impossible (Stages 3 and 4 on Figure 1.1). These species need to be contained as far as possible by preventing or slowing further spread (Stage 3), or, if they are already widespread, managed to reduce or mitigate impacts (Stage 4).

6.2. Current situation in South Africa

6.2.1. General

As outlined in Chapter 1, South Africa has a long history of alien species management, and it is one of only a few countries that direct substantial resources towards addressing the problem. South Africa was one of the first countries to use classical biological control. *Dactylopius ceylonicus* was released in September 1913 to control infestations of the drooping prickly pear (*Opuntia monacantha*). More biological control agents followed over the years, and today South Africa is among the top five countries in the world with respect to the implementation of weed biological control. In the 1960s, growing invasion of fynbos shrublands by pines, hakeas and wattles led to the establishment of widespread alien plant control operations in the fynbos region in the 1970s and 1980s. In 1995, invasive alien plant control operations were taken to new levels with the creation of the Working for Water programme. Working for Water sought to address the problem of invasive alien plants in all parts of the country, while at the same time using the opportunities offered by control projects to create employment in poverty-stricken rural areas. Working for Water is often cited as an example of best practice and innovation in the field of alien plant control worldwide.

Alien invertebrates that have becomes serious pests of significance in agriculture have also been an on-going focus for management. There are various “commodity-based” institutes that serve particular agricultural segments, currently coordinated by the Agricultural Research Council (see 6.7.3). These institutes are tasked with the development of control options for invertebrate pests, many of which are alien.

6.2.2. The use of laws and regulations

There are several lists of alien species in different categories in South Africa (Tables 7.2 and 7.3), but there are two separate formal lists of regulated invasive alien species in South Africa, one in terms of the CARA, and another, currently being promulgated, in terms of the NEM:BA). Regulations that governed the management of “declared noxious weeds” in terms of CARA were put in place in 1983, when 56 alien plant species were listed as declared weeds or invaders. Landowners who had declared weeds or invaders on their land were required to take adequate steps to control these, and to prevent spread. This initial list contained few weed species that were of value. However, following the promulgation of the National Water Act, a new set of regulations was published in the Government Gazette (Vol. 429, no. 22166 of 30 March 2001), resulting in the listing of 198 alien plant species as weeds or invaders. The revised approach classified the plants into three categories: (1) weeds of no value; (2) recognised

invaders that also have commercial value; and (3) recognised invaders that have ornamental, but no commercial value. For species in the first category, eradication (where possible) or control is required, and trade is banned. Landowners require permits to grow species in the second category, and are required to take steps to limit their spread; trade in these species and their products are permitted. Species in the third category (created to accommodate popular ornamental plants) require steps to limit their spread, and further plantings, and sale of plants and their products, are prohibited. The list of 198 species has not been updated since 2001. All relevant species on the CARA list have now been incorporated into the interim regulations in terms of NEM:BA were published in February 2014 (Government Gazette Vol. 584, no. 37320 of 12 February 2014). The regulations include eleven lists of alien species that require management in South Africa (Table 6.1).

Table 6.1. The number of species in different groups listed in the draft National List of Invasive Species under NEM:BA, which includes both established alien species, and species that are candidates for eradication.

Group	Number of established species that require management	Number of species listed as candidates for eradication
Plants	342	33
Mammals	36	4
Birds	14	0
Reptiles	23	1
Amphibians	7	0
Freshwater fish	17	0
Marine fish	0	0
Terrestrial invertebrates	21	2
Freshwater invertebrates	6	2
Marine invertebrates	12	1
Microbial species	7	0

The lack of a strong legal framework has been a significant constraint to implementing effective management of invasive alien species until recently. In particular, it has hampered the ability of government to enforce the obligations of private landowners to control invasive species. The recent publication of regulations under NEM: BA will now provide the legal backing to enforce such obligations.

6.2.3. Existing invasive alien plant control projects

The invasive alien plant control projects funded by Working for Water lie at the heart of current efforts to control established invasive species in South Africa today. Working for Water's operations have dual goals, with a focus on the creation of employment in impoverished rural areas, and on the control of invasive alien species to prevent harm. This strategy has allowed the programme to secure substantial amounts of funding, which in turn have been used to incubate and grow a wide range of control and other environmental projects. The funding for control operations is channelled through the DEA to a series of implementing agents. These include, among others, government departments, provincial nature conservation authorities, municipalities, irrigation boards, South African National Parks, the South African National Defence Force, and the private sector. In turn, implementing agents appoint contractors who carry out clearing and follow-up operations. The methods used are deliberately labour-intensive, given that funding in support of this work is sourced from poverty-relief budgets that aim to create employment and to provide developmental opportunities. The approach has resulted in large areas being cleared across the country. Working for Water's projects are planned within the broader context of the imperative for poverty relief, and it is recognised that project planning needs to be improved to support the attainment of the goals of this strategy (see 6.3, Key actions).

6.2.4. Biological control

Weed biological control is extensively used in support of labour-intensive control effort. Weed biological control has been responsible for some of the most noted successes in the implementation of alien plant control in South Africa. Although biological control requires research, the identification and use of biological control options is in fact an essential part of the execution of control programmes. In South Africa, 106 weed biological control agent species have been released on 48 invasive alien plant species. The investments into weed biological control programmes have brought about substantial economic benefits. The cost of implementing biological control has been modest when compared to the value of ecosystem benefits being protected, indicating very attractive returns on investment, with estimated benefit: cost ratios of between 50:1 and >3000:1. In addition to weed biological control, some species of alien invertebrates are also under biological control in South Africa. Between 1970 and 2000, 217 potential biological control agents were imported, 146 were released, and 38 established on insect pests of forestry, sorghum, sugarcane, wheat, citrus, fruit, nuts, and vegetable crops, as well as pastures (Figure 6.2.1). Many, but not all, of these pests were alien species.

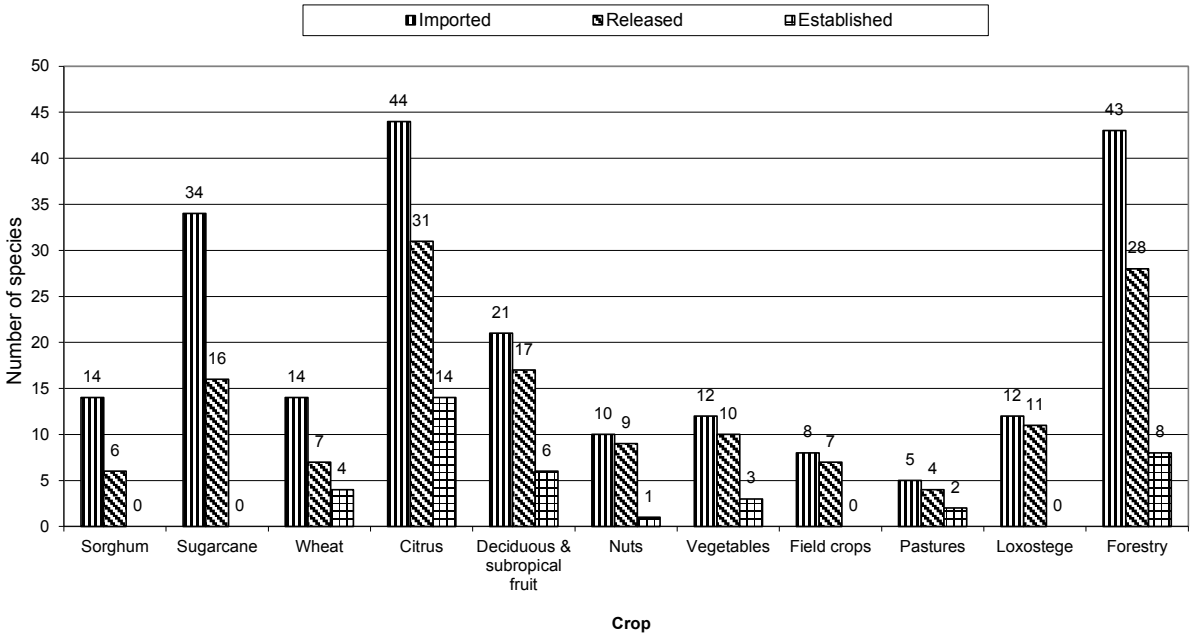


Figure 6.2.1. Biological control agents imported, released, and established on a range of invertebrate pests of agricultural and forestry crops in South Africa between 1970 and 2000.



Figure 6.2.2. A dam infested by aquatic weeds (left), and the same dam one year later following the introduction of biological control agents.

6.2.5. Existing freshwater fish control projects

Attempts to manage established populations of invasive alien fish have come in the form of projects aimed at extirpation (localised eradication) in priority areas (see Box 6.6.1). Early indications of success have been attributable to several factors, including careful planning, close and enthusiastic collaboration between affected state and private landowners, public participation to address concerns, the simultaneous and co-ordinated application of mechanical, and chemical and biological control of alien plants and chemical control of alien fish (see 6.6).

6.2.6. Existing invertebrate control projects

Many innovative approaches have also been developed to deal with invertebrate pest species. These include the development of pesticides, biological control, sterile insect techniques and mating disruption. Many are effective, although the effectiveness of specific pesticides is limited, as invertebrates usually evolve resistance over time (see 6.7).

6.2.7. Leveraging benefits

Projects that will leverage the benefits of control projects aimed at established alien species are planned, or have been initiated, to operate in parallel with control projects. These projects are a major strategic intervention that will further spread the benefits of alien plant control programs, and that will enable a far greater proportion of the problem to be addressed nationally. The Eco-Furniture Factories programme seeks to make optimal use of some of the biomass cleared by Working for Water in creating work opportunities to make products that help Government to meet its needs, and notably the pro-poor opportunities within this. Five Eco-Furniture Programme factories have been established, and up to thirteen further factories or partnerships are under consideration. The programme will provide sustainable employment for over 3,200 previously unemployed people, and will make products that government needs from wood obtained from the clearing of invasive alien trees. The target is, *inter alia*, to put up to 500,000 school learners behind a solid desk in the next year, at costs per desk that are significantly lower than is being paid by schools at present. The programme intends to build on the range of products to meet the needs of hospitals, clinics, and community centres. The Working for Energy initiative plans to make optimal use of the biomass cleared through the Working for Water programme, by creating work opportunities to generate energy. The programme also intends to promote the general use of biomass through biogas digesters, in providing energy and jobs to the rural poor. In addition, there is potential to use wood chips from invasive trees and shrubs to make wood-wool cement board fibre, that might be highly competitive in dealing with the need for housing, and other buildings. All of these interventions are politically very attractive, as they address multiple needs. Their potential to enlarge the pool of funding available for managing biological invasions is substantial.

6.2.8. Monitoring and evaluation

Monitoring and evaluation are essential components of management, necessary for a number of reasons. These include:

- The need to accurately account for public funds expended, especially with regard to the intended benefits of improved ecosystem services;
- The need to assess the degree to which the goals of control programmes are being met;
- The need to evaluate priorities and approaches to management in the light of the achievement (or not) of stated goals; and
- The need to adjust management approaches, goals and policies in response to improved understanding (adaptive management).

Monitoring and evaluation practices need to be strengthened. With this in mind, the responsibility for Quality Management has been moved into a separate Directorate on its own, with an increased budget. This unit will be responsible, *inter alia*, for monitoring the outcomes of the improved management plans that will be required under the NEM:BA regulations.

6.3. Key actions

Key actions and targets are summarised in the table below, but most actions for the containment and control of established invasive alien species are dealt with in the sections that follow – plants (6.5), vertebrates (6.6), invertebrates (6.7), microbial organisms (6.8) and marine species (6.9). The actions in this section are those relevant to all invasive species.

KEY ACTION	TARGET
Finalise the guidelines for the development of monitoring, control and eradication plans for listed invasive species, as provided for in the NEM:BA in Chapter 3, paragraph 5(1). In these explicitly separate eradication, containment, control and monitoring.	Completion of guidelines for the development of eradication, containment, control and monitoring plans, with guidelines for species, areas (ecosystems) and pathways. The guidelines should adopt an adaptive approach to management, and should have clear targets for the achievement of desired levels of control within a reasonable timeframe.
Management plans should be drawn up for priority ecosystems, in line with Guiding Principle 3 adopted at the sixth Convention of Parties of member states to the Convention on Biodiversity.	Completion of plans for the management of all priority ecosystems.
Improve participation in the formulation of lists by experts, practitioners and the affected public.	A process for adequate public participation in operation.
Develop a robust transparent risk assessment process so that the inclusion or exclusion of species on lists can be legitimately justified. This should include the justification for listing species with invasion potential.	Risk assessment process in place, with qualified staff to manage the process.

6.4. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 28, 83, 95, 120, 124, 179, 170.

6.5. Plants

6.5.1. Established alien plant invasions in South Africa

Thousands of alien plant species have been introduced into South Africa, and many of these have become invasive. These invasive species include trees and shrubs, herbaceous plants (grasses and forbs), succulents, and freshwater aquatic plants. Of these, 198 species have been listed under the Conservation of Agricultural Resources Act as declared weeds, while the proposed national list of invasive alien species under the NEM: BA includes 381 invasive alien plant taxa that would require management. A subset of these invasive alien plants is already widespread and prominent in South African ecosystems, where they affect a number of different biomes (Table 6.5.1). Each of South Africa's terrestrial biomes has a distinctive suite of invasive alien plants (Table 6.5.2). Invasive alien plants can and do cause substantial negative impacts (Box 6.5.1).

6.5.2. Current management of established populations of invasive alien plants

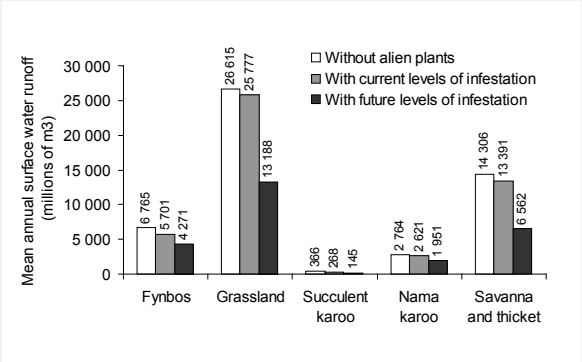
Most of the management of invasive alien plants in South Africa over the past 18.5 years has been undertaken as part of the large, national-scale, government-sponsored 'Working for Water' programme. This initiative has adopted a comprehensive approach to alien plant control, characterised by several distinguishing features. The programme combines mechanical and chemical control of all invasive alien plant species in targeted areas with the provision of employment to people from impoverished rural communities as its main thrust. This has been supplemented by the development of biological control options that target selected priority alien plant species. The current annual budget is over R1.2 billion.

There is little in the way of robust evidence against which the effectiveness of clearing efforts can be assessed, and available assessments are contradictory. On the positive side, a recent study in the fynbos biome suggests that, in localised areas where Working for Water teams had been active for over a decade, there has been a marked decline in the density of pine tree invasions. Combining biological control with mechanical control, or in some cases using biological control alone, also appears to have assisted in reducing the extent and impacts of some invasions. One estimate suggested that, had no historic control been carried out, the annual economic losses from alien plant invasions could have been as high as 41.7 billion rands (instead of 6.7 billion rands), and that a significant proportion of these savings arose from the biological control of invasive alien plants. In addition, Working for Water was able to create tens of thousands of jobs annually over 15 years in impoverished areas, that would not have been there had the programme not existed. On the other hand, despite significant spending, records show that the control operations have in many cases only reached a small percentage of the estimated invaded areas. For example, only 7% of the estimated area under mesquite invasions has been treated in arid areas, and only 16% of the area affected by black wattle (*Acacia mearnsii*) invasions in the savanna and grassland. A study in the Kouga catchment estimated that, at current rates of clearing invasive black wattle trees, it would take 695 years to clear the catchment, assuming no further spread. If spread was considered, it seemed that current control efforts were completely inadequate, and invasions were likely to continue to spread in the catchments. Management plans need to be adapted in response to these findings, and more such assessments are urgently needed to improve current control operations.

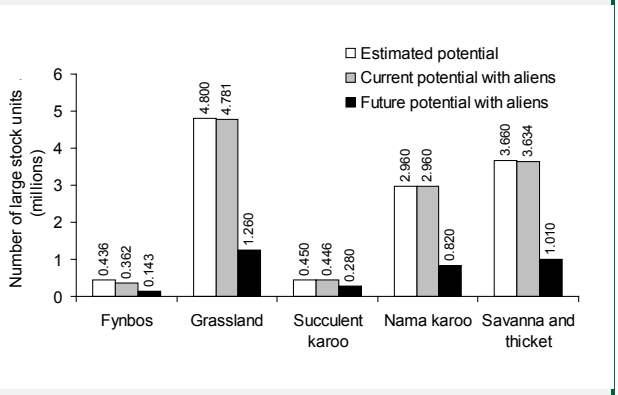
Box 6.5.1. Impacts of invasive alien plants in South Africa

Invasive alien plants can have substantial impacts, but very few studies have quantified these impacts. Many studies have of necessity been at a small scale, or have focussed on the impacts of a single invasive alien species. For example, the impacts of invasive mesquite trees (*Prosopis* species) have been quantified in a few separate studies. Mesquite trees have lowered the water table, resulting in the death of camel thorn trees (*Acacia erioloba*), a keystone species for both wildlife and domestic livestock. Invasion by mesquite has also radically changed bird habitats, leading to reduced bird species richness and diversity. These changes include the elimination of raptors, and reductions in frugivores and insectivores. Mesquite invasions also reduce the numbers of dung beetle species, with the most marked declines being found among large species and rare species.

While the types of studies described above can illustrate impacts at a small scale, only one study has attempted to scale up and provide a national-scale perspective on such impacts. This national-scale study estimated the value of water and grazing in South Africa's biomes under three scenarios: (1) if no alien plants were present; (2) reductions due to current levels of invasion; and (3) reductions that would come about if alien plants were allowed to invade all suitable habitats. Estimates suggest that reductions in surface water runoff as a result of current invasions amount to > 3000 million m^3 (about 7% of the national total), most of which is from the fynbos (shrubland) and grassland biomes; the potential reductions would be more than eight times greater if invasive alien plants were to occupy the full extent of their potential range. Reductions in grazing capacity as a result of current levels of invasion were estimated to be just over 1% of the potential number of livestock that could be supported. However, future impacts could increase to 71% should invasive alien plants occupy their full potential range. Thus, while the current impacts of invasive alien plants are relatively low (with the exception of those on surface water runoff), the future impacts could be very high.



Estimates of the current and potential impacts of invasive alien plants on surface water runoff in five biomes in South Africa.



Estimates of the potential numbers of large stock units that could be supported in five biomes in South Africa, the degree to which these numbers are currently and potentially reduced by invasive alien plants.

While the errors in these estimates could be large, the predicted impacts are of sufficient magnitude to suggest that, even with significant over-estimates, there is cause for serious concern; for example, even if the levels of impact are a quarter of those predicted, they would result in significant losses of benefit.

Sources of information for this Box:

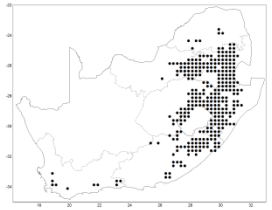
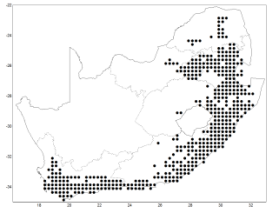
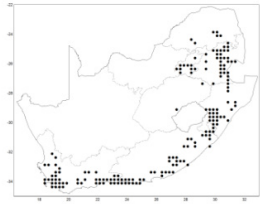
Dean, W.R.J. et al. (2002). Avian assemblages in native Acacia and alien Prosopis drainage line woodland in the Kalahari, South Africa, Journal of Arid Environments 51: 1–19.

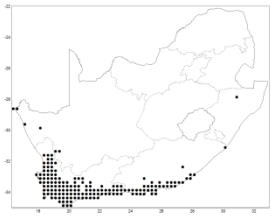
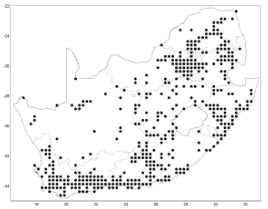
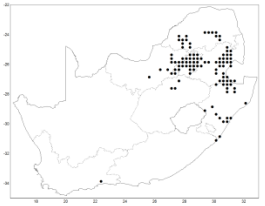
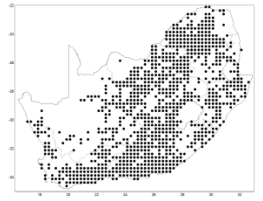
Dzikiti, S. et al. (2013). Water relations and the effects of clearing invasive Prosopis trees on groundwater in an arid environment in the Northern Cape, South Africa. Journal of Arid Environments 90 103 – 113.

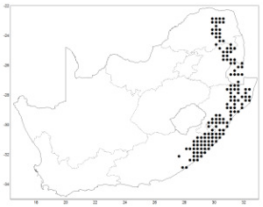
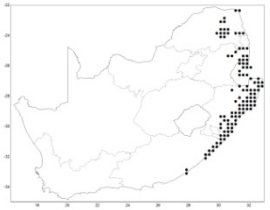
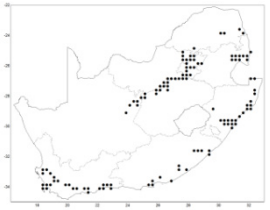
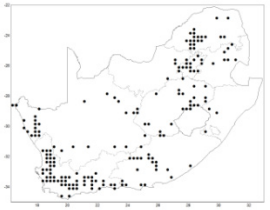
Steenkamp, H.E. and Chown, S.L. (1996). Influence of dense stands of an exotic tree, Prosopis glandulosa Benson, on a savanna dung beetle (Coleoptera: scarabaeinae) assemblage in southern Africa, Biological Conservation 78, 305 311.

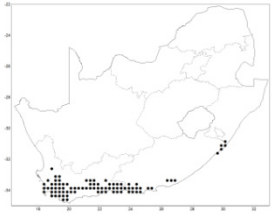
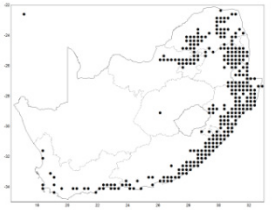
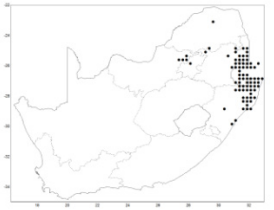
van Wilgen, B.W. et al. (2008). A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. Journal of Environmental Management 89, 336 – 349.

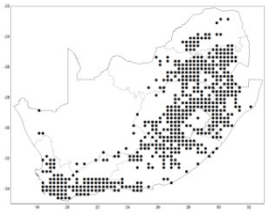
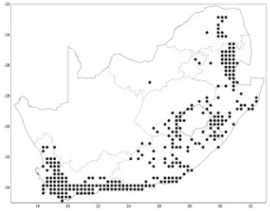
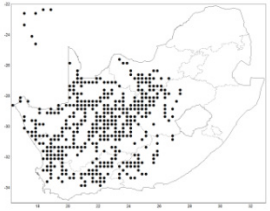
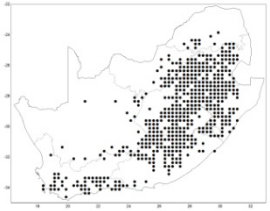
Table 6.5.1. Twenty of the most prominent invasive alien plant taxa (species or groups of species) in South Africa. Distribution maps are from the South African Plant Invaders Atlas.

Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Acacia dealbata (silver wattle)	Australia	Savanna, grassland and fynbos, especially along water courses			Seed feeders, moderate damage to seeds
Acacia mearnsii (black wattle)	Australia	Savanna, grassland and fynbos, especially along water courses			Flower gallers and seed feeders, good control potential
Acacia melanoxylon (blackwood)	Australia	Indigenous forests and watercourses			Seed feeder, extensive damage to seeds

Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Acacia saligna (Port Jackson willow)	Australia	Fynbos lowlands and coastal areas			Seed feeders and flower gallers, extensive damage to seeds
Arundo donax (Spanish reed)	Mediterranean region	Watercourses and drainage lines			None
Campuloclinium macrocephalum (pom pom weed)	Argentina and Brazil	Grasslands and savannas			Several under investigation
Cactaceae (cacti)	North and South Americas	Arid areas (karoo and thicket)			Several have biocontrol agents that do extensive damage, but other species have no biological control yet.

Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Caesalipinia decapetalata (Mauritius thorn)	Asia	Forest margins, watercourses			Only one released, but not effective
Chromolaena odorata (triffid weed)	Central America	Savannas and watercourses			Many considered, two released, one does considerable damage
Eichhornia crassipes (water hyacinth)	South America	Water bodies			Several agents available, inflicting considerable damage
Eucalyptus camaldulensis (red river gum)	Australia	Banks of rivers			None

Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Hakea sericea (sweet hakea)	Australia	Fynbos shrublands			Two seed feeders inflicting extensive damage to seeds. Attacked by an indigenous fungal pathogen as well.
Lantana camara (lantana)	Central and South America	Savanna and watercourses			At least 13 agents released, some inflicting extensive damage.
Melia azedarach (syringa)	India	Savanna and watercourses			None
Parthenimum hysterophorus (feverfew; famine weed)	Caribbean	Savannas			Several under investigation

Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Populus species (poplar trees)	Northern hemisphere	Watercourses and wetlands			None
Pinus species (pine trees)	Northern hemisphere	Fynbos and grassland			None
Prosopis species (mesquite trees)	North and central America	Arid areas, especially dry water courses			One seed feeder that does considerable damage to seeds. More agents under consideration.
Salix babylonica (weeping willow)	China	Watercourses			None

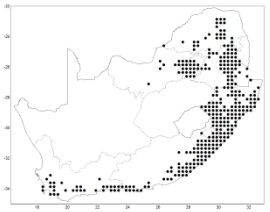
Species or group	Origin	Habitats invaded	Image	Distribution	Biological control
Solanum mauritianum (bugweed)	South America	Forest margins, savannas and watercourses			Two released, but not effective

Table 6.5.2. Terrestrial biomes in South Africa, and the major prominent invasive alien plant species in each biome.

Biome	Extent (km^2)	Prominent invasive alien plant species
Fynbos	83 964	Trees and shrubs in the genera *Acacia* (wattles), *Pinus* (pines), *Hakea* (shrubs in the family Proteaceae) and *Leptospermum* (myrtles).
Grassland	354 953	Important trees include wattles (*Acacia* species), willows (*Salix* species), poplars (*Populus* species) and gums (*Eucalyptus* species), notably along rivers. Shrubs include brambles (*Rubus* species), firethorns(*Pyracantha* species) and cacti (*Opuntia* species).
Savanna	412 544	The most widespread invasive shrubs are triffid weed(*Chromolaena odorata*) and lantana(*Lantana camara*). Important invasive trees include wattles (*Acacia* species), syringa(*Melia azedarach*), bugweed(*Solanum mauritianum*), guava(*Psidium guajava*) and jackaranda(*Jackaranda mimosifolia*). Mesquite trees (*Prosopis* species) are predominant in arid parts.
Albany thicket	29 127	Invasive succulents, mainly cacti (*Opuntia* and related genera).
Nama karoo	248 728	Mesquite trees (*Prosopis* species). Sponge-fruit salt-bush(*Atriplex lindleyi*)and sweet prickly pear (*Opuntia ficus-indica*) are also predominant. The pepper tree (*Schinus molle*) is becoming increasingly widespread.
Succulent karoo	83 283	Trees in the genera *Acacia* (wattles), *Prosopis* (mesquite) and *Populus* (poplars), and the shrubs *Nicotiana glauca* (wild tobacco) and *Atriplex lindleyi* (sponge-fruit salt-bush) *and A. nummularia* (old man saltbush). The cactus *Opuntia ficus-indica* (sweet prickly pear) is also predominant.
Indian Ocean coastal belt	14 282	Triffid weed (*Chromolaena odorata*) and lantana (*Lantana camara*) are the most important invasive species. Additional species include Mauritius thorn (*Caesalpinia decapetala*), inkberry (*Cestrum laevigatum*) and guava(*Psidium guajava*).
Forest	4731	Dominant invasive trees include wattles (*Acacia* species) and bugweed (*Solanum mauritianum*). Triffid weed (*Chromolaena odorata*) and lantana (*Lantana camara*) are important invasive shrubs.
Desert	7166	Invasions of mesquite trees (*Prosopis* species) in dry river beds.
Rivers, wetlands and dams	Not known	Several aquatic weeds, of which red water fern (*Azolla filiculoides*), water hyacinth (*Eichhornia crassipes*), parrot's feather (*Myriophyllum aquaticum*), water lettuce (*Pistia stratiotes*) and Kariba weed (*Salvinia molesta*) are the most prominent.

6.5.3. Elements of alien plant control programmes

Invasive alien plant control programmes need to be tailored to suit each particular set of circumstances, including the ecology (for example the ability of the target species to resprout, or the seed dispersal mechanisms of combinations of co-exiting species), and features of the environment (for example, whether it is fire-prone, affected by flooding, or difficult to access). The most important approaches to the control of invasive alien plants that are relevant to the South African situation are outlined below.

Labour-intensive mechanical control: Almost all invasive alien plant species have to be cleared mechanically, using chain-saws in some cases, or hand-weeding in others, in combination with the application of herbicides where appropriate. The need for labour-intensive methods provides the opportunity to create employment in impoverished rural areas. The creation of employment and development opportunities, in combination with control efforts has made it possible to secure substantial amounts of funding for these activities, and has been the cornerstone of control programmes across the country since 1995. In order to implement control projects, contracts are awarded to individuals who then clear invasive plants from agreed areas, and conduct follow-up work. This system

has drawbacks, notably that employment on short-term contracts does not provide a reliable source of steady income, and can result in a high turnover of workers; this in turn means that new workers have to be trained each time a new area is subjected to control. The dual goals of job creation and effective control have to be accommodated, in line with the strategy that strives to maximise funding potential through accommodating diverse benefits.

Dealing with invasions in inaccessible areas: Many alien plant species invade areas that are rugged and inaccessible, especially in mountain areas, but these need to be prioritised for control in many cases. Studies have shown that an individual plant on an exposed slope or mountain top can contribute more to increases in the area invaded than do all the plants in a hectare of dense infestation in a lowland, as seeds from a single isolated plant on a mountain top will be dispersed much further and over a wider area. This suggests that plants in inaccessible areas need to be cleared as they would otherwise provide a constant source of seeds that would drive re-invasion of more accessible areas that have been cleared.



Figure 6.5.1. High-altitude teams comprising specially-trained workers are used to remove invasive trees from inaccessible areas.

In order to deal with this problem, the Working for Water programme has trained, equipped and deployed teams of workers to clear cliff faces and other inaccessible areas across the country (so-called "high-altitude teams"). To date there has been no assessment of how effective this approach has been, but high-altitude teams plan and execute tasks independently of other control operations. However, if planned and executed in collaboration with adjacent projects, the approach offers a solution to the problem of dealing with invasive alien plants in inaccessible mountain areas.

Biological control: Biological control of invasive alien plants involves the use of agents introduced from the country of origin (plant-feeding insects and mites, and plant pathogens) after rigorous testing under quarantine conditions to ensure that they do not pose a substantial risk to any agricultural crop or indigenous plant species. Release applications are extensively scrutinised (see Chapter 4).

The biological control of invasive alien plants, using plant-feeding insects and mites, and pathogens, is an attractive management option because: (i) it is relatively cheap and very safe compared with the costs and risks associated with herbicide development and deployment; (ii) biological control can be

successfully integrated with other management practices; (iii) biological control agents can often (though not always) disperse to and control plants in otherwise inaccessible areas; and (iv), most compelling of all, biological control is self-sustaining. Without biological control, invasive alien plant management would be beyond the capabilities and resources of South Africa.

For biological control to be integrated with other control measures it is crucial to understand the impact of the agents. This requires pre- and post-release evaluation of the target plant. This has too often been assigned a low priority, and once an agent was released, researchers were redeployed to work on new agents. Some agents also need to be manually redistributed around the country or repeatedly released for control to be achieved.

Herbicide control: The use of herbicides is an important component of invasive alien plant control. Many species have the ability to sprout after cutting, and the targeted application of herbicides to cut stumps is essential for ensuring that felled trees or cut plants are killed. In addition, the broad application of herbicides is sometimes the only effective way of dealing with regrowth or emerging seedlings that follow clearing operations, although there are concerns over potential environmental toxicity and non-target effects. Under South African law, herbicides must be registered for use against particular plant species, and this can lead to problems where there is no registered herbicide for use against the target weed species, or if changes are made to the registration.

Dealing with conflict species: Some alien plant species can both bring benefits, and cause harm if they become invasive, leading to conflict. The magnitude of benefits and of impacts can be viewed as separate, independent axes, which allows for the classification of species into four broad types (Figure 6.5.2).

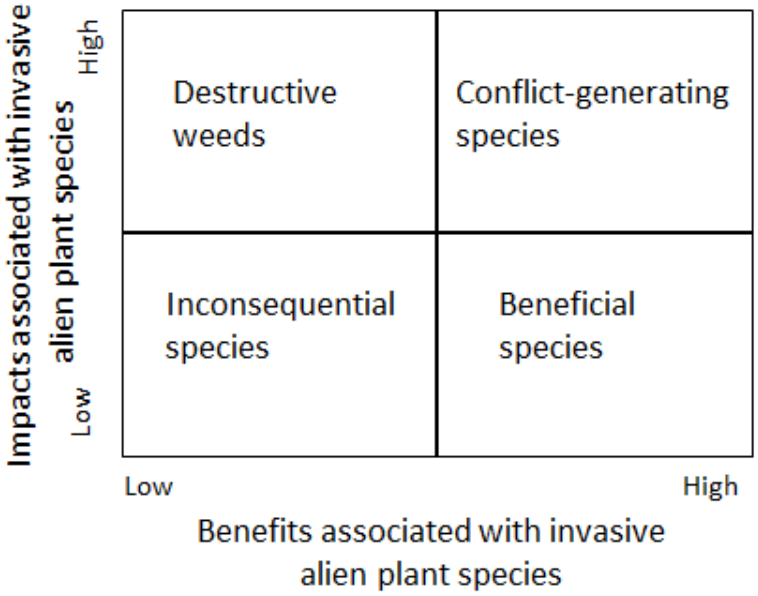


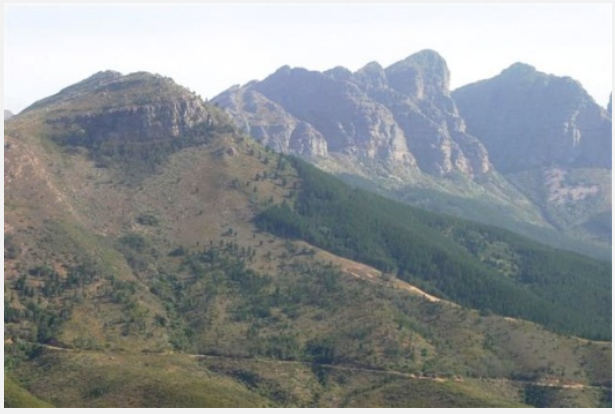
Figure 6.5.2. Types of invasive alien plants based on their relative degree of impact on the environment and the benefits associated with their cultivation and utilization (note that this scheme would apply to organisms other than plants, for example damaging alien freshwater fish that are also important for recreational angling).

Many introduced plant species are not invasive, and are either inconsequential, as they have neither substantial impacts nor benefits, or beneficial in cases where they produce useful products. Those invasive alien plant species that provide very little in the way of benefits can easily be classified as destructive weeds; in such cases there is little disagreement with respect to any attempts to control such species. The final type includes species that are both useful and invasive – it is these species that generate much of the controversy and conflict. Finding sustainable solutions to their management is a considerable and escalating problem (see Box 6.5.2). The number of species falling into this category is increasing rapidly, since the initial benefits of many alien plant species become negated by the impacts when the species become invasive.

In South Africa, allowance has been made for conflict species in both CARA and the draft regulations under NEM:BA. This approach classifies species into three categories (see section 6.2.2 for details). New or rationalised legislation could accommodate similar categories for invasive alien species (Box 3.1).

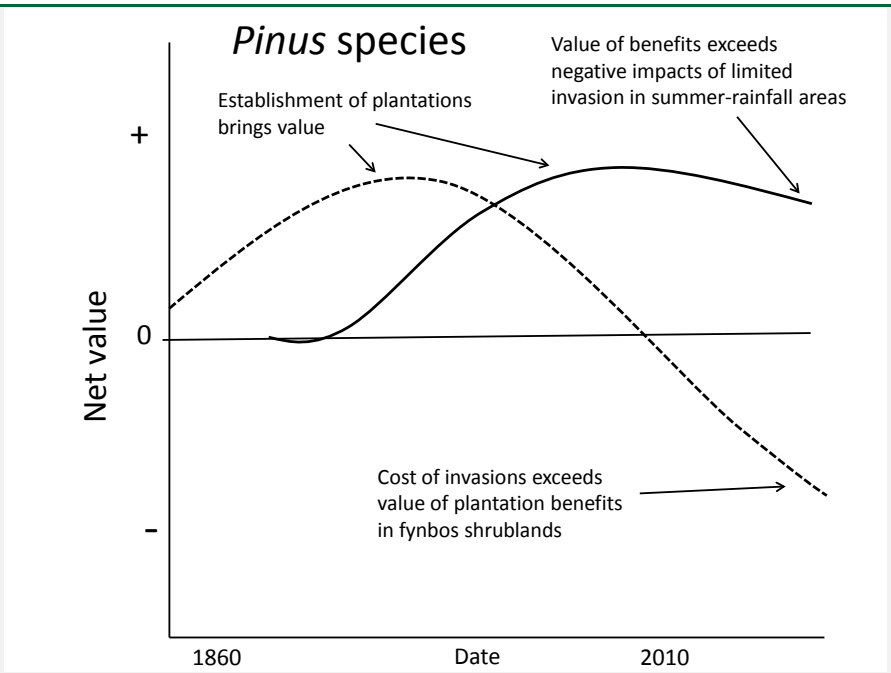
Box 6.5.2. Conflicts over introduced trees – the example of alien pines in fynbos

Pines (trees in the genus *Pinus*) provide a good example of conflict species. Pines are important forestry trees in South Africa, but are highly invasive in the fynbos biome. About 6% of South Africa's forest plantations are within the fynbos, and almost all of this area is planted to pines. Roundwood sales in the fynbos region generated R146 million in 2009, and the forest industry is an important employer in rural areas and supplies several sawmills. The estimated loss of ecosystem services (mainly water) attributable to alien trees outside plantations in the fynbos biome was R495 million annually at current levels of invasion. These impacts will increase as invasive pines spread and become denser, leading to water shortages that would constrain development. The unique biodiversity of the fynbos would suffer severe degradation and loss of endemic species. In addition, recurring damage from the ever-escalating frequency of fires is currently placing additional burdens on the forestry industry. Phasing out of pine-based forestry in the region could possibly deliver the most beneficial outcome, but this would be a controversial option. A more thorough economic assessment of the costs and benefits of these trees is needed to inform policy in this regard.



Box Figure 6.5.2.1. Pines invading fynbos from a nearby plantation

In the case of pines, the initial net benefits arising from the introduction of alien trees can be lost once the associated invasions reach a certain threshold area (Box Figure 6.5.2.2). However, by the time that this situation comes about, there is a heavy dependence on the planted trees as a resource, and consequently there can be considerable resistance to any attempts to contain or remove the trees. There are options that can be explored, and that would allow the benefits to be maintained, such as the introduction of seed-feeding biological control agents, or the use of sterile cultivars.



Box Figure 6.5.2.2. Conceptual illustration showing changing values associated the trajectory for alien *Pinus* species in summer-rainfall areas (solid line) and in winter-rainfall areas (dashed line). The hypothetical historic trajectory of net value (sum of benefits minus sum of impacts) is shown over time.

Sources of information for this Box:

van Wilgen, B.W. and Richardson, D.M. (2012). Three centuries of managing introduced conifers in South Africa: Benefits, impacts, changing perceptions and conflict resolution. Journal of Environmental Management 106, 56 – 68.

van Wilgen, B.W. and Richardson D.M. (2014). Managing invasive alien trees: challenges and trade-offs. Biological Invasions 16, 721–734.

Biomass for energy: Currently there are proposals to make optimal use of the biomass cleared through the Working for Water programme to generate energy, and to create employment opportunities. Some invasive alien plants, notably trees, can provide substantial amounts of biomass. A preliminary feasibility study has indicated that such a project could be financially viable if the clearing costs are borne by the state, but this needs to be verified by means of field trials.

Biomass for furniture and other products: A programme has been initiated to make optimal use of the biomass cleared through the Working for Water programme (see 6.2.7). The use of biomass for energy, furniture and other products is a key way in which this Strategy will ensure that maximum benefits are leveraged (see Chapter 11).



Figure 6.5.3. Examples of furniture manufactured from wood harvested from stands of invasive alien trees that have been cleared as part of the Working for Water programme's control operations.

Conversion of "wattle jungles": Several degraded plantations of invasive alien trees occur across the country, notably in areas that were designated as independent homelands under the apartheid government. Work has been initiated to convert these areas into productive plantations or woodlots, providing utilizable resources for meeting basic community needs. The ultimate goal is to convert these areas to plantations of non-invasive species that are simultaneously resilient under changing climates and fire regimes.

6.5.4. Strategic approaches adopted

From the outset in 1995, the Working for Water programme in South Africa adopted a strategy of linking the need to control invasive alien plants with the employment opportunities offered by labour-intensive clearing methods. By utilizing the substantial amounts of funding available for poverty relief, much larger areas have been cleared than would have otherwise been possible. The combination of labour-intensive control of invasive alien plants, and the creation of employment, with biological control and innovative use of by-products has provided a strong platform on which to build future interventions. The relatively generous funding allocated to the programme has allowed for diversification into additional, necessary interventions that would not have been possible without the economies of scale that are associated with poverty-relief funding. These approaches will be continued, and expanded, in future. It may also be necessary or prudent to shift focus in future to areas that are deemed to be of higher priority, but all commitments that have been made in areas where current projects are active will have to be honoured. Thus, should changes in focus be necessary, a phased approach will be followed.

6.5.5. Work on privately-owned land

Most land in South Africa is in private ownership, and consequently most alien plant invasions are on private land. Working for Water has developed a detailed policy for working on privately-owned land,

which includes the use of incentives and disincentives to assist or regulate land-users with regard to controlling invasive alien plants. The policy allows for substantial assistance to land-users in the form of clearing (an incentive), and requires land-users to maintain the cleared land after initial clearing and follow-up have been completed, failing which they would be liable for the costs of clearing; non-compliance could lead to the state doing the work at the landowner's cost (both of the latter are disincentives). A weak point in the implementation of this policy has been the absence of legislation that would support the policy, but this is set to be addressed with the finalization of the regulations on alien species under NEM:BA. Given the magnitude of the problem on private land, and the lack of capacity to implement the necessary projects, a phased approach to implementation will be required.

6.5.6. Key actions

Key actions and targets are summarised in the table below.

KEY ACTION	TARGET
Prioritize control operations to address invasions in key ecosystems. This will ensure that available funding is effectively utilized where it is most needed, and to avoid dilution to a point where funding becomes ineffective.	Identification of priority areas at a range of scales (national, provincial and local)
Phase in the migration of funding to higher priority projects, taking into account the need to meet commitments in existing projects. Ensure that any new projects are initiated in priority areas.	Phased re-allocation of available funds to priority areas.
Improve capacity to conduct research into biological control solutions, and implement these solutions	See section 8.3.
Implement the policy relating to work on privately-owned land in high-priority areas, using incentives and disincentives, and backed by legislation.	Phased implementation in priority areas.
Ensure that adequate funding and capacity are made available for planning, monitoring and evaluation.	All priority projects to have management plans with clear targets to be achieved within defined timeframes.
	Institute regular (annual) evaluations of progress against targets in plans.
Improve capacity to professionally manage invasive alien plant control projects	See section 8.3.
Conduct transparent, participatory, expert assessments of conflict species, so that policies regarding their future management can be based on the best available information.	Complete an assessment of *Pinus* species in the fynbos biome
	Complete an assessment of *Prosopis* species in arid regions
Conduct assessments on the feasibility, viability and effectiveness of programmes aimed at the utilization of plant material	Complete an assessment of the feasibility, viability and effectiveness of projects aimed at producing energy from plant biomass, and make clear recommendations regarding these projects.

6.5.7. Sources

All sources are listed numerically in Chapter 6.5 of this Strategy. Information in this section was obtained from the following sources: 7, 9, 15, 69, 40, 82, 105, 120, 121, 135, 171, 178, 179, 180, 195.

6.6. Vertebrate animals

6.6.1. Established vertebrate animal invasions in South Africa

Compared to plants, relatively few alien vertebrate species have become invasive in South Africa. The draft regulations under the NEM:BA list 40 mammal, 14 bird, 24 reptile, seven amphibian and 17 freshwater fish species (Table 6.1). Freshwater fish have become the most problematic group of vertebrate alien species, and have received the most attention to date.

Among the mammals, the NEM:BA list includes the feral pig (*Sus scrofa*),the Himalayan tahr (*Hemitragus jemlahicus*), the goat (*Capra hircus*), several species of deer, the house mouse (*Mus musculus*), the brown rat (*Rattus norvegicus*) and the ship rat (*Rattus rattus*). There are also 17 African species that are listed, as a result of concerns about potential hybridization with indigenous species, or ecological impacts. The domestic cat (*Felis catus*) is listed as a candidate for eradication on offshore islands, while the domestic dog (*Canis lupis familiaris*), the horse (*Equus ferus*), and the donkey (*Equus asinus*), all of which have established feral populations, are not currently listed as they are important as pets or have other utility value.

The most important invasive alien bird species include the common myna (*Acridotheres tristis*), the mallard duck (*Anas platyrhynchos*), the Indian house crow (*Corvus splendens*) and the common starling (*Sturnus vulgaris*). The mallard duck hybridises freely with the African black duck (*Anas sparsa*), Cape Shoveler (*Anas smithii*) and yellowbilled duck (*Anas undulata*). The draft NEM:BA list includes all hybrids between indigenous and introduced bird species.

Although 24 reptile species are listed under the draft NEM:BA regulations, only one alien reptile species (the Brahminy blind snake, or flower-pot snake, *Ramphotyphlops braminus*) has unequivocally been shown to have established wild populations in South Africa. However, growing volumes of trade and the increasing popularity of reptiles as pets means that many more reptile species may become established in future, and threaten indigenous reptile fauna through predation, competition, and the transmission of pathogens.

Although no alien amphibians are currently established in South Africa, the likelihood of introduced species establishing will increase in future as trade and commerce increase. However, several indigenous species have greatly expanded their ranges across biomes and climatic barriers in response to landscape change and increased translocation opportunities.

Alien freshwater fish have been introduced to South Africa to establish a source of food, to create new fisheries and to control plants and invertebrates. Additional accidental introductions are linked to escape from aquaculture facilities and the pet trade. It is important to differentiate between the pet trade and other modes of introduction, because South Africa has up to now permitted the import and sale of ~1600 freshwater fish species in the pet trade. These fish are introduced for keeping in aquaria and they are often not suited to the environmental conditions when they escape captivity. As a result, of the 28 alien fishes with introduction records into the wild, only 5 are linked to the pet trade. Currently, there is evidence that at least 18 species of alien freshwater fish have established self-sustaining populations (Table 6.6.1).

The most successful and widespread species are those that were stocked to create opportunities for fisheries. These introductions into natural (rivers) or man-made (dams) water bodies were, until the mid-1980s, facilitated by government-supported stocking programs. This was followed by private stocking, both permitted and illegal, ensuring the continued spread alien fishes, particularly those that are of interest to anglers (e.g., largemouth bass (*Micropterus salmoides*), brown trout (*Salmo trutta*) and common carp (*Cyprinus carpio*). Many introductions resulted in the desired economic outcomes, i.e., the establishment of fisheries for food and recreation. While the magnitude of these contributions has not

been formally assessed at a national level, local-scale assessments indicate that they are considerable. Alien fishes are also essential in aquaculture development, a sector earmarked for growth by the DAFF. Currently-farmed species include species that are also listed in the draft NEM:BA regulations: rainbow trout *Oncorhynchus mykiss*, Nile tilapia *Oreochromis niloticus*, common carp *Cyprinus carpio*, grass carp *Ctenopharyngodon idella*, largemouth bass *Micropterus salmoides*, Atlantic salmon *Salmo salar* and many aquarium species (e.g. goldfish *Carassius auratus* and guppies *Poecilia reticulata*). Escapes from captivity have contributed to the establishment of silver carp *Hypophthalmichthys molitrix*, Nile tilapia *Oreochromis niloticus* and grass carp (*Ctenopharyngodon idella*) in South African rivers.

In addition to species that are alien to South Africa, 27 South African species have been introduced into waters outside of their indigenous range (extra-limital species), causing severe impacts in the recipient environments. Such species include the African Sharptooth catfish (*Clarias gariepinus*), which is spreading rapidly through the Eastern and Western Cape, and where it threatens indigenous fishes and has had negative impacts on recreational angling. Another species is the Orange River mudfish (*Labeo capensis*), a species that was introduced into the Eastern Cape through the Orange-Fish River inter basin water transfer scheme. In the Eastern Cape this species hybridises with, and threatens the genetic integrity of, indigenous moggel (*Labeo umbratus*).None of these species have been listed in the draft regulations under NEM:BA, rather, the approach has been adopted that no fish – indigenous or alien – may be introduced into a river system in which it does not occur naturally.

6.6.2. Impacts of invasive alien animals in South Africa

For most vertebrate groups, there is very little in the way of documented evidence regarding impacts. Studies have been limited to the results of *ad hoc* research projects, driven by researcher's interests rather than national information needs. As a result, information is often limited to isolated case studies that are often not geographically relevant for management advice.

There are anecdotal accounts of the impacts of Himalayan tahrs on Table Mountain, where overgrazing putatively led to soil and rock erosion, as well as evidence of impacts from other parts of the world (New Zealand) where tahrs became invasive.Feral pigs can have a range of impacts, including damage to crops and pastures, competition with (and even predation on) domestic livestock and indigenous wildlife, and causing erosion by rooting and wallowing (especially in wetlands).

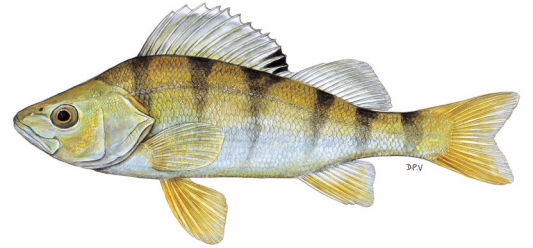
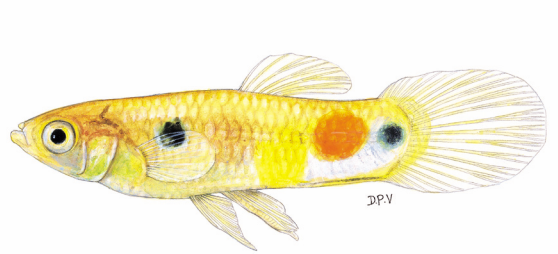
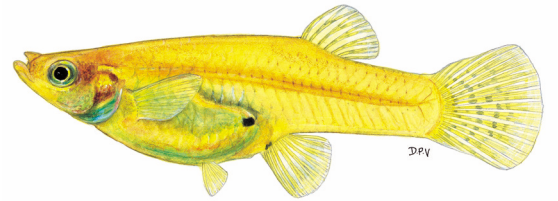
High rates of introduction and translocation of certain parasites and pathogens through the trade in alien vertebrates can increase the risk of disease outbreaks.For example, *rana* viruses, which infect fish, amphibians and reptiles, have likely played a role in global amphibian declines. Similarly, the Asian tapeworm, *Bothriocephalus acheilognathi*, and fish louse, *Argulus japonicas*, were both introduced to South Africa via the common carp, and have had serious pathological effects on indigenous fishes.

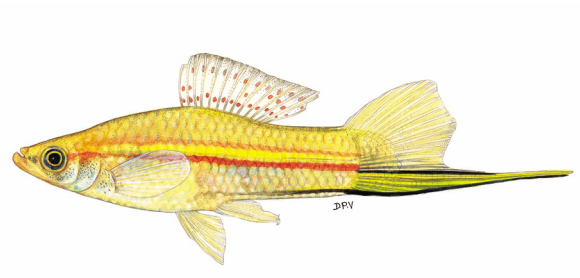
Table 6.6.1. Alien fish species that have established self-sustaining populations in South Africa. Images are copyright of the South African Institute for Aquatic Biodiversity.

Species		Origin	Reason for introduction	Status
Bluegill sunfish (*Lepomis macrochirus*)		North America	Fisheries	Established, widespread
Florida bass (*Micropterus floridanus*)		North America	Fisheries	Established
Largemouth bass (*Micropterus salmoides*)		North America	Fisheries	Established, widespread

Species		Origin	Reason for introduction	Status
Smallmouth bass (*Micropterus dolomieu*)		North America	Fisheries	Established, widespread
Spotted bass (*Micropterus punctulatus*)		North America	Fisheries	Established, widespread
Nile tilapia (*Oreochromis niloticus*)		Africa	Aquaculture	Established, spreading

Species		Origin	Reason for introduction	Status
Common carp (*Cyprinus carpio*)		Asia	Fisheries	Established, widespread
Goldfish (*Carassius auratus*)		Asia	Pet trade	Established, localised
Grass carp (*Ctenopharyngodon idella*)		Asia	Control of aquatic weeds	Established
Silver carp (*Hypophthalmichthys molitrix*)		Asia	Aquaculture	Established

Species		Origin	Reason for introduction	Status
Tench (*Tinca tinca*)		Europe	Fisheries	Established, localised
Perch (*Perca fluviatilis*)		Europe	Fisheries	Established, localised
Guppy (*Poecilia reticulata*)		Central America	Pet trade	Established, localised
Mosquitofish (*Gambusia affinis*)		Central America	Control of mosquito larvae	Established, widespread

Species		Origin	Reason for introduction	Status
Swordtail (*Xiphophorus hellerii*)		Central America	Pet trade	Established, localised
Brown trout (*Salmo trutta*)		Europe	Fisheries	Established, widespread
Rainbow trout (*Oncorhynchus mykiss*)		North America	Fisheries	Established, widespread
Vermiculated Sailfin (*Pterygoplichthys disjunctivus*)		South America	Pet trade	Established, localised

Invading alien fish impact on the ecology of freshwater ecosystems through competition, predation, habitat interference, and disease and hybridization at genetic, individual, population, community and ecosystem levels. Impacts are most severe where indigenous fishes or amphibians have not evolved together with indigenous predatory fishes. In streams in the Cape Floral Region, for example, alien fishes have caused range contractions and fragmentation of populations of endemic fishes, many of which now only occur in non-invaded stream reaches, often above natural barriers such as waterfalls which inhibit alien fish dispersal. In KwaZulu-Natal, tadpoles of the Natal cascade frog (*Hadromophryne natalensis*) **are** up to 15 times lower in stream reaches that had been invaded by brown trout and rainbow trout than in non-invaded reaches. Changes in invertebrate community structure have been documented following bass (*Micropterus* species) and trout introductions at several localities. In South Africa, studies on the impact of introduced Nile tilapia in the Limpopo River system indicate extensive hybridisation with indigenous Mozambique tilapia (*Oreochromismossambicus*). Hybridisation is recognised as a primary threat to Mozambique tilapia, and they are consequently IUCN red-listed as 'Near Threatened'.

Alien fish can also impact on water quality. Common carp, for example, are aggressive invaders that are widely considered as a pest species, and have been linked to habitat alterations, brought about by increased turbidity due to their bottom-grubbing feeding behaviour. This increased turbidity impacts on indigenous ecosystems by increasing nutrient loading, smothering fish eggs and decreasing the efficiency of sight-feeding predators, as well as increasing the cost of water purification for human consumption.

6.6.3. Current management of established vertebrate animal invasions in South Africa

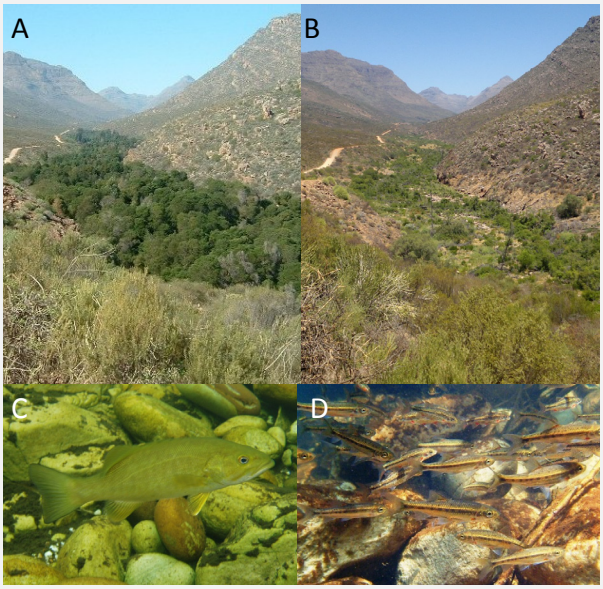
Almost all management of established populations of vertebrate invasive alien species has focussed on freshwater fish (e.g. Box 6.6.1) (see Chapter 5 for a discussion on eradication attempts for vertebrates). One of the few exceptions is the implementation of a feral pig management project in the Western Cape Province. An integrated approach is used, and employs a variety of methods including educating landowners and creating awareness, detection using cameras, trap cages and hunting. The intention is to use lessons learned from two pilot sites (Porseleinberg and Kasteelberg) in the implementation of further control projects in other affected areas.

Box 6.6.1. Successful chemical removal of smallmouth bass from the Rondegat River

In February 2012, the Rondegat River (a small perennial tributary of the Olifants River in the north-western Cape Floristic Region), was rehabilitated by removing alien fish using the piscicide Rotenone. The Rondegat is recognised as one of South Africa's Freshwater Ecosystem Priority Areas and contains a conservation-worthy assemblage of threatened fish species and regionally endemic freshwater fishes. The lower reaches of the river between a weir and a waterfall barrier had been invaded by the alien North American smallmouth bass, *Micropterus dolomieu*, a voracious predatory fish that had extirpated two species of redfin minnows and Clanwilliam rock catfish. The rotenone treatment was preceded by an environmental impact assessment (EIA), which showed that the rehabilitation project was justified, and that the choice of Rotenone was appropriate.

Following the EIA, several organisations collaborated to initiate the Rondegat pilot project. Funding was allocated from the Department of Environmental Affair's Working for Water Programme to simultaneously fund alien plant control and fish eradication, and the Citrusdal Irrigation Board was appointed to manage the plant control operation. The provincial conservation authority (CapeNature) took responsibility for the fish eradication. The South African Institute for Aquatic Biodiversity carried out pre- and post-treatment monitoring of aquatic fauna with funding from the Water Research Commission. CapeNature also focused on raising awareness by organising meetings with riparian landowners and water users, and by providing regular progress reports to stakeholders.

The project employed international best practice in piscicide treatments, and was further guided by on-site advice from experts from the USA and Norway. The target area was first treated on 28 February 2012 by dispensing rotenone at seven treatment stations. At the end of the treatment area, immediately downstream of the weir, rotenone was de-activated using potassium permanganate. During the 2012 rotenone operation, 470 smallmouth bass and 139 Clanwilliam yellowfish were collected. According to standard operating procedure, a second treatment was conducted on 13 March 2013, and no further bass were collected, indicating that the prime objective had been met. During the 2013 treatment, ~3000 young-of-year (<10 cm) indigenous fishes were collected from the treatment area, including Clanwilliam yellowfish, fiery and Clanwilliam redfins, and Clanwilliam rock catlets. These fish were absent from the treatment area prior to bass removal, and their presence 1 year later suggests that a large number of indigenous fishes were previously consumed by bass, and also that indigenous fishes are likely to rapidly re-colonise areas where bass are eradicated. Preliminary results of monitoring the aquatic invertebrate community response to the rotenone treatment indicated that invertebrate biomass and diversity are also recovering rapidly after treatment.



Box Figure 6.6.1.1. A: View of the Rondegat River in 2004, showing heavy invasion by black wattle (*Acacia mearnsii*). B: The same site early in 2013, following clearing and removal of invasive wattles, and the initiation of recovery of the indigenous riparian vegetation. C: Smallmouth bass, indigenous to North America, were the dominant fish in the lower river reaches prior to restoration, having eliminated all smaller indigenous fish. D: A mixed school of the endangered Fiery Redfin and the vulnerable Clanwilliam Redfin, which have started re-colonizing the lower reaches of the Rondegat River following the local eradication of smallmouth bass.

Sources of information for this Box:

Impson N.D., van Wilgen B.W., Weyl O.L.F. (2013). Coordinated approaches to rehabilitating a river ecosystem invaded by alien plants and fish. South African Journal of Science 109(11/12), Art. #a0041, 4 pages. http://dx.doi. org/10.1590/sajs.2013/a0041

Jordaan M.S., Weyl O.L.F. (2013) Determining the minimum effective dose of rotenone for eradication of alien smallmouth bass Micropterus dolomieu from a South African river . African Journal of Aquatic Science 38, 91 – 95.

Marr S.M., Impson N.D., Tweddle D. (2012) An assessment of a proposal to eradicate non-native fish from priority rivers in the Cape Floristic Region, South Africa. African Journal of Aquatic Science 37, 131–142.

Weyl O.L.F., Finlayson B., Impson N.D., Woodford D.J., Steinkjer J. in press. Threatened Endemic Fishes in South Africa's Cape Floristic Region: A New Beginning for the Rondegat River. Fisheries

6.6.4. Features of proposed management

Future management programmes for established populations of invasive alien vertebrate species should be based on best-practice guidelines from elsewhere, in conjunction with the legal principles outlined in Chapter 3. The sections below consequently relate to alien and extra-limital freshwater fish species.

Many alien fishes in South Africa are potential conflict species (see Figure 6.5.1), where they threaten biodiversity but also have economic value. There are no peer-reviewed studies that describe these economic benefits undertaken at national level, although data from case studies support international evidence that recreational fisheries based on alien fishes such as bass, carp and trout do make a considerable contribution to the national economy. This justifies the policy of actively managing some alien fishes both to limit further impact, and to maximise social and economic benefits from the resource in areas that are already invaded. This would require a national management plan to guide eradication in areas of biodiversity concern (e.g., sanctuary areas for critically endangered fish), but also to permit persistence and use in others. It is clear that in some areas the major impact (local biodiversity loss) has already occurred, and that it would not be economically desirable to remove the alien fish. In these areas, populations should be managed for maximum economic benefits e.g. through sport fishing. In other areas, however, river rehabilitation through removal of alien fish is a desirable conservation action, for example to improve local ecosystem function or to expand the range of threatened species in the catchment (see Box 6.6.1).

Import and movement controls: Because invasive alien fishes are difficult to eradicate once established, the most important management actions are import and movement controls. In future, all applications to import fish species will be subject to risk assessments. There is, however, increasing evidence of misidentifications and mislabelling in this sector. For this reason, the DEA has actively supported DNA bar-coding initiatives, including for indigenous species that may become invasive extra-limitally, or elsewhere in the world.

Manual removal: The manual removal of alien fish from small streams is being tested as an alternative to the use of chemical methods. Manual removal of spotted bass *Micropterus punctulatus* was attempted in the Thee River in the Western Cape. This project was the first rehabilitation project in South Africa to attempt mechanical eradication methods that included electro-fishing, gill netting and snorkelling with hand held nets. The manual eradication efforts (which also involved the construction of temporary gabion barriers) resulted in 350 spotted bass being removed during 2011. Although repeated surveys since March 2012 failed to locate any bass in the Thee River, surveys in 2014 located spotted bass above the removal zone. The long term efficacy of manual removal is therefore questionable, and needs to be evaluated.

Piscicide control: Direct intervention through the use of piscicides is the most appropriate control method because complete eradication of non-indigenous fish from a particular area is usually required to restore a indigenous ecosystem to its original healthy balance (see Box 6.6.1); typically, if not all fish are removed from an isolated area, they are able to reproduce and the problem continues. The use of piscicides, or draining (e.g., removal of all water from the habitat) have the highest success rate in eliminating populations of fishes from isolated areas.

Mapping tools: During the development of the draft NEM:BA regulations, maps were developed in which areas were demarcated to indicate where various alien species would be allowed or prohibited. The maps were based on consultation with various experts and interest groups (aquaculture and angling organisations). This resulted in a series of maps that delineated desirable distributions that accommodated trade-offs between biodiversity, existing protected areas, and the needs of anglers and aquaculturists. These maps are excellent conservation support tools, and can be used to guide management decisions regarding the use of alien fish species.

6.6.5. Key actions

KEY ACTION	TARGET
Undertake and co-ordinate national surveys to assess the current distribution of alien fishes in South African rivers and identify areas that are at high risk of invasion or where eradication of alien species is an urgent requirement.	Invasion state of priority rivers listed in the National Freshwater Ecosystems Priority Areas is available based on quantitative methods.
Develop a list of rivers that should be prioritized for intervention.	List of national river reaches for alien fish control or management is available.
Formalise and update list of alien or extra-limital vertebrate species permitted in the pet trade	Permitted ornamental vertebrate species list is updated.
Develop decision-support tools to guide decisions about stocking permits at implementation level.	Decision support tool is used to guide alien fish permits in two provinces.
Eradicate predatory alien fish from priority river stretches	Demonstrated eradication from suitable river stretches.
Develop management plans for conflict species that differentiate between areas earmarked for conservation, and for economic benefits, and that address pathways of escape/release and assumed economic benefits of trade.	Management plans are available for rainbow trout, brown trout, common carp, largemouth bass, smallmouth bass, Florida bass and Nile tilapia (and any other non-fish vertebrate species that may be identified.
Developing appropriate monitoring protocols for aquatic invasive alien species in South Africa.	Alien fish monitoring protocols are developed and used in national alien fish surveys.
Develop a procedure for national co-ordination and assessment of vertebrate control programmes	• List of priority control programmes determined and funded • Protocol and procedure for evaluating control operations at a national level

6.6.6. Sources

All sources are listed numerically in Chapter 6.6 of this Strategy. Information in this section was obtained from the following sources: 5, 30, 78, 104, 108, 131, 167.

6.7. Invertebrate animals

6.7.1. Invertebrate animals as invasive species in terrestrial and freshwater ecosystems

Invertebrates are a very large and important group of animals (see Table 6.7.1 for the main groups). However, a general lack of understanding of the taxonomy complicates their recognition, management and regulation. When a new pest species is detected, it is usually not known whether it is indigenous or alien. It is therefore not possible to estimate accurately the number of naturalised and invasive alien invertebrate species in terrestrial and freshwater ecosystems in South Africa. Nonetheless, it is known that thousands of alien invertebrate species have been introduced into South Africa, along with alien crop plants, or accidentally. As an example, about one third of over 600 species of insects have been recorded as serious pests on cultivated plants, or in natural pastures, are known to be alien species in South Africa. Thousands of other species have naturalised in South Africa, but have not yet been noted as serious pests. This suggests that a serious invasion debt exists with respect to invertebrate species (Box 1.3).

The draft regulations under the NEM:BA currently list 23 alien terrestrial invertebrate species. These include 15 species of insect, six nematode species, and two mite species**.**

6.7.2. Impacts of invasive alien invertebrates in South Africa

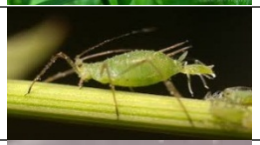
Many invertebrate species can and do have positive effects, and are in fact essential for the normal functioning of natural ecosystems (for example bees for honey production and as pollinators, insects as decomposers and as biological control agents). However, many introduced species are major pests, causing substantial damage in terms of agriculture, forestry, animal husbandry, human health, ecosystem functioning and biodiversity. The cost of controlling invertebrate pests, in order to prevent impacts, runs into billions of rands annually. The impacts of alien invertebrate species on commercial crops, livestock, foodstuffs, wood, paper and textiles are generally well-studied, given the economic imperative to protect these products. However, the impacts of alien invertebrates on natural ecosystems have been poorly studied, so that ecological impacts are not well understood at all. A few examples are provided to illustrate some of the problems caused:

Agricultural impacts

Alien insects that have become established in South Africa are some of our worst agricultural pests. Examples include the codling moth (*Cydia pomonella*, established since 1885), which can infest 50-80% of apple and pear crops if not controlled; and the Mediterranean fruit fly (*Ceratitis capitata*) which can cause similar damage to peaches. Potentially the worst insect pest of grapevines is the grapevine phylloxera (*Viteus vitifoliae*) which arrived in South Africa in 1886 and caused near total destruction of all grapevines until a remedy (the use of resistant rootstocks) was found. Presently the most troublesome insect pest in vineyards is the alien grapevine mealybug (*Planococcus ficus*). The potato leaf miner (*Liriomyza huidrobensis*) caused extensive damage to potato crops in the Western Cape after it was detected here in 1999. The sap-sucking Russian wheat aphid (*Diuraphis noxia*), which arrived in South Africa in 1978, is a serious pest of wheat.

Some alien insect pests that have established in South Africa currently impede the export of agricultural products to countries where these insects do not occur. An example is the Mediterranean fruit fly (*Ceratitis capitata*) which does not occur in the USA. In pine plantations, the Eurasian wood wasp (*Sirex noctilio*) causes extensive damage, while in eucalypt plantations two alien, sap-sucking psyllid species (*Ctenarytaina euclypti* and *Blasopsylla occidentalis*) cause leaf drop.

Table 6.7.1. Groups of invertebrate animals that occupy terrestrial and freshwater environments, with examples of the most important impacts with which they are associated. Many alien species from each of these groups are known to occur in South Africa. Note that many invasive alien invertebrates will have substantial impacts on the functioning of natural ecosystems, but these have been poorly studied, and definitive statements on their environmental impacts cannot yet be made, although they are expected to be substantial.

Group	Description		Impacts
Insects - Lepidoptera	Caterpillars and moths		Major pests of agriculture, with many alien examples. Substantial damage to living plant crops, stored agricultural products, foodstuffs and textiles.
Insects – Hemiptera - Homoptera	Aphids, scale insects, leafhoppers and cicadas		Major damage to cultivated crops, and ornamental plants in gardens. Vectors of many plant diseases.
Insects – Hemiptera-Heteroptera	So-called 'true bugs'. Stink bugs, shield bugs.		Damage to plants and seeds. Include predators of other invertebrates. Bedbugs impact on humans.
Insects - Coleoptera	Beetles and weevils		Major pests of plant crops and tree plantations, wood, and stored foods. Predators of other insects.
Insects - Diptera	Flies, mosquitoes, gnats and midges		Major vectors of human disease. Damage to cultivated plants.
Insects - Orthoptera	Grasshoppers, locusts and crickets		Damage to plant crops, and ornamental plants in gardens.

Group	Description		Impacts
Insects - Isoptera	Termites		Damage to wood, also paper and textiles.
Insects - Thysanoptera	Thrips		Pests of commercial crops and damage flowers and vegetables.
Insects - Collembola	Springtails		There is only a single known species that is a significant pest of commercial crops.
Insects - Hymenoptera	Ants, bees and wasps		Several important household pests, often venomous, and pests in agriculture. Alien species can disrupt ecosystem processes.
Arachnids	Spiders, mites, scorpions and ticks		Ticks are major pests of livestock and wildlife, and vectors of livestock diseases. Some spiders are venomous. Mites are major pests in agriculture and horticulture, and, one mite species is ectoparasitic in bee colonies.
Molluscs	Slugs and snails		Pests in crop agriculture, and on ornamental plants in gardens. Intermediate hosts of human diseases. Serious damage to natural ecosystems.

Group	Description		Impacts
Annelids	Earthworms and leeches		Major drivers of soil dynamics, but impacts are unknown.
Nematodes	Roundworms		Soil-dwelling and many, possibly thousands of species, are detrimental in crop agriculture, and on ornamental plants. Parasitic in plants and humans. Major and ubiquitous drivers of nearly all ecosystems.
Crustaceans	Freshwater crayfish, crabs, woodlice and pill bugs		Alien freshwater crayfish can be extremely damaging to aquatic ecosystems. Vectors of parasites.
Platyhelminthes	Flatworms		Parasites on crustaceans in freshwater ecosystems.
Diplopods	Millipedes		Minor garden pests. Problematic in greenhouses.
Chilopods	Centipedes		Minor pests (known to bite humans)

The Asian Harlequin ladybird beetle (*Harmonia axyrides*) is considered very harmful as it is a voracious feeder on a range of insects in natural and transformed ecosystems, including other ladybird beetles which they can outcompete. It was first noticed in South Africa during 2001 in the south-western Cape and has spread rapidly to other regions. It may affect the taste of wine when present in harvested grapes.

In addition the alien insects affecting agricultural crop production, there are also a number of alien species that cause damage to stored products such as grain, flour and dried fruit. Examples are the lesser grain borer (*Rhysopertha dominica*), the granary weevil (*Sitophylus granaries*), the Indian meal moth (*Plodia interpunctella*) and the Mediterranean flour moth (*Ephestia kuehniella*). The larger grain borer (*Prostephanus truncates*), which was introduced in 1999, is particularly damaging, and seen as a threat to food security in rural areas.

Alien mites are important pests on agricultural crops in South Africa. The European red mite (*Panonychus ulmi*) and the two-spotted mite (*Tetranychus urticae*) are serious pests of apples in South Africa. The latter can also cause damage to vegetables and ornamentals. Seven alien mite species require control measures on citrus in South Africa. They are the citrus bud mite (*Aceria sheldoni*) the citrus rust mite (*Phyllocoptruta oleivora*), the citrus red mite (*Panonychus citri*), the citrus flat mite (*Brevipalpus californicus*) the reddish–black flat mite (*B. phoenicis*), the ornamental flat mite (*B. obovatus*) and the citrus silver mite (*Polyphagotarasonemus latus*). The alien brown clover mite (*Bryobia praetiosa*) and the black sand mite (*Halotydeus destructor*) are pests of cereals and pastures, while a recently recorded (2013) tarsonemid mite from England, (*Tarsonemus mycelophagus*) is causing serious damage to cultivated mushrooms in KwaZulu-Natal.

An important mite pest of a different nature is the Asian varroa mite (*Varroa destructor*) that has rapidly spread to all parts of the country since 1997. It is an ectoparasite of the honey bee (*Apis mellifera*), sucking out the body fluids of the young and adult bees and causing premature death. As a result bee colonies decline and, if not treated, may be totally destroyed within two years. The varroa mite is also associated with the transmission of the deadly deformed wing virus and together they are important causative agents in the universal Colony Collapse Disorder of honey bees. The decline in honey bee numbers is a great cause for concern because of their important role in the pollination of many crop (e.g. apples, pears, and sunflowers) and native plants.

Amongst the ticks, the Asiatic (or Southern) cattle tick (*Rhipicephalus microplus*) has a widespread distribution in South Africa. It was introduced to South Africa with cattle brought in to replenish stocks after the rinderpest epidemic of 1896. It affects cattle through sucking of blood and the transmission of the organisms *Babesia bigemina* and *B. bovis* that cause the disease known as redwater, and the bacterium *Anaplasma marginale* that causes Anaplasmosis.

Both the European brown garden snail (*Cornu aspersum*) and the white garden snail (*Theba pisana*) can cause severe damage to plants in home gardens and agricultural crops such as grape vines and cereals if not controlled. The dune snail rests on the plants during the day and can clog harvesting equipment. It can also transmit plant pathogens and animal parasite. The small conical snail (*Cochlicella barbara*)from the Mediterranean is also pest in home gardens and cereal crops when abundant.

A number of alien plant-parasitic nematodes are significant but underestimated agricultural pests. The Bolivian golden potato cyst nematode (*Globodera rostochiensis*) has spread to most potato-producing areas in South Africa, where seriously damages potato crops if not controlled; it also occurs on tomatoes. The Californian dagger nematode (*Xiphinema index*) not only feeds on the root tips of grapevines, but is also a vector of the destructive Grapevine fanleaf virus. The burrowing nematode (*Radopholus similis*) is a pest of many agricultural crops, but is particularly damaging to bananas in South Africa.

Domestic impacts

Numerous South African household pests that cause damage or constitute a nuisance are alien species. They include the German and American cockroaches (*Periplaneta americana* and *Blatella gemanica* respectively), the bed bug (*Cimex lectularius*), the grey silverfish (*Ctenolepisma longicaudata*), the clothes moth (*Tinea pellionella*), the Argentine ant (*Linepithema humile*), and a range of wood-boring beetles, for example the furniture beetle (*Anobium punctatum*), the powder post beetle (*Lyctus brunneus*) and the European house borer (*Hylotrupes bajulus*). A number of insect pests of human and their pets, such as fleas and lice, have a cosmopolitan distribution and have also been introduced to South Africa.

Some of the introduced spiders are venomous, for example, the brown button spider(*Latrodectus geometricusi*) which is common around houses. The venom of the Mediterranean long-fanged six-eyed spider (*Dysdera crocata*), which is found around Cape Town and the Witwatersrand, is particularly toxic and can cause necrotic wounds. Three recently-introduced spiders are a nuisance in houses where they can rapidly increase in numbers: an unidentified species of the family Dictynidae, a daddy-long-legs (*Crossopriza lyoni*) and the badumna spider (*Badumna longiqua*), the latter only in Port Elizabeth and Bloemfontein.

The Portuguese millipede (*Ommattoiulus moreleti*) is common in gardens of the Western Cape where it feeds mostly on detritus, but can cause damage to soft fruits such as strawberries, and is occasionally troublesome when large numbers of them enter homes.

Several alien plant-feeding slug species can cause considerable damage to vegetables, home gardens, as well as canola and pastures if not controlled. Amongst them are the brown field slug (*Deroceras panormitatum*), the grey field slug (*D.* reticulatum) and the black-keeled slug (*Milax gagates*).Two other alien slug species (the striped and three-banded garden slugs, *Lehmannia nyctelia* and *L. valentiana* respectively) are particularly troublesome in greenhouses.

Many alien earthworm species may have a beneficial effect in improving soil conditions. For example, the alien earthworms *Aporrectodea caliginosa* and *A. rosea* can occur in large numbers in cultivated soils where indigenous species could not survive. Others, such as *Eisenia fetida* and *E. andrei*, turn garden waste into compost in home gardens and are used in commercial vermicomposting practices. Earthworm invasions have, however, caused significant ecosystem-level impacts in other countries and it is not clear what risks such species pose to the natural ecosystems in South Africa.

Impacts in natural ecosystems

The extent to which alien invertebrate species have been able to invade natural ecosystems in South Africa is poorly understood, but some examples have been studied. The Argentine ant (*Linepithema humile*) replaces the local ant species responsible for the dispersal of the seeds of about a third of the plant species in fynbos. The overall result is reduced regeneration of fynbos plants after fire. The 'redclaw' freshwater crayfish (*Cherax quadricarinatus*) poses a real threat to freshwater ecosystems, where it has escaped from aquaculture projects and established itself in the wild. Not only can it compete with and replace indigenous crabs and shrimps, but the species was also found to be infested with an alien flatworm parasite *Dioceratocephala boschmani*, which could also infect local crabs.

6.7.3. Current management of established vertebrate animal invasions in South Africa

There is no generic solution to the management of the alien invertebrate species that are important problems in crop agriculture, livestock husbandry, human health or biodiversity conservation. Different agricultural and environmental situations require different approaches and management strategies. To

address these needs, various specialized research institutes, focussed on particular agricultural commodities, have been established in South Africa over the years. These include facilities at Nelspruit for tropical and subtropical fruit, Nietvoorbij, Stellenbosch for fruit and vines, Bethlehem for small grains, Potchefstroom for summer grains, Roodeplaat for vegetables and the Plant Protection Research Institute in Pretoria (which also includes the very active unit working on the biological control of weeds). Some agricultural industries, for example Citrus Research International in Mbombela (Nelspruit) and the South Africa Sugarcane Research Institute in Mount Edgecombe, have their own researchers. Medical and veterinary insects are studied at the Malaria Entomology Research Unit, University of the Witwatersrand and the Veterinary Research Institute at Onderstepoort. The establishment and funding of these institutes has been driven by economic rather than environmental imperatives. Millions of rands are spent annually on research and control of invertebrate pests, and an impressive amount of understanding and expertise has been developed.

When alien invertebrates are detected in South Africa it almost always too late to attempt eradication. This is particularly true for insects, characterized by large progenies, short life cycles and the ability to fly. They therefore can disperse rapidly over a wide area. They usually escape early recognition because of their small size and limited numbers initially. By the time they are detected, usually when they start to cause damage, they are already widely distributed and impossible to eradicate. A wide range of methods are available to manage pest species of invertebrates. The most important are the following:

Chemical pesticides: The use of pesticides is still the most widely used control measure and a large industry is based around the discovery, registration, manufacture, distribution and selling of pesticides. They are mostly very effective, but not target-specific, so that many non-target organisms, including humans, are affected. The registration of many pesticides has therefore been withdrawn when it was shown that they have undesirable toxic or environmental effects. So-called “organic” pesticides (which are less toxic, but often less effective) are gaining momentum. The effectiveness of specific pesticides is limited, as pests usually evolve to become resistant over time. Pesticides should only be used when monitoring results indicate that the pest numbers have exceeded acceptable thresholds.

Biological control: This is the use of parasitoids, and predators to control pest organisms. Classical biological control is where a specific parasitoid or predator is introduced from the country of origin of an introduced pest to bring the latter under control. This has often been done successfully in South Africa. Examples are the introduction of the predatory ladybird *Rodolia cardinalis* in 1892 for the control of the Australian bug *Icerya purchasi*, in South Africa since about 1873, and the wasp parasitoid *Aphytis lepidosaphes* in 1966 for the control of citrus mussel scale *Lepidosaphes beckii.* Some species of parasitoids are host-specific and their introduction is preferredabove the more generalist predators.

Biological control with augmentative releases is practiced where parasitoids or predators are mass-reared (usually commercially) and released to augment the numbers of existing natural enemies. This is practiced in greenhouses for the control of two-spotted spider mite and at feedlots for the control of house flies.

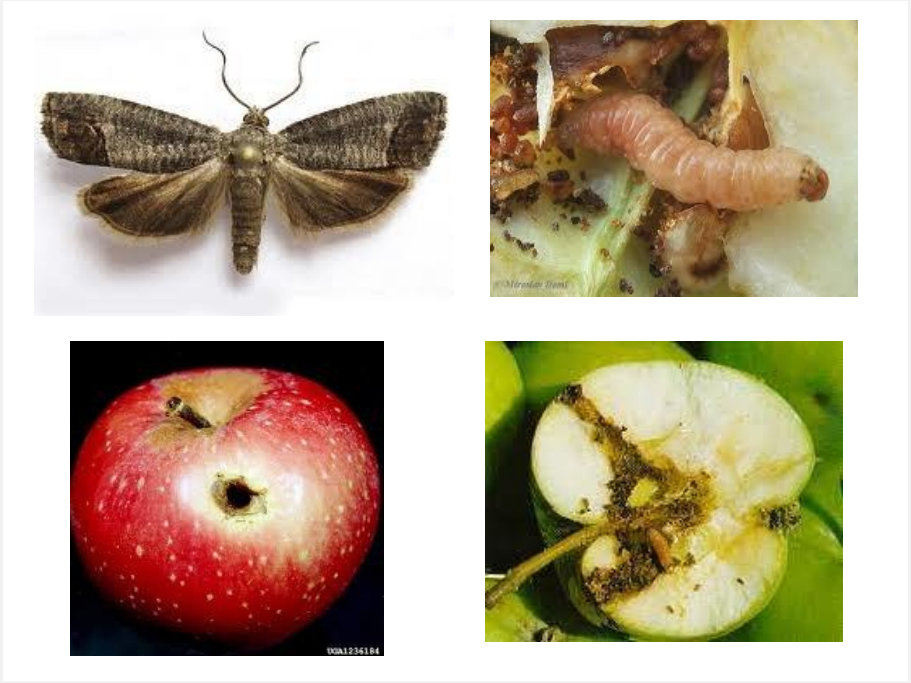
Sterile insect technique: With this technology the pest insects are mass-reared, the males sterilized using irradiation, and released. Usually the pest numbers are first reduced with pesticides so that the sterile males can outnumber and out-compete the fertile males. This method is presently used in the Western Cape Province to suppress Mediterranean fruit fly in fruit orchards.

Mating disruption: With this method, the female pheromone that attracts males is isolated, synthesized and distributed in orchards, with the result that the odour is everywhere and males are unable to locate females for mating. This method is presently used in South African apple orchards to suppress codling moth numbers (see Box 6.7.1).

The last three control methods have the advantage of being target-specific, with few if any negative effects on the environment. Ideally a combination of these methods should be used, together with cultural practices and trapping that suppress numbers (i.e. 'Integrated Pest Management').

Box 6.7.1. Codling moth control in South Africa

The continuous struggle of farmers to control the codling moth(*Cydia pomonella*) provides but one example of the serious consequences of the inadvertent introduction of an alien pest into South Africa. The codling moth is a key pest of apples and pear fruits in South Africa, where it would damage 85% of the crop if not controlled. It probably originated in Eurasia, and was first reported in South Africa from Graaff Reinett around 1885. Over the years the insect has dynamically adapted to overcome most of the control measures used against it.



Box Figure 6.7.1.1. Adult and larva of the coddling moth (above left and right respectively), and typical damage to apples (below).

The first method was to use bands of twisted cloth around the trunks of infested fruit trees to trap the mature larva after they leave the fruit to seek a site for pupation. This was followed by four to six sprays with lead arsenate, but after some 20 years the concentration had to be doubled, and eventually the method had to be abandoned as the insect became resistant and the health authorities in Britain placed restrictions on the amount of arsenious oxide tolerated on imported fruit. Summer oil was then added to normal strength lead arsenate to kill the eggs and the residue on fruit was reduced by replacing the last two lead arsenate sprays with a mixture of oil and nicotine sulphate. Eventually up to 17 applications of lead arsenate, 10 together with summer oil as an ovicide, were used.

Many parasitoids have also been introduced for codling moth control without much success. In the early 1940s the failure of insecticides to control codling moth led to the resuscitation of biological control. Parasitoids were mass-reared to be released after the use of insecticides was discontinued. However, they were susceptible to chemicals used against other pests in the orchard.

The discovery of the synthetic organic compound DDT was significant in reducing the threats posed by these moths. DDT was cheap and effective. Initially three or four sprays were sufficient, but by 1958 they had to be increased to eight or more to be effective as resistance had developed. DDT has subsequently been replaced

by a sequence of organophosphate and carbamate insecticides, of which some are still used, despite a degree of resistance against them.

In response to resistance and the environmental and health problems associated with the use of traditional insecticides, new technologies have been developed to augment or replace insecticides. One of them is the application of a granulosis virus that is ingested by the young larva and kills it after few days. Another is the use of insect growth regulators that interfere with the development of the insect (residues of these persistent chemicals are not allowed on exported fruit, reducing their usefulness). A third and widely used new method is mating disruption, where the environment is permeated with the female sex pheromone. As a result the male cannot locate the female for mating. This method is only effective if moth numbers are low or reduced by insecticides. A fourth method, under evaluation, is the release of large numbers of males sterilized by irradiation. All four methods are target-specific and therefore do not disrupt ecosystems, or pose a health risks to consumers.

Sources of information in this Box:

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Riedl, H., Blomefield, T.L. & Giliomee, J.H. 1998. A century of codling moth control in South Africa 2. Current and future status of codling moth management. Journal of the South African Society for Horticultural Science 8: 32-54.

6.7.4. Key actions

There are well-established, specialised commodity-based research institutes in South Africa today, that deal with established invertebrate pests. These institutes will probably continue to function, and be funded, as they are driven by real economic imperatives. It would therefore be more cost-effective to concentrate efforts on the prevention of new introductions of potentially high-risk invertebrate species, as the control of damaging, established populations of economically-important species are being catered for.

Key actions and targets are summarised in the table below.

KEY ACTION	TARGET
Identify important gaps in taxonomy, understanding of impacts (particularly those on biodiversity), and control methods, and encourage research to fill gaps.	See section 9.4.
Develop a directory of source materials and expertise.	See section 7.4.
DEA should align any efforts that deal with invasive alien invertebrates with initiatives and capacity within DAFF and DoH and their institutions.	Co-ordinated control of invertebrates informed by the Alien and Invasive Species Coordinating Forum (see section 3.5).

6.7.5. Sources

All sources are listed numerically in Chapter 6.7 of this Strategy. Information in this section was obtained from the following sources: 4, 8, 11, 58, 64, 65, 83, 84, 110, 116, 132, 133, 153, 154.

6.8. Microbial organisms

6.8.1. Introduction

For the purpose of this Strategy, 'microbial organisms' are organisms whose mode of dissemination is microscopic (i.e. not visible to the naked eye). These include organisms as diverse as viruses, bacteria, fungi, algae, and many other microbes from lesser known eukaryote kingdoms. Microbes are typically only considered invasive when they cause disease to humans, animals and plants (e.g. agricultural or forestry crops). Rarely considered is the less visible, but possibly catastrophic, impact that invasive microbes might have on natural ecosystem biodiversity and the environment. There are many challenges when dealing with microbes, outlined below.

Microbes are everywhere and on everything, and are entering the country continuously on a daily basis through a wide variety of means: The growth in global trade has led to an increase in the introductions of microbes that are present on commodities such as livestock, pets, nursery stock, plants, produce from forestry and agriculture, and packing material. In addition, the spores of many types of microbes are present in the air, water and soil. Soil microbes can attach with small amounts of soil to vehicles, shoes, and camping gear and can thus be introduced into countries by these means. However, many microbial species have symbiotic relationships with larger organisms (e.g. humans, animals, insects, and plants), and should be expected to be present on such vectors entering the country. This omnipresence of millions of known and unknown microbes should be especially considered when new legislation regarding the movement of biological material is considered to ensure that the implementation and application of such measures are realistic and feasible.

The species diversity of microbes is much greater than previously recognized:Recent studies have shown that the numbers of undiscovered and undescribed microbial species are orders of magnitude greater than the numbers of species known to science (Box 6.8.1). DNA barcoding and other DNA-based techniques can aid in the rapid identification of species (e.g. on imported agricultural crops), but these techniques can only be applied to identify the small percentage of known microbial species. Most species to be detected will be unknown to science.

The identification of microbes requires taxonomic specialists: Historically, microbial species were identified based on morphological features as observed under a microscope. However, in recent years DNA technology has revealed that one such 'morphological species' can consist of many different species that look similar, but that have very different abilities. Thus, many microbial species can only be correctly identified by specialists on the particular groups of organisms. In many groups of microbes, the definition of species is still debated and refined by the taxonomists. The implication of this is that reports of species occurring in countries or specific host organisms, predating the late 1990's, when DNA technology was first applied to the taxonomy of microorganisms, are very often misleading and should be critically considered (Box 6.8.2). Considering the high risk of misidentification by non-experts in the past and present, the compilation of lists of species names of microbes should be used with extreme care, if not avoided altogether.

Microbes can form new symbiotic relationships or infect new host species when introduced into new environments: The majority of microbial human, plant and animal pathogens are more or less host-specific (for example, tree pathogens are often restricted to tree species of the same genus). However, many examples are known where these microbes adapt and infect new host species or genera when introduced into new environments. The absence of a particular host species in a country, therefore, cannot always be regarded as safeguard that a particular microbe will not become invasive in that country.

Microbes evolve much faster than higher organisms and can adapt and change rapidly:There are many examples of rapid microbial evolution. For example, every year multiple new variants of the influenza (flu) virus arise across the globe with the result that new vaccines have to be developed continuously. Another example is bacterial human and animal pathogens that develop resistance to antibiotics. An important result of this is that new pathogens might arise within South Africa that are not known elsewhere. South Africa thus cannot only rely on research results conducted in other parts of the world, but will have to build capacity and train local experts in the various groups of microbes.

The invasive potential of only a few out of the millions of species of microbes is known. The concept of microbial organisms as invasive alien species is a poorly-studied field. The poor understanding of microbial taxonomy adds to the complexity of this issue.

The natural origin of by far the majority of microbes is unknown: To determine the origin of microbial species, and thus whether a specific microbe is 'alien' or 'native' to a specific region, typically requires population genetic studies. Such studies require collections of populations of the organism from various countries, and are thus costly and can take years to complete (Box 6.8.3).

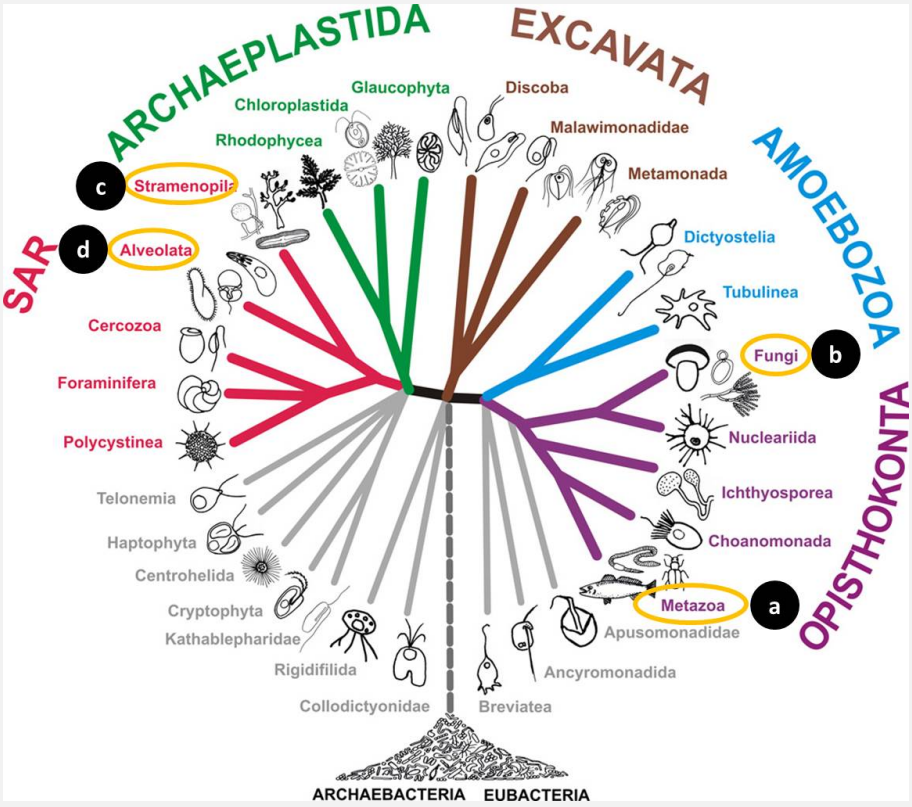
Native (extra-limital) microbes also have invasive potential: Environmental changes resulting from human activity or climate changes can disturb ecosystem processes sufficiently to cause naturally-occurring microbial organisms to become invasive.

Box 6.8.1. The diversity of viruses, bacteria and fungi

Microbial species have an enormous diversity on Earth, and almost all of it is unknown to science. **Viruses** are the most abundant and diverse biological entities on earth. It is estimated that the total numbers of virus particles on earth are more than 2×10^{31} (twenty billion trillion trillion – a very big number). Viruses infect all other life forms, from microbes like bacteria and fungi, to higher organisms like humans.

Almost 16 000 species of **bacteria and archaea** are currently known to science. However, estimates based DNA based studies from the environment suggest that there are somewhere between 1 and 10 million species on earth. For example, a few grams of soil can contain more than 50 000 species of bacteria.

Recent DNA-based studies showed that in natural ecosystems a few grams of soil might contain between 800 to 1000 species of **fungi**. To date only about 100 000 fungal species have been discovered and named. Scientifically-founded estimates suggest that these represent only about 2% of the fungal species on earth. This implies that more than 6 million species of fungi might exist on earth. The invasive potential, as well as the unknown and unseen impacts on natural ecosystems, of millions of these species remains unknown to science.



Box Figure 6.8.1.1. Recent DNA-based studies have revealed just how diverse the microbes are and that many microbes previously treated as fungi or protozoa are unrelated to these two groups, and belong to completely different kingdoms. This diagram based on DNA sequences, illustrates that humans, animals, insects and plants (a) are more closely related to each other, than for example (b) the fungi and (c) Stramenopiles (that include *Phytophthora* species, see Box **Box Figure 6.8.3.1**.). The five *Plasmodium* species that are transmitted by mosquitos and cause malaria are classified in yet another distinct Kingdom, the Alveolata (d).

Sources of information in this Box:

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Box 6.8.2. Plant pathogenic bacteria and fungi reported from South Africa

A recent study considered 86 of the most important **bacterial pathogens** on 126 plant species, mostly agricultural and forestry crops, from South Africa. For many of these species, polymerase chain reaction (PCR)-based detection methods exist, although these have to continuously be refined as whole genome sequence data become available. However, this is a modest number considering the vast numbers of unknown bacterial species (Box 6.8.1).

In an earlier review, more than 3400 species of **'phytopathogenic' fungal species** were listed from about 1500 plant species in South Africa. A more focussed survey of fungi from 29 species of Proteaceae in Western Cape Province, revealed 141 fungal species, 59 of which were new to science. However, the majority of these fungal species were merely isolated from or observed on plants, but their pathogenicity towards plants had never been tested. Therefore, few of these can be considered plant pathogens while the rest are most probably saprotrophes (feeding on dead or decayed organic matter), doing no or very little harm to the plants on which they occur. Furthermore, almost all these species were identified based on morphology, which means their identity remains to be confirmed using DNA-based techniques, as identifications based on morphology only can be very misleading.

Recently a book was published on the diseases occurring on Proteaceae globally. Among the causal agents of various types of disease symptoms, almost 100 fungal species were listed of which the identity of most have been confirmed with DNA sequences. Another 42 species are described from elsewhere and have not yet been found in South Africa.

Sources of information in this Box:

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Box 6.8.3. The origin of invasive microbes in South Africa

The origin of invasive microbes can only be determined with careful, time-consuming studies using DNA-based techniques, and has been confirmed for only a few microbial pathogens in South Africa. Some examples are listed below.



Box Figure 6.8.3.1. Mushrooms of the tree-killing fungus *Armillaria mellea*, on the base of a dead tree in Kirstenboch Botanical Gardens.

Armillaria mellea is a basidiomycete fungus with the ability to infect roots of woody plants and to kill these plants. The fungus was discovered killing oak trees in the Company Gardens in Cape Town in the mid-1990's, and was shown to belong to the same genotype as European specimens of the fungus. The data suggested that the fungus was introduced into Cape Town already by the early Dutch settlers, most probably on potted plants, such as grapes or citrus. In 2010 the same fungus was observed killing native trees and *Protea* species in Kirstenbosch Botanical Gardens, where it formed many fruiting bodies (mushrooms). Although the initial introduction of the fungus into South Africa was probably on infected roots, from where the mycelium of the fungus spread below ground level, the mushrooms produce airborne spores which increase the risk that the fungus might spread into neighbouring natural fynbos ecosystems. (Box Figure 6.8.3.1).



Box Figure 6.8.3.2. A native silver tree (*Leucadendron argenteum*) killed by the invasive alien stramenopile, *Phytophtera cinnamomi*, on Table Mountain.

Phytophthora cinnamomi is an invasive plant pathogen that was previously classified as a fungus, but belongs to the recently-discovered Eukaryote lineage Stramenopiles. The Stramenopiles are only distantly related to fungi, and much closer related to algae and higher plants. *Phytophthora cinnamomi* is an invasive soil- and waterborne pathogen that could infect more than 3000 plant species. In South Africa it is most important as a pathogen of *Eucalyptus*, avocado trees, grapevines and many native members of the *Protea* family. Population genetic studies suggest that this organism is native to Papua New Guinea and has been introduced into South Africa and many other countries worldwide. It is one of a very few plant pathogens for which the centre origin has been confirmed with reasonable certainty based on scientific data. Similar to *A. mellea*, this organism poses a great threat to natural fynbos ecosystems.



Box Figure 6.8.3.3. Carcasses of ostriches culled during the 2004 avian influenza outbreak in South Africa, leading to losses of millions of rands to the ostrich industry.

Influenza A viruses emerging and mutating from wild, migratory birds are a constant threat to South Africa's valuable ostrich industry. In 2004 and again in 2006, low pathogenicity avian influenza H5N2 strains introduced from a wild waterfowl reservoir mutated in ostriches to high pathogenicity avian influenza (HPAI), with serious economic consequences and export bans imposed by the European Union (Figure 2). It is suspected that the viruses were introduced to the waterfowl communities by long-distance migratory bird species that share their habitat.

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6.8.2. Key areas affected by microbial invasions

Microbial invasions can have impacts in a number of ways, discussed briefly below:

Human and animal health: Most human and animal diseases are caused by microbes. Apart of the ultimate risk of death, the impacts of diseases are varied, and they lead to an increase in medical costs, precautionary measures, and losses of income to industry and families.

Plant health: Microbial diseases of plants can significantly lower crop yields in the agricultural and forestry sectors, increase production costs (crop protection and veterinary costs) to unsustainable levels, threaten food security, as well as impact negatively on trade and exports.

Ecosystem health: The ecological impacts of microbial invasions are often less visible and can occur undetected for years. Microbial invasions can threaten natural ecosystem biodiversity (e.g. mycorrhizal fungi in association with the roots of native plants can be replaced by invasive fungi, but the effects might only be visible years later). Native microbial species might go extinct during such invasions. Water resources can also be affected by invasive microbes such as algae. The impacts of these invasions on ecosystems are very difficult to quantify.

6.8.3. Management of microbial invasions

The fact that microbial invasions can affect so many spheres of life is a major challenge for the implementation of accepted principles for the management of invasive species, and thus effective management. Currently, the strategy adopted is to base interventions on the impact areas of microbial invasions, rather than based on the various taxonomic groups of organisms. Typically, microbes affecting human and animal health are treated under 'sanitary' principles, and those affecting plant health are treated under 'phytosanitary' principles. However, in the strictest sense this approach would then exclude those microbes affecting ecosystem health where animals or plants are not affected, but, for example, the biodiversity of other microbes. The result is that different aspects of management are the responsibility of a wide array of government departments and institutions, in collaboration with a disjunct assembly of academic researchers based at universities and other research bodies. Government departments that are directly involved in the management of, or affected by, microbial invasions include Agriculture, Forestry & Fisheries; Environmental Affairs; Health; Science and Technology; Tourism; Trade and Industry; Transport; and Water Affairs.

6.8.4. Key actions

A first step towards an integrated or coordinated management strategy for microbial invasions, a public database of all the role players in the field will be built. This will include their involvement (e.g. legislation, fields of expertise, or research topics and results), and will have active links to their websites. This would include the various government departments and subsidiaries, research councils and their divisions, as well as research groups at universities, focusing on the various groups of microbes.

Secondly, a task team should be formed with representatives of the different key areas affected by microbial invasions, as well as the different groups of microbes, to evaluate the details of current management strategies and the efficiency of communication between all the different role players. Furthermore, areas of research currently being addressed by research groups across the country, should be considered in order to identify areas where capacity is lacking. This task team should then make recommendations to the government as to align and improve current management efforts of microbial invasions.

Key actions and targets are summarised in the table below.

KEY ACTION	TARGET
Build and maintain a public database of all the role players in the field.	See Section 7.4.
Form a task team to evaluate the current management strategies and the efficiency of communication between all the different role-players.	Terms of reference and membership of task team agreed upon.

6.8.5. Sources

All sources are listed numerically in Chapter 6.8 of this Strategy. Information in this section was obtained from the following sources: 6, 21, 74, 129, 147, 149.

6.9. Marine organisms

6.9.1. Marine invasions in South Africa

Biological invasions are a significant threat to marine and coastal ecosystems worldwide, having been documented in the majority (84%) of the world's 232 marine ecoregions. In South Africa, marine alien and invasive species have been continuously introduced at least since the earliest European explorers landed. The rates and mechanisms of such introductions, sites of importation, and types of species introduced, have, however, changed considerably over time. Early wooden vessels carried both external fouling species and wood-boring shipworms and gribbles (that caused considerable damage to both the ships themselves and to wooden structures in harbours). They were also stabilized by dry ballast (sand and rock), which was dumped upon arrival, along with drift-line fauna and flora from the ports of origin.

Dry ballast and wooden vessels are no longer significant, but new vectors have emerged, notably use of ballast water and marine aquaculture, and these have resulted in importation of a new wave of invasive alien species that have different characteristics and that may be introduced to new sites. While fouling has remained a dominant vector throughout history, the nature of the fouling community has changed with the nature of shipping vessels and the routes they follow. In general, modern vessels have become larger, faster, and better protected by anti-fouling paints. This is not universal, however, and towed rigs, for example, move very slowly and may carry entire communities, including schooling fish, with them. The development of new harbours and shipping routes has also resulted in new nodes of infestation and novel introduction pathways. Ship fouling and ballast water are the most important vectors for the introduction of marine species (Figure 6.9.1).

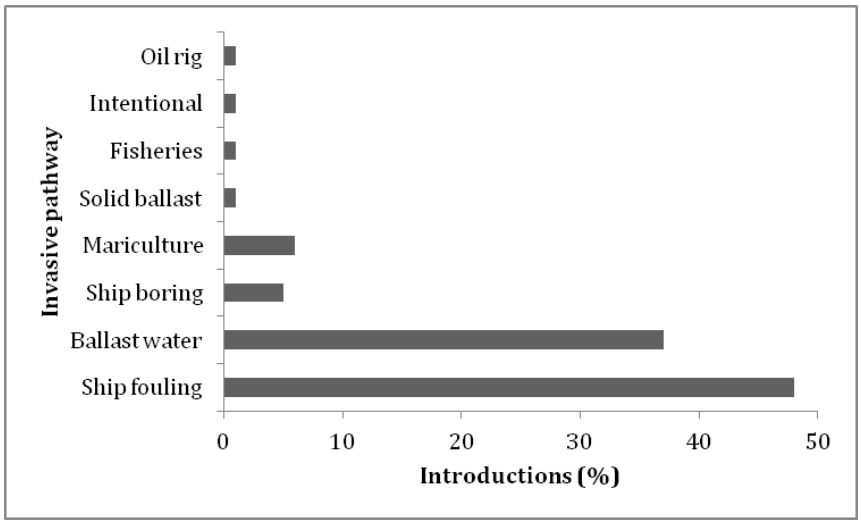


Figure 6.9.1. Summary of suspected pathways of invasion of South African Marine invasive alien species.

Interestingly, almost all alien marine species have been introduced accidentally, whereas in terrestrial and freshwater habitats many have been deliberately introduced, either as crop or ornamental species.

Rates of (detected) introductions are continuing to accelerate over time, based on first record for each species (Figure 6.9.2). This can be attributed to accelerated real rates of invasion, due to increased volume and variety of trade, and the introduction of new vectors (e.g. marine aquaculture), but also to increased rates of detection, due to more research and awareness of the issue.

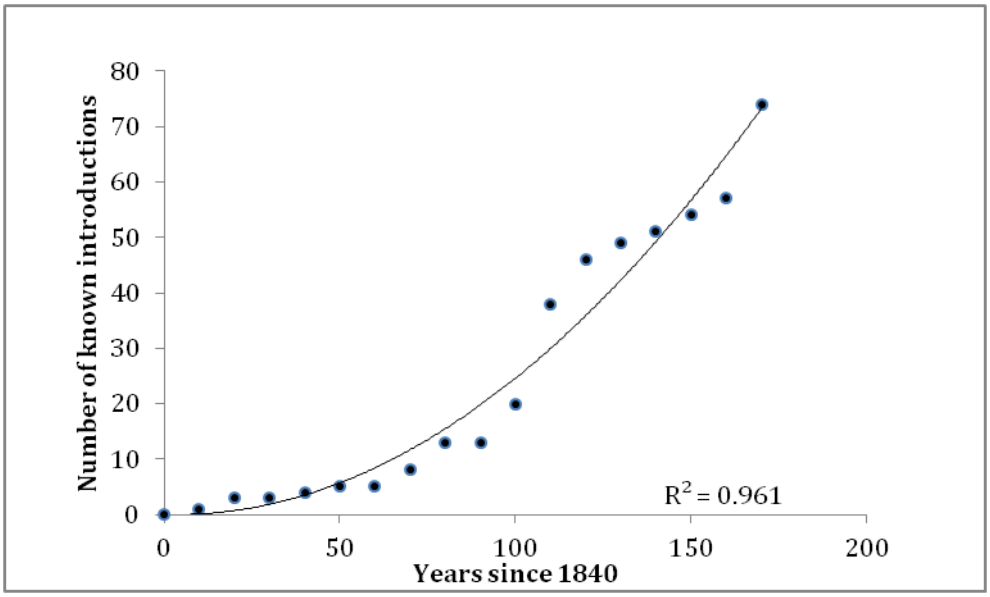


Figure 6.9.2. Cumulative number marine introduced species, indicating the rate of discovery in South Africa, since 1840.

Despite the long history of marine bio-invasions in South Africa, the first paper specifically listing introduced marine species only appeared in 1992 and listed just 15 species. This number has since escalated rapidly to reach 86 confirmed and a further 39 suspected or 'cryptogenic' species in the most recent synthesis. Even this number is certainly a considerable underestimate and several additional introductions continue to be discovered annually. Detection of introduced marine species is complicated by several factors. The status of those species introduced centuries ago is difficult to determine (since they were already present when local research began), while recently-introduced species are inherently hard to identify (since they do not appear in local identification guides). In addition few likely invasion sites in South Africa, including major harbours, have been adequately surveyed for aliens; also many introductions belong to taxa (such as nematodes or benthic copepods) for which there is a lack of adequate taxonomic expertise to make accurate identifications of even native species.

In terms of taxonomic composition, a wide range of marine taxa have been introduced, but the most common groups are fouling organisms such as hydrozoans, tube-dwelling polychaetes, small crustaceans, molluscs, bryozoans and ascidians (Figure 6.9.3). Vertebrates are notable in their absence: only one fish (the common carp *Cyprinus carpio*) is listed and this is really a freshwater species, but is included as its range extends into the upper reaches of estuaries.

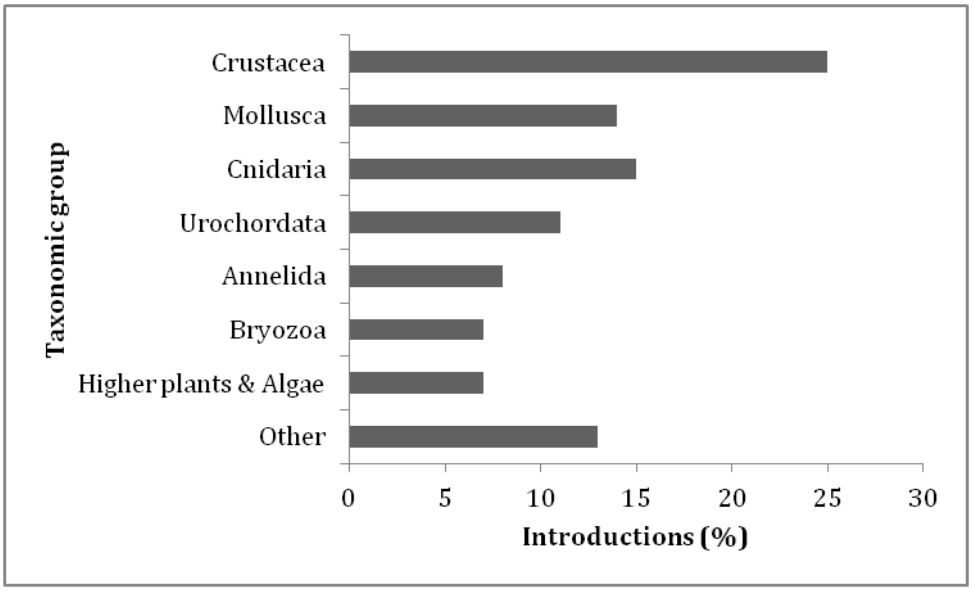


Figure 6.9.3. A taxonomic breakdown of marine invasive alien species recorded in South Africa

6.9.2. Impacts and risks

Globally, marine invasions have negative effects on biodiversity, and also impact significantly on commercial fisheries, mariculture, and other natural resource-based industries, with serious economic implications for those communities dependent thereon. In addition, fouling of physical structures by introduced species has major economic impacts on other industries by, for example, decreasing the speed of vessels and clogging water intake pipes.

The distribution patterns and impacts of marine alien and invasive species in South Africa have received far less attention than those from terrestrial and freshwater systems. However, most marine invasive alien species are relatively inconspicuous and the majority remain restricted to sheltered harbours and estuaries, probably since conditions there most closely resemble their areas of origin. Relatively few marine invasive alien species have invaded the open coastline and hardly any occur in deeper waters, one notable exception being the anemone *Metridium senile*, recently reported as abundant on oil and gas installations on the Agulhas Bank.

As a result, few South African marine introductions are known to have significant ecological or economic impacts, although it must be emphasized that most remain un-studied. The reef-building worm *Ficomomatus enigmaticus* has resulted in massive increases in biomass in a few estuarine systems, where it is a problematic fouling organism on boats, bridges and canal walls. Significant marine introductions include the transparent sea squirt *Ciona intestinalis,* which is an important fouling species that causes economic damage, particularly by smothering farmed mussels. The European shore crab *Carcinus maenas* is a voracious predator, currently confined largely to harbour areas on the Cape Peninsula. Experimental studies indicate that it is incapable of surviving on the open wave-swept coastline, but it will almost inevitably spread to the important aquaculture centre of Saldanha Bay, where it may have significant impact on shellfish stocks. The Pacific barnacle *Balanus glandula* has also become the dominant barnacle along much of the west coast, where it is expected to displace some intertidal species, such as highshore limpets, but it also provides additional habitat for other smaller species.

The most significant introductions to date are the two mussel species. The Mediterranean mussel *Mytilus galloprovincialis* now dominates most exposed rocky shores along the west and much of the south coast. It has numerous ecological impacts, moving the centre of gravity of mussel beds much higher into the intertidal, greatly increasing overall intertidal biomass, providing habitat for many small invertebrates and displacing some larger limpets. It also provides additional food resources for predatory species, such as the African black oystercatcher (*Haematopus moquini*) and is now the preferred prey of oystercatchers feeding their chicks. This mussel forms the basis of a significant mariculture industry. The second mussel invader is the smaller *Semimytilus algosus*. This was first reported on South Africa's west coast only in 2009, but already occupies a geographic range of ca 500 km, between Groenriviersmond in the north and Melkbosstrand in the south. The two invasive mussels display strong spatial segregation within the intertidal, with *M. galloprovincialis* dominating in the midshore and *S. algosus* blanketing the lower shore (Figure 6.9.4). Indeed, as the upper shore in this same region is coated with invasive barnacles *Balanus glandula*, the entire rocky intertidal zone along much of the West coast is now heavily transformed by alien species, while the south coast is moderately transformed and the east coast remains largely unaffected.



Figure 6.9.4. Invasive mussels cover the intertidal at Elands Bay on the West coast. *Mytilus galloprovincialis* (pale) dominated the midshore a *Semimytilus algosus* (black) the lowshore.

6.9.3. Current management efforts

In comparison to terrestrial and freshwater alien and invasive species, the management of marine alien and invasive species in South Africa is in its infancy. In fact, although a number of species were detected some years ago, there are currently no active marine invasive management programmes in place. However, South Africa does have international obligations with respect to marine invasives and they are covered – along with other invasives – by the relevant sections of NEN: BA. In addition, there are some other national laws and regulations – and a Bill currently under consideration – which deal more specifically with the management of marine alien and invasive species and their pathways.

There is also a new management-oriented initiative which will be implemented during 2014 under the joint auspices of the South African National Biodiversity Institute, and the International Ocean Institute of Southern Africa, and which includes the following components:

- Development and implementation of a National Marine Invasive Species Monitoring Strategy for Port and Coastal Areas;
- Development of an Emergency Response Plan for Marine Invasive Species;
- A pilot project on the eradication of the Black Sea Urchin from Aquaculture Facilities;
- A pilot project on the Design and Implementation of a Control Programme for the Green Shore Crab (Box 6.9.1);
- A pilot project on the Development of a Management Plan for the Coral Worm (*Ficopomatus enigmatus*) in the Zandvlei Estuary.

Box 6.9.1. Proposed management plan for the green shore crab



Carcinus maenas, the European green shore crab, is native to the eastern Atlantic Sea, the Baltic Sea and the North Sea. It is a highly successful invader and an aggressive predator with major ecological impacts across much of its invasive range, with some commercial species also affected. However, the impacts within South Africa are yet to be identified but will be the subject of a research project scheduled to begin in 2014.

The European green shore crab was first discovered in South Africa in Cape Town harbour in 1983. Since then,

it has been found at several sites on the west Coast and the Atlantic seaboard. It is currently listed as a species requiring management in the draft regulations under the National Environmental Management: Biodiversity Act.

International attempts at eradication and control of this species have had limited success. The project will therefore start as a pilot in Hout Bay harbour and will assess the current distribution of the species and the efficacy of various control methods including baited and non-baited trapping, as well as physical collection of crabs by divers. This research will inform a local management programme for *C. maenas* in Hout Bay. Depending on its success, the management programme can then be expanded and applied to other invaded areas in the Western Cape.

The future management of marine alien and invasive species is particularly challenging given the difficulties of detecting introductions in marine habitats, of eradicating species that have become established, and of functional control and mitigation programs. Efforts to date have focused on developing preventative measures, but a comprehensive and effective prevention framework remains far from complete. Current initiatives are aiming to harmonize components of the national management regime, while also bolstering capacity for post-incursion response. The attention to feasible and appropriate implementation targets and mechanisms is necessary to ensure the successful roll out of an integrated management framework addressing both intentional and unintentional marine introductions.

Potential control methods in the marine environment include:

- Physical removal - the most acceptable method due to the minimal impacts on native species;
- Biological control; and
- Genetic manipulation.

However, to date there have been no successful examples of biological control or genetic manipulation of marine alien species. This may be an artifact of limited research of these options relative to terrestrial biocontrol. In the absence of technological developments, any attempts at control should be limited to physical removal methods.

6.9.4. Invasions on marine islands

Islands are often highly impacted by biological invasions, given their biogeographical (and hence often evolutionary) isolation, and the often large volume of human traffic and impact. There are two quite distinct categories of islands that are governed by South Africa. First, South Africa governs the small sub-Antarctic archipelago of the Prince Edward Islands, comprising Marion Island (290 km²) and Prince Edward Island (45 km²), approximately 1770 km south east of Port Elizabeth and 2300km north of Antarctica. They are administered by a specific directorate of DEA (Antarctica and Islands), and have been intensively managed with the specific aim of ensuring protection and conservation for many years. The processes that have been developed with respect to biological invasions arguably represent a model for pre- and at-border security (Chapter 4), and post-border management (Chapter 5).

Introduced cats (*Felis cattus*) had a major impact on native birds on Marion Island, notably burrowing petrels and common diving petrels (which are thought to have been exterminated by cats by 1965). Cats were subsequently eradicated through an intensive campaign of biological control using viruses, trapping, and hunting that started in 1977 and resulted in the extermination of all cats by 1991. Several other species have been targeted and eradication remains the primary goal of many management plans for introduced species.

A Prince Edward Islands Environmental Management Plan was developed in 2006. It sets out all aspects of management including reducing the risks posed by biological invasions. Steps are in place to expand the legal protection. The Prince Edward Islands Marine Protected Area has been declared, and an application has been submitted to proclaim the islands as a World Heritage Site. Given the successes to date and the particular challenges faced, biological invasion on the Prince Edward Islands should continue to be administered separately to other parts of South Africa, but opportunities for greater transfer of skills and personnel will be considered.

Quite separate to the Prince Edward Islands, South Africa administers several coastal islands. Islands and their associated sub-tidal habitats are recognized as distinct habitat types because of dominance by island-breeding marine predators and associated unique features, including those related to nutrient input (e.g. from guano) and predation pressure. The recent national biodiversity assessment recognized twenty "minor islands" (≤ 0.025 km2 with dense seal colonies and low numbers of seabirds) and fourteen "major islands" (>0.02 km2 with permanent seabird colonies and possibly also seal colonies). Several of these islands give their name to Marine Protected Areas, but all island-associated habitat types are threatened by biological invasions. All of these islands receive either no, or a poor level, of protection. All environmental plans should contain an explicit consideration of the threat of biological invasions, likely with the assessment specific to each island.

6.9.5. Key actions

KEY ACTION	TARGET
Update lists of prohibited, exempt and listed species.	More comprehensive lists in place.
Prioritise species for urgent management action.	List of species which require urgent action agreed, with action plans in place.
Develop national control plans for priority species listed in the draft regulations under the National Environmental Management: Biodiversity Act.	Control plans in place for priority listed species.
Undertake a review of biological control methods for marine invasive alien species.	Review on biological control methods for marine invasive alien species completed, with recommendations.
Identify potential case studies for marine biological control and run pilot programmes.	Improved research and management capacity with respect to the use of biological control in the marine environment.

6.9.6. Sources

All sources are listed numerically in Chapter 6.9 of this Strategy. Information in this section was obtained from the following sources: 26, 27, 34, 38, 55, 56, 57, 60, 66, 97, 106, 107, 114, 127, 139, 151, 164, 199.

7. INFORMATION MANAGEMENT

7.1. Broad principles for the management of established species

Information is essential for the development of appropriate policies, for the prioritization of management actions, and for monitoring and evaluating management efforts and their outcomes. Such information needs to be accurately collected, subjected to adequate quality control, and safely curated. In addition, systems need to be developed to integrate, summarise and present information from a range of sources so that information can be easily accessed and appropriately used.

Different types of information on biological invasions will be needed for different purposes. Broadly speaking, such information can be divided into information essential for policy development and prioritization; information essential for decision-making; and information that, while not essential, can be used to support decision-making (Table 7.1).

There are many gaps in our knowledge of biological invasions in South Africa, and where information does exist, it is often dispersed and not easily accessible. This chapter examines the current management of information relevant to biological invasions in South Africa, and identifies high-level key actions for the development of information portals to facilitate access to this information.

7.2. Current situation in South Africa

7.2.1. Lists of alien species

Alien species lists are very useful sources of information, and different types of lists are required for different purposes (Table 7.2). There are several lists of alien species in South Africa, but none are comprehensive. Several scientific publications and books provide lists of specific taxa or for specific reasons (e.g. there is a list of cultivated plants based chiefly on herbarium records). The Agricultural Research Council maintains information on biological control releases, which is collated every year and published online, although data on the redistribution of biological control agents is incomplete.

Various species lists have been published in legislation (Table 7.3), both in the draft regulations in terms of NEM:BA, and in the CARA.

7.2.2. Permits

The DAFF currently issues permits for the introduction of alien species. For veterinary permits, templates and copies of permits are stored on a central system or on paper respectively in the Pretoria permit office. Permits that were issued to import commodities are collected and stored at the ports of entry through which the imports took place. The permits are not publicly available. Records of interceptions are not publically accessible, in part due to possible trade consequences. In future, permits will be required in terms of NEM:BA legislation.

Table 7.1. Information needs related to biological invasions in South Africa.

Approach	Goal	Information essential for policy development and prioritization	Information essential for management	Supporting information
Species-based	All goals	• List of native species • List of alien species including status (alien, naturalised, established, invasive)	• Control costs and efficacy • Management plans including goals • Information on monitoring of progress against goals	• Sound understanding of ecology of target species
	Prevention	• Prohibited list • Exempted list • Watch lists	• Import permit applications • Risk assessments • Permits themselves, with conditions and monitoring of compliance • List of species requiring emergency response plans	• List of species invasive elsewhere • List of at-border interceptions
	Eradication	• List of eradication targets	• Detailed distribution maps with populations delimited at a landscape scale • Details of introduction and dispersal pathways • Detection probabilities	• Estimate of threats posed • Detailed knowledge of dispersal pathways • Climatic and physiological limits of target species
	Containment	• List of containment targets	• As for eradication	• As for eradication
	Reduction of impacts	• Knowledge of conflicts of interest (including extent of use or cultivation) • Estimates of impacts (based on range, density and negative effects)	• Distribution maps • History of control effort • Knowledge of biological control options • Knowledge of habitat requirements	• Rates of spread • Climatic and physiological limits of target species
Area-based	All goals	• List of (priority) areas for management	• Detailed maps of habitat types • History and potential for future major disturbances (e.g. fire regimes) • Level of invasion in a given area • Area management plans with clear goals	• Projected impacts of global change

Approach	Goal	Information essential for policy development and prioritization	Information essential for management	Supporting information
	Prevention	• Watch lists for respective area	• Lists of sentinel sites, or areas where likely to be first detected	• Information on potential and high risk ports of entry
	Eradication	• Lists of alien species already present in the area and invasion status	• Accurate distribution maps of aliens present • Sites of high naturalisation	• Maps of main distribution routes
	Containment	• Maps of containment zones	• Landscape context • Rates of discovery in containment zones	• Control history
	Reduce impact	• Level of impacts of biological invasions	• Invasion extent and density • Projections of spread under different control scenarios	• Maps of ecosystem services • Maps of biodiversity
Pathway-based	All goals	• Size and type of different trade pathways	• Maps of physical infrastructure	• Projections of changes in infrastructure and trade (trends)
	Prevention	• Knowledge of vectors that could introduce species to the country	• Lists of vectors including destinations and sizes • Trade routes and origins, as well as lists of species there	• Rates of interception for different pathways to allow profiling
	Eradication	• Knowledge of vectors post-border and at eradication sites	• Information on transport routes within country • Vectors and destinations of pathways within country	• Information on natural dispersal routes
	Containment	• Knowledge of vectors post-border and at containment areas		
	Reduce impact	• List of species banned from export	• Potential vectors for export of known invaders	• Interceptions recorded pre-export or from the recipient countries

Table 7.2. The definition and purpose of types of lists used to support the management of alien species in South Africa.

NEM:BA = National Environmental Management: Biodiversity Act; CARA = Conservation of Agricultural Resources Act.

Name of list	Definition	Link to legislation	Purpose
Alien species	Includes all species that have been moved, on purpose or accidentally, outside of their natural distribution range (including species indigenous to other parts of the country, see extralimital species below). Synonymous with “introduced species”, “non-native species” or “neobiota”.	Required as part of the National Biodiversity Assessment which is mandated under the NEM:BA (Act 10 of 2004)	The basis for reporting on state of biodiversity, and for the formulation of other lists below.
Eradication targets	Species targeted for nation-wide eradication.	Category 1(a) in draft NEM:BA regulations, described as "listed species requiring compulsory control"	Record of intent to assess feasibility of eradication.
Established invasive species	Alien species where nation-wide eradication has been ruled out, and where plans for impact reduction and/or containment should be put in place. These are species against which responsible authorities should be legally mandated to take action. Note that this is a small proportion of all invasive species.	Category 1(b) in draft NEM:BA regulations, described as "listed invasive species controlled as part of an invasive species management programme"; also includes category 2 and category 3 species	Record of legal mandate to take action
Exempted species	Alien species assessed to be of low risk, for which import permits may be granted, subject to conditions. “permitted list”.	Conditions for the exemption of species are listed in the draft NEM:BA regulations	Record of exemption of an obligation to control or contain species
Extralimital species	Species indigenous to one part of South Africa, but which have been moved to areas outside of their natural distribution range.	These can potentially be Category 1a, 1b, 2, or 3 under NEM:BA regulations for a specified part of the country.	Identify species that are native to one part of the country but invasive in another part (so management plans need to explicitly vary over the country).

Name of list	Definition	Link to legislation	Purpose
Prohibited species	Species known to be invasive elsewhere, but not yet found in South Africa, for which import permits should not be granted.	List suggested as part of NEM:BA regulations, lists in Notice 4, in terms of section 67(1)	Basis for the prohibition of import of high-risk species
SUSPECT species	Species Under Surveillance for Potential Eradication or Containment Targeting, i.e. alien species that are not yet listed in regulations but that need to be considered for listing. Such species will either have been screened using an initial risk assessment and this assessment raised sufficient concern to trigger a detailed risk assessment or they have been identified as possibly requiring regulation during a previous consultative exercise.	CARA Table X	To highlight species where there is an identified risk but where more information is sought before a species is subject to regulation.
Watch list	Species known to be invasive elsewhere and that are likely to be introduced and to establish in South Africa. Synonymous with “alert list”.	International Plant Protection Convention	Used to prioritise active surveillance efforts at ports of entry and of particular vectors, and to highlight which species require an emergency post-border response plan.

Table 7.3. Lists of alien species in the National Environmental Management: Biodiversity Act (NEM:BA, published in terms of sections 66(1), 67(1), 70(1)(a) and 71A); and the Conservation of Agricultural Resources Act (CARA). None of these lists is comprehensive. "Content" refers to currently listed species; numbers will change as lists are updated.

Legislation	Name of list	Content	Purpose
NEM:BA	Notice 3: List 1: National list of invasive plant species	Lists 381 plant species with categories and area, as well as special conditions and exceptions	Categories of listed invasive species indicated in Notice 1, in terms of which certain restricted activities are prohibited in terms of section 71A(1); exempted in terms of section 71(3); require a permit in terms of section 71(1)
NEM:BA	Notice 3: List 2: National List of Invasive Mammal Species	Lists 39 mammal species plus all hybrids between native and alien species	
NEM:BA	Notice 3: List 3: National List of Invasive Bird Species	Lists 13 bird species plus all hybrids between native and alien species	
NEM:BA	Notice 3: List 4: National List of Invasive Reptile Species	Lists 23 reptile species plus some hybrids between native and alien species	
NEM:BA	Notice 3: List 5: National List of Invasive Amphibian Species	Lists six amphibian species, plus some hybrids between native and alien species	
NEM:BA	Notice 3: List 6: National List of Invasive Fresh-water Fish Species	Lists 17 fish species	
NEM:BA	Notice 3: List 7: National List of Invasive Marine Fish Species	No species listed at present	
NEM:BA	Notice 3: List 8: National List of Invasive Terrestrial Invertebrate Species	Lists 23 invertebrate species	
NEM:BA	Notice 3: List 9: National List of Invasive Fresh-water Invertebrate Species	Lists eight invertebrate species	
NEM:BA	Notice 3: List 10: National List of Invasive Marine Invertebrate Species National	Lists 13 invertebrate species	
NEM:BA	Notice 3: List 11: List of Invasive Microbial Species	Lists seven microbial species	

Legislation	Name of list	Content	Purpose
NEM:BA	Notice 4: List of prohibited alien species	Lists 239 plants, 18 mammals, 39 birds, 14 reptiles, 10 amphibians, 110 freshwater fish, 4 marine fish, 6 fresh-water invertebrates, 140 terrestrial invertebrates, and 5 microbes	Prohibited alien species in terms of section 67(1)
CARA	Table 3: Declared weeds and invader plants	Lists 77 invader (category 2 and 3) and 120 weed (category 1) plants and their status according to CARA Regulation 15.	Declares how certain species need to be treated, and where they are allowed and prohibited, respectively

7.2.3. Management plans

Plans for the management of invasive alien species in South Africa are of varying quality, but they often lack statements of the goals of management, and there is often no monitoring and evaluation of progress against goals. Plans for the management of invasive alien species should be required under law (section 3.4, principles 17 and 18), but currently this is not the case except for protected areas, where management plans are required in terms of the NEM:PA. Existing plans under NEM:PA cover all aspects of the management of protected areas (not just alien species management). In many cases, the sections of those plans that deal with invasive alien species are not detailed—the norms and standards for the preparation of these plans only mention alien species once in passing. Management plans for invasive species control projects under the Working for Water programme are drawn up annually as part of annual plans of operation, linked to budget cycles, but often lack objective medium-term goals (in terms of target areas to be cleared). The costs of control have been recorded by Working for Water in a spatially-explicit database since 2002. Many of Working for Water's control operations are carried out by contractors. The records include the species treated, the density of the invasions, the number of treatments carried out, and the direct costs paid out to contractors.

Management plans for the extirpation (localised eradication) of alien fishes from some priority freshwater ecosystems have been drawn up (but only four such priority rivers have been recognised). The South African National Biodiversity Institute's Invasive Species Program had developed eradication plans for seven species by 2012, and is now assisting implementing agents to execute these plans.

7.2.4. Distribution

The distribution of alien species in South Africa has been mapped in two ways. The first involves an "atlas" approach, in which records of occurrence are mapped, and recorded on a database. The second approach (which applies to plants only), has been to map distributions and densities at a national scale. Each is described briefly below:

The South African Plant Invaders Atlas (SAPIA): This is the only atlas database that is devoted entirely to mapping the distribution of alien species. SAPIA is an ongoing project, which aims to collate information on the distribution and abundance of invasive and naturalised alien plants in southern Africa. Initially, the

atlas was populated with data collected during roadside surveys, but was later broadened to accept inputs from volunteers, who were supplied with survey sheets to ensure the standardisation of inputs. By 2013, the SAPIA database contained over 75,000 geo-referenced records of alien plant species presence and abundance. Currently, this database is maintained by the Plant Protection Research Institute of the Agricultural Research Council, with funding from the Department of Environmental Affairs.

Other atlas databases: Several other atlas databases have been developed to record the distribution of birds, frogs, freshwater fish, and butterflies. These atlases all differ from SAPIA in that they are primarily aimed at recording the distribution of indigenous, rather than alien, species. However, they are also an important repository for information about the distribution of alien animals for the groups that they cover. The freshwater fish atlas is maintained by the South African Institute for Aquatic Biodiversity, and the bird, butterfly and frog atlases by the Animal Demography Unit based at the University of Cape Town.

iSpot: iSpot provides an online platform to share and identify pictures of living organisms (http://www.ispot.org.za/). Observations of any species (alien or not) can be added, together with locations, photographs and identification. iSpot is maintained by the South African National Biodiversity Institute as a "citizen science portal", and it already contains over 100 000 data entries. Such information can in certain cases be used for species distributions, i.e. if the species is identifiable on a picture.

Alien plant distribution map: A preliminary alien plant distribution and density map for South Africa was drawn up at a national scale by the Council for Scientific and Industrial Research in 1996, but was meant only to serve as a preliminary illustration of the extent of the problem of invasive alien plants. In 2008, the distribution of 27 alien plant taxa was mapped by the Agricultural Research Council (species in the genera *Pinus* and *Eucalyptus* and some *Acacia* were mapped collectively). This map is the best currently available source of information on the density and distribution of major invasive alien plants.

Other sources: Many other sources of data on alien species distribution are not currently collated into relevant databases. For example, environmental impact assessment reports often include inventories of alien taxa for the area of the assessment.

7.2.5. Current proposals for information management

Draft regulations under NEM:BA mention a few requirements for information management for alien species. Guidelines for monitoring, control, and eradication plans, as mentioned in Regulation 8(1) are to be developed and made publically available. Additional information, collected by a competent authority, needs to be collated in a national register. This includes lists of all alien species present; a list of prohibited and watch-list species; permits and their conditions, including risk assessments, restricted activities, dates, locations, and recommendations; management plans drawn up for all protected areas and organs of state; research proposals and research findings arising from these proposals; notifications and directives.

7.3. Information Gaps

Much information needed for effective management and policy implications is not readily available in South Africa. Other information exists, but is not collected in a central place or in a standardized manner, or is very patchy. The list below examines the main gaps in information that would be required to underpin an effective system for managing biological invasions.

7.3.1. Prevention

Prevention can be improved by having access to lists of the alien species already in the country, prohibited species, exempted species, and watch lists. Lists of alien species and their completeness vary greatly between taxa, some lists are clearly incomplete, and for certain taxa, no lists exist. Effective prevention also relies on risk assessments, and South African-specific risk assessments and guidelines need to be improved for all taxa. Likewise, there is no general information on important pathways and vectors of introduction to guide management.

7.3.2. Eradication

A list of eradication targets exists in the draft regulations in terms of the NEM: BA, but the distribution of most of these species is poorly mapped at best, and their vectors of distribution are also not well understood.

7.3.3. Containment and impact reduction

For those species that need to be contained, detailed distribution maps, and details of introduction and dispersal pathways are only partially available. Most information for area-based management is also missing, for example the agreed boundaries of containment zones, landscape context, rates of discovery, and control history.

For those species that have been allowed into the country, information about the import permits with conditions and monitoring of compliance, as well as risk assessments are only partially available and are not centrally stored.

For both containment and impact reduction, policy-makers and managers require information about impacts, distribution, and control options, and much of this information is not available, or at best partially available, for most species and areas.

7.4. Key actions and targets

It is clear from the discussion above that, while much information exists, it is scattered and patchy, with many gaps. In addition, much of the information that does exist was designed to serve a purpose other than informing and supporting a national Strategy on biological invasions. Good information will be vital for achieving the goals of this Strategy. It will therefore be necessary to develop a system that will allow users to integrate and interrogate existing information in a way that will effectively support policy development and management (Figure 7.1). Several steps would be necessary to achieve this, and these form the basis of the key actions in the table below.

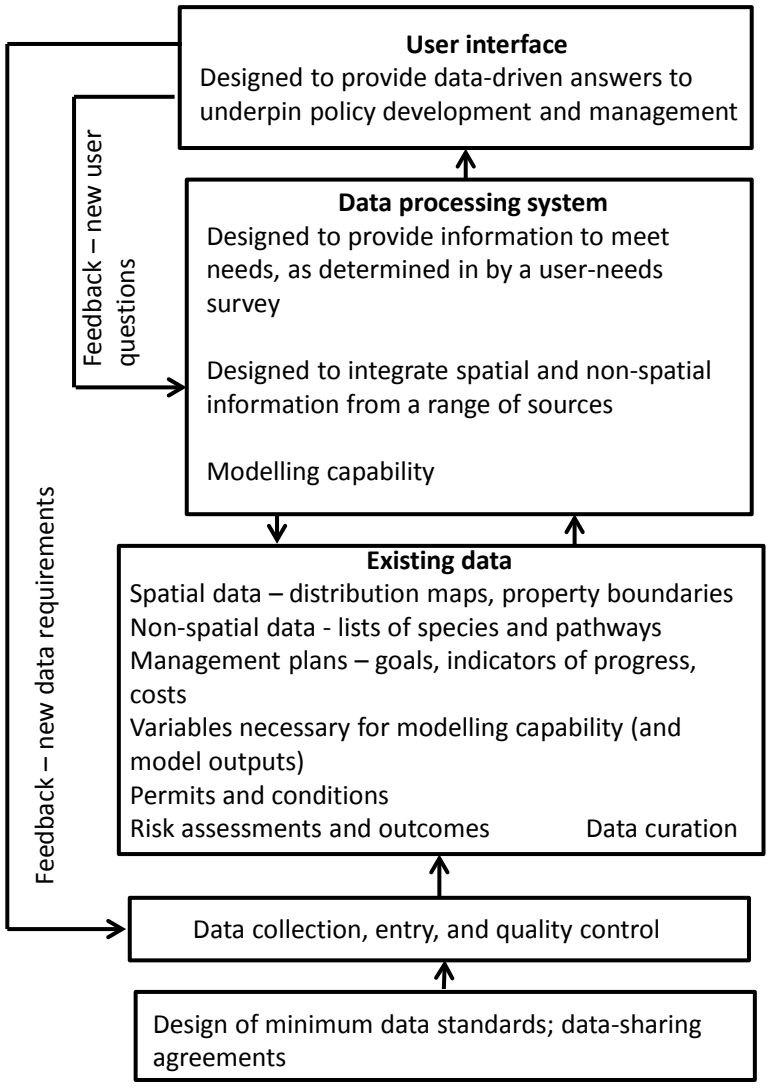


Figure 7.1.The basic structure of an integrated information system to underpin policy-development and effective management of biological invasions in South Africa.

KEY ACTION	TARGET
Conduct a survey of potential users of an information system (including managers of all aspects of biological invasions) to determine their information needs.	Survey completed.
Facilitate data-sharing agreements among all custodians of relevant information, and agree on responsibility for data entry, quality control, and curation.	Data-sharing agreements in place.
Develop minimum standards for data collection and storage, to ensure compatibility between different data sources, and to enable the detection of trends over time.	Minimum standards in place.
Identify the most important gaps in information, and initiate programs to collect data to fill those gaps where possible and desirable.	New data-gathering programs initiated.
Develop data-processing software that will enable appropriate analysis of data.	Software developed.
Develop user interface.	User interface developed
Design and implement web-based interface to enable public access to information, with the following features: • A portal to all atlas data; • Access to all lists, permits and risk assessments; • Access to distribution maps; • Information on available biological control agents; • Norms and standards for management plans; and • A query function, based on key user needs • Directories of relevant expertise.	Web-based interface developed and implemented.

7.5. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 59, 81, 85, 109, 113, 150, 178, 187, 192.

8 CAPACITY BUILDING

8.1 Current capacity to manage invasive alien species in South Africa

8.1.1 Background

The rapid escalation in the scale and magnitude of invasions by all taxonomic groups and in all types of ecosystems has radically changed the requirements for management. This Strategy must therefore cater for the development and deployment of adequately-trained personnel if the goals of the Strategy are to be achieved.

Managing biological invasions requires expertise in numerous disciplines, not only in many of the biological sciences, but amongst others economics, public relations, mathematics, enforcement and compliance, sociology, supply chain management, geography, health and safety, history, law and land management. Efficient and sustainable management interventions will require multi- and trans-disciplinary approaches with expertise in project management and in various technological areas for on-the-ground interventions.

Notable successes in managing invasive species in South Africa can be attributed to the integrated application of appropriate skills at different levels of management. However, there are also many examples of where management interventions have been less successful, especially in earlier parts of the 20th century. The initiatives of the Department of Environmental Affairs need to be strengthened with appropriate capacity and expertise to plan, implement and monitor the effectiveness of the types of management that are needed to make a difference to the rapidly escalating problem of biological invasions in South Africa. There is a need for a detailed assessment of capacity requirements in all spheres related to invasive species management in South Africa, and for action to be taken to alleviate shortages where necessary.

The South African National Biodiversity Institute has been designated to lead, in partnership with other key players, the strengthening and diversification of human capital for South Africa's biodiversity sector (identified as necessary in both the National Biodiversity Strategy Action Plan of 2005 and the National Biodiversity Framework of 2007). The Ministerial Delivery Agreement for Outcome 10 (The environment) of the President's Outcomes Approach includes a target on the full implementation of the Environmental Sector Skills Plan (ESSP) and the 20-year Biodiversity-sector Human Capital Development Strategy (HCDS), which is fully aligned with the broader ESSP and the biodiversity-related components of the Department of Science and Technology's Global Change Grand Challenge Human Capital Development Strategy. The contents of this chapter, including the key actions, need to be integrated with the above-mentioned initiatives.

8.1.2 What capacity is there for invasive species management?

8.1.2.1 The current situation

South Africa's initiatives to take control of invasive alien plants grew rapidly following the establishment of the Working for Water programme in 1995. The programme was initially housed in the Department of Water Affairs and Forestry, but it drew on existing experience from other departments, notably from provincial conservation agencies, South African National Parks, the Council for Scientific and Industrial Research, and the Agricultural Research Council, as well as from the private sector, notably the forest industry. The goals of achieving transformation and promoting development were built around this core of experienced capacity. The need to create employment and to address many social development issues

also demanded the employment of people with skills that were different to those found in conservation agencies, science councils and forestry companies. Much experience has been built over the past two decades, but much remains to be done. Ensuring that adequate capacity is trained and employed is therefore a key intervention envisaged by this Strategy.

8.1.2.2 Capacity required for managing biological invasions

A range of skills and experience will be required to manage biological invasions (Table 8.1).

Table 8.1. Types of jobs, level of training and experience needed to manage biological invasions, and the current capacity available to address issues within poverty-relief programmes in South Africa.

Type of capacity needed	Level of training needed	Desirable minimum post-qualification level of experience needed	Notes
Senior management	Post-graduate training in ecology and/or project management.	10 - 20 years	Efforts are under way to recruit senior managers, to fill key positions in the expanded Environmental Programmes within the DEA, and to relieve pressure on current managers.
Regional management	Graduate or post-graduate.	5 – 10 years	Need a broad set of skills.
Field supervisors (project clusters)	Diploma.	5 – 10 years	Currently there is a need to strengthen this level of management through formal training in invasive species management.
Field team leaders	Diploma or tailored training courses.	1 – 5 years	Currently there is a need to strengthen this level of management through formal training in invasive species management.
Field workers	In-house and on-the-job training.	Not required, as long as trained.	Initially, field workers have no training, and most receive on-the-job training. However, turnover tends to be high, for a variety of reasons, meaning that training is constantly required.
Planners	Graduate or post-graduate.	2 – 10 years	Currently under capacity. People tasked with planning also have many other responsibilities.
Field auditors, quality control	Graduate or diploma.	2 – 10 years	There are currently about 100 field auditors/quality controllers across the country.
Monitoring and evaluation (M&E)	Graduate or post-graduate.	2 – 10 years	Currently under capacity.
Researchers	Post-graduate training in ecology, environmental management, risk assessment, and other relevant skills.	2 – 10 years	The country is in a strong position to train researchers.
Permitting and law enforcement personnel	Graduate or diploma.	2-10 years	Training in interpersonal skills essential.

Type of capacity needed	Level of training needed	Desirable minimum post-qualification level of experience needed	Notes
Specialists	Varies depending on the type of specialist	At least 10 years	Specialists include biological control professionals, high-altitude teams, risk assessment experts, species control specialists (e.g. in the use of specialised techniques such as the application of piscicides). The required capacity should be assessed for each specialist area.
Taxonomists	Post-graduate training	5-10 years	There should be a focus on lesser-known groups, such as invertebrate and microbial organisms.
Customs supervisors	Graduate or diploma	5 – 10 years	
Customs inspectors	In-house and on-the-job training	2 – 5 years	
Risk assessment practitioners	Graduate or post-graduate	2 – 10 years	No formal training courses exist.

To resolve this shortfall, several initiatives have already been launched. These include a series of training courses for management officials at national, provincial and local government levels; several training courses for Working for Water middle management on developments in invasion ecology; and multi-pronged initiatives aimed at building capacity in the area of weed biological control (Box 8.1).

Such interventions have been successful and need to be continued and applied in more areas, but more comprehensive and strategic programmes are required to supply regular and repeated training activities coordinated with the requirements of new management initiatives. For example, specific attention needs to be given to developing taxonomic expertise who will be crucial to the detection of problem species.

Box 8.1. Capacity-building initiatives for weed biological control

The Working for Water Programme identified a lack of capacity in the field of the biological control of invading alien species and initiated a Capacity Building Programme towards the end of 2003.This programme was established both to expand the limited, largely white, capacity that existed in the weed biological control fraternity in South Africa and to engage more directly with different stakeholders. Two of the main initiatives are highlighted below:

Capacity-building at Rhodes University

Several capacity-building initiatives at Rhodes University have been funded directly through the WfW programme, or through supervision by people funded through the WfW weed biological control research projects. These include the following:

- **Schools Programme**. A collaboration with Victoria Girls' High School in Grahamstown employs five Grade 10 learners during their vacations to work on weed biological control projects.
- **Undergraduate Projects**. Since 2003, 27 third-year and 12 Honours projects on the biological control of weeds have been supervised at Rhodes University. A number of the graduates have continued to higher degrees.

- **Postgraduate Projects**. Since 2003, 17 MSc and eight PhD students have worked on weed biological control projects under (co)supervision of Rhodes University staff. This has afforded young research and technical staff working on biological control projects, including at the Plant Protection Research Institute of the Agricultural Research Council, the opportunity to register for MSc and PhD degrees.
- **Disabled Persons Programme**. Three disabled men from Grahamstown have been employed to assist in mass-rearing and release of biocontrol agents for waterweeds and have been trained in aspects of biocontrol.
- **WfW Biological Control Short Course**. Rhodes University has hosted 16 short courses on the biological control of weeds run by weed biological control practitioners in South Africa (160 delegates have attended; 97% pass rate). Delegates are from government agencies including WfW, SANParks, provincial conservation agencies, DEA, DAFF, PPRI, SASRI, university students, and members of "Friends" groups involved in alien pant management. The course is fully accredited.

Capacity-building at the University of KwaZulu-Natal (UKZN)

UKZN has, since 2005, run a programme for undergraduate students in the life sciences. 12–18 undergraduate biology students each year during the university vacations have had work experience at various institutions to develop their skills and interests in the biological sciences. Most of these students continue with Honours and several have progressed to undertake MSc and PhD projects or to work for the Plant Protection Research Institute or the South African Sugarcane Research Institute.

The Biodiversity-sector Human Capital Development Strategy provides guidelines for training a larger pool of biodiversity professionals and technicians. Special emphasis is given to black South Africans, with high level skills (level 6 and higher in the National Qualifications Framework) to undertake biodiversity conservation, management and related natural and social science research, and take leadership roles in organisations with a biodiversity mandate. It outlines interventions required in primary schools, high schools, universities and the work place.

Key scarce skills for the biodiversity sector in South Africa have been identified, several of which are "absolute scarce skills" (where South Africa does not have enough people to perform these tasks), in alphabetical order:

1. Agricultural extension officers specializing in biodiversity issues;
2. Curators of biodiversity collections;
3. Ecologists (in aquatic and terrestrial but especially marine systems);
4. Environmental managers, conservation and environmental scientists;
5. Engineers (civil) with special knowledge in biodiversity;
6. Geneticists (genomic investigators, molecular biologists, molecular geneticists, molecular biologists);
7. GIS specialists and (to a lesser degree) technicians;
8. High-level human-capacity development, human resource and training professionals;
9. Specialists in information and computer technology (e.g. service managers, systems analysts, web and multimedia developers, applications programmers, database designers and administrators) with biodiversity skills;
10. Lawyers and legislators with knowledge of environmental issues;
11. Monitoring specialists, species protection officers and inspectors;
12. Policy developers and analysts;
13. Urban and regional planners specializing in biodiversity issues;

14. Resource economists with biodiversity-related specialisation;
15. Social scientists specialising in environmental issues;
16. Intellectual property and indigenous biodiversity knowledge specialists;
17. Soil scientists;
18. Statistical ecologists and modellers; and
19. Taxonomists and systematists.

8.2 Current capacity to train people

Many personnel currently involved in invasive species management have received tertiary training from universities or other institutions – mainly in the pure (botany, zoology, biology) or applied (agriculture and forestry) biological sciences. While invasion science features in some university curricula—for example Stellenbosch University has a full third year BSc semester module "Invasion Ecology", and a corresponding Honours module—there are no full-length undergraduate or diploma courses on alien species management.

In terms of post-graduate training with a focus on biological invasions, the DST-NRF Centre of Excellence for Invasion Biology is the major national programme. There are other nodes of research on issues related to invasive species at other universities, notably Rhodes University, and the Universities of KwaZulu-Natal and the Witwatersrand. Several of South Africa's Universities of Technology provide diploma-level training in nature conservation, but these courses include only basic information on invasive species ecology and management. These institutions do not focus on training managers, however, and only the Biological Control Short Course at Rhodes University (see Box 8.1), ad hoc short courses at the Centre for Invasion Biology and the apprenticeship programme at UKZN address this need. There are several courses on herbicide application, but a broader course is required.

8.3 Key actions

Key actions and targets are summarised in the table below.

KEY ACTION	TARGET
Create a dedicated 2-3 year diploma course in the management of biological invasions, geared towards producing graduates trained in science-based environmental management; goal-setting and planning; monitoring and evaluation; labour management and administrative skills designed for legal requirements.	Course designed and implemented at an appropriate University of Technology.
Recruit and finance participation of students in above course.	Bursaries in place; students enrolled
Employ bursary recipients who qualify from this program.	>50% of graduates employed per year from 2019
Establish accredited short-courses addressing key	Courses established in a broad range of topics.

KEY ACTION	TARGET
aspects of the management of biological invasions at research universities, technical universities and FET colleges. Courses should be modular and modules customised for on-the-job training of managers at all levels.	20% of staff attending in-service training courses annually at appropriate universities and colleges (including part-time attendance of the above diploma)
Improve the level of training and experience of field workers.	Establish training courses for field workers.
	Phase out the contractor model in favour of employing permanent control teams in priority areas.
Build capacity to implement risk assessment.	Risk assessment training courses set up (potentially a short-course as per above). Lines of responsibility and staff in place.
Increase the capacity in basic traditional morphological taxonomy, with resources and time dedicated for detecting new incursions.	Status report on the capacity needed to meet the demands for identification of new invasive alien species, with recommendations and review schedule.
	Training and appointment of required taxonomists in appropriate institutions with a requirement to work partly on non-native species, with regular international collaboration and visits
Improve the capacity for research and implementation of weed biological control	Double the biological control research capacity in South Africa over the next decade.
	Expand the biological control programme to include species for which eradication from South Africa has been ruled out but for which widespread impacts are predicted but have not yet been demonstrated.
	Expand the capacity of the biological control implementation programme (100% growth over the next 5 years), with explicit targets and ring-fenced funding for pre- and post-release monitoring; mass rearing; and agent distribution.
Maintain existing collaborative agreements with organizations that have relevant capacity, such as Universities, Science Councils or research institutes, to ensure access to expertise, information, and research capacity.	Collaborative agreements remain in place.

8.4 Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 18, 37, 53, 183, 101.

9. RESEARCH

9.1. Background

Research and development (R&D) covers three activities: basic research, applied research and experimental development. *Basic research* (also called "blue sky research") is work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any immediate application or use in view. *Applied research* is original investigation undertaken to acquire new knowledge that is directed primarily towards a specific practical aim or objective. *Experimental development* is systematic work, drawing on existing knowledge gained from research and/or practical experience, directed at producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. *Technology transfer* is needed to ensure that all of these forms of research results are applied in practice.

There is an increasing demand for R&D to support policy and decision-making relating to the protection of biodiversity and the sustainable realisation of benefits from our natural ecosystems. South Africa's National Development Plan (Box 1.5) is firmly grounded on the goal of sustainable development, paving the way for human development needs while staying within sustainable boundaries. This idea of bounded growth calls for new knowledge and new ways of thinking, and must be supported by interdisciplinary research. Priorities to this end are outlined in South Africa's National Biodiversity Research Development and Evidence Strategy (NBRDES; 2013-2020). NBRDES is structured around the following principles:

- *Knowledge that informs policy and decision-making* (knowledge generated through research should not just contribute to academic debates, but must be relevant to the needs of decision makers and the issues that affect society);
- *Accessible information*(information generated by research must be accessible to government and society);
- *Building on structures that work* (NBRDES seeks to build on existing research structures that have delivered good results in the past and to strengthen these systems while addressing gaps in research);
- *Innovative solutions*(research should enable innovative solutions through experimental testing of ideas and technologies, modelling, piloting, and scenario testing); and
- Development of new tools and technologies.

9.2. Goals of research to support biological invasions

This proposed research strategy for invasive species fits firmly within the scope of NBRDES. It requires basic research, applied research and experimental development on a wide range of topics and issues, and structures for effective technology transfer. It has as its overarching goals:

- To ensure the existence and strengthening of research infrastructure, networks, and funding security required to undertake R&D on all aspects of invasive species;
- To bridge the gap between invasive species managers and the research community;
- To move invasion science from a reactive to a predictive discipline;
- To develop technological innovations to deal with all aspects of invasions;
- To deliver the knowledge and tools needed to reduce, minimize or eliminate the potential for introduction, establishment, spread and impact of invasive species in all taxonomic groups across all ecosystems in South Africa;
- To facilitate the improved detection of newly-introduced and newly-invasive invasive species;

- To develop methods for evaluating options for cost-effective intervention, including the assessment of eradication feasibility, and the optimum integration of methods for reducing the extent and/or negative impacts of species that are already widespread;
- To develop and make available analytical tools for objective prioritization of management at all spatial and temporal scales;
- To improve the understanding of all types of impacts of invasive species (and of interactions and synergies between invasions and other facets of global change);
- To improve the understanding of the options for restoring ecosystems affected by invasive species;
- To apply trans disciplinary research methods to ensure that socio-economic aspects are fully integrated in the elucidation of problems and solutions relating to invasive species; and
- To develop methods for the objective evaluation of economic and public health impacts of invasive species.

9.3. Existing relevant research capacity in South Africa

South Africa has a long history of research on invasive species and was one of the core contributors to recent major international programmes, including the two programmes on biological invasions under the auspices of the Special Committee on Problems of the Environment (SCOPE), and the Global Invasive Species Programme (GISP). South Africa is also one of the top five countries in the world in terms of research investment on the biological control of plants. South Africa has by far the most active research programmes on invasions of any African country, and produces at least two-thirds of the invasion-related publications from the continent.

Research on invasive species in South Africa is undertaken by a number of institutions and partnerships between these. A milestone in research on biological invasions in South Africa was the establishment, in 2004, of the DST-NRF Centre of Excellence for Invasion Biology (C•I•B), a national, distributed network of researchers working on biological invasions from microbes to macro fauna. The C•I•B is globally recognized as one of the most productive and innovative centres for research in the field. The C•I•B has its headquarters at Stellenbosch University, a secondary node at the University of Pretoria, and research partners at many other universities and parastatal organizations throughout South Africa. Other key institutions include components within the Department of Environmental Affairs (Oceans and Coasts, Environmental Programmes, Biodiversity and Conservation) and its entities (SANParks and the South African National Biodiversity Institute), the Department of Agriculture, Forestry and Fisheries and its entities (notably the Agricultural Research Council), universities, science councils, museums and provincial conservation agencies. Funding from Environmental Programmes, Department of Environmental Affairs, is currently facilitating research through partnerships with several organizations (Box 9.1).

South Africa also has a strong history and international reputation for research excellence in the field of biological control, particularly for invasive plants. This work is carried out by a network of researchers at the Plant Protection Research Institute and several universities. Achievements have been reviewed in several recent synthesis volumes. Substantial research on invasive alien invertebrates has been conducted by several specialized research institutes focussed on particular agricultural commodities (see 6.7.3). The South African Institute for Aquatic Biodiversity (SAIAB), a National Research Facility of the National Research Foundation and an internationally-recognised centre for the study of aquatic biodiversity, conducts research on invasive aquatic organisms. The Natural Resources and the Environment programme of the Council for Scientific and Industrial Research (CSIR) has produced a substantial body of research on invasive species, mainly in terrestrial environments. Most research on alien microorganisms is conducted at the Forestry and Agricultural Biotechnology Institute at the University of Pretoria. The South African Medical Research Council conducts research on many human diseases involving alien species.

Box 9.1. Research partnerships

The Natural Resource Management Programmes of the Department of Environmental Affairs has formal links with several research organizations. Some of these links have been formalised by means of Memoranda of Agreement (MoA). The relevant research organizations will (where relevant under the auspices of these MoAs) provide support that requires expert knowledge, or the use of complex technology, to the DEA, in the interests of achieving the goals of this Strategy.

The following research organizations are involved:

- The Council for Scientific and Industrial Research (CSIR). The CSIR is a state-funded research council with expertise in natural resources and the environment.
- The Centre for Invasion Biology (C•I•B). The C•I•B was launched in 2004 as one of the first six national Centres of Excellence established by the Department of Science and Technology.
- C4 Ecosolutions, a consulting company with a focus on the provision of innovative, evidence-based solutions for adapting to climate change, conserving and restoring ecosystems, and mitigating climate change through carbon sequestration.
- The Forestry Department, an academic department in the Faculty of Agricultural Sciences at Stellenbosch University, with expertise in forestry and land management.
- The Institute for Natural Resources, a Section 21 company and a registered public benefit organisation that promotes the wise use and management of natural resources for the good of the environment and society.
- The Institute for Soil, Climate and Water, a research institute within the Agricultural Research Council, with expertise in remote sensing and mapping.
- Nelson Mandela Metropolitan University, with expertise in land management and conservation.
- The Plant Protection Research Institute, a research institute within the Agricultural Research Council, specializing in weed biological control.
- Rhodes University, with expertise in weed biological control.
- Sigwela And Associates, Environmental Consultants
- The South African National Institute for Biodiversity, an arm of the DEA tasked with research on biodiversity.
- The University of Cape Town, with expertise in land management and conservation.
- The Water Research Commission, a research funding body established in terms of the Water Research Act (No 34 of 1971) to promote co-ordination, co-operation and communication in water research and development.

9.4. Research needs

While more still needs to be done to improve the administration of research (Box 9.2), there are several areas that stand out as requiring more research. These include risk assessment, the taxonomy of important groups of potentially invasive species, biological control of weeds, and the development, monitoring and assessment of indicators of the extent of invasions in different ecosystems.

There are also a number of immediate needs for the Natural Resource Management Programmes of the Department of Environmental Affairs that stand out. There is an urgent need to understand the returns on investment that are gained from different interventions, many of them innovative. To understand the returns on investment, more research will be needed on the impacts of invasive species. Steps also need to be taken to correct the imbalance between research into invasive alien plants versus the other invasive alien taxa. Finally, there is a real and urgent need to address the lack of alignment between researchers and managers. The two groupings seldom act as a team, sometimes with very negative consequences – see the proposals in Box 9.2 regarding reviews of the challenges facing managers.

There are also several areas of research where new technologies, or new approaches to gathering data, can be useful. These include engaging with "citizen science" (e.g. iSpot; the South African Plant Invaders Atlas; and other atlas projects), remote sensing, and DNA-barcoding.

9.5. Key actions

The key actions below are aimed at moving from the current situation, where much research is guided by a science agenda (with a focus on publications and the completion of post-graduate degrees), or driven by the interests of individual researchers, or by the perceived needs of managers, to a situation where decisions about the prioritization and commissioning of research can be pro-active, and directed towards relevant questions within an agreed set of research priorities.

KEY ACTION	TARGET
Review the knowledge gaps and important challenges identified in this strategy, and compile a list of priority research needs that will be required to generate information and methods to support the implementation of the strategy.	Research strategy in place.
Set up a mechanism for commissioning and funding priority research by DEA, DAFF and the Water Research Commission, in collaboration with key research institutes, including the Agricultural Research Council, the Centre for Invasion Biology, the Council for Scientific and Industrial Research, , the Forestry and Agricultural Biotechnology Institute, and the Human Sciences Research Council.	Memoranda of Understanding negotiated between key collaborators. Funding mechanisms in place.
Establish a Scientific Advisory Panel (SAP) to provide ongoing advice on research trends, to guide a strategy for effective research, and to assess the quality of research carried out (see Box 9.2).	SAP in place.

Box 9.2. Proposed terms of reference for a Scientific Advisory Panel to guide research in the field of biological invasions

The establishment of a Scientific Advisory Panel (SAP), to provide ongoing advice on research trends, to guide a strategy for effective research, and to assess the quality of research carried out under the auspices of this Strategy is a key action. The SAP should be chaired by the South African National Biodiversity Institute, and should have representatives from important government stakeholders, notably the Departments of Environmental Affairs, and of Agriculture, Forestry and Fisheries. Prominent, experienced experts from a range of relevant fields would be appointed to the RAP to provide the necessary scientific and research inputs. The RAP would have the following terms of reference:

- Act as a scientific advisory body to departments responsible for the implementation of this strategy.
- Act as a pool of scientific knowledge and experience, that can be called on when required.
- Review the challenges and needs of managers in departments responsible for the implementation of this Strategy, and provide science-based advice for addressing these needs.
- Periodically review research progress in key areas that have relevance for policy and management, and propose mechanisms to encourage uptake of research findings.
- Review the research portfolio of departments responsible for the implementation of this Strategy, and assess its scope in terms of covering the most important areas requiring research, and gaps that are not covered.
- Review research proposals in terms of alignment to priority needs, quality, and likelihood of success.
- Assess the quality of research outputs and outcomes.
- Facilitate the assessment of progress of this Strategy in terms of meeting desired outcomes (see Chapter 12).

9.6. Sources

All sources are listed numerically in Chapter 13 of this Strategy. Information in this section was obtained from the following sources: 120; 126; 148.

10. RAISING AWARENESS

10.1 Current levels of awareness in South Africa

The successful implementation of this Strategy will require support from a wide range of stakeholders, as well as the broad pubic. Biological invasions are a complex issue, and can be perceived as good or bad depending on an individual's perspectives and value systems. It would therefore be vital to develop a strategy to communicate important messages to stakeholders and the public, in a way that supports the objectives of this Strategy. Currently, levels of awareness across the country vary from high to low, depending on the aspect of the problem.

There are *high levels of awareness* regarding:

- Which plant species are invasive (among landscapers, garden centre owners, conservationists and passionate gardeners); and
- Which species can be sold or traded (among landscapers and traders).

There are *moderate levels of awareness* regarding:

- The concept of invasive species (it has been taught in schools for five years);
- Isolated cases where high-profile species have received coverage in the press, leading to debate over the advantages and disadvantages of control (for example jacaranda trees in Pretoria, or pine trees and Himalayan thars on Table Mountain); and
- Certain high-profile invasive species such as water hyacinth (*Eichhorniacrassipes*) and pompom weed (*Campulocliniummacrocephalum*).

There are *low levels of awareness* regarding:

- The public understanding of the concept of biological invasions (although public understanding is much higher than in most countries, and is moderate to good in some rural communities that are particularly affected);
- Anything to do with faunal invasive species (up until very recently, the focus has been on invasive alien plants, and the concept of animals as invasive species is new to many people);
- What the legal requirements are for importing, keeping, growing or trading in alien species, especially regarding how to go about obtaining permits; and
- Regional crises, such as the one brought about by the rapid spread of famine weed (*Partheniumhysterophorus*) in the KwaZulu/Natal province.

10.2 Approaches to awareness-raising in South Africa

Advocacy is a key element of this Strategy for dealing with biological invasions in South Africa. Individuals, organizations, and businesses in the private and public sectors all drive the introduction and spread of alien species in the country, and it is vital to ensure that people are aware (1) of the risks associated with any activity involving biological invasions, and (2) of the legal requirements that regulate the ownership, cultivation, trade and transport in or of alien species. Direct communication with key stakeholders is required. These include, for example, farmers with invasive species on their land; people who use invasive species for commercial gain; people who sell invasive species, or purchase them to plant in their gardens, or to keep as pets; government officials who have to make decisions about the use of alien species; and so on. A great deal of progress has been made, but more needs to be done.

The government has run very successful partnership programmes with landscapers, garden centre owners, conservationists and passionate gardeners since 2001. As such, their participation in the issue of biological invasions has been high. This has been borne out by a recent study in 2013 which found a 100% compliance with legislation in garden centres across the KwaZulu/Natal province. Several other successful initiatives have been carried out:

Environmental Programmes Nurseries Partnership: Over a period of 12 years, this partnership has brought the nursery partners so close to the government that growers in this group report on invasive species being discovered by growers in Australia. Another example of the success of the initiative is snake grass (*Equisetum hyemale*). The invasive threat posed by snake grass was identified and recognised by the industry such that, in the absence of any formal legal requirement, the industry has self-regulated the cultivation, distribution and sale of the species (the species is now listed in the draft regulations under the NEM:BA). The nursery industry has also run very successful "Plant me Instead" campaigns and has used the gardening media and other opportunities in television, radio, print media and social media to reach the public.

Invasive species forums: Two forums have flourished in Durban and Cape Town for over a decade. The first is the KwaZulu/Natal Invasive Species Forum, organised by the Department of Environmental Affairs in collaboration with the South African National Biodiversity Institute. This forum meets up to four times a year and has over 100 members. At any one meeting, there can be 70 people attending. This forum disseminates information to an informed group of individuals. It also rewards journalists and scientists who liaise with the media or schools - a platform to share their communication successes among peers. The second is the Cape Invasive Animal Species Forum, managed by the City of Cape Town. This forum focussed on providing advice on the management of invasive animal projects, including on the dissemination of information relating to invasive fauna, and produced pamphlets, posters and fact sheets on a host of invasive fauna.

National Invasive Species Website: For the past decade, www.invasives.org.za has provided a centralised and neutral focal point for the invasive species awareness campaigns. The website is a repository for hundreds of academic papers, includes all the fact sheets produced on invasive species by the Australian government, has every news bulletin issued by the South African Plant Invaders Atlas since its inception and includes every relevant pamphlet or poster ever produced in South Africa (in a print-ready, high resolution format) for download by any organisation wishing to print materials for a campaign. The website is funded by the Department of Environmental Affairs, and has a Google Group reaching 380 professionals, an e-Newsletter that reaches 3 500 interested members of the public and is a resource for pupils and teachers at schools, and has given rise to several additional social media components, including a Facebook Site. As a centralised operation, it brings together the work of over 25 different agencies working at a national, regional and local level. The Australians are currently using it as an international example of best practice in awareness and communications.

Media liaison: Government officials need clear guidelines for dealing with the media regarding biological invasions. They should have relative freedom to provide information when such is needed urgently to clarify concepts, but should work through official structures when communicating policies that may be controversial or sensitive. They should also build relationships with experts in relevant fields, and refer queries to such experts for responses as needed.

10.3 Key actions

KEY ACTION	TARGET
The Department of Environmental Affairs should identify key stakeholder groupings, and disseminate information as needed.	Key stakeholder groupings identified.
Establish an Invasive Species Forum Outreach Programme that would be able to set up, support and sustain invasive species forums (similar to those in KwaZulu/Natal and Cape Town) in other regions and towns.	Outreach Programme in place, and new forums established to serve stakeholder groupings, including invasive species professionals, interested members of the public, farmers and conservation officers.
Institute a National Invasive Species Week, assigned to a national public - private joint venture organisation.	National week instituted.
Develop communications toolkits based on the communications strategies of the UN World Water Week or the International Day of Forests.	Toolkits freely available to the media, schools, pupils, partner organisations and stakeholder groups.

11. FUNDING THE STRATEGY

11.1 Introduction

South Africa needs to address the issue of biological invasions in order to prevent a substantial erosion of the nation's natural capital. Although the implementation of various interventions is obviously necessary, the reality remains that, to be effective, these interventions will require more funding than will be available, given the considerable competition for such funds. This chapter presents the history of funding, the current budget available, and high-level demands that will need to be traded off. It also examines possible future scenarios that need to be considered in longer-term planning.

11.2 Historic funding and achievements

South Africa's Working for Water programme was initiated in 1995 with an initial budget of R25 million. This rose steeply over the next three years, with the annual budget reaching R250 million in 1997, then stabilising between R300 and R400 million until 2010, following which it again climbed steeply to its current level of R1078 million in the 2012/13 financial year (Figure 11.1). The programme has performed exceptionally well with respect to reaching expenditure targets (97% spent over the life of the programme to date), indicating that the money earmarked for poverty relief found its way to the pockets of the rural poor. The number of people that benefitted from the programme varied over time, and currently stands at over 40 000 people (Figure 11.2).

The programme has succeeded in clearing invasive alien plants from almost 2.5 million hectares since its inception. On average, cleared sites have also received 2.7 follow-up visits in which regrowth was cleared; the work has thus taken place over 9.3 million hectares (Figure 11.3). There are, however, examples of areas that were cleared but not followed up, or were not followed up timeously. This has led to some cleared areas becoming re-invaded, and it is something that needs to be investigated and corrected.

Nonetheless, historic control efforts have, according to one estimate, saved ~R40 billion annually in ecosystems services that would otherwise have been lost, had control not taken place. This was in turn based only on water, grazing and biodiversity losses, see Box 6.5.1; other benefits were not quantified. Although this estimate should be treated with caution, it does indicate that the relatively modest expenditures on control have been a good investment of public funds.

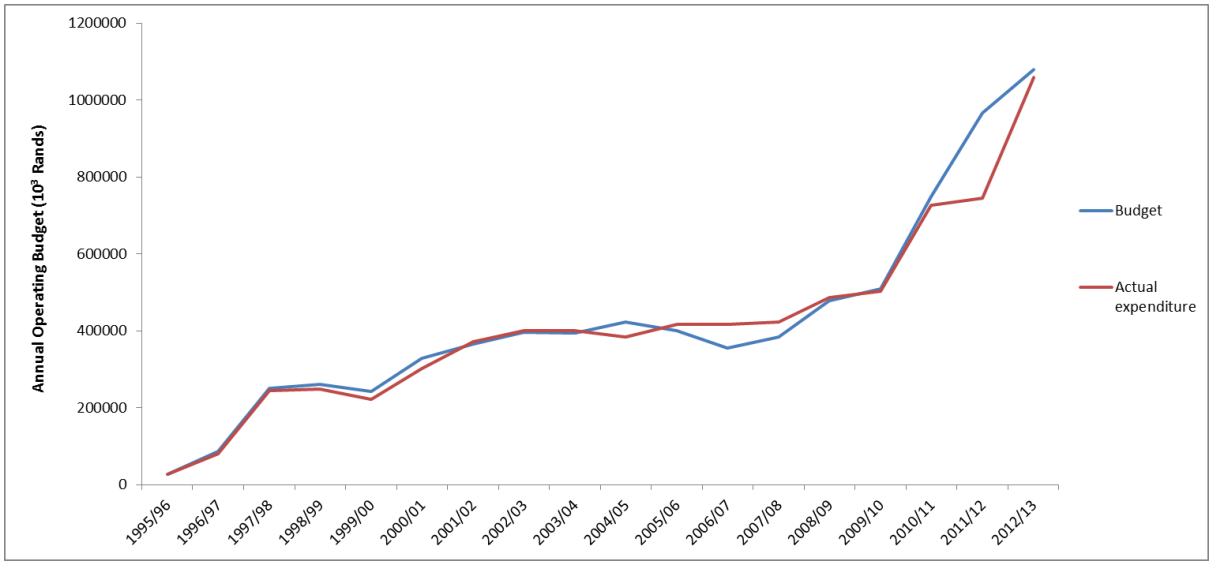


Figure 11.1. Annual operating budget of the Working for Water programme since its inception in 1995.

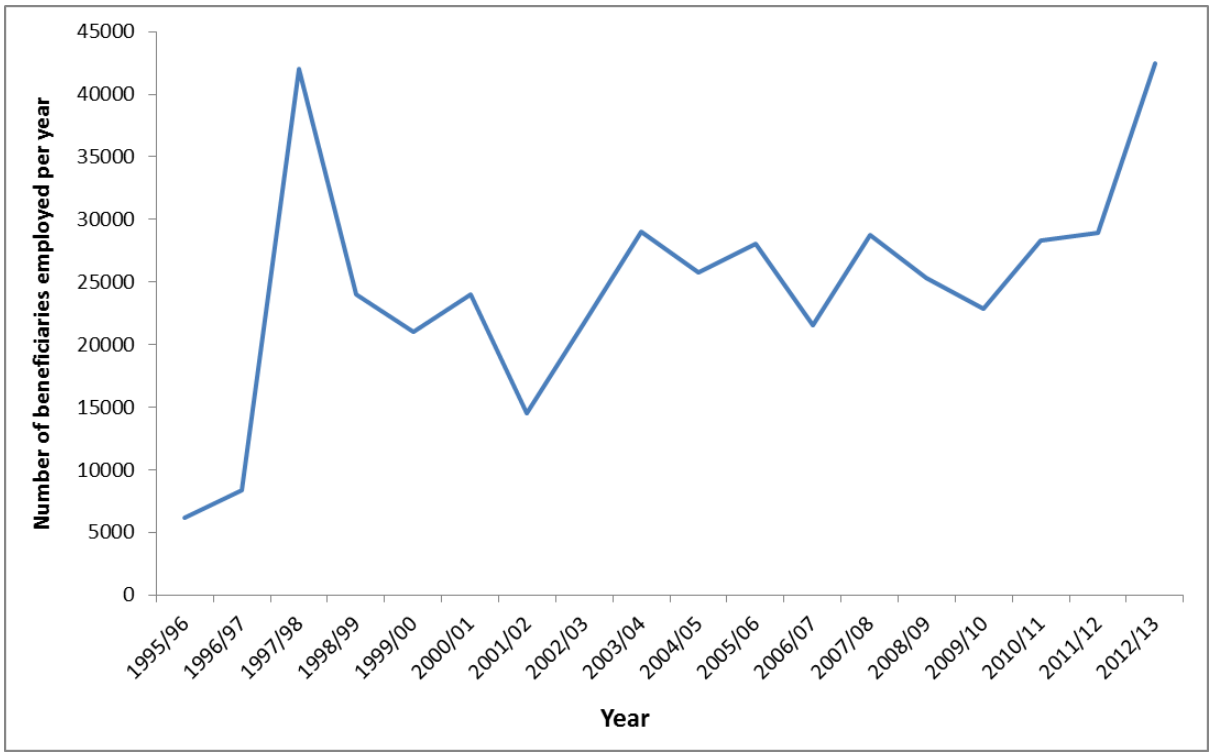


Figure 11.2. The numbers of poor people that benefitted from of the Working for Water programme since its inception in 1995.

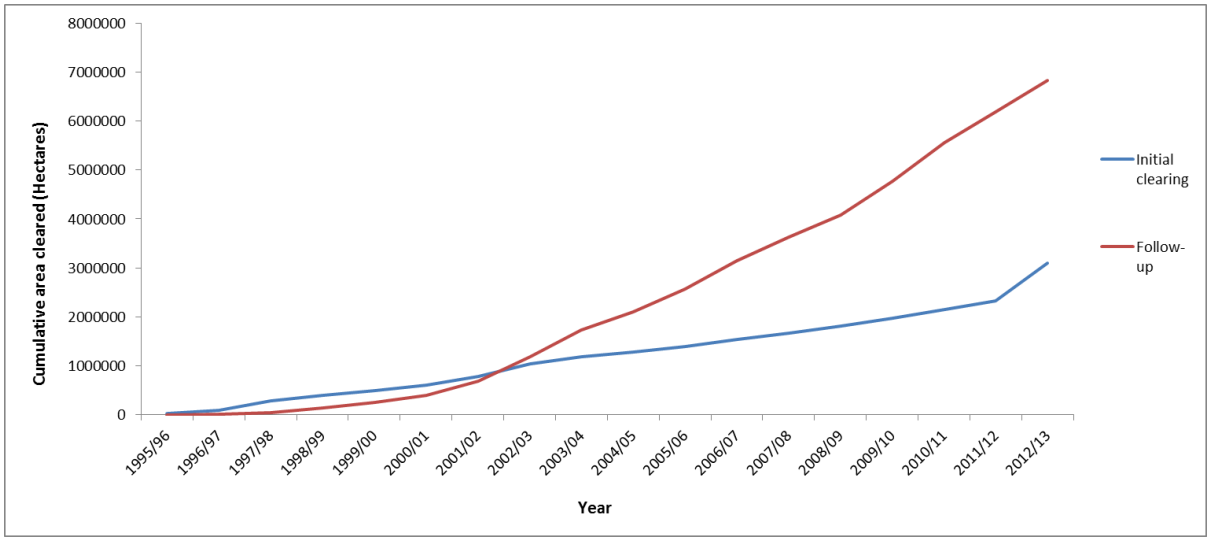


Figure 11.3. The cumulative area cleared of invasive alien plants, and subjected to follow-up clearing, by the Working for Water programme since its inception in 1995.

11.3 Drivers of funding growth

Since its inception, Working for Water has followed a strategy of combining the need to control biological invasions (initially restricted to invasive alien plants) with the need to alleviate poverty by utilizing the employment opportunities associated with labour-intensive control work. This basic strategy, combined with a demonstrable ability to employ large numbers of people and to disburse the available funds, has been the prime reason that the programme has been able to secure substantially more funding than would otherwise have been made available for an environmental project, and to grow. Working for Water was the catalyst and role model for all of the Extended Public Works Programmes, including the 14 very successful programmes (such as Working on Fire and Working for Wetlands) run within the Department. There is nonetheless a great deal of pressure to maximise the number of people that benefit from the programme, measured by the degree to which the ratio of costs to person-days of employment can be minimised. This pressure will continue to increase as other poverty-relief programmes, potentially with more attractive ratios, are developed and implemented.

Clearly, the programme needs to address a wider range of issues than simply mechanically clearing invasive alien plants (Chapter 2), including paying adequate attention to other (non-plant) groups, and to biosecurity through pre-, at- and post-border management. Some of the required interventions in these areas may not yield competitive ratios of costs to person-days of employment. In order to secure additional funding, the Strategy has been widened to include the opportunities offered by utilization of biomass made available by clearing operations (see section 6.5.3). It is envisaged that, potentially, these activities could generate hundreds of millions of rands in additional funding; in addition to increasing the employment opportunities within the programme (see 11.5).

11.4 Current budget allocations and demands

Funding available for the management of biological invasions within the Natural Resource Management Programmes of the Department of Environmental Affairs amounts to 1.22 billion rands for the 2014/15 financial year. Similar amounts, with modest projected increases to cater for inflation, have been set

aside for the 2015/16 and 2016/17 financial years, and can be assumed for further years. The bulk of these funds (75%) are currently set aside for operational clearing and running costs, almost all of which goes to invasive alien plant control operations (the 75% includes 5% that is ring-fenced for use by high-altitude clearing teams). A further 7% has been set aside for value-added industries, mainly the Eco-Furniture Programme currently, which also contribute to invasive alien plant clearing. Biosecurity operations by the DEA will be scaled up in the coming year, in collaboration with DAFF, and 4% of the funds have been set aside for this purpose. It is planned to grow the funding for biosecurity by 40% per year over the next two years, so that it will then constitute almost 6% of the total spend. The remainder of the funds will be utilized for overhead costs (7%), operations support, planning and capacity-building (4%), and biological control (3%).

In addition to the main DEA budget, additional funds are also available for the management of biological invasions. These include a projected R100 million from the Department of Water Affairs' Trading Account (for the management of water-consumptive invasive alien plants along rivers and in catchments); R100 million allocated by the KwaZulu/Natal provincial government for invasive alien plant management in that province; R62 million to be sourced from the Jobs Fund for the Eco-Furniture Programme; and a further amount (potentially as high as R300 million) derived from the sale of eco-furniture products. The Department of Agriculture, Forestry and Fisheries also invests in the management of biological invasions, with R273 million budgeted for Inspection and Quarantine Services, and R489 million for plant production and health.

This level of funding is substantial, but will nonetheless fall short of what would be required for a comprehensive programme that could effectively address all aspects of the management of biological invasions (Box 11.1).

Box 11.1. What could the implementation of a comprehensive Strategy to address biological invasions cost?

As part of the drafting of this Strategy, a theoretical exercise was conducted to estimate the potential levels of funding that would be needed to address the management of biological invasions in South Africa. This estimate is based on a rough costing of the main high-level interventions (as listed in Chapter 2, Table 2.2, under the column headed "Intervention") that would be required (see the heading of Box Table 11.1 for further explanation).

Each management intervention was categorised in terms of a base unit, an estimated annual cost of implementing one base unit, and the number of base units to be managed each year. The total estimated amount required for the implementation of the Strategy is R4.95 billion per year, based on a *business-as-usual* implementation scenario using current management practices and procedures.

Box Table 11.1. Finances required for implementing a national Strategy for biological invasions in South Africa. In the case of managing species at stages 3 and 4 (containment and impact reduction), the five interventions as numbered in in Table 2.2 (prioritization of species [C1], prioritization of areas [C2], planning [C3], implementation [C4], and monitoring and evaluation[C5]) have been costed jointly for biological control, labour-intensive control, and mechanised control. For the cross-cutting interventions, the development of legislation and its enforcement [D1 and D2 in Table 2.2] have been combined under "legal interventions", while information management [D4], research [D6], and awareness-raising [D7] have been combined under "Knowledge development and communication".

Key management interventions	Base units used to quantify management intervention	Unit cost	Units treated or managed per annum	Cost (2014-equivalent rands)
Prevention				
Joint inspectorate at borders	Vectors	4 000	34 000	136 000 000
Identify high-risk pathways and implement management for each	Pathways	3 000 000	50	150 000 000
Implement risk assessment protocol	Species assessed and permits issued	100 000	2 000	200 000 000
Early eradication				
Monitor key sites	Sites	1 000	100 000	100 000 000
Emergency response	Emergency events	5 000 000	5	25 000 000
Eradication of target species	Species	3 000 000	60	180 000 000
Containment and impact reduction				
Weed biological control	Species	4 000 000	30	120 000 000
Labour-intensive control	Sites	28 000	120 000	3 360 000 000
Cross-cutting activities				
Legal interventions	People or business entities	100 000	1 000	100 000 000
Collaborative governance	Participants	60 000	500	30 000 000
Capacity-building	People	100 000	1 000	100 000 000
Knowledge development and communication	People	400 000	1 000	400 000 000
			Total indicative expenditure required	**R4.95 billion**

It should be noted that it was necessary to make a number of assumptions in order to arrive at these estimates. They are therefore preliminary, and should be treated as such. It would be important for future revisions of this Strategy to build on these initial estimates by clarifying the assumptions where necessary.

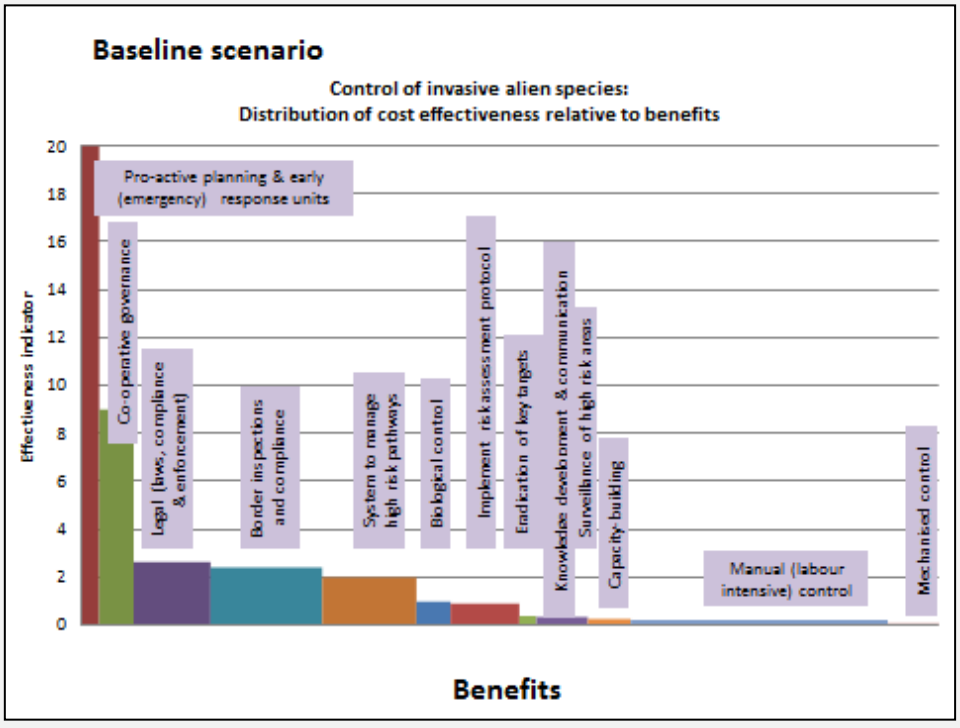
11.5 Potential future options for improving funding

In the medium term, during the implementation of this Strategy, attention should be given to assessing various options that could improve the funding situation. These are outlined briefly in Box 11.2. The various options and schemes that should generate additional funds for the management of biological invasions are provided in Box 11.3.

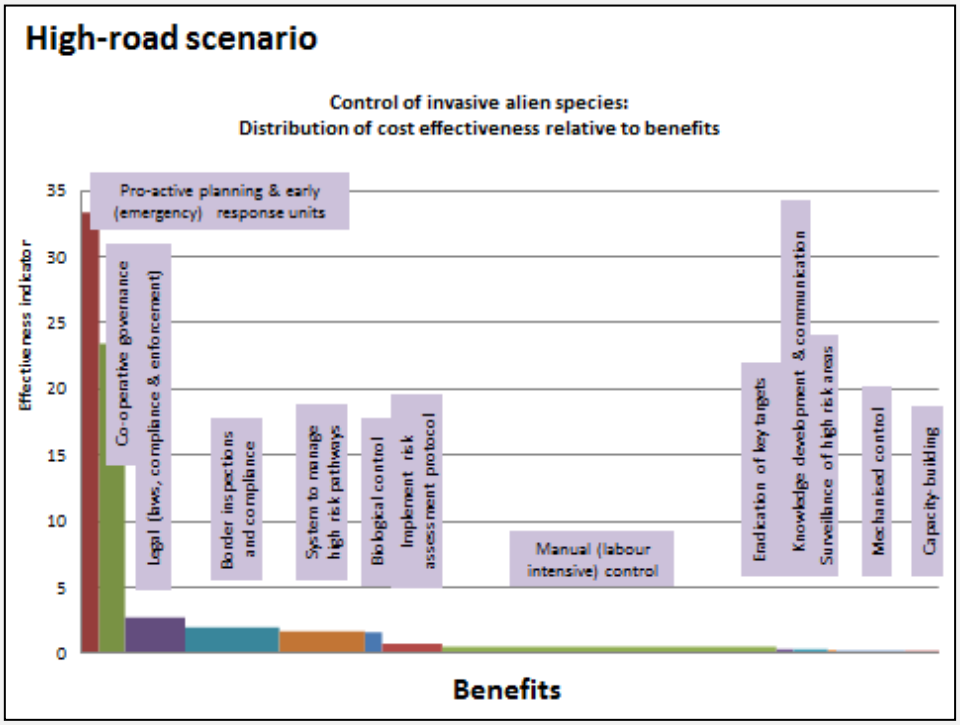
Box 11.2. Options for improving funding: A preliminary scenario exercise.

Funding for the management of biological invasions could be improved by changing several approaches, and these will be considered in the medium-term planning of the Natural Resource Management Programmes of the DEA. The ideas provided here are preliminary. Each is described briefly below.

Investing in more efficient management interventions (changing *what* is done): Available funding could be used for different (more efficient) interventions; it could be used to change the relative amounts spent on different interventions; or it could be used in different areas where the overall benefits would be greater. A preliminary analysis has identified several actions which are comparatively or relatively more effective than others (Box Figures 11.1 and 11.2; see the explanation in Section 2.5). This suggests that it would be prudent to provide adequate resources for those management interventions identified as highly effective, such as pro-active planning and early (emergency) response units, and cooperative governance, as a matter of priority, given their relative effectiveness. This method will be very useful for examining priorities in future. However, in order for this model to effectively guide the development of policy, it will be necessary to ensure that the concepts are fully understood by policy-makers and senior managers. This will require ongoing engagement with the economists engaged in the development of the model.



Box Figure 11.1. A baseline scenario (i.e. best possible outcomes under business-as-usual conditions) for the relative effectiveness (given by the height of the bar) and the relative quantum or size of the benefits (given by the width of the bar) of various invasive species management interventions.



Box Figure 11.2. A high-road scenario (i.e. best possible outcomes after implementing improvements) for the relative effectiveness and the relative quantum or size of the benefits of various invasive species management actions Note the higher effectiveness indicator for proactive planning and cooperative governance (compared to Figure 11.1), and the shift in ranking and quantum of benefits supplied by manual control.

Reducing inefficiency in management (changing *how* things are done): To examine this question, four measures were used to define the benefits associated with management interventions: (1) the number of species affected by the intervention; (2) the likelihood of success of the intervention; (3) the number of people affected by the implementation of the intervention; and (4) the time needed to generate the benefits (see section 2.5). Thus, increasing the number of species targeted, or increasing the likelihood of success through better planning, improved management and quality control, or moving projects to areas where more people would benefit would all increase efficiencies. The number of species targeted by interventions such as border inspections could be increased if border officials and implementing agents could identify more priority, high risk species on the same budget. There are also a myriad of ways in which the likelihood of success should be improved through better training and improved professional management. Significant gains should be sought by making more efficient use of existing funds (compare Box Figures 11.1 and 11.2). The comparison shows, for example, the potential to improve manual (labour intensive) control from being ranked 11th to 8th in terms of effectiveness and to increase the magnitude of benefits. This is especially important given that while manual clearing is highly beneficial to a lot of people (the width of the bar), even though it is among the more expensive options (indicated by the height of the bar). It is therefore one of the essential actions because of the large relative benefits gleaned from it.

Eliminating duplication of effort: There may be similarities between current and proposed management interventions by different arms of government and the private sector. Besides the proposed interventions of the Department of Environmental Affairs (DEA), other departments and the private sector also make substantial investments into actions aimed at managing invasive species. Efforts could be made to align the resources available for invasive species management with the priorities of this Strategy, so as to improve the overall efficiency of management.

Sharing the cost burden: Travellers, traders, farmers, foresters and horticulturalists who import or otherwise make use of alien species, or who unintentionally transport such species across borders, all contribute to the risk of introducing a potentially invasive and harmful species. It could reasonably be expected that such people or organizations should contribute to the costs of reducing these risks. Likewise, those groups who benefit from the management of invasive species should make a contribution to the costs of such management. Such cost-sharing would reduce the burden on the national fiscus. See Box 11.3.

Box 11.3 Options or schemes that should generate additional funds for the management of biological invasions.

Box Table 11.3.1. Outline of potential funding sources and distribution mechanisms associated with key interventions for the management of biological invasions. Definitions are provided in the footnotes to this Table.

Management actions	Who is responsible for management and implementation, and raising the funds	Who generates the risk, or is liable to pay for the management costs or the agent responsible for funding	Pricing option (Revenue raising mechanism)	Financing option (Disbursement mechanism to implementing agent)
Prevention				
Joint inspectorate at borders	Customs officials	Vector/carrier	User charges (inspection charge for planes and ships) and penalties	Department budget
Identify high-risk pathways and implement management for each	National government	Vector/carrier (industries/businesses)	User charges (levy on trade) and penalties	Department budget
Implement risk assessment protocol	National government	Vector/carrier (importing industry/businesses)	User charges (government to fund developing protocol, trader to pay assessment costs) and penalties	Department budget
Early eradication				
Monitor key sites	National and provincial government	National and provincial government	Taxes	Department budget and PPP
Emergency response	National and provincial government	Vectors and national and provincial government	User charges and taxes	Department budget and PPP
Eradication of target species	National and provincial government	Vectors and national and provincial government	User charges and taxes	Department budget and PPP
Containment and impact reduction				
Weed biological control	Government and land owners and user	Vectors, government and land owners and user	User charges, taxes; environmental funding; private sector; penalties	Department budget, PPP and offsets
Labour-intensive control	Government and land owners and user	Vectors, government and land owners and user	User charges, taxes; environmental funding; private sector; penalties	Department budget, PPP and offsets
Mechanised control	Government and land owners and user	Vectors, government and land owners and user	User charges, taxes; environmental funding; private sector; penalties	Department budget, PPP and offsets

Cross-cutting				
Legal interventions	National and provincial government	National and provincial government	Taxes and penalties	Department budget
Collaborative governance	National and provincial government	National and provincial government	Taxes	Department budget
Capacity-building	National and provincial government and research institutes	National and provincial government and research institutes	Taxes, user charges and private sector	Department budget and PPP
Knowledge development and communication	National and provincial government and research institutes	National and provincial government and research institutes	Taxes, user charges and private sector, e.g. scholarships	Department budget and PPP

Definitions:

User charge: When an entity is to pay for services delivered, i.e. directly requited payments linked to a specific quality and level of service delivered; these are a form of payment for the use of resources, infrastructure, and services.

Taxes: These are charges, usually levied by central government, on individuals and businesses with the specific purpose of raising funds for the activities of the state and parastatal organisations

Environmental funding: These include payment for environmental services systems, but could also be linked to water charges for either the use and/or the reduction in flow of water. In its strictest sense payment for environmental service is a voluntary transaction in which a well-defined environmental service, or land use likely to secure that service, is being "bought" by a minimum of one service buyer who in return compensates a minimum of one service provider, if and only if the environmental service provider secures the quality and quantity of that environmental service. Broader definitions would include 'in kind transactions' as well as risk mitigation/minimisation and insurance-like payments for activities that has the potential of reducing risk or delivering a service at a future date.

Private sector: Private sector investment in a sector to either avoid losses (e.g. the avoidance of losses due to pests), and/or for commercial purposes, such as the clearing of invasive alien plants for the purpose of generating electricity

Penalty: A non-compliance fee imposed on a user who does not comply with environmental requirements and regulations

Department budget: Changes in the budget allocation to a government department to fund the necessary management actions.

PPP: Public-private partnerships, where an entity can act as an implementing agent on behalf of government.

Offsets: Means by which public and private sector entities can generate goodwill by contributing to environmental improvements. Benefits are tailored to the local environment

11.6 Key actions

KEY ACTION	TARGET
Undertake a rigorous re-alignment of the five-year projected budget, based on estimated returns on investment, within the constraints imposed of existing commitments.	Re-aligned budget that considers the returns on investment from various interventions, including bio-security, legal compliance, clearing, herbicide assistance, biological control, high-altitude work, plants *vs* other taxa, and value-added industries (separating out the Eco-Furniture Programme, biomass-to-energy, and building materials as three major foci).
Undertake a strategic alignment of the investments of various government departments to eliminate duplication.	Strategic alignment completed and implemented.
Improve efficiencies by examining and re-aligning the current mix of interventions, and by taking steps to improve the efficiency of implementation and to increase the quantum of benefits.	Complete report with agreed steps, and initiate implementation.
Develop a program to pursue the funding options listed in Table 11.2. This would include the development of legislation to enable the generation of revenue from the different user groups and to facilitate the distribution of management funds to implementing agents.	Programme, supported by appropriate legislation, in place.

12. INDICATORS

This chapter provides high-level indicators to monitor the implementation and the track progress of the National Strategy for dealing with biological invasions in South Africa. The indicators are aligned with the objectives of the Strategy as set out in Chapter 1, Section 1.5. Data on indicators should be obtained on a regular basis, and can be used to assess progress towards the achievement of the objectives of the Strategy, as well as to provide information for other purposes, for example reporting on the state of the environment. The responsibility for ensuring that regular assessments are carried out should lie with the DEA, and can be delegated as a standing item on the agenda of the proposed Research Advisory Panel (see Chapter 9, Box 9.2).

A baseline for each of the indicators below should be established as soon as possible.

Table 12.1.Proposed indicators and potential sources of data to be used to monitor the progress of this strategy towards achieving its goals.

GOAL OF STRATEGY	PROPOSED INDICATOR	DATA SOURCES
Prevent the introduction of new species that pose a risk of becoming invasive	Number of completed pre-border risk assessments	Records of risk assessments
	Number of permit applications evaluated, and number of permits granted for import of new alien species	Records of permit applications and results
	Number of pathways or vectors regulated	Department of Environmental Affairs
	Decrease in rate of introduction of new alien species	Records of border interceptions, and of permits granted
	Number of alien species present in South Africa	Information from various sources
	Number of inspections of goods	Department of Agriculture, Department of Environmental Affairs, SARS
Eradicate introduced species where possible and desirable	Number of post-border risk assessments performed (both initial assessments and full detailed assessments)	Information from South African National Biodiversity Institute
	Number of alien species with naturalised populations	New records of naturalisation collated by the South African National Biodiversity Institute from various projects including iSpot, Southern African Plant Invaders Atlas, and other atlas projects.
	Emergency response plans in place.	Department of Environmental Affairs
	Number of formally-approved projects aimed at eradication of alien species	South African National Biodiversity Institute's Invasive Species Programme
	Number of alien species successfully eradicated	South African National Biodiversity Institute's Invasive Species Programme

GOAL OF STRATEGY	PROPOSED INDICATOR	DATA SOURCES
Reduce the rate of spread of invasions	Change in area occupied by priority listed invasive alien species	Information from South African National Biodiversity Institute (including iSpot), South African Plant Invaders Atlas, and other atlas projects.
	Number of invasive populations of species	As above
	Proportion of assessed fish sanctuary and protected areas in which alien fish are detected	South African Institute for Aquatic Biodiversity
Reduce the impacts of existing invasions	Change in area occupied by priority listed invasive alien species	Information from South African National Biodiversity Institute (including iSpot), South African Plant Invaders Atlas, and other atlas projects.
	Kilometres of river from which invasive alien fish have been locally extirpated	South African National Biodiversity Institute
	The number of alien plant species that reach a specified level of biological control (complete, substantial, negligible, not determined)	Plant Protection Research Institute, Agricultural Research Council
	Number of management plans in place, and meeting the minimum requirements of norms and standards for management plans; area covered by adequate management plans	South African National Biodiversity Institute
	Proportion of area invaded by alien plants under active management (management plans in place, and meeting the minimum requirements of norms and standards)	Records of the Department of Environmental Affairs
	Proportion of private sector investment	Records of co-agreements to fund control projects, recorded in management plans.
Establish an effective legislative and regulatory environment	Successful prosecutions of offenders	Department of Justice
Develop adequate capacity	Number of diplomas and undergraduate degrees awarded in accredited training programs	Accredited training institutions
	Number of post-graduate (honours, masters or doctoral) degrees awarded in the field of biological invasions	Accredited training institutions

GOAL OF STRATEGY	PROPOSED INDICATOR	DATA SOURCES
	Numbers of appropriately-trained people (at tertiary or post-graduate levels) employed in post structures of implementing agents	Human resources records within implementing agents
Research and development	Number of publications in ISI-accredited journals, located using appropriate keywords	Google Scholar
	Number of citations to articles produced over the past five years in ISI-accredited journals	Google Scholar
	Funding allocated to relevant research projects	Records of the Research Advisory Panel
	Evidence of technology transfer (research-based solutions taken up in policy or management)	Policy documents Management plans
Ensure cross-sector co-ordination and collaboration	Number of meetings of Working Group 1 that specifically address biological invasions	Minutes of Working Group 1 meetings
	Number of national meetings and research workshops on biological invasions	Minutes and attendance
Raise awareness	Number of information brochures and leaflets published and distributed	Department of Environmental Affairs
	Number of awareness events hosted	Department of Environmental Affairs
	Number of media stories	Surveys of press articles published
Expand the benefits of control projects	Number of full-time employment opportunities created	Department of Environmental Affairs
	Number of processing plants that utilize harvested biomass	Department of Environmental Affairs
Ensure effective monitoring and evaluation	Number of projects reportedly on track to achieving medium-term goals	Annual assessments of progress against goals as set out in approved management plans

13. REFERENCES

This section lists some of the key sources of information about biological invasions in South Africa, and illustrates the breadth and depth of research that has been conducted into the topic. Information in this Strategy drew from these sources. The sources used in individual chapters are listed as numbers at the end of each chapter, following the numbered list here.

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