

GISP

The Global Invasive Species Programme



AFRICA
invaded

**The growing danger of
invasive alien species**



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FOREWORD

Who benefits and who pays? This question is increasingly being asked in countries vulnerable to 'development' proposals that have unstated or unknown risks. And high on the list of dubious proposals are those that carry risks of invasive alien species (IAS). Ostensibly favourable aid or trade options may have devastating consequences, when IAS risks are not contained. Imported pet or ornamental plant species may have a frivolous financial benefit for a few, but impose major costs for countries and regions. And the hardest hit are invariably the poor.

The New Partnership for Africa's Development (NEPAD) offers a compelling opportunity for economic development in Africa, and greater equity in the global economy. It is fitting that NEPAD has placed a particular emphasis on the need to prevent and control invasive alien species. Africa already has too many examples of unwanted alien species that have severe constraints on its development potential, through impacts on biological diversity, the productive use of land, water security, fire, human health and many other usually unforeseen impacts. And things are rapidly getting worse.

The Global Invasive Species Programme (GISP) is an international partnership that aims to co-ordinate and facilitate responses to the growing threat of invasive alien species. The decision of GISP to base its Secretariat in Africa is an opportunity for us to take advantage of the experience and expertise that can help us to optimise Africa's development. This booklet is intended to raise awareness of this severe threat, and to promote the implementation of the relevant provisions of the Convention on Biological Diversity. GISP offers its services to assist African countries to deal with this debilitating scourge.

Dr Guy Preston
Chairperson
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INTRODUCTION



The Global Invasive Alien Species Issue

Invasive alien species are those that become established in a new environment, then proliferate and spread in ways that are destructive to biodiversity and / or human interests.

The spread of invasive alien species (IAS) is now recognised as one of the greatest threats to the ecological and economic well-being of the planet. It is creating complex and far-reaching challenges that threaten both the natural biological riches of the earth and the well-being of our people. These species are causing enormous damage to biodiversity and the valuable natural agricultural systems upon which we depend. Direct and indirect health effects are increasingly serious and the damage to native biodiversity is often irreversible. The effects may be exacerbated by global change and chemical and physical disturbance to species and their habitats.

Continuing globalisation, with increasing trade, travel, and transport of goods across borders, has brought tremendous benefits to many people. It has, however, also

facilitated the spread of IAS, with increasing negative impacts. The problem is global in scope and requires international cooperation to supplement the actions of governments; the private sector and organisations at national and local levels.

IAS are found in nearly all major taxonomic groups of organisms. Invasive species include viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals.

Even though only a small percentage of species that are moved across borders become invasive, these may have extensive impacts. Economic costs alone run into hundreds of billions of U.S. dollars per annum. Other serious impacts are on human health, native biodiversity and ecosystems.



INTRODUCTION

Socio-economic costs

Invasive alien species have many negative impacts on human economic interests. Weeds reduce crop yields, increase control costs, and decrease water supply by degrading water catchment areas and freshwater ecosystems. Tourists unwittingly introduce alien plants into protected national areas, where they degrade protected ecosystems and drive up management costs. Pests and pathogens of crops, livestock and trees, destroy plants outright, or reduce yields and increase pest control costs. The discharge of ballast water introduces harmful aquatic organisms to both marine and freshwater ecosystems, in some cases reducing the yield of commercially important fisheries.

DIRECT AND INDIRECT COSTS

Considerable uncertainty remains about the total economic costs of invasions. However, estimates of the economic impacts on particular sectors indicate the seriousness of the problem. The varroa mite, a serious pest in honeybee hives, has recently invaded New Zealand and is expected to have an economic cost of **US\$267-602 million**, forcing beekeepers to alter the way they manage hives. Beekeepers argue that had border rules been followed or had surveillance detected the mite earlier, the problem could have been avoided entirely. It now appears too late to eradicate the mite, requiring a mitigation plan that is expected to cost \$1.3 million in its first stage.

A 1992 report by the Weed Science Society of America estimated that the total **cost of invasive weeds was between \$4.5 billion and \$6.3 billion**. While the range of these figures indicates their uncertainty, they also indicate the serious impact of IAS and argue for significant

investments to prevent the spread and proliferation of these species.

In addition to the **direct costs** of management of invasives, the economic costs also include their **indirect environmental consequences and other non-market values**. For example, invasive species may cause changes in ecological services, including:

- **flood control and water supply**
- **waste assimilation**
- **recycling of nutrients**
- **conservation and regeneration of soils**
- **pollination of crops, and**
- **seed dispersal.**

In the **South African Cape Floral Kingdom**, the establishment of invasive tree species has decreased water supplies for nearby communities, increased fire hazards, and threatens native biodiversity, justifying government expenditures of **US\$40 million per year for a control programme**.

EXTERNALITIES

Although the loss of crops due to weeds or other alien pests may be reflected in the market prices of agricultural commodities, such costs are seldom paid by those who introduce the pests. Rather, these costs are negative 'externalities', i.e., costs that an activity unintentionally imposes on another activity, without the possibility of compensation for such costs. One special feature of biological invasions, as externalities, is that the costs of invasions are largely self-perpetuating, once they are set in motion. Even if confirmed introduction ceases, damage from the invasives already established continues, and may increase.





INTRODUCTION



THE DEVELOPING WORLD

Most evidence of economic impact of IAS comes from the developed world. However, there is strong evidence that the developing world is experiencing similar, if not proportionally greater, losses.

Invasive alien insect pests, such as the **white cassava mealybug and larger grain borer in Africa pose direct threats to food security.** Invasive weeds constrain efforts to restore degraded land, regenerate forests and improve utilisation of water for irrigation and fisheries. The control of water hyacinth and other alien water weeds affecting water use currently costs developing countries over US\$100 million annually.

Further, many introductions are unintentional, including most invertebrates and pathogens. Prices or markets



cannot readily reflect the costs of these introductions. But even in the case of introductions involving deliberate imports to support agriculture, horticulture, forestry, and fisheries, market prices for seeds, plants, or foods, do not generally reflect the environmental risks associated with their use. Thus producers have little financial incentive to absorb the potential cost of the loss of native species or disturbance to ecosystem functions. The policies developed to deal with incentives to reduce biodiversity

loss – **economic tools such as taxes, subsidies, permits, and so forth** – may not always be well suited to deal with the problem caused by invasions. This point highlights the urgent need for new economic approaches to deal with IAS.

Human health costs

The dynamic interactions among invasive pathogens, human behaviour, and economic development are complex. They depend on interactions between the virulence of the disease, the susceptibility of populations, the pattern of human settlements, and their level of development.

Large development projects, such as dams, irrigation schemes, land reclamation, road construction and population resettlement programmes, have contributed to the spread of **diseases such as malaria, dengue fever, schistosomiasis and trypanosomiasis.**

The clearing of forests in tropical regions to extend agricultural land has opened up new possibilities for wider transmission of viruses that carry haemorrhagic fevers that previously circulated benignly in wild animal hosts. Examples include Argentine haemorrhagic fever, 'Guaranito' virus, Machupo virus, and Basia virus. Some pathways for the biotic invasion are complicated. For example, the prevalence of lymphatic filariasis in the southern Nile Delta has increased 20-fold since the building of the Aswan dam in the 1960s. This increase has been due primarily to the increase in breeding sites for the mosquito vector of the disease, following the rise in the water table caused by the extension of irrigation. The problem has been exacerbated by increased pesticide resistance in the mosquitoes, due to heavy agricultural pesticide use and by rural-to-urban commuting among farm workers. Thus invasive species combined with variations in rainfall, temperature, human population density, population mobility and pesticide use all contribute to one of the most profound challenges of invasive species: the threat to human health.



INTRODUCTION

IAS AS INFECTIOUS DISEASE AGENTS

Infectious disease agents often, and perhaps typically, are invasive alien species. Unfamiliar types of infectious agents, either acquired by humans from domesticated or other animals, or imported inadvertently by travellers, can have devastating impacts on human populations. Pests and pathogens can also undermine local food and livestock production, thereby causing hunger and famine. Examples include:

- The **bubonic plague** spread from central Asia through North Africa, Europe and China using a flea vector on an invasive species of rat.
- The viruses carrying **smallpox and measles** spread from Europe into the Western Hemisphere shortly following European colonisation. The low resistance of the indigenous peoples to these parasites helped bring down the mighty Aztec and Inca empires.
- **Rinderpest**, a viral disease, was introduced into Africa in the 1890s via infected cattle, subsequently spreading into both domesticated and wild herds of bovids throughout the savannah regions of Africa, changing the mammalian composition of much of the continent. Up to 25% of the cattle-dependent pastoralists may have starved to death in the early 20th Century because rinderpest wiped out their cattle populations.
- The **influenza virus** has its origins in birds but multiplies through domestic pigs which can be infected by multiple strains of avian influenza virus and then act as genetic 'mixing vessels' that yield new recombinant-DNA viral strains. These strains can then infect the pig-tending humans, who then infect other humans, especially through rapid air transport.

Cost to biodiversity

Invasive alien species can transform the structure and composition of ecosystems by repressing or excluding native species – either directly by out-competing them for resources, or indirectly by changing the way nutrients are cycled through the system. IAS can affect entire systems; for example, when invasive insects threaten native species of insects, they can also have cascading effects on insect-eating birds and on plants that rely on insects for pollination or seed dispersal.

Increasing global domination by a relatively few invasive species threatens to create a relatively homogeneous world rather than one characterised by great biological diversity and local distinctiveness.

No criteria have yet been agreed upon for the minimum damage, spread or size of population needed for an alien species to be considered invasive. However, it is clear that a very small number of individuals, representing a small fraction of the genetic variation of the species in its native range, can be enough to generate massive environmental damage in a new environment.



The Convention On Biological Diversity –CBD

Numerous international instruments, binding and non-binding, have been developed to deal with aspects related to the IAS issue. The most comprehensive is the Convention on Biological Diversity (CBD), which calls on its parties – 188 governments as of 2003 – TO PREVENT THE INTRODUCTION OF, CONTROL OR ERADICATE THOSE ALIEN SPECIES WHICH THREATEN ECOSYSTEMS, HABITATS, OR SPECIES (Article 8h).

The CBD was one of the main results of the UN Conference on Environment and Development, held in Rio de Janeiro in 1992, and it entered into force in 1993.

The CBD commits governments to:

- take appropriate measures to conserve biological diversity
- ensure the sustainable use of biological resources, and
- promote the fair and equitable sharing of benefits arising from the use of genetic resources.

Under the CBD, governments agree to:

- prepare national biodiversity strategies and action plans
- identify genomes, species, and ecosystems crucial for conservation and sustainable use
- monitor biodiversity and factors that are affecting biological systems
- establish effectively managed systems of protected areas
- rehabilitate degraded ecosystems
- exchange information
- conduct public information programmes, and
- implement various other activities to meet the objectives of the CBD.

A set of guidelines entitled 'Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species' has been developed to assist countries with the implementation of Article 8(h). These guidelines can be found as an Annex to Decision VI/23 of the 6th meeting of Contracting Parties.

www.biodiv.org

The Global Invasive Species Programme – GISP

The GISP mission is to conserve biodiversity and sustain human livelihoods by minimising the spread and impact of invasive alien species (IAS).

To this end, GISP seeks to:

- Improve the scientific basis for decision-making on invasive species
- Develop capacities to employ early warning and rapid assessment and response systems
- Enhance the ability to manage invasive species
- Reduce the socio-economic impacts of invasive species and control methods
- Develop better risk assessment methods, and
- Strengthen international agreements.

GISP strives to:

- Develop public awareness and education about invasive species
- Improve understanding of the ecology of invasive species
- Examine legal and institutional frameworks for controlling invasive species
- Develop new codes of conduct for the movement of species, and
- Design tools for quantifying the impact of invasive species.

The goal of GISP is to enable governments and other organisations to use the best practices available to control IAS and to promote the development of additional tools and strategies needed to improve global management of IAS. GISP recognises that it is dealing with dynamic ecosystems; it does not advocate attempts to ‘freeze’ any particular ecosystem in an imagined pristine state. Rather, it realises that active management of human effects on ecosystems is required in a time of increasing human impact.

Key GISP activities:

- A key focus for GISP is to support the implementation of relevant international legal instruments such as the Convention on Biological Diversity, **in particular by acting as the focal point on IAS for its Clearing House Mechanism.**
- GISP is a facilitating and enabling body, supporting a variety of global players in the IAS field. To this end, the GISP Secretariat works closely with various partner organisations all over the world.
- The newly established GISP Secretariat is based in Kirstenbosch Gardens in Cape Town, South Africa. Apart from facilitating IAS work, the Secretariat supports work in the areas of communications, education and training, information management, IAS management, evaluation and assessment, economics and law and policy. Within South Africa, GISP has a special partnership with Working for Water and Ukuvuka – two highly successful local IAS programmes.
- A variety of multi-lingual publications and tools are developed and disseminated by GISP, including procedural best practice manuals, toolkits, educational material and regional / thematic specific information packages.

www.gisp.org



AFRICA invaded

The growing danger of invasive alien species

This publication is one of the first products to emerge from the GISP Secretariat, established in South Africa in June 2003. It is designed to be part of a series of similar publications, focusing on various regions, continents and ecosystems around the world, especially those in the developing world. The publication should be seen as part of a wider awareness raising and information programme, complementing other GISP projects and documents like the GISP Global Strategy and the GISP Toolkit, both available in various languages from the website.

The publication aims to raise general awareness in Africa, and elsewhere, about some of the more prominent IAS issues facing the Continent today. It is not a technical document, but rather aims to demonstrate the diversity of the IAS issue to a broad audience, including decision- and policy-makers, government departments and the general public. Focusing not on a list of top invaders, but rather showcasing diverse species, affecting different ecosystems and regions within Africa, it highlights but a small percentage of IAS invading Africa today. What is clearly evident, is that the IAS issue in Africa is enormous and continuously growing – both in terms of the number and diverse range of species invading the continent, and their impact on native biodiversity and on the lives of all Africans.

It should be noted that some very prominent and serious health issues like HIV Aids and others – which are regarded by many experts as **the** global IAS issue – have not been included, because of the amount of existing information already published on them. Rather, IAS with perhaps less publicised impacts are introduced in this publication, in order to demonstrate the widespread effect of IAS.

The people of Africa are constantly in contact with and surrounded by IAS. Addressing the IAS issue requires urgent and consolidated national, regional and international action. GISP hopes that this publication, in a small way, may assist the Continent in its efforts to win the battle against IAS.

LANTANA



Lantana camera is indigenous to South and Central America, but was widely introduced as an ornamental plant and is now considered a weed in about 50 countries worldwide. In Africa it has invaded much of sub-Saharan Africa, forming dense thickets that displace natural communities and compromise agricultural productivity.

Weed of many colours

Lantana is a **highly variable species**, with hundreds of different cultivars that differ in appearance and in their tolerance to environmental conditions. The plant may occur as a compact shrub or a scrambler more than 5 metres high, and is often used as a hedge plant because it forms impenetrable barriers. However, it is this quality

that makes it such a menace when it invades agricultural land and forestry plantations. The thickets disrupt access of livestock to grazing and water, interfere with farming and forestry activities, and increase the intensity of fire. By encroaching onto pastures, they reduce the carrying capacity and productivity of agricultural land. Lantana is also a weed in a variety of crops, including coffee, coconuts, cotton, bananas, pineapples and sugarcane.

Furthermore, **the entire plant is toxic** and ingestion of the leaves and fruit can poison cattle and sheep, exhibiting as increased sensitivity to sunlight. The soft skin of the nose, eyes, ears and lips become covered in sores that make eating and breathing painful, causing the animals to lose condition or even die. In some areas, lantana thickets provide a breeding ground for tsetse flies, which transmit the parasitic trypanosomes that cause *nagana*, an animal form of sleeping sickness.

LANTANA



Unfriendly neighbour

Little else can grow in lantana thickets because the plant releases chemicals into the soil to prevent other plants from germinating. The absence of an understorey community to provide groundcover results in increased erosion, particularly on steep slopes. By excluding other species the thickets reduce plant biodiversity and change the composition of associated animal communities.

Lantana is able to spread rapidly once introduced to an area as the seeds are widely dispersed by birds eating the fruit, and are sometimes also washed from infested areas during floods, causing sudden invasions downstream.

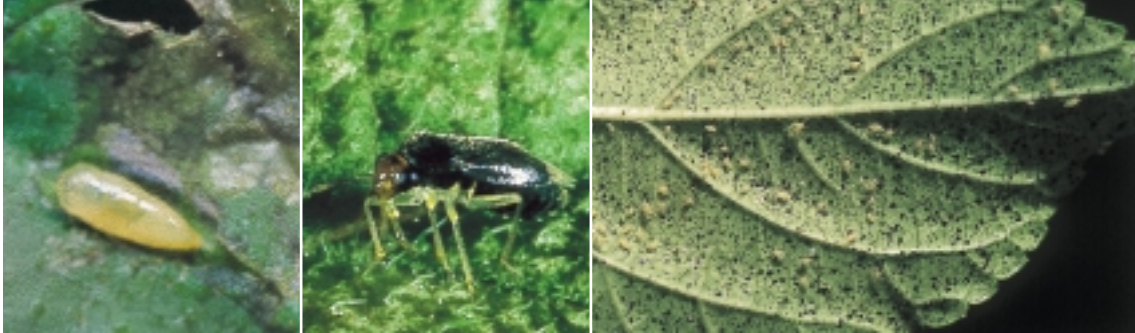
Control

Lantana is difficult to control, as it will coppice and form denser thickets if it is simply slashed and left. **Mechanical control** is labour-intensive, and should only be used on its own for seedlings and small, individual plants. These can

be uprooted by hand-pulling when the soil is moist or first loosened with a hoe, pick or fork. Uprooting of large plants or dense thickets is not recommended as it results in soil disturbance, increasing the risk of soil erosion and re-infestation by lantana seedlings and other opportunistic weeds.

A combination of mechanical and chemical control is best used for larger plants and dense thickets. Top growth should be cut away and the plant felled close to the ground, after which the stump should be treated with a registered herbicide. Foliar application of herbicides is suitable for small lantana plants and re-growth. But for large, dense bushes it is expensive and not very successful, since the maximum height that can be reached using a knapsack sprayer is about 2 metres. All forms of control should be followed by **revegetation**, ideally with indigenous groundcovers, to prevent seedlings from forming new thickets. It is also essential that ongoing follow-up work, involving handpulling of seedlings and spot-spraying of regrowth, is conducted at least annually.

LEFT: Pupa of the herringbone leafminer MIDDLE: Adult *Falconia* on lantana leaf RIGHT: Young *Falconia* nymphs on lantana leaf



A long history of biological control

Internationally, there is a long history of biological control of lantana, but there are few completely successful examples. In South Africa **at least 12 biocontrol species** have become established on lantana, yet it remains one of the country's most vigorous invasive weed species. The biocontrol agents include two leaf-sucking bugs, two leaf-mining beetles, a seed-feeding fly, a leaf-mining fly, two leaf-feeding moths and a flower-feeding moth.

The most promising agent is the **lantana mirid *Falconia intermedia***, first released in 1999. Both the adults and nymphs are sapsuckers that feed on the leaves, removing the chlorophyll that is vital for photosynthesis, which causes white specks on the upper surface of the leaf. Severe feeding damage can result in the entire plant taking on a silvery white appearance and losing leaves prematurely. This starves the plant of resources and limits

its capacity to produce flowers, new leaves and shoots. By reducing the plant's aggressive growth rate, the mirid allows other species to compete with lantana for space.

The latest biocontrol agent to become established is a leaf-mining fly, the **herringbone leafminer *Ophiomyia camarae***. Owing to its short generation time and high egg-production rate, it has the potential to increase rapidly in numbers. During her 18-day lifespan the female lays approximately 92 eggs, depositing them singly inside the veins of lantana leaves. When the eggs hatch, the larvae feed on leaf tissue by mining through the leaf for 8 to 10 days before pupating. The mining damages the fluid transport system of the leaf, causing it to drop prematurely.

By suppressing growth and reproduction of lantana, biological control will not only reduce the cost of conventional control, but also help decrease the invasive potential of the weed.



Damage to lantana bush (foreground) caused by *Falconia*

CHROMOLAENA



Chromolaena odorata – commonly called chromolaena, triffid weed or Siam weed – is one of the worst invasive plant species in the humid tropics and sub-tropics of the world. Its native range extends from Florida in the United States to northern Argentina, but it has invaded south-east Asia, parts of Oceania, and West, Central and southern Africa, where it is a major threat to biodiversity, agriculture and human welfare.

One continent, two invasions

Chromolaena occurs as both a shrub standing at least 3 metres tall in the open, and as a scrambler reaching a height of 10 metres among trees. It grows rapidly and produces massive quantities of small, light seeds – more than a million per plant – which are dispersed over long distances by wind, and also by humans, animals and water. The plant thrives on disturbed land and readily invades

crops, pastures and plantations. It tends to form dense thickets, which smother indigenous vegetation and increase the intensity of fire.

In Africa there are two centres of invasion, each with a distinct form – or biotype – of chromolaena. The **west African** form was introduced from an invasive population of chromolaena in south-east Asia, while the morphologically different **southern African** form apparently originated from a northern Caribbean island, possibly Jamaica.

Chromolaena was first introduced to Nigeria in the late 1930s, and spread rapidly through most of West and Central Africa. It now occurs from eastern Guinea to the central parts of the Democratic Republic of Congo and the Central African Republic, and southwards to northern Angola. It decreases the region's agricultural productivity by invading crops, grazing areas and young or neglected plantations of timber, cocoa, citrus, rubber and oil palm. The leaves cause acute diarrhoea of cattle when browsed, and skin rashes and irritation in some people after contact.

Chromolaena was probably introduced to southern Africa either deliberately as an ornamental plant, or accidentally in seed-contaminated packing material off-loaded at Durban harbour from the West Indies. The plant was recorded as naturalised in the Durban area in the 1940s, and by the 1970s had spread throughout the subtropical areas of KwaZulu-Natal province. It has since invaded other provinces to the south and north, as well as the neighbouring countries of Swaziland, Mozambique and possibly Zimbabwe. It is anticipated that the invasion front will in time converge with that of the West African / Asian biotype (which also occurs in Mauritius), as the intervening region is climatically suitable.

Threatening conservation and ecotourism

In South Africa, chromolaena is mainly considered a threat to conservation and ecotourism, as it has primarily invaded natural areas. It reduces the biodiversity of grassland, savannah and forest, and compromises game-viewing in nature reserves and national parks. It also impacts on commercial forestry, both by suppressing the growth of young pine and eucalypt trees through competition, and by allowing fire to penetrate deeper into plantations. The plant impinges on agriculture to a lesser extent than has been reported for other invaded regions. While it does affect subsistence grazing and cropping, commercial sugarcane and fruit-farming enterprises are able to afford the costs of control.

Control

Chromolaena control requires an integrated approach, the methods used being dependent on the size of plant and the type of vegetation infested. Repeated follow-up



Pareuchaetes moths

work is necessary, as the plant is capable of vigorous growth from stem coppice, root suckers and seed.

Seedlings and young plants can be removed by handpulling, while herbicides are available for cut-stump treatment and for foliar application to seedlings and coppice growth. An annual burning regime effectively controls chromolaena invasions in grassland by killing mature plants and preventing new seedlings from establishing.

Initial attempts to achieve **biological control** of chromolaena in Africa failed, after the **leaf-feeding moth *Pareuchaetes pseudoinsulata*** and a **seed-feeding weevil** released in Nigeria and Ghana in the early 1970s failed to establish. The programme was revived by Ghana in 1989, and a decade later *P. pseudoinsulata* was well-established in the country's infested areas. Feeding by the moth has significantly reduced chromolaena populations, while other herbaceous species have recovered. Additional potential biocontrol agents are also being investigated, particularly the **stem-galling fly *Cecidochares connexa***, which has proved very successful in Indonesia.

However, in the rest of the West and Central African region there has been little progress with regard to biological control, due to a perceived conflict of interest



Pareuchaetes caterpillars

CHROMOLAENA



with the agricultural sector, which views chromolaena as an important fallow crop.

In South Africa, both *P. pseudoinsulata* and the related *P. aurata aurata* failed to establish, but a third species, *P. insulata*, is now being released in large numbers. The adult moth lives for about a week, during

which time it does not feed but mates and lays eggs, the female depositing groups of up to 80 eggs on the underside of chromolaena leaves. After hatching the caterpillars feed on the leaves, sometimes completely defoliating plants. The resulting reduction in plant height and density allows other plant species to compete for the newly created space.

Other biocontrol agents that are currently being assessed in field trials, in quarantine, or in their country of origin include a leaf-mining fly *Calycomyza eupatoriavora*, a stem-boring weevil *Lixus aemulus*, a stem-galling weevil *Conotrachelus reticulatus*, a root-boring flea beetle *Longitarsus horni*, a stem-tip mining moth *Carmenta* sp., a stem-galling fly *Polymorphomyia basilica*, and a shoot-tip mining fly *Melanagromyza eupatoriella*, as well as two leaf-attacking pathogens.

TRIFFID SCIENCE FICTION

Triffid weeds were walking, man-eating plants in the science-fiction book *The Day of the Triffids*, written by British author John Wyndham in the 1950s. The name was adopted for chromolaena because of the plant's monstrous, alien-invading characteristics!

Chromolaena and crocodiles

Chromolaena is the main invasive plant species in South Africa's Greater St Lucia Wetland Park, a World Heritage Site in the province of KwaZulu-Natal. The infestations are not only threatening the breeding habitat of crocodiles in the park, but also causing a gender bias in their offspring!

The crocodiles lay their eggs in sand on the banks of Lake St Lucia, but chromolaena is

encroaching onto these sites and shading the nests. Gender in crocodiles is determined by the temperature at which the eggs are incubated, and shading by chromolaena stands has been shown to lower the temperature of nesting sites by 5-6°C. This is sufficient to induce female-biased sex ratios, or may even prevent embryonic development altogether.



ACACIAS



The genus *Acacia* comprises some 1500 species, and close to 1000 of these are indigenous to Australia, where they are commonly known as wattles. Many other *Acacia* species naturally occur in Africa, spreading to other parts of the continent where they are considered serious invaders. Because of the vast number of acacia species, only a few are highlighted below, with a focus on some of the more serious Australian invasive species introduced to South Africa, highlighting a variety of negative consequences deriving from these introductions.

Loss of water and land

Alien acacias generally have higher water requirements than the indigenous vegetation they replace, so infestations in catchment areas and along watercourses reduce runoff and hence river flow. This not only has detrimental impacts on riverine and wetland ecosystems, but ultimately translates to less water in dams for agricultural, industrial and domestic use. Impenetrable thickets along watercourses block access of people and livestock to water, and obstruct the flow of rivers – particularly during floods, when fallen trees create logjams and blockages that cause further flood damage.

Dense stands of acacias also reduce the productive potential of land by taking over agriculturally valuable

areas, and heighten the risk and intensity of fire by increasing the fuel load. Very hot fires destroy the seeds of indigenous species, compromising post-fire regeneration.

Invading the Cape Floristic Region

Alien acacias also cause a loss of biodiversity by out-competing indigenous species and disrupting natural ecosystem functioning. **The Cape Floristic Region – world renowned for its rich biodiversity – is particularly vulnerable in this regard.** The indigenous fynbos plants are adapted to nutrient-poor sandy soils, but acacias are nitrogen-fixing plants that increase nitrate levels in the soil. Many indigenous species cannot survive in the enriched soils surrounding acacias, allowing the alien invaders to form bland monocultures. These spoil the Cape Floristic Region's natural beauty and detract from the tourism experience. Furthermore, the absence of ground-cover in acacia thickets may result in increased soil erosion.

Australian acacias that have become invasive in the Cape Floral Kingdom include rooikrans (*A. cyclops*), Port Jackson (*A. saligna*), long-leaved wattle (*A. longifolia*), black wattle (*A. mearnsii*) and blackwood (*A. melanoxylon*), as well as golden wattle (*A. pycnantha*), which is Australia's national floral emblem.

Ironically, an African acacia, *A. nilotica*, is one of Australia's worst invasive weeds!

Rooikrans

Rooikrans was originally introduced for drift-sand control, but is now well established in coastal and lowland fynbos throughout the Cape Floristic Region. Along the coast, the plant usually takes the form of a low shrub, but further inland it occurs as a tree with an average height of 3 metres, although it can grow as tall as 8 metres. Rooikrans is commonly used for firewood, and farmers value it as a source of stockfeed. The foliage is eaten by game and goats, while the pods can be fed to cattle.

Rooikrans produces massive quantities of seeds, which are widely dispersed by birds. Seeds can also be spread by coastal sand blown inland or taken from infested areas by birds and used for building. Like all invasive acacias, the seeds can remain viable in the soil for long periods prior to germination. However, rooikrans is one of the few species that can be **effectively controlled using mechanical methods alone** – since the plant does not coppice, it is not necessary to treat the stumps of felled rooikrans with herbicides.

Nevertheless, **biological control** offers the most sustainable control method in the long term. **The acacia seed weevil *Melanterius servulus*** was first released for the biological control of rooikrans in 1994. During spring, when mating occurs, the adult beetles feed on rooikrans flowers and developing seeds. The female beetles then chew small holes through the walls of developing pods

and lay their eggs singly on young seeds, so that the larvae will have a ready food supply after they hatch. The larvae burrow into and feed on the seed tissue, destroying the developing seeds in the process. After about six weeks they chew their way out of the pods and drop to the ground, where they pupate in the soil until they emerge as adult beetles six to eight weeks later (December-March). The beetles spend the remainder of the year overwintering under bark, becoming active in spring to begin the cycle again.

By destroying the viability of seeds, seed weevils not only reduce the rate of spread of rooikrans and other invasive acacias, but also limit regeneration from the soil seedbank after mechanical and chemical clearing.



Port Jackson

Port Jackson was introduced to South Africa for sand stabilisation and as a source of tannin, used in the leather industry. Once it was discovered that black wattle produced tannin of a superior quality, the Port Jackson plantations were neglected, and the species started spreading uncontrollably. It is now a serious invader in the coastal areas of the Cape Floral Region, and has also penetrated into the interior, especially along river valleys.

Control of Port Jackson is difficult, because the plant coppices after being cut down or burnt, and new seedlings can continue germinating from the soil seedbank for many years. **Control is therefore best achieved through a combination of mechanical, chemical and biological methods.**

Biological control of Port Jackson has to date relied mainly on the **gall rust fungus *Uromycladium tepperianum***, introduced from Australia. The fungal spores are dispersed by wind and rain, and when germinating on a Port Jackson plant they send thin filaments into the plant to extract nutrients from the cells.



The effect of the gall rust fungus

Eventually the fungus causes galls to develop on the branches and foliage of the Port Jackson plant. These are the spore-producing structures of the fungus, and they further drain the host plant of nutrients that would normally be used for growth and reproduction. A severe infestation of the gall rust fungus will kill the host tree by predisposing it to other stress factors, such as drought stress.

The acacia **seed weevil *Melanterius compactus*** has recently been introduced as an additional biocontrol agent for Port Jackson.



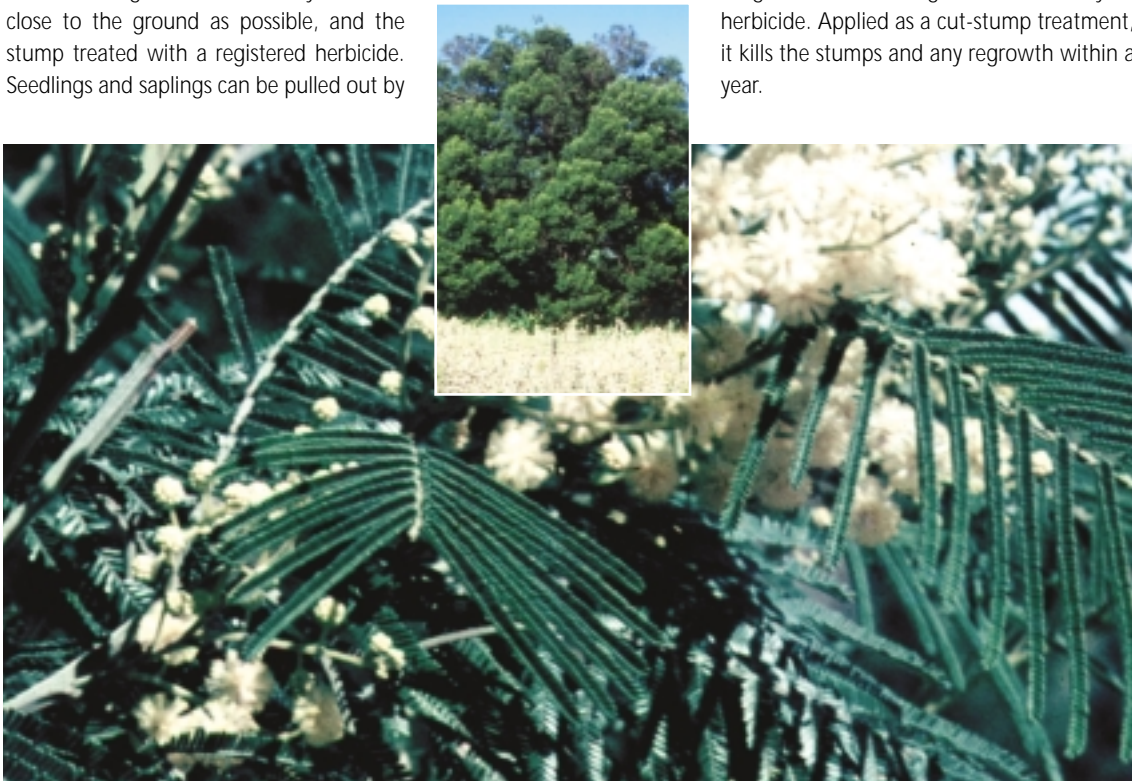
Black wattle

The black wattle is an evergreen tree normally 5-10 metres tall, although it can reach a height of 15 metres. **It is commercially cultivated for its tannin-rich bark, which is used in the leather industry, and also for its timber – a source of woodchips, firewood and building material.** However, the species has spread from plantations and is now widespread in South Africa. It invades fynbos, grasslands, forest gaps and roadsides, but is especially prolific along watercourses.

Black wattle is a vigorous resprouter, so felled trees will coppice unless the stump is treated or the entire plant is removed. Large trees are usually felled as close to the ground as possible, and the stump treated with a registered herbicide. Seedlings and saplings can be pulled out by

hand when the soil is damp, but **chemical control** is often preferable if growth is very dense as large-scale uprooting results in soil disturbance, which promotes the germination of wattle seeds. However, it is important that selective herbicides are used where grasses are present, and that diesel-based herbicides are not used along watercourses, so as to avoid contaminating the water.

The **seed-feeding weevil *Melanterius maculatus*** is available for the **biological control** of black wattle, while two gall-forming midges are being considered as supplementary biocontrol agents. In addition, an indigenous fungus has been registered as a myco-herbicide. Applied as a cut-stump treatment, it kills the stumps and any regrowth within a year.



Working for Water

South Africa's Working for Water programme is an internationally acclaimed model for invasive species control. By training and employing unskilled people from previously disadvantaged communities to clear invasive alien plants, the programme has the twin benefits of conservation and job creation.

More than 160 introduced plant species have become invasive in South Africa and most of these are water-guzzling plants, together

consuming about 7% of annual runoff. In recognition of their impact on the country's limited water resources, the South African government launched the Working for Water programme in 1995, with a R25 million allocation of poverty-relief funding. Since then the programme has cleared invasive alien plants from about a million hectares of land at more than 300 sites, created employment for at least 20 000 workers, and by 2004 had an annual budget of over R400 million.



Long-leaved wattle



The bud-galling wasp



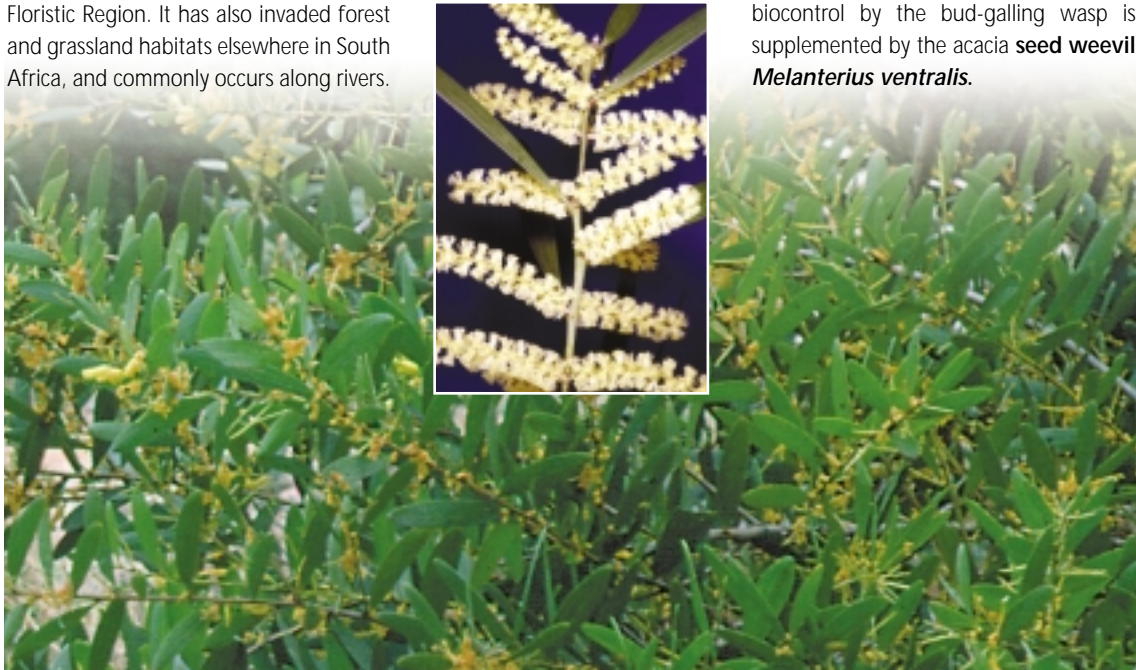
Galls on long-leaved wattle

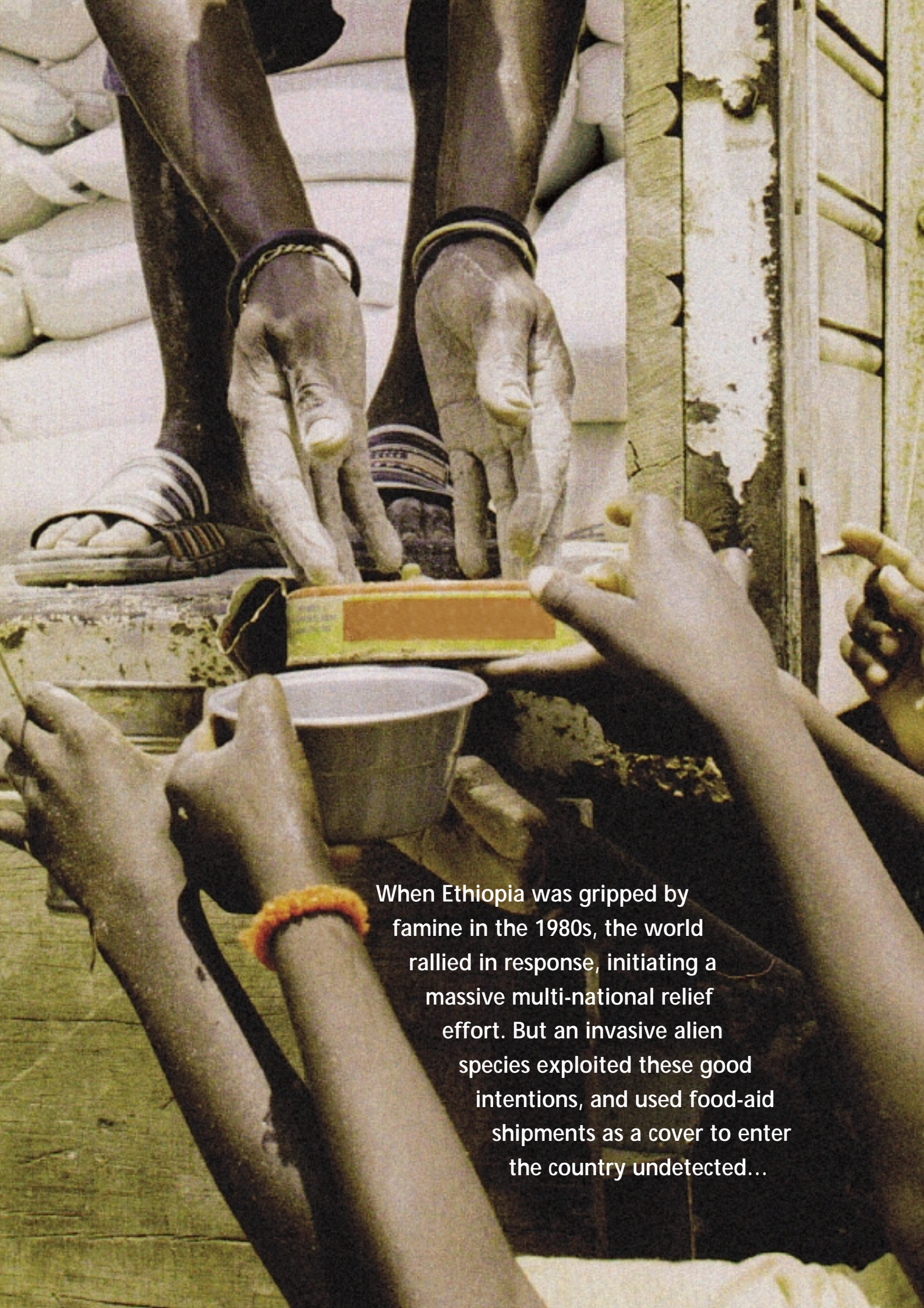
Like rooikrans and Port Jackson, the long-leaved wattle was originally introduced to stabilise drift-sand, but it failed to establish on coastal dunes. Instead it spread rapidly along the drier mountain slopes and became a major threat to mountain fynbos in the Cape Floristic Region. It has also invaded forest and grassland habitats elsewhere in South Africa, and commonly occurs along rivers.

Fortunately, the long-leaved wattle has been successfully brought under biological control. This has been achieved with two biocontrol agents that reduce both the rate of invasion and the density of existing infestations.

The bud-galling wasp *Trichilogaster acaciaelongifoliae* lays its eggs in immature flower buds on the plant. After the eggs hatch, the feeding larvae secrete chemicals that cause the buds to develop into round, fleshy galls. These not only prevent seed production in the affected buds, but also deprive other plant parts of nutrients and water. As a result, the plant grows more slowly and becomes susceptible to environmental stresses such as drought. Where water is not a limiting factor the reduction in seed production is not as marked, so in these areas

biocontrol by the bud-galling wasp is supplemented by the acacia seed weevil *Melanterius ventralis*.





When Ethiopia was gripped by famine in the 1980s, the world rallied in response, initiating a massive multi-national relief effort. But an invasive alien species exploited these good intentions, and used food-aid shipments as a cover to enter the country undetected...

PARTHENIUM



Parthenium hysterophorus, commonly called parthenium or congress weed, is an aggressive invader that is native to Mexico. The weed was first seen growing in Ethiopia in 1988 near food-aid distribution centres, so it is presumed that imported wheat grain was contaminated with its seeds. Once introduced, the weed was able to spread rapidly, as the seeds are readily dispersed in mud adhering to vehicles, machinery and animals, as well as by water and wind. The seeds can remain viable on the soil surface for up to two years, while buried seeds can stay dormant for as long as 20 years before germinating.

‘No crop’

Parthenium is a herbaceous annual with an erect stem that becomes woody with age, allowing it to reach a height of two metres. It colonises disturbed land, including overgrazed and recently ploughed or cleared areas, and because it has an allelopathic effect – the chemical inhibition of growth and seed germination of other plants – it can quickly dominate pastures and crop fields.

Indeed, it has had such a devastating effect on crop production in Ethiopia that it has earned a local name meaning ‘no crop’. The weed is unpalatable to livestock, so its invasion results in grazing shortages; if it is mixed in with fodder, it taints the meat and milk. Parthenium also poses a health problem for both humans and livestock, because contact with the plant or pollen can cause allergic reactions such as dermatitis, asthma and hay fever.

Elsewhere in Africa the weed has invaded the sub-tropical regions of South Africa – where it is especially problematic in sugarcane and banana plantations – as well as Swaziland, Mozambique, Zimbabwe and Madagascar. Although individual plants can be killed with foliar application of herbicides, rapid regeneration from seed soon follows. The only successful **chemical control** method is to use residual soil-applied herbicides to kill pre-emergent plants, but these are non-selective and environmentally hazardous. The best method of control is to maximise competition against the weed by maintaining good grass growth. This requires exclusion of grazing livestock until grass has become re-established, followed by a reduction in stocking rates to prevent reinvasion by the weed. Biocontrol agents have been released in some countries, but these have not yet achieved adequate control.

PROSOPIS



The genus *Prosopis*, commonly known as mesquite, includes more than 40 species, most of which are indigenous to an area ranging from Argentina to the southern United States. Several species have become invasive in Africa and other parts of the world, particularly the sub-tropical *Prosopis glandulosa* and *P. velutina* and the tropical *P. juliflora* and *P. pallida*. These species have been widely introduced as a source of fuelwood, fodder and shade, and are also used for sand stabilisation, soil improvement, or for hedges to contain livestock.

Impenetrable thickets

Prosopis are fast-growing, nitrogen-fixing trees that are tolerant of arid conditions and saline soils. They are valued as a source of fodder because the seed pods are a nutritious food for livestock when ripe. However, green pods are bitter and can poison livestock in large quantities, while the foliage is unpalatable due to the high tannin content.

Although individual prosopis occur as small trees, invading populations tend to form dense, impenetrable thickets made up of shrubby, multi-stemmed plants that provide minimal shade and produce fewer pods. The thickets reduce grass cover, so they limit natural grazing and hence stocking density. They also restrict the movement of livestock and obstruct their access to water, since they frequently invade watercourses. Long tap roots

allow the plants to reach deep water tables, so invasive prosopis may deplete vital groundwater reserves in water-scarce environments. Furthermore, the thickets impact on biodiversity by excluding indigenous vegetation and associated animal life.

The success of prosopis species as invaders is largely attributable to the massive number of seeds produced – about 60 million per hectare per year – and their efficient dispersal. Some seeds are carried far from their source by flowing water, especially during floods, but on a more local scale livestock and wild animals disperse the seeds after feeding on the pods. The hard-coated seeds are softened during their passage through the digestive tract, which enhances their germination, while the animals' droppings provide a ready supply of nutrients for the developing seedling. If the seeds fail to germinate immediately they may lie dormant in the soil for up to 10 years. Destruction of surrounding vegetation and exposure of the soil often stimulates mass germination of the soil seedbank, resulting in a sudden infestation.

A win-win solution

Prosopis is considered a valuable asset in many arid regions of Africa, where few other trees could survive, so eradication of this alien invader is generally not an option. A possible solution to the conflict of interests surrounding prosopis is to control invasive populations and manage

them as agro-forestry plantations. Apart from providing fodder and fuelwood, prosopis trees may yield hard and durable timber that can be used to make furniture and parquet flooring, while the protein-rich pods can be used in the manufacture of various food products. Unfortunately, the shrubby, multi-stemmed plants typical of invasive thickets generally only yield small pieces of lower-quality wood, with a large amount of wastage. Nevertheless, the wood may be suitable for making handles for appliances, brushes and tools, as well as charcoal and wood chip products.

In South Africa, prosopis is being controlled through an integrated approach incorporating mechanical, chemical and biological control methods.

Where feasible, control costs are offset by commercial exploitation of wood generated from clearing operations. Control of prosopis is especially difficult because the plants can re-grow from vegetative buds just below ground level. These buds sprout new shoots if the above-ground parts of the plant are damaged, with the result that a small shrub may become a dense bush if attempts at control are inefficient. The plants are therefore felled close to the ground, preferably below the point of branching, after which an appropriate registered herbicide is sprayed on both the cut surface and surrounding bark.

Biocontrol

Two biocontrol agents – *Algarobius prosopis* and *Neltumius arizonensis* – are currently available in South Africa for prosopis control, after being introduced from



Algarobius prosopis



Neltumius arizonensis

Arizona in the United States. Both are seed-feeding beetles that reduce the invasiveness of prosopis plants, without affecting their useful attributes. The female beetle lays its eggs on the prosopis seedpods, and when a larva hatches it chews its way through the pod and into the seed. Here it feeds for several weeks, destroying the seeds' ability to germinate in the process. The larva then pupates in the seed, but not before it has tunnelled up to the surface of the pod and made a circular trapdoor. When the adult beetle emerges from the pupa a few days later it is able to push out the trapdoor and escape from the seed pod.

Since the beetles are able to fly long distances, they have dispersed widely within areas invaded by prosopis. However, their effectiveness as biocontrol agents is compromised by the fact that livestock and game eat most pods before the larvae have had a chance to colonise them. Additional biocontrol agents that will attack immature pods, as well as other reproductive organs such as flowers and flower buds, are therefore being explored. A number of fungi that infect prosopis are also being investigated, to assess their potential for development as mycoherbicides.

LEUCAENA

Leucaena leucocephala is another tree species that has been promoted by international agroforestry organisations as a fodder and firewood resource, but is widely reported as an invasive weed.

Miracle tree?

Called the 'miracle tree' in the early years of its global cultivation, leucaena is a fast-growing, nitrogen-fixing and drought-tolerant tree that is native to Mexico and Central America. It is widespread in Africa, and in places provides a nutritional food source for livestock. However, both the foliage and seeds contain the amino acid mimosine, rendering them toxic in large quantities. Leucaena tends to invade forest margins, roadsides, wasteland, riverbanks and sometimes also cultivated land, forming dense thickets that are difficult to eradicate because the plant resprouts vigorously after cutting.



WATER HYACINTH



The water hyacinth *Eichhornia crassipes* is considered the world's worst invasive aquatic weed. Indigenous to the Amazon Basin of South America, it was introduced to many parts of the world as an ornamental plant, and today occurs in more than 50 countries on five continents.

In Africa, it was first recorded in the 1890s from the River Nile in Egypt, but has since become widespread throughout the continent. The plant thrives in still and slow-moving water-bodies that have become nutrient-enriched through eutrophication, and dense mats of water hyacinth now blanket many of Africa's dams, lakes, rivers and canals.

Understanding our worst invader

Water hyacinth is a perennial aquatic weed that is usually free-floating, although its long, feathery hanging roots may anchor it in shallow water. Individual plants are typically 100-200 millimetres high, but can reach a height of 1 metre when growing in dense mats. The showy flowers are lilac-blue with yellow markings, and each produces about 300 seeds.

The seeds sink after being released from the seed capsule and can remain viable for up to 20 years, contributing to the plant's success as an invader. Once a seed germinates, on moist sediments or in warm shallow

water, the plant grows rapidly and can flower within 10 to 15 weeks. Individual plants or small clumps of water hyacinth may disperse downstream and can easily spread to new areas during floods. The population increases mainly through vegetative reproduction, the plants budding to form daughter plants that break off and become entangled in dense mats.

Devastating impact

Water hyacinth infestations are associated with a variety of socio-economic and environmental impacts. Dense mats that block waterways inhibit boat traffic, and hence disrupt trade, fishing and recreational activities. They also clog irrigation canals and pumps, and threaten hydroelectric power schemes. By impeding water flow and trapping particles in suspension they increase siltation of rivers and dams. They adversely affect the quality of drinking water, and pose a health risk by creating conditions suitable for mosquitoes and bilharzia-carrying snails. The thick mats reduce light penetration into the water, which causes a decline in phytoplankton concentrations that support the zooplankton-fish food chain, resulting in ecosystem changes. Rotting material depletes oxygen levels in the water, further impacting aquatic biodiversity. Furthermore, vast quantities of water hyacinth can damage road and rail bridges when swept downriver during floods.

Control

As a readily available resource, water hyacinth has been used in paper, rope, basket and biogas production, as fodder for livestock, as mulch and compost for crop cultivation, and as a biological filter in water treatment schemes. Although some of these uses are successful as cottage

industries, they are not commercially viable on a large scale. This is because water hyacinth is more than 90% water, so it is not cost-effective to remove and transport.

Manual removal of water hyacinth, although very labour-intensive, can be useful in controlling small infestations. For example, community groups using rakes and pitchforks removed over 200 tonnes of the weed from landing beaches in the Mara district of Tanzania in one year. However, in many parts of Africa such work carries the risk of exposure to attack by snakes and crocodiles and to waterborne diseases such as bilharzia.

Even **mechanical harvesters** are impractical in infestations larger than a hectare, due to the rapid rate of increase of the weed. These machines are also very expensive to purchase and operate, and the harvested material must be removed for utilisation or proper disposal to prevent plants and seeds returning to the water.

Nevertheless, mechanical harvesters have been successful in some areas. On the Ugandan side of Lake Victoria, for instance, they have been used to provide ships' access to Port Bell and prevent weeds from entering the intake pipes of the hydroelectric power scheme at Owen Falls Dam. **Floating booms** have also helped protect the hydroelectric schemes at Owen Falls Dam and Zambia's Kafue Gorge Dam, and have been widely used in other areas to contain the weed.

On the Vaal River in South Africa, cables spanned across the river have been used to accumulate isolated plants moving downstream, allowing them to be more easily treated with herbicides. **Herbicides** such as glyphosate, diquat and 2,4-D amine, sprayed from aircraft, boat-mounted units or knapsack sprayers, provide a relatively cheap control option, and rapid results can be obtained. However, although relatively safe if applied by skilled operators, these herbicides are non-selective, and require ongoing follow-up spraying to control reinfestation.



WATER HYACINTH



sap-sucking mirid *Ecritotarsus catarinensis*, a leaf-mining mite *Orthogalumna terebrantis* and a fungal pathogen *Cercospora rodmaini*, while the potential of a number of other natural enemies of water hyacinth are currently being considered.

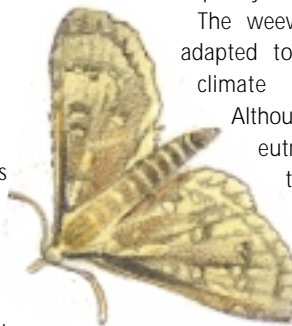
The existing biocontrol agents have been successful in controlling water hyacinth in some areas of South Africa, but not in others. This is partly because the worst areas of infestation are in high-altitude regions subject to cold winters. The mite *O. terebrantis* cannot establish in such a climate, and population increase of the weevil *N. eichhorniae* is suppressed. The moth *N. albiguttalis* can withstand cold winters, but since it prefers feeding on young or actively growing plants that are not always found in mature infestations, its distribution is patchy, seasonal and temporary.

Biological control – a sustainable option

Biological control is the only control option that is sustainable in the long term. The first successful biological control programme in Africa was in Sudan, after the weevils *Neochetina eichhorniae* and *N. bruchi* were released on the White Nile in the 1970s. These biocontrol agents have proved so effective that they have since been released in about 20 countries across the continent.

The adult weevils feed on the leaves of water hyacinth, while the larvae eat their way down the petioles and into the crown, the growth point of the plant. This feeding damage stunts growth, impedes reproduction of the plants, and at high intensities causes them to rot, die and sink. Wind and wave action help to break up water hyacinth mats already weakened by the weevils.

Other biocontrol agents have also been introduced to supplement the effectiveness of the two weevils. In South Africa, these include a petiole-boring moth *Niphograptia albiguttalis*, a



The water hyacinth moth *Niphograptia albiguttalis*

The weevil *N. eichhorniae* also seems poorly adapted to the Western Cape's Mediterranean climate and nutrient-enriched conditions.

Although *N. bruchi* is more effective in such eutrophic conditions, and is also cold-tolerant, populations of both species have been negatively impacted by seasonal flooding and mechanical control operations to remove water hyacinth.

Indeed, the failure of biological control in many instances can be attributed to inappropriate integration with chemical and mechanical control. It is therefore imperative that integrated management plans are implemented on a site-specific basis. Furthermore, since eutrophication and reduction in water flow create a stable and nutrient-rich environment in which water hyacinth flourishes, these plans should include nutrient and hydrological control where possible.



The *Neochetina* weevil



Damage by *Niphograptia albiguttalis* larva



Mechanical control of water hyacinth

Lake Victoria - a success story in biological control



A *Neochetina* weevil feeds on a water hyacinth leaf

One of the most notorious cases of water hyacinth infestation and subsequent control occurred at Africa's Lake Victoria, the second largest freshwater lake in the world.

During the 1980s, water hyacinth invaded the headwaters of Rwanda's Kagera River, which empties into

Lake Victoria at the Tanzania-Uganda border. The weed was first noticed in the lake in 1989, but it thrived in the eutrophic conditions and spread rapidly. By the mid-1990s it covered about 12 000 hectares of the lake surface. Dense mats of water hyacinth collected against the shorelines of Kenya, Tanzania and Uganda, disrupting fishing and trade by blocking ports and landing areas. In Uganda, the weed interfered with operations at the Owen Falls Dam hydroelectric scheme, resulting in power cuts that

affected the country's industrial output. The water hyacinth mats also impeded water circulation, creating an ideal breeding ground in the stagnant water for malarial mosquitoes and the snail hosts of bilharzia. The cumulative affect of these impacts was a downturn in the region's economic productivity.

Biological control was considered the only viable method of dealing with the weed, so the two weevils *Neochetina eichhorniae* and *N. bruchi* were released there in 1995. A number of weevil-rearing stations were set up around the lake and along the Kagera River. With the help of local fishing communities, several million weevils were released. Some manual removal and mechanical control efforts continued, but by

late 1999 much of the weed had died off. Many bays were already clear of weed, and the remaining mats were heavily damaged by weevils. Fishing activities had recommenced, and the lake's transport system had been revived.

Today water hyacinth has been effectively brought under control, and now covers only 2 000 hectares of lake surface.



KARIBA WEED



The Kariba weed *Salvinia molesta* is a free-floating water fern that is native to Brazil. It was first recorded in Africa in 1948, when it was found on the Zambezi River, but is now widely distributed throughout southern Africa. The species has also invaded other parts of the continent, as well as warm regions around the world, where it is commonly referred to as 'giant salvinia'. It is usually introduced as an ornamental plant for ponds and aquaria.

Rapid expansion

Kariba weed was only recognised as a problem species in Africa in the early 1960s, when the Zambezi River was impounded by Lake Kariba. As the dam began filling up, organic-rich runoff and decomposition of flooded plant material enriched the water with nutrients, providing an effective fertiliser. By 1963 dense mats of the weed covered about 22% of the dam surface, threatening the operation of the hydroelectric power plant.

Similar scenarios are reported wherever Kariba weed invades. The plants grow rapidly, and in favourable conditions may double in number within a week. In the early stages of an infestation, the plants are small and have green leaves that lie almost flat on the water surface. Over

time the leaves turn yellowish-green to brown and fold, causing them to interlink when pressed together in dense infestations.

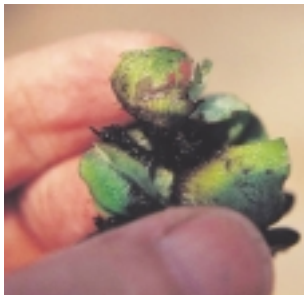
Severe environmental and socio-economic impact

The resulting mats – sometimes up to a metre thick – tend to block waterways, obstructing boat traffic and disrupting fishing activity. They impede access to water by rural communities and their livestock, and clog intake pipes for water supply facilities, irrigation schemes and hydroelectric power plants. They also pose a health risk as they provide a safe and ideal habitat for mosquitoes and other vectors of disease.

Apart from these socio-economic impacts, the dense mats have a variety of negative effects on the environment. They out-compete indigenous species by crowding out floating weeds and reducing the light available to submerged plants and phytoplankton. By blanketing the surface of waterbodies, they prevent atmospheric oxygen from entering the water. As the plants die and sink to the bottom, bacterial decomposition further depletes oxygen levels, creating conditions unsuitable for invertebrates and fish. The overall effect is a

decline in water quality and a reduction in biodiversity.

Kariba weed reproduces vegetatively, and is able to regenerate from any fragment that includes a node. This facilitates its spread by water currents, by birds and mammals, and by boats and vehicles that enter infested waters.



Control

Attempts have been made to control Kariba weed by **physical removal**, but the plant outgrows most efforts. Herbicides such as terbutryn, diquat and glyphosate have sometimes proved effective, but these put other species at

risk as they are non-selective. They also need to be reapplied on an ongoing basis.

Biological control using the host-specific weevil *Cyrtobagous salviniae* is the most sustainable option for controlling Kariba weed. The adult weevils, which are only about 2 millimetres long, feed on leaf buds and young terminal leaves, while the larvae tunnel in the rhizome and also feed externally. The resulting feeding damage causes the plants to become waterlogged, and they eventually sink.

The weevil was first introduced to Africa in 1983 in Eastern Caprivi, Namibia, where it proved very effective. It was subsequently released in a number of other African



countries, in many cases reducing Kariba weed by more than 90% in less than a year. In cooler areas, control takes longer, but usually no more than three years. However, the weed's tissue nitrogen content must be above 1% dry weight, or the weevils fail to establish.

More ornamentals turned invasives

Other invasive aquatic weeds that are particularly problematic in Africa are **red water fern *Azolla filiculoides*, parrot's feather *Myriophyllum aquaticum* and water lettuce *Pistia stratiotes*.** All are native to South America and were introduced as ornamental plants to Africa, where they thrived in the absence of natural enemies. Fortunately, biological control agents have been identified for all of these species, and the prospect of bringing the weeds under control is very favourable, should the necessary control initiatives be put in place.

Lessons from Papua New Guinea

During the 1980s, a severe outbreak of salvinia on the island of New Guinea in Papua New Guinea seriously affected the livelihoods of the island community.

The lives of the people of the region are linked very closely with the river, as a main source of food and water and as a principal means of travel in the more remote parts. By completely dominating the river system, the salvinia invasion caused some villages to be abandoned altogether when access became impossible, leaving communities without critically needed medical care and food aid assistance. Although largely undocumented, the negative impact on biodiversity in the region was most likely equally significant.

An innovative control programme was initiated during 1982–85 by UNEP and CSIRO Australia, where the biological control agent, *Cyrtobagous salviniae* was introduced into the

more accessible parts of the river system.

The challenge was to redistribute it to the rest of the affected area – and this is where radio proved to be a remarkably effective means of spreading the weevil.

The radio-transmitted message was simple: visit already infested lagoons and collect bags of material (salvinia and weevils), take these home and introduce them into the salvinia-invaded areas. Using canoes to ferry weevil-infested bags of salvinia, the local community actively supported the operation, thus ensuring a quicker establishment of the control agent.

This method proved to be extremely successful and the weevil quickly infiltrated the entire infested system with resounding success. The resultant rapid control of salvinia on this island is still quoted as one of the most successful cases of biological control to date.

CAULERPA SEAWEED



Caulerpa taxifolia is a green seaweed that is widely distributed in the world's tropical seas. In Africa it occurs naturally in the Gulf of Guinea in the west, and Tanzania, Kenya, Somalia and the Red Sea in the east, as well as Madagascar, the Maldives and Seychelles.

However, a robust, cold-tolerant strain has become an aggressive invader outside the natural range of the species. It has spread throughout the northern Mediterranean, where it has had a devastating impact on local biodiversity. It has also been found in the coastal waters of Tunisia in North Africa, as well as the United States and Australia. Now there are concerns that it might be introduced to other parts of Africa, and threaten marine communities there too.

Rapid and serious impact

In 1984, a small patch of *Caulerpa taxifolia* was discovered growing in the sea outside the Monaco Aquarium, from which it probably escaped. It began spreading rapidly, colonising the seafloor from the shore down to a depth of 100 metres. Before long the species had invaded France, Spain, Italy and Croatia, and now carpets more than 11 000 acres of the northern Mediterranean seafloor. It forms dense monocultures, excluding indigenous seaweeds and seagrasses as well as corals, seafans and sponges.

Caulerpa has caused a reduction in the diversity and abundance of invertebrates and fish, both by destroying natural habitat and by producing toxic secondary metabolites that provide chemical defence against herbivores. The

seagrass beds originally served as important nursery areas for many fish species, so the invasion has likely affected the overall production, biomass and distribution of fish in the Mediterranean. Furthermore, the caulerpa beds are an impediment to net fisheries and are of little interest to recreational divers because of their limited biodiversity. As a result, they have been accused of negatively impacting commercial fisheries and coastal tourism.

Super strain

It was long suspected that the seaweed is a hardier clone of the original tropical species, developed under artificial aquarium conditions. Genetic studies have lent support to this theory, and confirmed that the Mediterranean populations and collections in several European aquaria represent a single strain. The Mediterranean strain only reproduces asexually, allowing tiny pieces of the seaweed to grow into whole plants. This has facilitated its spread, as fragments dispersed on fishing nets and anchors are able to start new colonies. The species' chemical defences undoubtedly contribute to its invasiveness, by increasing its competitive success over indigenous seaweeds.

Introductions to the United States and Australia have probably been via releases from home aquaria. *Caulerpa taxifolia* is a popular aquarium plant and the Mediterranean strain has been widely traded.

Control

Numerous eradication methods have been used against caulerpa infestations, with varying effect. **Mechanical methods** have included hand-harvesting, suction-dredging and covering with sand or tarps to exclude sunlight. Some success has been achieved with **chemical control methods** involving the application of chlorine, copper sulphate, or even rock salt where caulerpa occurs in shallow areas on hard substrata.

Biological control options are also being investigated. Sea slugs belonging to the *Sacoglossan* group of molluscs feed only on seaweeds of the order *Caulerpales*, sucking out the cell sap and accumulating the toxins to make themselves less palatable to predators. Tests are therefore being conducted to assess their potential as biocontrol agents.



HARMFUL ALGAL BLOOMS



Algal blooms are a natural phenomenon in the Benguela region off the coasts of Namibia and South Africa, where wind-induced upwelling results in nutrient enrichment of coastal waters. However, some algal blooms have harmful effects such as shellfish poisoning and marine mortalities, which can adversely affect coastal tourism, mariculture operations and fisheries.

There has also been speculation that recent fish kills off the Kenyan coast were caused by a harmful algal bloom.

It is quite possible that some of the species responsible for harmful algal blooms were introduced to African waters in the ballast of visiting ships, and there are fears that new and more problematic species might arrive in the future.

Benguela C.

South Atlantic gyre

Red tide

Phytoplankton such as diatoms, dinoflagellates and ciliates contain various photosynthetic pigments, and when they 'bloom' they reach such high concentrations that they discolour the water. These blooms are commonly known as **red tides**, although they may be **various shades of red, purple, green, yellow or brown, depending on the pigments involved**.

Some phytoplankton are able to produce powerful toxins, and blooms of these species are highly dangerous. Filter-feeding shellfish such as mussels, clams and oysters accumulate the toxins, and while they may be only slightly affected themselves, humans and animals that feed on them may become seriously ill, or even die. There are four different shellfish poisoning syndromes:

Paralytic shellfish poisoning in the Benguela region is associated with the chain-forming dinoflagellate *Alexandrium catenella*, which is widely distributed in cold temperate waters of the world. The toxin, known as saxitoxin, disrupts nerve functions and causes neuromuscular paralysis. In severe cases it results in death by respiratory failure.

Diarrhetic shellfish poisoning is usually caused by dinoflagellates of the genus *Dinophysis*, which produce the toxin okadaic acid. As the name suggests, symptoms include diarrhoea as well as nausea, vomiting and abdominal pain.

Neurotoxic shellfish poisoning has been linked to the dinoflagellate *Gymnodinium cf. mikimotoi*, which was recorded for the first time in South African waters in 1988. Members of the genus produce polyether toxins that interfere with the transmission of nerve impulses, causing sensory abnormalities such as dizziness, numbness, tingling sensations and hot-cold reversals. Noxious gases associated with such blooms also cause skin and respiratory irritations.

Amnesic shellfish poisoning was recorded for the first time in Canada in 1987, and is attributed to a toxin called domoic acid that is produced by a number of pennate diatoms, including species of *Pseudonitzschia*. Symptoms include vomiting, disorientation and memory loss. No

cases have ever been recorded in the Benguela region, but the responsible species are thought to occur in these waters.

Toxic red tides occasionally cause mass mortalities of marine life. For example, in 1980 an estimated 5 million white mussels were washed onto the beach at Elands Bay on the west coast of South Africa following a bloom of *Alexandrium catenella*. *Gymnodinium cf. mikimotoi* poses a particular threat to South Africa's abalone industry, since it caused the death of approximately 30 tons of abalone in 1989 and larval mortalities at several abalone culture facilities in 1996. *Gymnodinium galatheanum* releases powerful neurotoxins into the water, and has been implicated in fish mortalities off the Namibian coast.

Marine mass mortalities can also result from non-toxic harmful algal blooms. Fish sometimes suffocate to death after their gills become clogged or damaged by the phytoplankton, rendering them unable to extract sufficient oxygen from the water. More commonly, bacterial decomposition during the bloom's decay depletes oxygen in the water. Such low-oxygen events frequently cause mass strandings and subsequent mortalities of rock lobster in the Benguela region.



Alexandrium catenella



Dinophysis accuminata



Gymnodinium cf. mikimotoi

HARMFUL ALGAL BLOOMS



Brown tide

Toxic red tides periodically halt harvesting at shellfish mariculture operations, but a re-occurring non-toxic algal bloom has caused a dramatic decline in production at mussel and oyster farms in South Africa's Saldanha Bay since January 1997. These blooms are known as 'brown tides' because they colour the sea golden-brown. The tiny algae reach concentrations of over 3 million cells per millilitre, and inhibit bivalve filter-feeding. The responsible species, *Aureococcus anophagefferens*, was first described in 1988, after similar blooms impacted bays along the mid-Atlantic coast of the United States, crippling the local scallop fisheries and mussel farms. There is therefore speculation that the species was introduced to South African waters from the United States via ballast water.

Mussel farming at Saldanha Bay



Black tide

The worst marine mass mortality ever recorded in South Africa occurred in March 1994, in St Helena Bay on the west coast. The respiration and subsequent decomposition of a mixed bloom of dinoflagellates – trapped in the bay by gentle onshore winds – exhausted the oxygen in the water. This created an ideal environment for anaerobic, sulphate-reducing bacteria to convert sulphates in the water to hydrogen sulphide, which filled the air with the stench of rotting eggs. It also turned the sea black, with the result that the event was dubbed a 'black tide' by the media.

Marine organisms in the bay died because of suffocation or hydrogen sulphide poisoning, or from being stranded on the shore after moving into shallow water in search of oxygen. **A 30 kilometre stretch of shoreline was littered with the carcasses of over 1500 tons of fish and rock lobster.**



Ballast Water and Sediment

Ballast water and the associated sediment has been identified as a major pathway for the introduction of a variety of marine invasive alien species. Indeed, it has been estimated that up to 14 billion tons of ballast water are transferred globally each year, and that more than 7 000 species of marine organisms may be present in ballast water at any given time.



While many phytoplankton species are unable to survive weeks of darkness inside a ballast tank, as they need light for photosynthesis, dinoflagellates commonly form cysts when conditions are unfavourable. These cysts tend to accumulate in the sediments in ballast tanks, where they can remain in a state of dormancy until they are deposited in a suitable environment.

In 1997, in an effort to limit the transfer of marine species via ballast water, the International Maritime Organisation (IMO) adopted a set of ballast management guidelines. These guidelines recommend the exchange of ballast water at sea, regular removal of sediment from ballast tanks, and treatment of ballast water and sediment before discharge. The IMO has since developed a mandatory ballast water management regime – the draft International Convention for the Control and Management of Ships' Ballast Water and Sediments – which will be tabled for adoption in February 2004.



MEDITERRANEAN MUSSEL



The Mediterranean mussel *Mytilus galloprovincialis* is the mainstay of South Africa's mussel-farming industry, predominantly located in Saldanha Bay on the west coast. However, the species is an invasive alien, and has caused dramatic changes to intertidal communities.

Rapid spread

The indigenous mussel communities on South Africa's rocky shores are dominated by the ribbed mussel *Aulacomya ater* and the black mussel *Choromytilus meridionalis* on the cool west coast, and the brown mussel *Perna perna* on the warmer south and east coasts. The Mediterranean mussel closely resembles the black mussel, so it was only identified in 1984, when genetic analysis confirmed that it was a separate species. By that time it had already spread along the entire west coast, from Cape Point to Lüderitz in southern Namibia. By the early 1990s it had reached Port Elizabeth on the south-east coast, and had become the dominant intertidal organism along the west coast.

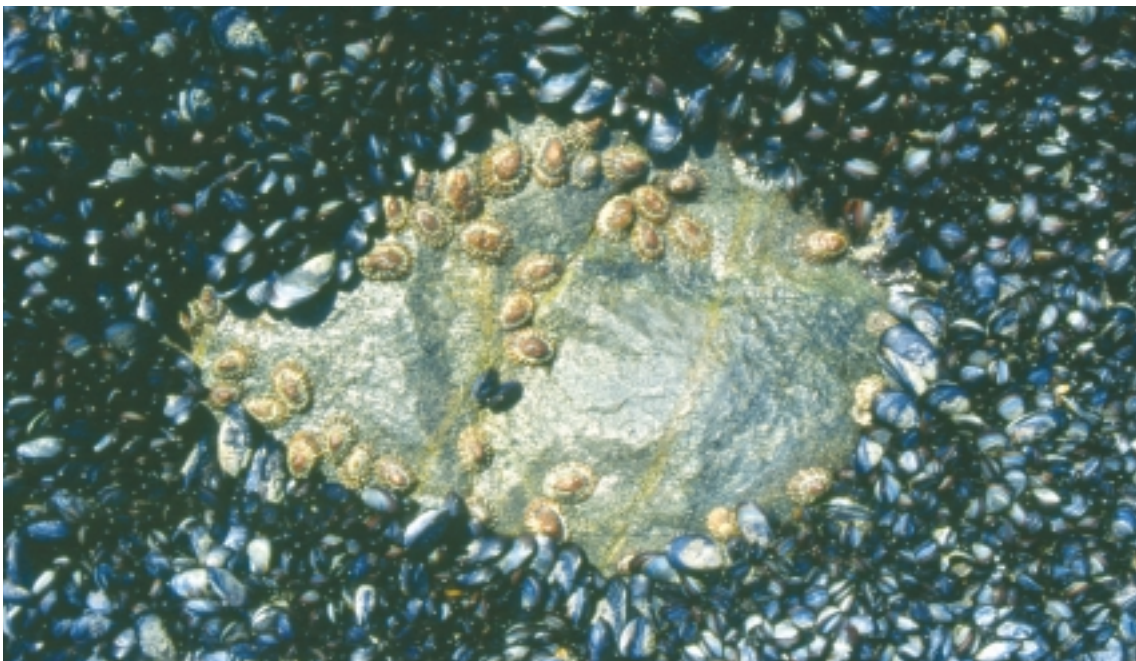
The Mediterranean mussel – native to Europe – is thought to have been introduced to South Africa in the late 1970s, probably on the hull of a ship. Its success as an invader can be attributed to its rapid growth rate, high fecundity, and increased tolerance to desiccation. The Mediterranean mussel grows faster and extends higher into the intertidal than the indigenous ribbed mussel, which it has largely displaced.

Out-competing limpets

The Mediterranean mussel has also been found to out-compete the limpet *Scutellastra argenvillei*, which grows to almost 100 millimetres. Before the alien mussel arrived, the limpet and the ribbed mussel were the dominant invertebrates in the west coast's mid to low intertidal, but there were large patches of open space, kept clear by the limpet's grazing. Now the alien invader forms a solid band of mussels on the shore, leaving little room for the large limpets.

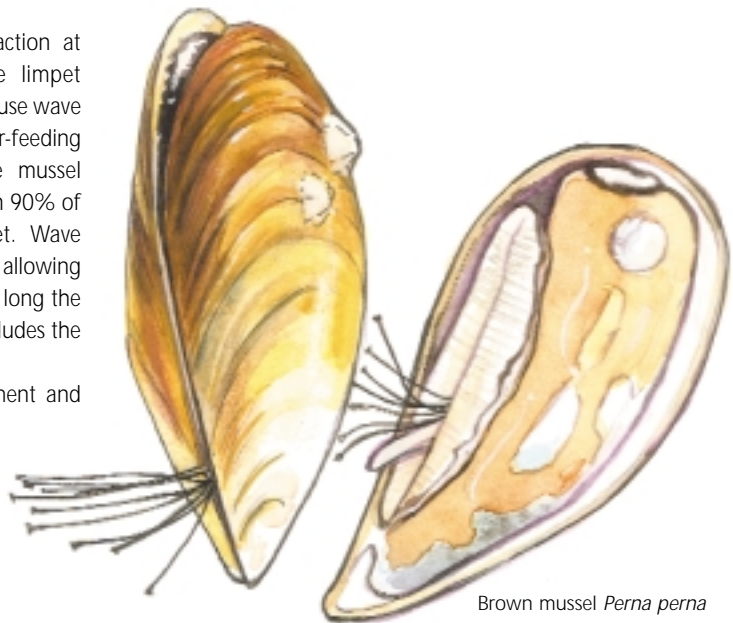
Recent studies have indicated that the competitive interaction between the Mediterranean mussel and the

The Mediterranean mussel displaces limpets on the rocky shore



limpet is influenced by the degree of wave action at different sites. On semi-exposed shores, the limpet dominates much of the rock space, probably because wave action there is unfavourably low for the filter-feeding mussel. However, at more exposed sites the mussel dominates – sometimes accounting for more than 90% of cover – and competitively displaces the limpet. Wave action periodically clears gaps in the mussel beds, allowing limpet patches to expand temporarily, but before long the mussel recolonises the cleared rock space and excludes the limpet again.

The mussel beds do provide a good settlement and recruitment ground for juvenile limpets, but as they grow they are unable to find a foothold on the rock substrate, and are eliminated. In fact, at the invaded sites studied, less than 3% of limpets reached the size of sexual maturity.



Brown mussel *Perna perna*

Beneficial to some... but at a price

Mediterranean mussel beds also support a denser invertebrate community than the indigenous ribbed mussel beds, and tend to provide refuge for larger infaunal organisms such as marine worms, because the mussel shells are thicker and the beds more structurally complex. This, together with the overall increase in mussel standing stock that has resulted from the invasion, is probably advantageous to rocky shore predators, such as fish, rock lobsters, starfish, predatory whelks, octopuses and shorebirds.

Indeed, the invasion seems to be beneficial to the endangered **African black oystercatcher**, which feeds predominantly on mussels and limpets. Since the alien mussel occurs higher on the shore than the indigenous species, it is providing an easily accessible and abundant food source, and the oystercatchers have evidently responded by raising more young.

Nevertheless, the ongoing invasion by the Mediterranean mussel is cause for concern from a biodiversity perspective,

and there are fears that it will spread further up the south and east coast, where the **brown mussel *Perna perna*** is dominant. In 1992, the alien species was estimated to make up only 1% of overall mussel standing stock on the southern Cape coast, but a survey in 2000 revealed that while it still occurred in relatively low densities in most places, it had become abundant in the Plettenberg Bay area and was well established in the adjacent Tsitsikamma National Park. The Mediterranean mussel may have a competitive advantage as it appears to be free of trematode parasites that are normally present in the brown mussel, affecting growth, reproduction, adductor muscle strength and water loss.

There are currently no initiatives to control the Mediterranean mussel in South Africa, apart from encouraging poverty-stricken communities on the west coast to harvest the species for subsistence use and small-scale commercial ventures.



The Mediterranean mussel provides an abundant food source for the African black oystercatcher

EUROPEAN GREEN CRAB



The European green crab *Carcinus maenas*, also called the shore crab, is a voracious predator of the marine environment. Indigenous to the Atlantic coast of Europe and North Africa, it has invaded numerous coastal communities outside its native range, including South Africa, Australia, and both coasts of North America. It was discovered in Cape Town harbour, South Africa, in 1983, and has since invaded the coastal waters of the surrounding Cape Peninsula.

The species has also been recorded 100 kilometres to the north in Saldanha Bay, another large port visited by foreign ships. Should the crab become established there, it could have a devastating impact on the bay's productive mussel-farming industry, and disrupt the food web of the adjacent Langebaan lagoon, a sensitive ecosystem conserved as part of the West Coast National Park.

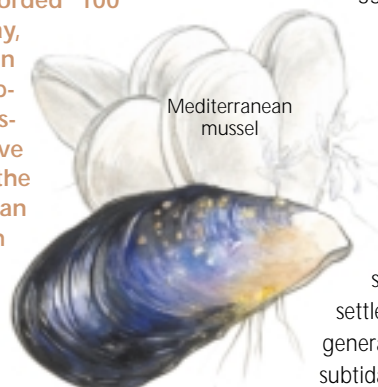
Not always green

Despite its name, the European green crab is not always green. While juvenile crabs are typically olive green, in older crabs the colour changes during the moulting cycle from mottled green and black to orange and then red. The crab can be identified by the series of five short spines on either side of the carapace and three rounded lobes

between the eyes. The legs are robust, although the last pair is relatively flat. All the legs have flattened but pointed tips.

In its native range – from Norway and the British Isles, south to Mauritania – the crab reaches a maximum size of 8.6 centimetres, but in North America sizes as large as 11 centimetres have been recorded. The crab has a maximum lifespan of five years, and reaches sexual maturity at two to three years of age. Females can breed up to three times per year, producing as many as 200 000 eggs at a time. The eggs may be carried on the pleopods for some months before hatching into planktonic larvae, which are widely dispersed by ocean currents.

After a 17 to 80 day period of growth and development, they settle out as juvenile crabs in the upper intertidal zone of sheltered bays and estuaries. Once settled they tend not to move very far, generally only migrating between the subtidal and intertidal zones with the tides. However, they are capable of remaining in the upper intertidal zone at low tide by sheltering under seaweed or large boulders, or in rock crevices. They can tolerate a wide range of temperatures and salinities – but not the strong wave action of the open coast – and are normally found in seagrass beds and in unvegetated sand and mud substrates in waters less than 6 metres deep.



A clever predator

European green crabs prey on a variety of organisms, preferring bivalve molluscs such as oysters, clams and mussels but also taking marine worms, insects and crustaceans. Adult crabs are capable of eating 30 to 40 clams or mussels per day. They are quicker and more dexterous than many other crab species, and can even devour crabs as large as themselves. Importantly, they can learn from their experiences and improve prey-handling techniques while foraging.

It is because of its efficiency as a predator that the European green crab is considered one of the world's worst invaders. Its huge appetite for bivalves and crabs, as well as its ability to outcompete commercially important crabs for food and habitat, makes it a threat to shellfish industries. By preying heavily on numerous other organisms, the crab may alter the structure of marine communities, with ripple effects throughout the food web, while competing with indigenous fish and birds for the same food sources.

Invasion

Apart from South Africa, the European green crab has invaded both coasts of North America, Hawaii, Australia, Japan and Sri Lanka. In most cases it is presumed to have been introduced in the ballast of ships, and then spread via larval dispersal. More recently, it may also have been introduced and spread in seaweed packed with bait and live shellfish.

The crab first appeared on the east (Atlantic) coast of North America in the early 1800s, when wooden vessels typically used sand and rocks for ballast. It soon extended its range from Nova Scotia in the north to Maryland in the south, and is believed to have contributed to the collapse of the region's softshell clam industry in the 1950s.

In 1989 the crab was found on North America's Pacific coast for the first time, in San Francisco Bay, California. It rapidly invaded coastal embayments to the north and south, and in 1997 was discovered in Oregon, followed by Washington in 1998 and British Columbia in 1999. The crab poses a threat to the region's commercial and recreational fisheries for Dungeness crabs, clams and mussels, as well as the United States' largest oyster mariculture operations in Washington.

In Australia the crab was first discovered in 1902, when it was already abundant in Port Phillip Bay, Victoria. It is believed to have been introduced during the 1850s, when wooden ships visited the bay to offload passengers destined for the gold fields. During the 1900s the crab

invaded the entire southern coast of Australia, and in the early 1990s it also colonised the island state of Tasmania.

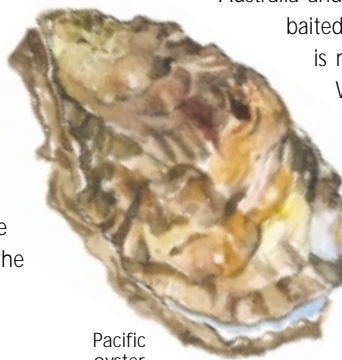
Control

At present there is no initiative underway to control the European green crab in South Africa. However, the crab's distribution may be naturally restricted by the high-energy wave action along the country's rugged coastline, which has relatively few sheltered bays.

In other parts of the world, the only control method currently implemented is **physical removal** of the crab. In

Australia and the Pacific coast of North America, baited traps are set in areas where the crab is most likely to occur. In addition, the Washington Department of Fish and Wildlife in the United States has instituted several measures to regulate all shellfish, aquaculture and other aquatic invertebrate imports and movements within the state to prevent the species from spreading further.

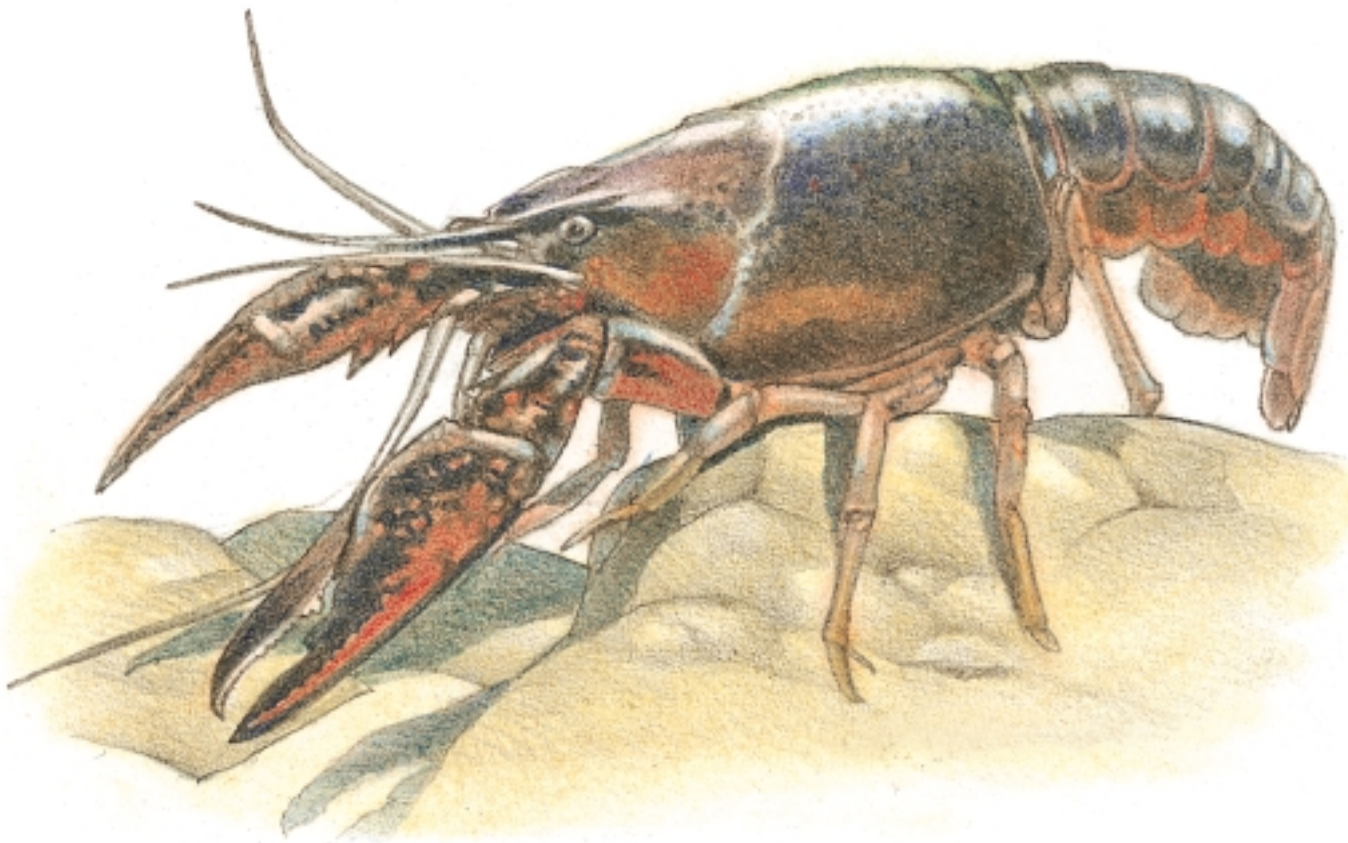
American and Australian scientists are also investigating the host-specificity of a potential **biological control** agent. In its native range, the crab is parasitized by a rhizocephalan barnacle *Sacculina carcini*, the larvae of which bore into the crab and develop in its tissues. The parasite blocks moulting and effectively castrates the crab, causing female sterility and male feminisation. Should the parasite be found to pose no risk to indigenous species, it may be considered for future release.



Pacific oyster



LOUISIANA CRAYFISH



The Louisiana crayfish *Procambarus clarkii*, also known as the red swamp crayfish, supports a lucrative aquaculture industry in its native range, and is a popular component of the region's Cajun cuisine. Over the last 50 years it has been introduced to Africa, Europe and Asia, in most cases with negative consequences.

A food source, a biocontrol agent and even a popular family pet

The Louisiana crayfish is indigenous to the southern parts of the United States and northern Mexico. It has been introduced to other regions primarily to diversify local fisheries or for aquaculture purposes; although in a few cases in Africa it was released as a biological control agent against the snail hosts of bilharzia (schistosomiasis). In the United States it was stocked outside its natural range as a food source for gamefish such as largemouth bass and bluegill, and spread by anglers using it as bait. In Japan it became a popular family pet, and was also traded by aquarium and garden pond hobbyists in parts of Europe.

Highly adaptable

Once introduced, the species quickly becomes established in the wild through escaped or deliberately released

animals. Louisiana crayfish can survive in a variety of natural and manmade habitats, such as rivers, wetlands, dams and irrigation canals, where they burrow into soil banks along the shoreline. They are able to tolerate a wide range of salinities as well as oxygen-poor conditions, high pollution levels and fluctuating water levels, and adults can travel long distances over land to colonise new areas. More importantly, the Louisiana crayfish is a prolific breeder and a generalist feeder, able to exploit most available food sources.

Apart from plants, the Louisiana crayfish also eats insects, worms, snails, amphibians, crustaceans and small fish, as well as their eggs and fry. Its huge appetite has been blamed for the disappearance of some species of snails in African wetlands, and for the decline of certain amphibians in parts of the United States. In addition, the crayfish is aggressively territorial, so it frequently out-competes and excludes indigenous predators, further reducing local biodiversity.

A number of other impacts are associated with invasion by Louisiana crayfish. Their burrowing weakens dam walls, creates leaks in levees and aquaculture ponds, and increases erosion along watercourses. Although they are often farmed in combination with rice crops, they inevitably raise the cost of rice culture by burrowing into dykes and eating the rice plants.

The Louisiana crayfish is a vector of the 'crayfish plague' *Aphanomyces astaci*, which caused a collapse of the crayfish industry in Europe after it was introduced with

the American red signal crayfish in the 1860s. In some parts of the world it is also a vector for harmful human parasites, including the lung fluke *Paragonimus westermani* and the rat lungworm *Angiostrongylus cantonensis*, which are passed on to humans who eat undercooked crayfish.

Control

Once established in an area, Louisiana crayfish are extremely difficult to eradicate. Limited success has been achieved with traps baited with fresh fish or meat and left overnight. Research is now being conducted using sex hormones – or pheromones – as bait, in the hope that crayfish looking for a mate will be more readily lured into traps. For small ponds and dams, drainage and **physical removal** of crayfish has sometimes been effective, but the animals can escape capture by burrowing deeper into the mud or moving over land to nearby pools.

Natural enemies have kept crayfish numbers in check in some areas. For example, where there are large heron colonies in wetlands in southern Europe, the birds exact a heavy toll on the crayfish population. In the United States, the species is not normally a problem in sport-fishing dams stocked with trout, bass, catfish and bluegills, but introducing these predatory fish to control crayfish in other areas has generally not been successful and causes secondary impacts.

Chemical control is not recommended for crayfish. Toxic pesticides are likely to kill non-target species, threaten water quality and contaminate water supplies. Recently, research has been conducted on the potential of a bio-degradable surfactant – Genapol OXD-080, a fatty alcohol polyglycol ether – to control crayfish in rice paddies. However, the non-selective action of the product means that it is a threat to biodiversity. Trials showed that it risked contaminating irrigation canals, and killed mosquitofish at concentrations well below those needed to achieve control of crayfish.

From Kenya to Europe's fine food outlets

In 1970, the Louisiana crayfish was introduced to Lake Naivasha – situated in the Rift Valley in Kenya – to diversify the lake's fisheries. The crayfish thrived, and a decade later the population had grown to a density of four individuals per square metre of shoreline. A flourishing fishery exported millions of crayfish to France, Holland and Belgium, where they were served in top city restaurants. Unfortunately, the crayfish population was consuming vast quantities of aquatic vegetation, and in 1982 the lake's indigenous floating and submerged plants completely disappeared. The following year the fishery collapsed, and in 1987 crayfish density was estimated at only 0.25 individuals per square metre. The aquatic vegetation slowly recovered, but crashed again in 1996, coinciding with a peak in crayfish numbers. It appears that the Louisiana crayfish is a keystone species in the lake ecosystem, resulting in a cyclical 'boom or bust' scenario for plant and crayfish populations.



COYPU



A Kenyan case

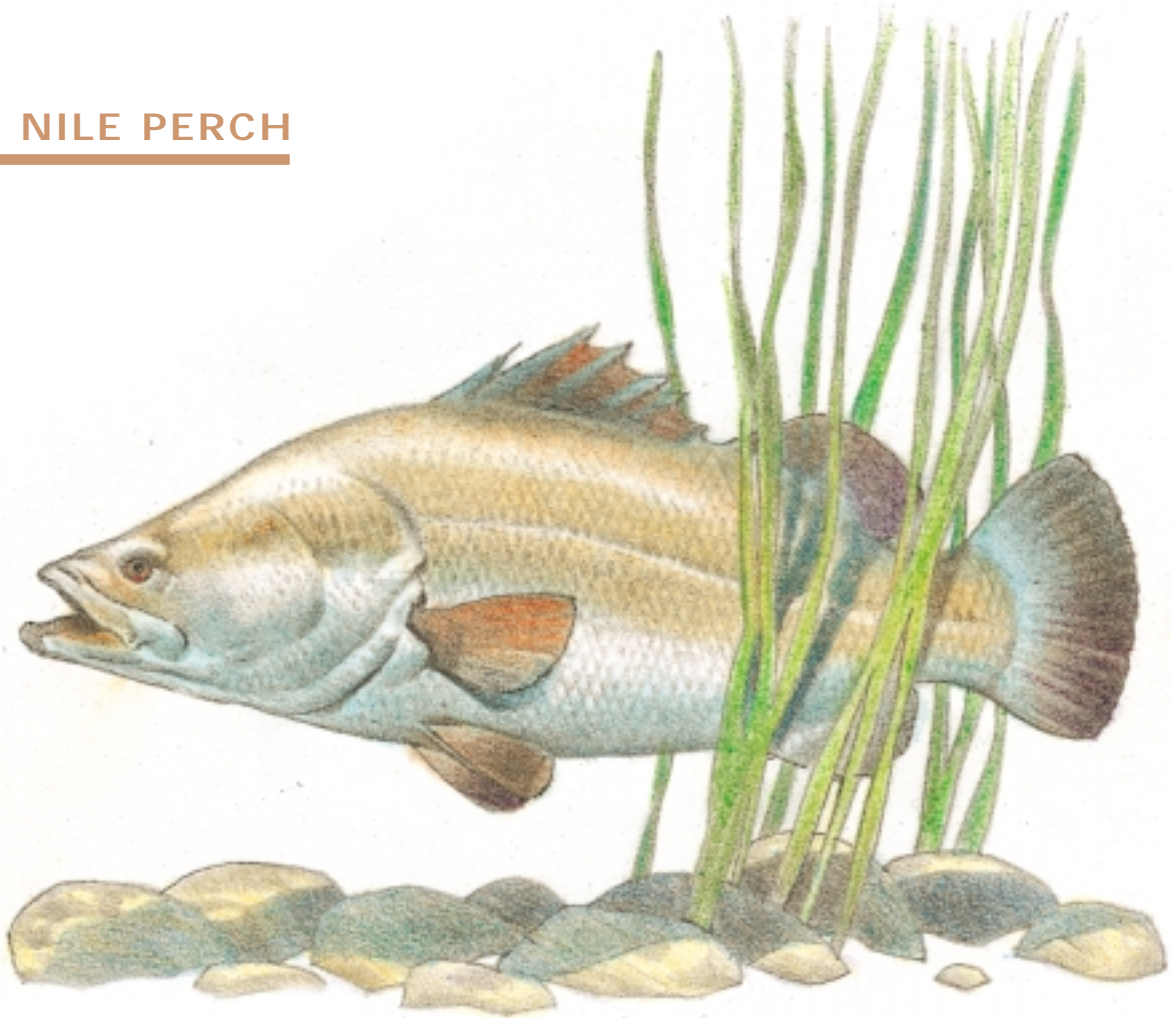
Another invasive alien species that may have contributed to the periodic collapse of Lake Naivasha's aquatic plants is the **coypu or nutria**, *Myocastor coypus*. This large semi-aquatic rodent is indigenous to South America, but was introduced to East Africa, North America, Europe and Asia to be raised for its fur. Since escaping from fur farms it has established large feral populations in some areas,

causing considerable damage in wetlands, rivers, dams and irrigation canals by burrowing into banks and dykes.

Coypu feed on aquatic vegetation, and in places have converted dense stands of reed to open water, destroying the habitat of some wetland birds. In Kenya, coypu escaped from a highland fur farm and became established in Lake Naivasha, where they consumed vast quantities of water plants. This probably compounded the problems caused by **Louisiana crayfish**. (See previous page.)



NILE PERCH



Mass murder in Lake Victoria

It's been called the biggest mass extinction of vertebrates in recorded history – at least 200 fish species erased from existence by a ravenous predator, the Nile perch.

The story starts a century ago, when British officials cleared the forests around Lake Victoria and planted cash crops such as tea, coffee and sugar. Migrant workers attracted by the plantations settled along the shores of the lake, which provided a ready source of food. Over a period of some 14 000 years, more than 400 species of cichlids – small freshwater fish, renowned for their ability to evolve rapidly in new niches – had evolved in the lake. The cichlids made up 80% of the lake's fish biomass, and together with more than 20 genera of non-cichlid fishes, they supported a thriving multi-species fishery.

As the local population grew and fishing techniques improved, fishing pressure on the lake increased, and by the early 1950s it was clear that overfishing had caused a drastic decline in fish stocks. In an effort to reverse the situation, British officials introduced the Nile perch *Lates niloticus*, as well as the Nile tilapia, into the lake.

With no natural predators and plenty of prey, the Nile perch flourished, sometimes growing as long as 2 metres and weighing up to 200 kilograms. It ate vast quantities of cichlid fish, driving at least 200 species to extinction in the process.

Far-reaching impacts

By 1980, cichlids made up less than 1% of the fish biomass in the lake, while the Nile perch had surged to 80%. Local fishers were landing ever-larger catches of Nile perch, which had a range of secondary environmental impacts. The flesh of Nile perch is oilier than that of local fish and must be dried over a fire, so more trees were felled for fuelwood. The resulting deforestation caused increased erosion and runoff, which raised nutrient levels in the lake, promoting infestation by water hyacinth.

The Nile perch's palatable bone-free white flesh, as well as products made from its swim bladder and hide, found favour on foreign markets, generating as much as US\$400 million in export income for the three countries bordering Lake Victoria – Kenya, Uganda and Tanzania. However, the export demand pushed up the price of fresh fish, making it too expensive for the local population. It also stimulated more intensive fishing, with the result that landings rose to 500 000 tonnes per year. By the mid-1990s it was clear that the Nile perch was being overfished. Catch rates declined, and the average size of landed fish dropped from over 50 kilograms in 1980 to less than 10 kilograms in 1996. In 2000, the Nile perch catch had fallen to below 85 000 tonnes.

COMMON CARP



The common carp *Cyprinus carpio* is undoubtedly the most widespread invasive alien fish in Africa, found in most of the continent's countries. Native to parts of Europe and Asia, it was one of the first species to be introduced outside its natural range, and now has a global distribution.

The carp was deliberately introduced for food in most cases, as it provides a cheap source of protein. In some regions of the world it was introduced for sport-fishing, but although it is considered a premier sport-fish in Europe and Asia, it is among the least favoured targets of anglers elsewhere, and is generally regarded as a pest because of the damage it causes to freshwater habitats. Furthermore, its introduction has resulted in the spread of a number of fish parasites.

Muddy giant

The common carp is a member of the minnow family, and is closely related to the goldfish. However, it can grow to **enormous sizes – exceeding a metre in length and reaching a weight of over 35 kilograms** – and in exceptional cases may live for up to 50 years. The carp is a bottom-dwelling fish, which prefers living in large, slow-flowing or standing water bodies with soft benthic sediments. It can tolerate low-oxygen conditions, as it is

able to gulp air at the surface, and can withstand temperature fluctuations and extremes. It thrives in muddy rivers and dams.

The carp is omnivorous, preferring water weeds and filamentous algae but also eating aquatic insects, snails, crustaceans, worms, snails and the spawn of other fish. It forages in bottom sediments, taking mud into the sucker-like mouth and then ejecting it after the food has been extracted.

Destructive feeder

It is because of its feeding activity that the carp is such an unwelcome invader. By uprooting plants and disturbing bottom sediments, it causes severe habitat damage – to the detriment of indigenous fish and other animals. Its grubbing behaviour muddies the water, reducing light penetration and thus inhibiting the productivity of submerged plants. It releases phosphorus normally locked up within the bottom sediments, which may result in phytoplankton blooms. The increased turbidity reduces visibility, so it affects feeding by sight-dependent fish, and limits their food availability because benthic organisms are smothered by resettled sediment. Stirred-up sediment also clogs the gills and filter-feeding apparatus of aquatic organisms. All of these impacts render the habitat

unsuitable for the survival of other species.

The carp's success as an invader can be attributed to its wide physiological tolerance, omnivorous diet, fast growth rate and high fecundity – a single female can lay well over 100 000 eggs per season. It also reduces the numbers of other fish predators that might prey on its young, both by eating the spawn of other fish and making the habitat unsuitable for them. As a result, carp generally monopolise water bodies to which they are introduced.

Control

Efforts have been made to control carp for more than a century, with varying success. The most basic method of **mechanical control** is to encourage people to harvest them, either by angling or seine-netting. Rich in protein, carp are an important source of quality food, and support commercially important fisheries in many parts of the world. Water level manipulation, traps and electro-fishing have also been used for mechanical control of carp, but have generally proved to be too labour-intensive or not cost-effective.

The most common method of preventing carp infestation is the use of barriers, such as metal grates, electrical barriers and culverts that channel outgoing water to produce high velocities, blocking the entry of carp.

However, the initial cost is high, and the structures may obstruct the spawning runs of other fish, as well as boat traffic. The effectiveness of metal grates is also limited, as they exclude adult carp but not their fry.

Chemical control usually involves the use of rotenone, a natural chemical extracted from the stems and roots of several tropical plants. It acts by being absorbed through the gills and inhibiting oxygen transfer at the cellular level, resulting in suffocation. It can be effective for controlling small, isolated populations of carp, and is environmentally non-persistent, so restocking of indigenous fish can occur in the same season of treatment. However, rotenone is non-selective, also killing non-target fish and many invertebrates.

In an effort to ensure more selective action, rotenone-impregnated baits have also been tested in recent years. Pre-baiting with non-toxic bait was conducted to attract carp to a feeding station, and hence maximise the number of fish poisoned. However, as soon as rotenone was added to the food supply, the carp detected it and stopped feeding.

Australian scientists are now experimenting with a method to achieve **biological control** of carp by limiting their reproduction. The 'daughterless gene method' aims to genetically modify carp so that they stop producing female offspring. It is hoped that the population will become biased towards males over time, and eventually decline.

Sport-fish or spoil-sports?

Some invasive alien fish species were introduced to Africa primarily for recreational angling, or sport-fishing. These include the largemouth bass *Micropterus salmoides*, the smallmouth bass *Micropterus dolomieu*, the rainbow trout *Oncorhynchus mykiss* and the brown trout *Salmo trutta*.

Both of the bass species are native to North America, and are aggressive predators of fish and aquatic invertebrates. While the largemouth bass favours clear, standing or slow-flowing waters, the smallmouth bass prefers flowing waters such as rivers and streams. In South Africa, it is considered primarily responsible for the threatened status of most of the indigenous fish species in the Western Cape's rivers.

The rainbow trout is native to North America, while the brown trout naturally occurs in Europe as well as the Atlas mountains of north-east Africa. However, these species now occur in more than 80 countries worldwide, and are widely accused of impacting on indigenous fish populations through competition and predation.

In addition, a number of species have been introduced as fodder for these sport-fish, including the bluegill sunfish *Lepomis macrochirus*, Nile tilapia *Oreochromis niloticus*, mosquitofish *Gambusia affinis* and red-belly tilapia *Tilapia zillii*.



TILAPIA



Tilapia are freshwater fishes belonging to the cichlid family. The various species are indigenous to different parts of Africa and the Middle East, but a number of them have been introduced to other African areas and the rest of the world. In some instances they were introduced as sport-fish, aquarium fish, or even as biocontrol agents to control waterweed or filamentous algae, but in most cases they were intended for aquaculture. However, some species have escaped or been deliberately released from captivity, and have established invasive populations in the wild.

Prolific breeder

Tilapia are second only to carp as the most widely farmed freshwater fishes on a global scale, and by the late 1990s the world harvest of farm-raised tilapia had exceeded 800 000 tonnes. They are ideal species for aquaculture because they are hardy fishes, with a wide environmental tolerance, and

they reach sexual maturity at a relatively young age, which allows for rapid population growth. However, in unfavourable conditions, such as limited food and space, they mature and breed at much smaller sizes than usual. This is known as stunting, and is undesirable in aquaculture as it results in large numbers of fish that are of sub-optimal size for the seafood market. Efforts to overcome the problem have included hybridisation between tilapia species to produce all-male or sterile offspring. These hybrid fish are commonly marketed as ‘red tilapia’.

In natural habitats, such prolific breeding means that tilapia very quickly become the most abundant fishes where they are introduced. Other features that contribute to the success of tilapia as invaders are their omnivorous feeding habits, which allow them to take advantage of available food sources, and the low mortality rate of juveniles due to parental care. All tilapia are either substrate-brooders – guarding the nest from predators and ventilating the developing eggs with their fins – or mouth-brooders, in which the eggs and fry are incubated in the mouth of one or both parents.

Impact

Tilapia impact local biodiversity because

- they **dominate the fish biomass** of waters in which they become established
- they **displace indigenous fish species** by competing with them for food, habitat and breeding sites, and aggressively defending their nests.
- they hybridise readily with other cichlids, resulting in genetic contamination of indigenous fish populations.

The introduction of tilapia around the world has probably also facilitated the **spread of fish parasites**.

Nile tilapia

As its name suggests, the native range of the **Nile tilapia** *Oreochromis niloticus* includes the Nile river basin, but the species also occurs naturally in the Rift Valley lakes, some West African rivers, and Israel. The present-day distribution is much broader, however, as the Nile tilapia has been widely introduced to south-east Asia, parts of Europe, and the Americas. It has also been translocated to many other areas of Africa, with negative consequences for indigenous fish populations. In the 1950s, for example, it was introduced to Lake Victoria to improve fishing, and – together with Nile perch – was responsible for the extinction of 200 species of cichlid fish. Today these two species dominate the lake's fish biomass.

Mozambique tilapia

The **Mozambique tilapia** *Oreochromis mossambicus* is indigenous to southern Africa, the natural distribution ranging from the lower Zambezi river system (Mozambique, Malawi, Zimbabwe and Zambia) to Bushman's River on the south-east coast of South Africa. However, it has been widely dispersed beyond this range, having been introduced to tropical and warm temperate localities throughout the world for aquaculture and sport-fishing.

Mozambique tilapia can grow to more than 36 centimetres, so in the natural environment there are few predators that can target adult fish. They do, however, prey opportunistically on other fish, although they are omnivorous feeders that eat whatever is available, and seem to prefer detritus and plant matter. They have a wide salinity tolerance, being able to live and even breed in seawater, and can withstand low-oxygen conditions.

Mozambique tilapia are prolific breeders, capable of reproducing several times per year when conditions are favourable. The female incubates the eggs and fry in her mouth, which ensures a high survival rate. This efficient reproductive strategy, together with the species' flexible habitat requirements, have allowed Mozambique tilapia to invade a variety of habitats, including dams, ornamental ponds, irrigation and stormwater channels, lakes, rivers and the upper reaches of estuaries. Since they inevitably dominate these habitats, to the detriment of indigenous fish populations, they are generally regarded as pests.

African tilapia explosion in Lake Nicaragua

An extensive stocking programme that introduced African tilapia into Lake Nicaragua during the 1980s proved to deliver much more than intended. The tilapia quickly adapted to their new congenial habitat and rapidly grew, feeding on local plants and fish. They formed large feeding schools moving through the lake system over long distances.

Being maternal mouth-brooders, it only takes a single female to colonise a new environment, carrying her offspring safely in her mouth. In confrontation, the odds are again counting in the invader's favour – being larger than the native species, they replace them quickly in territorial conflicts. Their special ability to adapt to salt-water conditions poses a serious threat to Nicaragua's coastal zone, where they may seriously affect the productive marine fisheries and adjacent estuarine nursing grounds.



INDIAN HOUSE CROW



As its name suggests, the native range of the Indian house crow, *Corvus splendens*, is centered in India, and extends from Iran in the west to Burma in the east. However, the bird was introduced to Africa in the 1890s, reportedly via Zanzibar, where it was brought to help keep the island free of rubbish. It subsequently spread along the coast of East Africa by hitching lifts on ships, and is now found right down to Cape Town at the southern tip of Africa. The crow also inhabits parts of the North African coast bordering the Suez Canal and Mediterranean Sea. It mainly occurs in urban and suburban environments, living in close association with humans.

A mean competitor

As an avian invader, the Indian house crow is undesirable for a host of reasons:

- It is an aggressive and opportunistic feeder, and has a devastating impact on indigenous bird populations by eating eggs and chicks, and mobbing other birds that might compete with it.
- It threatens the local wildlife by preying heavily on frogs, lizards, small mammals, fish, crabs and insects.
- It affects agricultural productivity by stripping fruit trees

in orchards and decimating grain crops, eating chicks of domestic poultry, and has even been known to peck out the eyes of sheep and pigs.

- It is unafraid of humans, and may enter houses to steal food, dive-bomb people walking past the nest, and frighten or even injure children by snatching food from their hands.
- In Cape Town many of the roosting areas are close to the airport, representing a bird-strike hazard for air planes.
- Indian house crows have also been blamed for causing power cuts in some areas, as they often construct nests out of wire in electric pylons.
- Furthermore, their droppings at roosts and feeding areas have been known to strip paint off walls and deface statues.

More seriously, however, the birds pose a threat to human health, because they are a vector for pathogens that cause cholera, typhoid, dysentery, and salmonella poisoning.

They scavenge for food in rubbish dumps, informal settlements, open-air abattoirs and markets, and may contaminate food and drinking water with their faeces. It is primarily because they represent a health hazard that efforts are made to control their populations.

Control

To date, the most effective control has been achieved using the poison Starlicide (3-chloro-p-toluidine hydrochloride). The poison is mixed with meat bait, ideally beef, which should be cut into small chunks and fed to the birds at a feeding site near their roost. However, before any poisoning takes place the birds should be accustomed to being fed by conducting pre-baiting for at least two weeks. A regular feeding routine should be established until the birds recognise the baiter and a large group gathers at the feeding site well before feeding. Pre-baiting also lessens the risk of ingestion by non-target species, as the crows will chase off any other birds approaching the feeding site.

Once the crows are habituated, they should be fed poisoned bait. Starlicide takes about 20 hours to take effect, but since it is metabolised during that period, the corpse will be free of poison and will not affect other animals that might scavenge on it. Dead crows around the roost site should be collected by somebody other than the baiter to avoid arousing the birds' suspicion.



ISLAND INNOVATION

An innovative 'bounty system' has proven highly successful in controlling the Indian house crow in the Seychelles. A cash reward is paid for each crow delivered to the authorities, which encourages community involvement in the control programme. In addition, a 'green line' has been set up, allowing members of the public to phone in and report sightings of the crow and other alien invaders. The initiative is part of an aggressive campaign to raise public awareness about the threats posed by invasive alien species to this island paradise.

DID YOU KNOW?

It is thought that the Indian house crow was introduced to Europe via Egypt as a stowaway on warships passing through the Suez Canal while returning from the Gulf War. The first European record was from Gibraltar in March 1991, and a small breeding colony has since become established in Holland.

The Indian house crow is known to stage gang attacks on domestic livestock, pets and even people in its native range. Records of the crow feeding on human corpses and killing young goats, calves, sheep and domestic cats are commonplace in India. It is not unusual to see the birds hitching rides on the backs of pigs, feeding on watermelon rinds and street garbage, flitting in and out of train stations or darting through open windows to snatch food.



HOUSE SPARROW



The house sparrow *Passer domesticus* is indigenous to Eurasia and North Africa. It is believed to have been introduced to southern Africa from India in the late 1890s, probably as a pet of Indian labourers working in the sugarcane fields around Durban, South Africa. Within 50 years it was widespread in KwaZulu-Natal province, and in 1948 was reported to have crossed the Drakensberg mountain range into the interior of South Africa. Thereafter, colonisation of the rest of southern and central Africa was very rapid, supplemented by additional minor introductions of escaped aviary birds in East London in South Africa, Harare in Zimbabwe, Maputo in Mozambique, and probably elsewhere.

The house sparrow has also been introduced to east Africa, where it is found on the coast of Kenya and along the railway route to Nairobi.

A human link

Today the house sparrow is widely distributed, but only where there are human settlements, as the bird nests in buildings and is largely dependent on people for food. As its name suggests, it is common around houses, where it

can forage for scraps of food discarded by people. There are many reports of it feeding in canteens in buildings, even learning to activate automatic doors to gain entry. It is often found in stables, barns and granaries, where it can eat seeds and grains, sometimes stolen from animal feed or pecked from droppings. It also feeds on a variety of insects, spiders, berries and flower buds. Indeed, it is the bird's generalist diet that has allowed it to become established throughout its introduced range.

Unfortunately, the house sparrow's success as an invader has been at the expense of indigenous birds, and it is accused of causing the decline of a number of cavity-nesting species where it has been introduced. The house sparrow out-competes such birds for nest sites and aggressively evicts those that attempt to nest in its territory. In doing so, the males may destroy the eggs of a nesting pair, kill nestlings and sometimes even kill incubating females.

The house sparrow has also been implicated as the main reservoir for mosquito-borne West Nile virus in the United States. The virus is widely distributed in Africa, Asia and Europe, but had never been recorded in the western hemisphere prior to August 1999, when there was an outbreak in New York. (See page 79.)

MALLARD DUCK



Some invasive alien species have a negative impact on biodiversity not by displacing indigenous species through predation or competition, but by compromising their genetic integrity.

Genetic invader

The mallard duck *Anas platyrhynchos* – possibly the world's most numerous duck – is native to Eurasia and North America. It has been introduced to a number of countries outside this range, where it poses a serious conservation threat by hybridising with related species and causing genetic contamination of indigenous duck populations. For example, the New Zealand grey duck, once considered the most widespread and abundant duck in New Zealand, today makes up only 5% of the total mallard-grey duck hybrid population. The Mexican duck is

now listed as extinct, as all the remaining birds were found to be hybrids. The mallard also hybridises with both the American black duck and the Australian black duck.

The mallard was first introduced to South Africa in the 1940s, and in the early 1960s was commonly sold by bird dealers. It has now been recorded at more than 70 sites throughout the country, and commonly hybridises with the **yellowbilled duck**, which fills the same ecological role and has similar behaviour. The yellowbilled duck is widely distributed in Africa, and the mallard invasion puts the entire population at risk. A yellowbilled duck banded in Cape Town was recovered in Zambia, and it can be assumed that hybrids would have the same motility.

The mallard has also been reported to hybridise with **the African black duck and the Cape shoveller**. Control efforts are underway in some centres, but these usually encounter strong public opposition, largely due to a lack of awareness around the dangers of visually appealing and seemingly harmless invasives like the mallard.



Yellow-billed duck with chicks

EUROPEAN STARLING



The European, or common starling, *Sturnus vulgaris* is native to Eurasia, migrating into North Africa to over-winter in more temperate African countries. The bird was intentionally introduced to South Africa, New Zealand, Australia and North America, mainly for aesthetic reasons but sometimes also to control insect pests. Ironically, it is now considered a pest itself, largely because the noisy habits and messy droppings of huge flocks are aesthetically unappealing.

Small beginnings

The European starling was introduced to South Africa in the late 1890s by Cecil John Rhodes, who had 18 birds released in Cape Town to diversify the region's bird fauna. By 1910 the species had extended its range to Stellenbosch, and by 1922 had crossed the surrounding mountain ranges, allowing it to become widespread in the Western Cape province by the 1950s. It reached the Eastern Cape in the 1960s and continued to spread along the east coast, being recorded for the first time in KwaZulu-Natal in 1973, and more recently in the adjacent interior in the Free State. On the west coast of southern Africa it

occurs in Oranjemund and is spreading into the southern parts of Namibia.

The species is probably not adapted to survive in the arid and warmer parts of southern Africa, and is generally confined to regions with relatively high rainfall. In the dry interior it is restricted to areas with irrigated fields, and although it has colonised parts of the semi-arid Karoo, it abandons these areas during prolonged droughts.

A similar invasion scenario, involving rapid spread from a relatively small founder group introduced at a single point, occurred in North America. The species was first introduced to the United States in 1890, when 100 starlings were released in New York's Central Park, apparently in the hope that all birds mentioned in Shakespeare's works would become established in the New World. Today the starling is widely distributed across the United States and Canada, with a population estimated at about 200 million birds.

The species' success as an invader can be attributed to the fact that it is a habitat generalist, able to exploit a wide variety of habitat types, nest sites and food sources. Its ability to co-exist with humans allows it to become established in agricultural fields, cities, around sewage treatment facilities and garbage dumps.

A human health risk

European starlings are highly colonial, gathering in flocks that may number in the thousands to feed, roost and migrate, although they tend to be solitary nesters. Their droppings cause sanitation problems in and around buildings, are corrosive to paint and plaster, and provide a growth medium for the fungus that causes the human respiratory disease histoplasmosis.

The birds themselves carry diseases that may be transmitted to humans, as well as itch-causing mites hidden in their feathers. Furthermore, large flocks of starlings close to airports pose a bird strike hazard to planes.

Destructive habits

European starlings also cause economic losses in agriculture. They are a potential threat to domestic animals, as they can transmit diseases by contaminating food and water sources at livestock and poultry facilities with their droppings. They sometimes impact on crop production by eating cultivated fruits, particularly berries and grapes, and by uprooting sprouting plants and eating sowed seed in grain fields.

The birds have a negative affect on biodiversity as they eat large quantities of insects, spiders, snails, earthworms, lizards and frogs, while competing with other birds for these resources. They also compete aggressively with indigenous hole-nesting birds for nest sites, often driving other birds from their nests, destroying eggs and killing nestlings. In addition, the birds cause secondary impacts on biodiversity by dispersing the seeds of invasive alien plants.

Control

In South Africa there is no systematic attempt to control European starlings. In most other invaded countries too, effort is focused instead on mitigating their impact. For example, birds can be excluded from buildings by sealing up holes or covering them with strong netting, while commercially available repellents, coiled razor wire or spiked boards can be used to discourage roosting on ledges or roof beams. Strips of plastic or rubber hung in open doorways of farm buildings have been successful in keeping birds out, while allowing access to people, machinery and livestock.

European starlings are less damaging to agriculture in South Africa than in some other regions, where innovative farm management practices may be employed to limit food and water available to starlings, making the livestock environment less attractive to them. Where cost-effective, netting can also be used to protect fruit crops such as grapes and berries.

Frightening is effective in dispersing starlings from roosts, small-scale fruit crops, and some other troublesome situations, including airports. However, poisoning with Starlicide is the only effective way to kill starlings. Poisoned birds experience a slow, non-violent death, usually dying 24 to 36 hours after feeding, often at their roost. Pre-baiting (using a non-poisonous bait) should be conducted for a few days prior to poisoning, to accustom the birds to feeding on bait at a particular location.



COMMON MYNAH



The common mynah *Acridotheres tristis* is another member of the starling family that is invasive in Africa. Sometimes called the Indian mynah because it is native to India and surrounding countries in south and south-east Asia, the bird has also become established in Australia, New Zealand, Hawaii, New Caledonia, Fiji, Western Samoa, the Solomon Islands, Cook Islands, and some other oceanic islands. In many cases it was introduced deliberately to control insect pests on crops, but sometimes accidentally when cagebirds escaped. The bird is an opportunistic feeder that eats almost anything, contributing to its success as an invader.

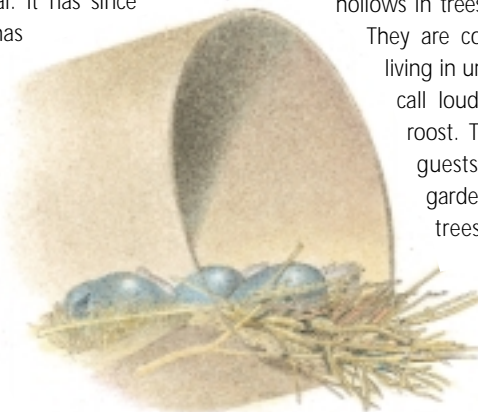
In South Africa the mynah was first recorded in Durban in 1902, and within 50 years it had colonised most of western and northern KwaZulu-Natal. It has since spread south along the coast, and has been reported to have bred successfully at Port Elizabeth. Further expansion of its range may be restricted, as the species seems to prefer warm climates and high-rainfall areas. However, there are concerns that global warming might shift the distribution limit further south-westwards and into the

country's dry interior, or even into adjacent countries. The mynah has already invaded a number of island states off the coast of Africa, including Mauritius, Seychelles, Madagascar and the Canary Islands.

In areas where it has invaded, the mynah reduces the biodiversity of local birdlife, as it competes aggressively with indigenous birds for food and nest sites, and eats their eggs and chicks. It damages fruit and grain crops in agricultural areas, and may cause a decline in populations of beneficial insects. It probably also facilitates the spread of invasive plants, by eating their fruit and dispersing the seeds in their droppings. **In Hawaii, for example, the mynah was introduced to control insects in sugarcane fields, but was later implicated in the spread of invasive *Lantana camera*.**

Mynahs often roost communally, and may nest in hollows in trees or walls and under roof eaves.

They are considered a nuisance by people living in urban areas, being noisy birds that call loudly as they enter and leave the roost. They are also unwelcome house-guests because they attack other garden birds, eat the fruit on garden trees, make a mess with their droppings, and may bring itch-causing mites into the home when nesting in the eaves.



ROSY WOLF SNAIL



The **rosy wolf snail** *Euglandina rosea* is a predatory terrestrial snail that is native to Latin America and the south-eastern United States. It has become invasive in a number of island states off the African coast, including Mauritius, Reunion, Madagascar and the Seychelles.

Biocontrol gone wrong

Starting in 1955 – when it was released in Hawaii – the rosy wolf snail has been introduced to more than 20 oceanic islands as a biocontrol agent against the **giant African snail** *Achatina fulica* and other snail pests. While there are no indications that it has been successful in controlling the giant African snail anywhere, it has caused the extinction or decline of indigenous snail species wherever it has been introduced.

In Mauritius, for example, it was introduced in 1960 to control the giant African snail, which had been introduced

as a potential food resource but had negatively impacted crops. Since then, 24 of the 106 snail species endemic to Mauritius have become extinct, and the rosy wolf snail is largely to blame.



The snail gets its common name from its rose-pink shell and its wolf-like habit of tracking and running down its prey. When it locates the slime trail of another snail, it quickens its pace, following the trail until it catches up with its victim. Small snails are swallowed whole, while larger ones are manoeuvred to expose their soft parts so that chunks can be torn off with the radula teeth.

Monkey business in Mauritius

Another invasive alien species that is problematic in Mauritius is the **crab-eating macaque**, *Macaca fascicularis*. Native to south-east Asia, the monkey is thought to have been introduced to Mauritius by the Portuguese in the early 16th Century, and the population has since grown to between 40 000 and 60 000.

The monkeys are regarded as agricultural pests because they steal sugarcane and other crops on the island. They also facilitate the dispersal of invasive plant species by feeding on fruits and seeds, which make up about 70% of the diet. They threaten indigenous forest birds

by competing with them for these food resources, and more importantly, by preying on their eggs and chicks. Indeed, nest predation by the monkeys, as well as by feral cats and rats, is compromising the recovery of the **endangered pink pigeon**, which is being brought back from the brink of extinction by a captive-breeding programme.

The monkeys cannot be killed for socio-religious reasons, but many are trapped and exported for biomedical research purposes. A levy is paid to the National Parks and Conservation Fund for each monkey exported.

ARGENTINE ANT



The Argentine ant *Linepithema humile* has spread from its native range in South America to parts of all other continents except Antarctica. Where it has become established, it is:

- a domestic nuisance in urban areas
- a destructive pest in agricultural areas, and
- an aggressive invader in natural areas, negatively impacting biodiversity both by killing and displacing other species and by altering ecosystem processes such as pollination and seed dispersal.

In Africa the Argentine ant has invaded the fynbos biome – world-renowned for its rich biodiversity – in the south-western Cape of South Africa. It was first recorded in Cape Town in 1908, and is thought to have been introduced in horse fodder imported from Argentina for the British cavalry during the Anglo-Boer war.

The Argentine ant and fynbos

Up to 30% of plants in fynbos communities rely on ecologically beneficial, native ants to disperse their seeds, a

strategy known as myrmecochory. The relationship is a mutually beneficial one, because in return for their services the ants receive a food reward in the form of a nutrient-rich food body – called an elaiosome – attached to the seed. The ants seek out seeds lying exposed on the soil surface and carry them into their underground nests, where they consume the elaiosomes, while leaving the seeds unharmed.

However, Argentine ants ‘cheat’ by eating the elaiosomes without taking the seeds underground. They leave the seeds on the surface, where they are exposed to fire and to heavy predation by rodents. Although fire is vital for fynbos regeneration – stimulating seed release or germination of most species – seed burial provides a buffer against intense heat, which destroys many seeds.

The Argentine ant co-exists with indigenous species of ant that disperse small fynbos seeds, but it displaces two species that are able to disperse large seeds by working cooperatively. Regeneration of large-seeded plants is therefore more likely to be impacted by fire and predation after invasion by Argentine ants, leading to a shift in the composition of fynbos plant communities. Furthermore, Argentine ants have been shown to deter some insect pollinators on protea flowers.

Cape fynbos

Fynbos means 'fine bush' and is the name for fine-leaved vegetation that makes up 80% of the Cape Floral Kingdom. Superficially, fynbos appears to be a uniform spread of greyish-green shrubs, but closer examination will reveal an amazing variety of plants, from majestic proteas to delicate ericas and reed-like restios.



A Global invader

Invasion by Argentine ants has resulted in equally dire consequences for ecosystems in other parts of the world. In California, for example, the ant thrives in temperate and damp coastal areas, and although only 2-3 millimetres in size, it kills and displaces indigenous ants up to ten times larger. This appears to be one of the main reasons why the population of the coastal horned lizard has declined by 50% or more in areas where the ant has invaded. The lizard prefers to feed on larger indigenous ants, and tends to starve where these have been displaced by the smaller Argentine ant.

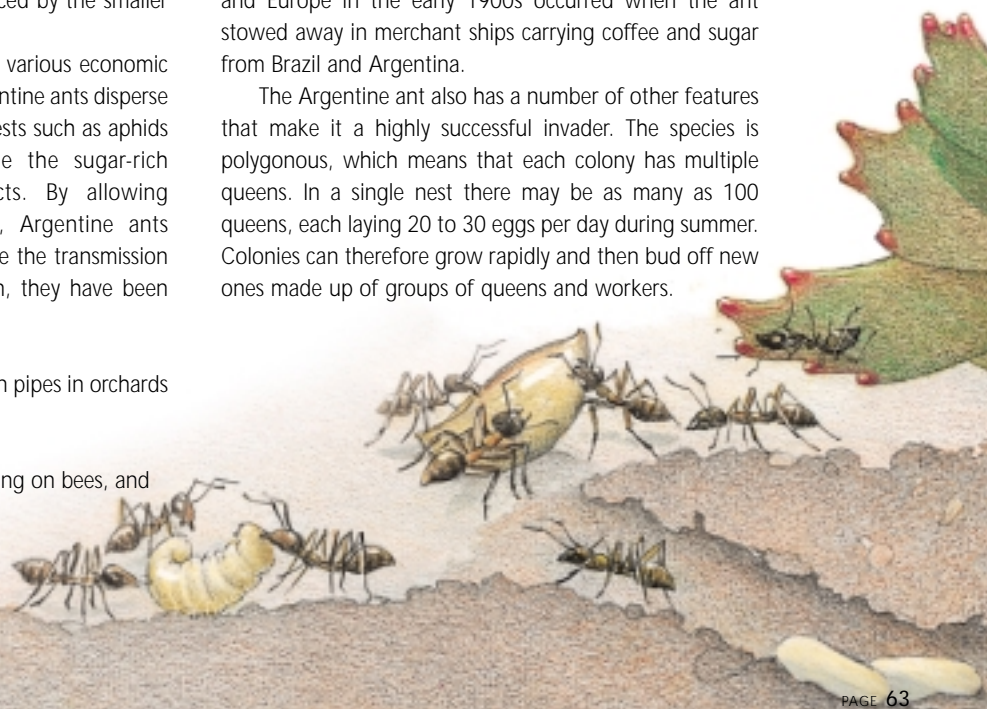
Invasion by Argentine ants also has various economic impacts. In orchards and vineyards, Argentine ants disperse and protect sap-sucking homopteran pests such as aphids and scales so that they can imbibe the sugar-rich honeydew secreted by these insects. By allowing homopteran infestations to increase, Argentine ants reduce the quality of crops and facilitate the transmission of diseases between plants. In addition, they have been known to cause losses by:

- chewing holes in plastic drip irrigation pipes in orchards
- causing stress to brood chickens
- killing hatchlings in poultry farms
- robbing bee hives of honey and preying on bees, and
- contaminating food products.

A sneaky stowaway

Without the help of humans, colonies of Argentine ant would not be able to disperse very far to invade new areas. Under normal circumstances, new nests are formed by a group of workers and queens leaving the home nest and starting up a new one within walking distance. Due to its tendency to associate with humans, however, the Argentine ant has been transported over large distances in food, rubbish, building material and cargo containers. Indeed, many of the introductions to Africa, North America and Europe in the early 1900s occurred when the ant stowed away in merchant ships carrying coffee and sugar from Brazil and Argentina.

The Argentine ant also has a number of other features that make it a highly successful invader. The species is polygynous, which means that each colony has multiple queens. In a single nest there may be as many as 100 queens, each laying 20 to 30 eggs per day during summer. Colonies can therefore grow rapidly and then bud off new ones made up of groups of queens and workers.



ARGENTINE ANT

The Argentine ant has a generalist diet, so it can take advantage of a variety of available food sources. It is also aggressive to other ant species while being non-aggressive to Argentine ants from different nests, allowing it to dominate ant faunas in its introduced range. Fortunately, expansion of its range appears to be limited both by insufficient moisture in arid areas and excessive moisture in humid areas.

Control

Toxic baits are probably the most effective way of controlling the Argentine ant, and products formulated with hydramethylnon, fipronil and sulfuramid have been used in agricultural, urban and natural areas. Sucrose solutions containing < 1% boric acid are effective in controlling workers, but not queens. Every queen needs to be killed if ants are to be eradicated from treated areas. Since queens are fed protein for egg development, protein-based baits will have the greatest effect on the colony. Baiting requires ongoing follow-up work to control ants reinvading from surrounding areas.

Argentine ants can also be excluded from trees by winding cotton twine permeated with Famesol and Stickem around the trunks. No biological control initiatives have been attempted as yet.



The little fire ant

In a case echoing the battle of David and Goliath, a tiny ant appears to be taking on the mighty elephants of Gabon, in West Africa.

The little fire ant *Wasmannia auropunctata* was probably introduced to Libreville in Gabon in about 1914, and now occurs up to 250 kilometres inland and along 600 kilometres of coastline, into neighbouring Cameroon. Recently, villagers in Gabon noticed elephants with white, cloudy eyes behaving strangely, as if almost blind, and based on circumstantial evidence stacked against it, the little fire ant is being held responsible. The ant's venomous sting had already been implicated in causing corneal clouding and blindness in house cats in Gabon, while a related species is known to have blinded dogs in the Solomon Islands. In the Galapagos Islands, little fire ants attack the eyes and cloaca of adult tortoises and eat the hatchlings.

More typically, the ants prey on insects and spiders, decreasing the abundance and diversity of these arthropods to such an extent that other predators, such as birds and lizards, may be negatively impacted. In addition, a large part of the diet is made up of honeydew, collected from homopterans. The ants protect these sap-sucking pests from predators, allowing them to increase in number to the detriment of crops. The ants are considered a menace by agricultural workers in orchards and plantations because of their painful sting, which also makes them unwelcome in homes. They commonly infest beds, clothing and furniture and contaminate food, preferring fatty and oily products such as peanut butter.

The little fire ant is native to Central and South America, but apart from West Africa it has invaded several Pacific Island groups, and is also a greenhouse pest in temperate regions such as England and Canada.

The ants often nest at tree bases and in potted plants, so they are easily spread by the nursery and cultivation industries, and were deliberately introduced to cocoa plantations in Cameroon as a biological control agent against mirids.

RATS



Rats are undoubtedly the world's most widespread invasive alien mammals, with the greatest economic impact. The costs associated with the approximately 250 million rats in the United States, for example, have been estimated at \$19 billion per year. However, rats also cause significant environmental impacts, and have contributed to the extinction of many species of wildlife.

Black and brown rats

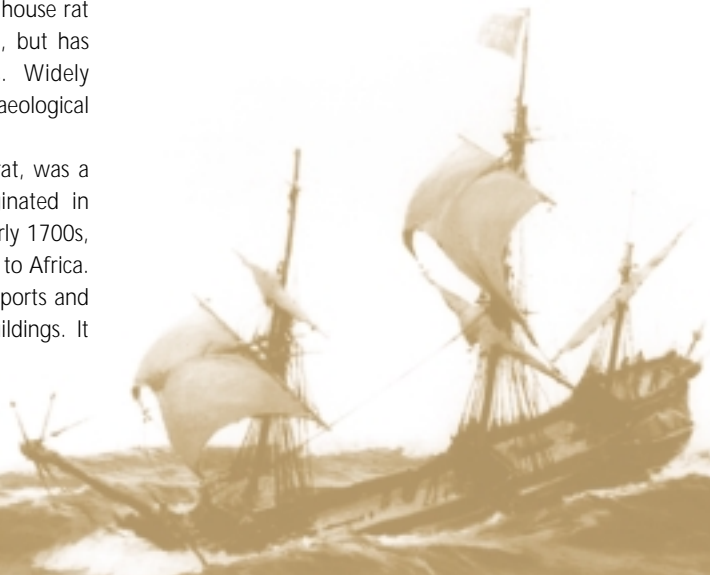
The two most common invasive alien rats worldwide are the **black rat *Rattus rattus*** and the **brown rat *Rattus norvegicus***. The black rat is also known as the house rat or ship rat. It is native to south and east Asia, but has spread around the world on sailing ships. Widely distributed in Africa, it is evident in the archaeological record from before 800 AD.

The brown rat, also called the Norwegian rat, was a later introduction. It is believed to have originated in northern China and spread to Europe by the early 1700s, after which it was probably transported on ships to Africa. Today its African distribution remains limited to ports and large cities, where it thrives in sewers and buildings. It

tends to inhabit the basements and cellars of buildings, while the black rat prefers the upper stories and ceilings.

Indiscriminate feeders

Both rat species are omnivorous, and eat a wide range of foodstuffs, including seeds and seedlings, fruits and berries, eggs and small animals. By preying on other species or competing with them for food, they have caused the decline of many small mammals, birds, reptiles and invertebrates. Their effect has been particularly severe on islands. In the Seychelles, for example, rats have had more impact on endemic biodiversity than any other factor.



In Mauritius, they are believed to have caused the extinction of a number of snakes and lizards, and contributed to the threatened status of many birds. The black rat is able to climb trees to prey on forest birds, while the brown rat targets ground-nesting species.

Rats also cause a variety of socio-economic impacts by eating crops and stored grain, contaminating food stocks with their waste, chewing through power cables and spreading diseases.

Control

Most successful control programmes have made use of **poisoned bait**, usually containing brodifacoum as the active ingredient. In the past, **cats** were sometimes released on islands to control rat populations, with devastating consequences for birds and other small animals. On the Seychelles, feral cats have been blamed for the extinction of magpie robins on Aride and Alphonse islands, and have even been observed preying on turtle hatchlings. Likewise, the Indian mongoose – introduced to Fiji, the West Indies, Mauritius and Hawaii to control rats – caused serious problems in these locations, including the extinction of several endemic species of birds, reptiles and amphibians.

Rats and ‘Black Death’

Rat-borne diseases have claimed more human lives than all the wars in history combined! As a reservoir for the bubonic plague bacterium *Yersinia pestis*, the black rat is held accountable for 200 million deaths in medieval times alone.

Bubonic plague is transmitted by fleas from rats to people, but then spreads rapidly as it is highly infectious. An outbreak occurred in China in the early 1330s, but the disease was not introduced to Europe until 1374, when several Italian merchant vessels returned from a trip to the Black Sea – a key trade link with China. Many of those onboard were already dying when the ships docked in Sicily, and the disease quickly spread through the surrounding countryside. The following year it reached England, where it was known as Black Death because its symptoms included black spots on the skin. The disease ultimately killed almost a third of Europe’s people.

Outbreaks of bubonic plague continue to occur – mostly in rural areas – with the World Health Organisation reporting 1000 to 3000 cases globally every year. Fortunately, the disease can nowadays be treated with antibiotics.



Tahr on Table Mountain

In the 1930s, a few Himalayan tahr *Hemitragus jemlahicus* escaped from a zoo on the slopes of Table Mountain, in the heart of Cape Town, South Africa. With no large predators remaining on this urban island, their numbers grew rapidly, peaking at about 600 in the mid-1970s. Their foraging and trampling threatened the mountain’s rich endemic plant life and increased erosion, so a culling programme was initiated in 1973. This continues to encounter opposition from animal rights groups, but live capture of the animals is near impossible. Himalayan tahr are relatives of ancient mountain goats, and are able to scramble over the most inaccessible terrain. Today just under 100 tahr remain on Table Mountain.

Feral farm animals

Feral populations of goats, pigs and rabbits invariably cause ecological degradation, particularly on islands, where they were often deliberately introduced as a food supply for passing or shipwrecked sailors.

Domestic goats – recognised as the single most destructive herbivore introduced to the islands of the world – are derived from species originating in Asia, while rabbits are indigenous to Spain and Portugal. Both animals tend to cause increased erosion owing to their overgrazing, trampling (goats) and burrowing (rabbits). They also impact indigenous communities by out-competing other herbivores and reducing the plant cover needed by other animals to shelter from predators or the elements.

Wild pigs – originally native to Eurasia and North Africa – eat large quantities of fruits, seeds, seedlings and roots, as well as invertebrates such as earthworms and snails. They not only reduce the food supply available for other animals, but impede plant regeneration by uprooting seedlings and disturbing the soil with their rooting behaviour. Furthermore, they disperse the seeds of alien plants in their faeces, and damage crops, including sugarcane. Pigs have had a major impact on islands by preying on the eggs and chicks of ground-nesting birds, and may have contributed to the extinction of the dodo on Mauritius.



INSECT PESTS

Some of the most important invasive alien species in Africa are agricultural pests, which often have crippling socio-economic consequences. While many introduced bacteria and viruses cause diseases of crops and livestock, insect pests are equally destructive.

Khapra beetle

The khapra beetle *Trogoderma granarium* is one of the world's worst pests of grain products and seeds. It is believed to have originated from the Indian subcontinent, but has spread throughout south-east Asia, the Middle East, parts of Europe, and much of Africa.

The beetle is only a few millimetres long and cannot fly, but commerce and trade has facilitated its spread. It hides away in cracks, crevices and even behind paint scales and rust flakes, allowing it to infest food stored or transported in warehouses, containers or packaging materials that were previously exposed to the pest.

The adult beetles live for only 5-10 days, and in favourable conditions the entire lifecycle – from eggs to larvae, to pupae to beetles – can be completed within a month or two. However, in adverse conditions, such as



food shortage, little moisture and low temperatures, the larvae enter a state of dormancy in which they can remain for as long as eight years.

It is the larvae that cause the damage to stored food, particularly wheat, barley, rice and seeds, but also spices, beans, lentils, nuts, pasta and powdered milk. They not only eat the food, but contaminate it with their excreta and shed skins, causing gastrointestinal irritation in human consumers. The larvae have five to nine stages, so large numbers of shed skins soon accumulate, and these are usually the first sign of infestation, although pheromone-baited traps can be used to detect the adult insects. The khapra beetle is particularly difficult to control with insecticides, and fumigation of the entire building with methyl bromide is usually necessary.



Cassava green mite

The cassava green mite *Mononychellus tanajoa* is a major pest of cassava, a starchy root crop that is a staple food for more than 200 million people in sub-Saharan Africa. It is an alien invader in Africa, being native to South America, the ancestral origin of cassava. The first outbreak in Africa occurred in Uganda in 1970, after which the pest spread rapidly to more than 25 countries throughout the cassava belt, causing an estimated 30 to 50% reduction in yield.

Biocontrol success

Fortunately, the cassava green mite is now being brought under biological control. The predatory mite *Typhlodromalus aripo* was introduced from north-east Brazil to Benin in 1993,

and is now established over more than 400 000 square kilometres in a dozen countries, mostly in West Africa. The biocontrol agent spreads about 12 kilometres in the first season after introduction, and as much as 200 kilometres in the second. Once established, it reduces green mite populations by half and increases cassava yields by about one third.

A related species, *T. manihoti*, shows promise as a biocontrol agent in humid areas, as it is established and spreading in Benin, Burundi, Ghana and Nigeria. Meanwhile, research on other potential natural enemies – including fungal pathogens – is continuing, in the hope of finding biocontrol agents best suited to the diverse environmental conditions within the cassava belt.



Spiralling whitefly

The spiralling whitefly *Aleurodiscus dispersus* is a serious pest of commercial fruit and vegetable crops, as well as many ornamental trees and shrubs. It is indigenous to Central America and the Caribbean region, but is spreading throughout the world's tropical and sub-tropical areas. It has occurred in the Canary Islands since 1963, but was first recorded on the African continent in 1992, when it was found in Nigeria. It rapidly invaded neighbouring Togo and Benin, and later some other African countries. In 2000 it was detected in Mauritius and has since been found in the Seychelles too.

Not a fly, but a bug

The spiralling whitefly is not a fly but a homopteran bug, related to the aphids and scales. It resembles a tiny white moth no more than 2-3 millimetres long, and lays its eggs on the leaves of plants in a characteristic spiral pattern. Both the immature and adult stages cause feeding damage by piercing the leaves and sucking the sap, which may lead



to premature leaf fall. Furthermore, they produce copious quantities of sugary honeydew, as well as a white, waxy flocculent material. The honeydew provides a substrate for the growth of sooty mould, which blackens the leaf and inhibits photosynthesis. Severe infestations result in defoliation and death of the plant.

Both the black mould and the white wax disfigure the plant, reducing its value or making it unmarketable. Among the plants that spiralling whitefly affects are **mango, pawpaw, banana, coconut, avocado, guava, citrus, chilli, lettuce, tomato, aubergine, poinsettia, hibiscus and rose bushes**. International trade of these plants has facilitated the pest's spread.

A number of **biocontrol** agents, including three coccinellid beetles and two parasitic wasps, have proved effective in controlling spiralling whitefly in some regions. For garden and household plants, contact and systemic insecticides, as well as dilute aqueous solutions of detergents and soaps, have been reported as helpful.



Larger grain borer

The larger grain borer *Prostephanus truncates* is a destructive pest of farm-stored maize and dried cassava in sub-Saharan Africa. Native to South and Central America, it was first detected in Africa in the late 1970s in Tanzania, where it increased maize losses by as much as five times. In 1984 the first outbreak in West Africa occurred in Togo. The pest subsequently spread throughout East and West Africa and also began invading southward, reaching South Africa at the tip of the African continent in 1999.

The larger grain borer is particularly damaging to maize stored on the cob. The adult is a small, dark beetle, which either attacks maize in the field or after the crop is harvested. The beetle bores into the grain, feeding as it goes and leaving maize dust in its wake. Eggs are laid in side chambers excavated off the main tunnels, and after hatching the larvae feed on the surrounding maize dust.

The pest also attacks dried cassava – causing losses as high as 70% after only four months of farm storage – as well as cereals, legumes, dried roots, tubers, peanuts, cocoa and coffee beans.

Control challenges

A **biological control** campaign was launched in 1991 with the introduction of the **predatory beetle** *Teretriosoma nigrescens*, but recent reports suggest it is not as effective as hoped. To date, pyrethroid insecticides – primarily Actellic Super Dust (ASD) containing permethrin and pirimiphos-methyl – have been the main line of defence against the larger grain borer. They necessitated a change in traditional storage practices, as efficient **chemical control** required that the maize be removed from the cob for treatment and storage. However, due to concerns about the safety of such insecticides, integrated pest management techniques and post-harvest management methods that are less of a risk to the environment and to human and animal health are now being explored.



AFRICA invading



Invasive Alien Species originating from Africa

While numerous invasive alien species occur in Africa, many of the continent's own plants, animals and micro-organisms have invaded other parts of the world. A few of these, such as *Acacia nilotica* and Mozambique tilapia *Oreochromus mossambicus*, have been mentioned elsewhere in this publication. The following pages highlight a small selection of other African invasive 'exports'.

Grasses

A wide variety of African grass species have been introduced to other parts of the world, mainly to provide grazing pasture for livestock or to rehabilitate rangeland degraded by drought or overgrazing. In many instances these grasses have spread to invade natural areas, where they represent a significant threat to biodiversity and ecosystem functioning.

Buffelgrass *Pennisetum ciliare* – the most popular of the African grasses planted to enhance livestock production in the dry tropics and sub-tropics – has even been planted in the Sonoran Desert of the American south-west. Converting desert vegetation to buffelgrass pasture will allow stocking rates to triple, but this comes at the expense of the desert's unique and exceptionally rich biodiversity. Where buffelgrass has escaped from pastures and invaded the surrounding desert, it fuels fires that cacti and other indigenous plants are not adapted to withstand.

A related species, kikuyu *P. clandestinum*, has been widely planted in more humid parts of the world, both for pastures and lawns. Its fast growth rate is considered a boon for grazing, but it displaces a variety of beneficial species, including nitrogen-fixing legumes that maintain nutrient levels in the soil. This necessitates heavier application of fertiliser, which is not only costly but has secondary environmental impacts, such as nutrient enrichment of watercourses and subsequent algal blooms and waterweed infestations. Kikuyu is listed as a noxious weed in many countries, as it rapidly encroaches into natural areas and swamps indigenous vegetation. It is also considered a water-thirsty and high-maintenance lawn plant in some regions.

Introduced African grasses are generally intensive water users that have high maximum photosynthetic biomass when water is available, but cease growth during dry periods. However, pastures dominated by South Africa's **Lehmann lovegrass *Eragrostis lehmanniana*** in southern Arizona produce forage more consistently in dry years than do native grass pastures, so ranchers often devote a portion of their land to lovegrass pasture as 'drought insurance'.

Among the many African grass species introduced for ornamental purposes is the **fountain grass *Pennisetum setaceum***, widely planted for landscaping in urban areas. Although a very attractive species, it is now considered an unwelcome guest in many regions, as it aggressively invades natural areas and poses a dangerous fire hazard.

African grasses are not always deliberately introduced – their small seeds often escape detection when hidden away in other imported goods. Indeed, it is thought that **Guinea grass *Panicum maximum*** and **Pará grass *Brachiaria mutica*** may have been inadvertently introduced to the West Indies and Brazil on slave ships, as far back as 1684.





Sour fig

The sour fig *Carpobrotus edulis* is a creeping succulent plant that is indigenous to the South African coast, but has become naturalised in parts of the United States, Australia and the United Kingdom after being widely planted for landscaping and soil stabilisation.

The species is particularly problematic in California, where it is known as the highway iceplant, as it was commonly planted on slopes alongside highways. However, it has spread beyond plantings and has invaded coastal habitats, forming dense mats that not only displace indigenous species, but also stabilise dunes and hence interfere with natural sediment dynamics.

The plant spreads both sexually – by seeds – and vegetatively. The fruits are eaten by mammals such as deer, rabbits and rodents, which disperse the seeds in their droppings, while new plants can easily regrow from segments. Providing a segment contains a growth node, it is able to produce new roots and shoots when in contact with the soil. This is an adaptation to sand burial in dune systems, allowing segments to continue growing if they are isolated from the parent plant. Efforts to eradicate this species therefore require the removal of all plant material to prevent resprouting. The plant can easily be removed by handpulling and killed by herbicides, but no biological control agents are currently available for the species.

Cape ivy

The Cape ivy *Delairea odorata* is another species from the Cape of South Africa that has been distributed around the world for landscaping. It is a popular ornamental climbing vine, but has become a weedy pest in England, Australia, New Zealand and the American states of California, Oregon and Hawaii.

The plant forms a thick carpet that smothers other vegetation, reducing local biodiversity. It often climbs into the canopy of trees, blocking out light needed by understorey plants. The weight of such infestations sometimes causes the canopy to collapse or entire trees to fall. The plant also contains toxic compounds that may poison consumers, and there are concerns that infestations along watercourses may threaten the survival of fish.

Cape ivy reproduces vegetatively and by seeds, which are dispersed by wind. In California – where the species currently occupies more than 500 000 acres – reproduction is by vegetative means only. Parts of the plant can resprout once broken off, facilitating the spread of the species if fragments are transported to new areas by machinery or runoff, or are dumped with garden waste. Mechanical control is therefore difficult, but the plant can be chemically controlled with herbicides. A number of potential biological control agents are currently being investigated, including a shoot-galling fruitfly, a leaf-mining and stem-boring moth, a leaf-feeding moth and a leaf-feeding beetle.

Boneseed and bitou bush

Boneseed and bitou bush are two sub-species of *Chrysanthemoides monilifera* – indigenous to southern Africa – that have invaded southern and eastern Australia respectively. Members of the daisy family Asteraceae, they are both fast-growing shrubs producing yellow, daisy-like flowers.

Boneseed (subsp. *monilifera*) – named for its hard, bone-coloured seeds – was first recorded in Australia in 1856 as a garden plant in Sydney, so it was probably introduced as an ornamental and later escaped from horticulture. **Bitou bush (subsp. *rotundata*)** was accidentally introduced through the dumping of seed-contaminated ballast during the early 1900s. Its ability to colonise and stabilise disturbed areas was subsequently recognised, and from the mid 1940s to the late 1960s it was widely planted along the New South Wales coastline, often to repair damage from dune-mining. Deliberate plantings were halted when it became obvious that the bush was aggressively invading coastal habitats, but today it is established along hundreds of kilometres of the eastern Australian coast.

Both sub-species invade a variety of disturbed and natural areas, including coastal heaths, open eucalypt

forest and littoral rainforest. They rapidly dominate these systems, excluding indigenous plants and driving threatened species closer to extinction. By altering habitat they also cause changes to the associated animal community, resulting in an overall loss of biodiversity. In some places, dense growth restricts human access to beaches.

The plants produce massive quantities of seeds – up to 50 000 per year – which can remain viable in the soil seedbank for as long as 10 years. Although the seeds are dispersed by birds, foxes, possums and rabbits, a large proportion simply falls to the ground around the parent plant. This hampers control of the species, as clearing stimulates germination of dormant seeds and results in dense regrowth of seedlings. Regular follow-up work is therefore a vital part of any control initiative using mechanical or chemical methods.

Biological control of boneseed and bitou bush started in 1987, and at least eight biocontrol agents have been released to date, including **two seed-flies *Mesoclanis* sp.**, **two leaf-rolling moths *Tortrix* sp.** and **the tip-moth *Comosotolopsis germana*.**

Giant African snail

The giant African snail *Achatina fulica* is typically about 7 centimetres tall, but can grow up to 20 centimetres and weigh as much as a kilogram. Native to East Africa, it has been widely introduced to Asia, a number of Indo-Pacific islands, and the West Indies.

Away from its natural enemies, the giant African snail is able to increase rapidly in numbers, and has become a destructive pest of crops and garden plants. It also feeds on indigenous vegetation, and often poses a conservation problem by altering habitat and out-competing other snails

for food. At times it may experience population explosions and become a public nuisance, hampering human movement by covering roads and paths. In addition, the snail is a vector for disease, including eosinophilic meningitis caused by the parasitic rat lungworm, which is passed to humans through eating raw or improperly cooked snails.

Although the giant African snail is a tropical species, it is capable of surviving cold conditions – even snow – by aestivating, so it is a potential threat to countries in cooler





Jackson's chameleon

climates. While the snail has often been deliberately introduced for food, medicinal use or as an ornamental species, it may also be accidentally imported by the nursery and agricultural trade when soil, plants or packaging material are contaminated with the snail or its eggs. Once introduced, the eggs are typically dispersed in garden waste and in soil adhering to construction and landscaping machinery.

The snails are hermaphrodites – having both male and female sex organs – and after a single mating can lay up to 1200 eggs in a year. The effectiveness of this reproductive strategy is highlighted by a case study of the snail's introduction and subsequent eradication from Florida in the United States.

In 1966 a boy returning from Hawaii smuggled three giant African snails into Miami, and his grandmother released them into her garden. Three years later state authorities launched an eradication campaign – which ultimately cost over \$1 million – and by 1973 more than 18 000 snails had been found and destroyed.

Jackson's chameleon *Chamaeleo jacksonii xantholphuster* is indigenous to the forest-covered mountains of Kenya and Tanzania, but in the 1960s and 1970s thousands were exported from the region for the pet trade. In 1972 a pet shop owner on the Hawaiian island of Oahu was granted a permit to import several dozen of the chameleons. They arrived thin and dehydrated, so he released them into his backyard, intending to recover them for sale later. The chameleons spread throughout the leafy neighbourhood, and by the late 1970s were well established along the island's Koolau mountain range. People took them to the surrounding islands, so today they also occur on the Big Island of Hawaii, Maui, Kauai and Lanai. Exportation of the animal from Hawaii and transportation between islands is now illegal, while Kenya banned all exportation of their chameleons in 1981.



African clawed frog

The African clawed frog *Xenopus laevis* is widely distributed throughout sub-Saharan Africa. During the 1940s it was shipped around the world for use in human pregnancy tests, after it was discovered that the frogs laid eggs when injected with the urine of pregnant women. Laboratories began rearing the frogs in large numbers to meet the high demand, and because they proved so easy to keep in captivity, a flourishing pet trade developed in the 1950s and 1960s.

In the late 1950s, new technologies for pregnancy diagnosis were developed, and many laboratories simply released their frogs into the wild. However, the frog remains an important subject for biological research, since it produces large numbers of eggs and its transparent embryos allow for easy observation of developmental changes. Laboratory escapes, as well as intentional releases of unwanted pets and escapes from home aquaria, therefore remain a likely mode of introduction.

The African clawed frog is a highly adaptable species with a wide salinity and temperature tolerance. It can inhabit almost any natural or manmade waterbody, and is now well-established in parts of Europe, South America and the United States. In southern California, it is considered a threat to indigenous fish and amphibians.

Cattle egret

Unlike most invasive species, Africa's cattle egret *Bubulcus ibis* has spread beyond its native range entirely on its own. In about 1880 it appeared in Surinam on the north-east coast of South America – after apparently flying over the Atlantic from Africa – and subsequently spread through much of South and North America. By 1972 it was nesting on the pampas of Argentina and five years later had reached Tierra del Fuego, at the southern tip of the South American continent. In North America it was first observed in the 1940s in Florida, and by the 1960s had reached California. Today, breeding populations are common throughout the United States and as far north as Ontario and Saskatchewan in Canada.

The birds' success at invading the Americas was largely attributable to it occupying a niche unfilled by native herons and egrets, which primarily consume fish and aquatic invertebrates. The cattle egret eats mainly insects – particularly grasshoppers, crickets, flies and beetles – and commonly associates with grazing animals, waiting for them to flush these prey items from the grass. The behaviour is believed to have evolved in partnership with wild animals in Africa, but the bird later adapted to following cattle. On arrival in South America, it found plenty of suitable habitat, as large areas of tropical forest had been cleared and converted to

ranches. Besides cattle, the bird also follows tractor-drawn ploughs, harvesters, lawnmowers and even workers harvesting crops such as sugarcane.

In the United States, the cattle egret is generally considered a welcome addition to the country's fauna, as it has little impact on indigenous species. In the northern states it does compete with resident species to some

degree for nesting sites and nest material, but in the southern states it nests later in the year than native herons, so any conflict is avoided.

The species has also spread into Europe, while a related cattle egret *B. coromandus* – native to southern and eastern Asia – has invaded China, Japan, Indonesia, Australia and New Zealand.

African green monkey

Vervet monkeys *Cercopithecus aethiops* are the most abundant and widespread monkeys in Africa, and are used throughout the world as laboratory animals. The West African subspecies *C. aethiops sabaesus* is sometimes known as the African green monkey because its fur appears green in some lights, although it is in fact brownish-grey with yellow and olive-green flecks.

During the 17th century, the African green monkey was introduced to the Caribbean islands of Barbados, St Kitts and Nevis, possibly by ships running the West African slave trade. With no natural enemies its numbers multiplied, and it became a serious agricultural pest on the islands due to its crop-raiding habits.

In 1994 the monkey population on Barbados was estimated at more than 14 000, despite the removal of about 10 000 animals through hunting and trapping over the previous 14 year period. Live monkeys are exported to laboratories in the United States and other countries, while the Barbados government encourages hunting by offering a bounty for each monkey's tail.



West Nile virus

The West Nile virus is a mosquito-borne member of the Flaviviridae family. It was first identified in 1937 in Uganda, near the western bank of the Nile valley, although the virus may not have originated in Africa. After its initial isolation, sporadic outbreaks of West Nile fever were recorded in other parts of Africa, as well as Eastern Europe, West Asia and the Middle East. During the 1990s, however, there was a marked increase in the frequency and severity of outbreaks, with epidemics in Algeria, Romania, Morocco, Tunisia, Italy, Russia and Israel. However, the virus had not been recorded in the Western Hemisphere until it caused an outbreak in New York in 1999.

West Nile fever is a mild disease in people, characterised by flu-like symptoms that only last for a few days. However, some cases develop into encephalitis and/or meningitis, which can be fatal. Since its introduction the virus has spread throughout most of the United States, and during 2003 alone there were more than 7 000 confirmed cases of infection, at least 150 of which were fatal. In

addition, the virus was detected in over 10 000 dead birds and more than 3 000 horses.

The West Nile virus perpetuates itself in a cycle that relies on certain bird species serving as a reservoir host. In the New York outbreak the virus killed hundreds of crows and jays, but the more abundant house sparrows appeared unaffected, and were identified as the main reservoir species. House sparrows remain viremic for five days – long enough to infect a mosquito – and tend to roost near people's homes, making them a highly effective propagator of the virus.

The exact mode of introduction of the virus to North America will probably never be known. One possibility is that an infected mosquito was transported in an aeroplane to Kennedy airport, which is home to thousands of house sparrows, starlings and crows. Alternatively, and perhaps more likely, the virus was introduced via one or more birds, either illegally imported for the pet trade (legally imported birds are quarantined), or through migratory or storm-driven birds that crossed the Atlantic.

