Quest

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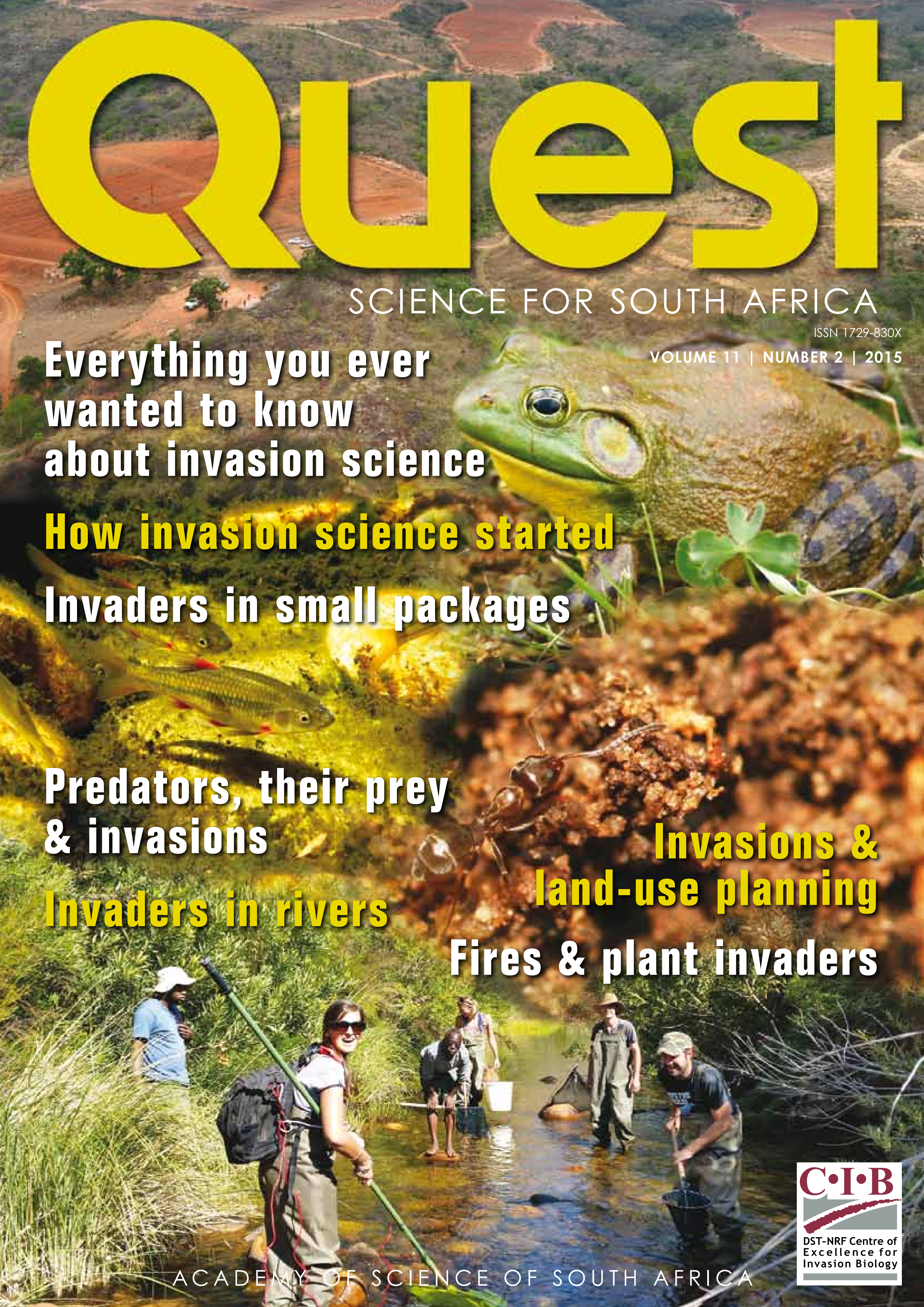

Everything you ever wanted to know about invasion science

How invasion science started

Invaders in small packages

Predators, their prey & invasions

Invaders in rivers

Invasions & land-use planning

Fires & plant invaders

C·I·B
DST-NRF Centre of Excellence for Invasion Biology

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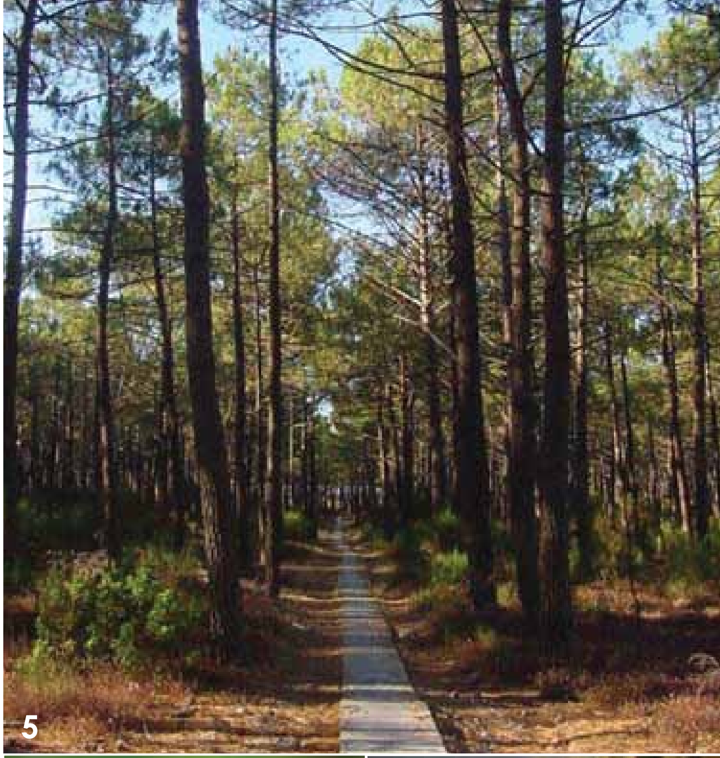

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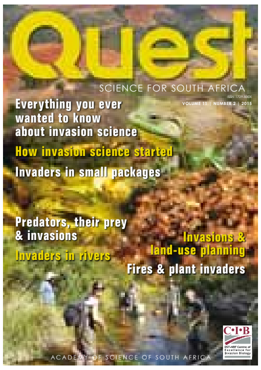

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The science of invasions

Early modern humans were the first of our species to start moving around the Earth. As a result of these migrations the species spread across the planet – the first alien invaders, you could say. And in many ways our species fulfils most of the criteria for an 'invasive' species – we transferred ourselves (human activity), we moved into completely new habitats, we changed our behaviour to suit those new habitats and we reproduced prolifically. It would appear that we were also instrumental in the extinction of other similar species – the Neanderthals. We probably played a part in the extinction of certain large mammal species in prehistoric times, although climate changes and other evolutionary pressures will also have played a role.

Now, however, as we have moved around the world in what are generally thought of as modern times, we have often deliberately and sometimes accidentally, introduced many different species of plants and animals to areas way outside their natural ranges, sometimes with disastrous results for the species native to these areas. Early explorers and traders saw nothing wrong in taking familiar species to distant lands with them, and in many cases no lasting harm was done. But, over time, with increasing understanding of the ecosystems around us, we have realised that many of these introductions have been disastrous – rabbits in Australia and cats on the sub-Antarctic islands are excellent examples.

It is in trying to understand the impact of these invasions and their complex effects on the ecosystems into which invasive species were introduced that invasion science has grown up. Invasion science can be thought of as the ultimate in applied biology. To successfully manage invasions you need to understand the native ecosystem thoroughly and to understand the biology of the invasive species. This involves a deep knowledge of complex systems and their interactions – at all ecological levels. It is also an interface between science and society, to understand and manage the inevitable conflicts of interest that arise where species have been introduced for economic reasons and where their management affects the communities who depend on them. An excellent career choice for anyone who enjoys a challenge.

Bridget Farham
Editor – *Quest: Science for South Africa*

The low-down on **invasion science**

QUEST talked to Professor Dave Richardson, Director of the DST-NRF Centre for Excellence for Invasion Biology (the C•I•B).

So what is 'invasion science'?
It is a rapidly growing field of study that seeks to understand the 'nuts and bolts' of how invasive species 'work', the multiple dimensions of the phenomenon of biological invasions, and options for managing invasions in the face of rapid global change.

The field seems to have a lot of definitions and emphasis on terminology. Why is this?
It is important to understand several basic principles when we talk about biological invasions and invasive species. Most important is that when we talk of alien species (also called 'exotic' or 'non-native' species), we are referring to those species that have been moved to new areas (outside the natural range of the species) *through human activity*. Such species, transferred by humans to completely new areas, very often behave very differently to those that change their distributions in response to alteration of habitats or changing climates. Alien species very often leave key natural enemies behind in their native ranges – this allows them to reproduce more prolifically in their new ranges.

Most alien species do no harm, and are either benign or useful. Useful alien species include most of our crops, livestock, garden plants and pets, and there is no argument that these species are highly beneficial.

Some alien species reproduce prolifically in their new ranges and can establish self-sustaining populations – they are termed 'established' or 'naturalised' alien species. Most species in this category of alien species also cause no harm.

A small proportion of alien species, in addition to being able to persist, can also disperse widely in their new ranges, bringing them into contact with native species and ecosystems in the new range. These are 'invasive' species, and many of them cause substantial damage by interfering in various ways with the invaded ecosystems. Such species often require expensive management.

The Cape Floristic Region is one of South Africa's biodiversity hotspots. Image: Bridget Farham

Arum lilies in their natural environment in South Africa. Image: Bridget Farham

A rainbow trout in hand. Image: Mike Anderson, Wikimedia Commons

What about alien species that are both useful and invasive?

This is a major challenge. Many alien species provide clear benefits, but also spread and cause substantial damage. The rainbow trout is a good example of a species that causes such a conflict of interests. Trout fishing is enjoyable for fishermen, and bodies of water containing trout can be a source of income for landowners who sell fishing rights. On the other hand, trout are voracious predators that threaten many of our native fish species. Stakeholders see things differently regarding such species, and conflicts are difficult to resolve. Attempts to manage such species are often controversial.

Why is the study of invasive species important in a country like South Africa?

South Africa is extraordinarily rich in biodiversity and is home to three biodiversity hotspots. Many invasive alien species that proliferate and spread have negative effects on native species and alter the functioning of our ecosystems. Many South Africans, especially people in rural areas, depend on services provided by natural and semi-natural ecosystems, such as water from mountain catchments and grazing provided by natural rangelands. Invasive species are an important threat to the sustainable delivery of services from our terrestrial, freshwater and marine ecosystems.

Do South African species become invasive elsewhere?

Definitely! Many South African plants and some animals have been taken to other countries for their commercial and/or ornamental value. Once in these countries some of the species have become invasive. Examples of these are the Arum lily (*Zantedeschia aethiopica*) and several species of *Watsonia* which are major invaders in Australia. The common platannna (*Xenopus laevis*) is indigenous to South Africa, but was exported to many parts of the world and is now invasive on four continents.

What can I do as a South African citizen to curb the spread of invasive alien species?

The most important thing is to be aware of the many problems associated with invasive species and to know which species are alien and which are invasive. Do not grow plants or keep animals that are known to be invasive – they may well jump your fence and establish along river courses or in protected areas where they could have serious impacts. Report new invasive species to the National Environmental Crimes and Incident Hotline – 0800205005.

Where can I find more information on results of the C·I·B's research?

The best way is to visit the C•I•B's website (http://academic.sun.ac.za/cib/) regularly and to like us on Facebook. We constantly update these sites with news of our research. Our annual reports, with details of our work, are published for public viewing on our website. Q

Biological invasions & the emergence of invasion science

Dave Richardson talks about milestones and trends in the study of invasive species.

Invasive species are currently regarded as one of the five major causes of biodiversity loss. The other causes are habitat destruction, over-exploitation of species, climate change and pollution. The relative importance of invasive species as a threat varies from place to place, but very few ecosystems anywhere on Earth have been spared the effects of invasive species.

Biological invasions

Let's take a quick look at the phenomenon of 'biological invasions', which is what happens when species are introduced to new environments and multiply and spread rapidly.

People have moved organisms around the world for thousands of years. Until fairly recently, however, the scale of these movements was too limited to affect native species or cause substantial changes to ecosystems. Few species were moved around, and those that were moved were moved in small numbers, over limited distances, and quite slowly. Only with the dawn of the Age of Discovery and European colonialism, and the technological innovations associated with these events, did human business and agricultural activities generate the widespread invasions that now pose such a threat to the biodiversity of our planet. Such movements often leave key natural enemies of organisms behind, helping the introduced species to reproduce more effectively or survive better in their new environment than they would in their native range. This is called 'enemy release' and, for some species, this explains why alien species behave very differently in new regions. The ways that humans use and move the species around within new regions also determines whether, and to what extent, such species are likely to spread. For example, widespread planting of alien plants in gardens creates multiple 'launch sites' and exposes many habitats to potential invasion.

Despite references to invasive species in the writings of Darwin and others in the mid-19th century, invasions were essentially viewed as curiosities and were not perceived as a major threat to global biodiversity. Invasive species started becoming much more widespread in the last few decades of the 19th century and the first few decades of the 20th century. Until the mid-1900s, invasions were mostly documented on a case-by-case basis; there was no theoretical framework or foundation for understanding the phenomenon or for evaluating particular invasions.

Studying biological invasions

The escalation of biological invasions in the 1950s, largely as a result of European colonisation of the globe a century or more before, was but one symptom of emerging changes to our planet that were about to force ecologists to vacate their comfort zones and start addressing issues relating to

Pioneers of invasion science

Charles Darwin as a young man. Image: Wikimedia Commons

Cardoon, growing in its native Europe. Image: Wikimedia Commons

The map of the voyage of HMS Beagle. Image: Wikimedia Commons

The milk thistle. Image: Wikimedia Commons

Several 19th century scientists, notably Charles Darwin, Alphonse De Candolle, Joseph Hooker and Charles Lyell, mentioned invasive species in their writings. Charles Darwin noticed several introduced species while he was ship's scientist aboard the *HMS Beagle* between 1831 and 1836.

In his famous book *On the Origin of Species*, Darwin made important observations on the ecology of introduced plants, such as two species of thistles, cardoon (*Cynara cardunculus*) and milk thistle (*Silybum marianum*), both native to Europe, which he found growing in Argentina. In the same book, Darwin advanced the first general hypothesis about which species are likely to be most invasive. He thought, based on ideas put forward previously by De Candolle, that introduced plant species that are not closely related to native plants are the most likely to succeed.

Stands of pine trees contribute to industry in South Africa, but pines are also invasive alien species. Image: Wikimedia Commons

Charles Elton: the father of invasion science

Ecologists today tend to forget that 50 years ago ecology was the domain of a few biologists who were concerned largely with natural ecosystems, and who sought, as a rule, to exclude things ‘unnatural’ from their studies. In 1958 a book entitled *The Ecology of Invasions by Animals and Plants* by the British zoologist Charles Elton was published. This book is now considered a milestone in the understanding of the global scale of invasions. Based on a series of BBC radio talks, Elton’s book put forward several hypotheses to explain the invasions of many types of alien species that were increasing in importance in the mid-1900s. To this day, scientists test Elton’s and Darwin’s ideas in different parts of the world and in different ecosystems. Elton also emphasised the need for scientists from different fields to work together to solve biological invasion problems, and many of these problems have been researched by large teams of scientists from different countries working together. In the digital age it is easy for people to research a common problem by using electronic tools such as email, Skype and Twitter. Researchers who specialise in biogeography, epidemiology, human history and population ecology, frequently work together to understand invasions.

sustainability in the face of rapid human-driven global change.

The study of biological invasions is currently approached from many angles and has many different goals. Some researchers use invasions as a global-scale experiment in biogeography (the branch of biology that deals with the geographical distribution of living organisms) to answer fundamental questions about why certain species occur where they do, and why certain types of species occur together.

Most work in invasion science is, however, directed at

Bio-invasion through cargo ships. Image: www.pitara.com

seeking solutions to problems that arise when alien species become invasive. Such research tries to understand why some species are more successful as invaders than others, why certain ecosystems are more open to invasions than others, and the many ways in which human activities affect these questions. Invasion science increasingly seeks to find ways to manage invasive species, which act as part of a ‘lethal cocktail’ of drivers of environmental degradation.

Most attempts to manage invasive species have, until recently, sought to deal mainly with the symptom of the problem – the spread of alien species. Eradication (the total elimination of an alien species from a given region) has been successful in some cases, but most attempts have failed. Eradication attempts are often unsuccessful because the alien species is already too widespread and abundant to make its total removal possible. Therefore in many cases, eradication is not the end goal of management; rather the aim is to reduce the distribution and abundance of invading species so as to reduce their negative impacts. This is the goal of the national Working for Water programme which seeks to reduce the density and distribution of many very widespread invasive plants, thereby reducing their impacts.

Until recently the unspoken assumption among many managers and researchers was that if the biology and ecology of the invading species and aspects of the invaded ecosystems are well understood, efficient management can be achieved. Very substantial progress has been made in understanding many aspects of the invasion ecology of many of the world’s worst invasive species. This has been achieved by combining methods and tools from different disciplines. For example, for invasive plants, much progress has been made by combining insights from population ecology, weed science and forest ecology. In recent decades, such studies have also benefitted hugely from insights from new technologies such as computer modelling, molecular ecology, and remote sensing. Such advances have enabled researchers to understand aspects of invasions over space and time scales to gain insights that were previously unavailable. Invasion ecology has made great strides towards understanding why some species are more successful as invaders than others, and toward reconstructing past invasion events to untangle the roles of different contributing factors. This helps to identify key introduction pathways (e.g. horticulture, forestry, ship ballast water, etc.), with crucial implications for management.

Managing invasions

Invasions are becoming so widespread and extensive that not all invasions can be comprehensively managed. Choices need to be made. Limited resources mean that managers need to decide which invasions are the most important. In some cases, there is a general agreement that a given invasive

Himalayan tahrs were introduced into the Cape Peninsula, but have now been culled and replaced with indigenous species. Image: Wikimedia Commons

species causes harm and that management is justified. However, different stakeholders have contrasting views about invasive species. A large proportion of invasive species in all parts of the world were introduced for specific purposes, such as providing timber, food or ornamentation. Many of these species still serve useful purposes in parts of their new ranges, but are invasive and cause major damage in other areas. For example, pine trees are crucial contributors to South Africa's forestry industry, but also cause harm when they spread from plantations to invade water catchment areas or nature reserves. The same applies to animal species introduced for aquaculture or in the pet trade.

Invasion science

For these reasons and others, the study of invasions now involves much more than ecological research of invasive species. The term 'invasion science' is now sometimes used to describe the full spectrum of fields of enquiry that address issues pertaining to alien species and biological invasions. The field embraces invasion ecology, but increasingly involves non-biological lines of enquiry, including economics, ethics, sociology, risk assessment, and inter- and transdisciplinary studies. For example, sustainable management of invasive freshwater fishes requires an understanding of the reasons for their introduction and spread by humans in the new region – for example, for recreational fishing, in which case it is necessary to engage with the recreational fishing industry to limit the spread of invasive freshwater fishes. In addition, researchers need to understand the impacts of these invasive species, as well as the perceptions of different stakeholders about these species. Attempts to manage invasive animals frequently encounter problems with animals-rights activists, as was the case in South Africa recently for Himalayan tahrs and mallard ducks. Both species have negative effects on native biodiversity, but some stakeholders maintain that such impacts do not justify efforts to limit their numbers or to eradicate them. Resolving such issues demands inputs from ethicists and philosophers besides ecologists who seek to devise cost-effective management plans.

The complexity of managing invasive species is increasing rapidly as more species become invasive, as invasive species affect more ecosystems, and as more stakeholders are affected. Luckily, invasion scientists now apply a range of tools such as niche models, genetic methods, impact assessment, and population modelling to help understand invasions, and they also use a variety of social media and other electronic tools to interact with the public and with invasive species managers. Citizen science projects are also useful to allow scientists to learn from members of the public who live close to invasive populations and who collect information which they submit via online tools. Even WhatsApp can be used to monitor invasive plant populations.

The importance of understanding, controlling and using invasive species to our advantage and to protect South Africa's biodiversity has never been higher. If you are looking for an exciting career, there has never been a better time to become an invasion scientist. **Q**

Dave Richardson is the Director of the DST-NRF Centre of Excellence for Invasion Biology and a Distinguished Professor at the Department of Botany and Zoology at Stellenbosch University. His research focuses on the ecology and management of plant invasions, especially trees.

Conflicts of interest

Conflicts of interest upset and complicate many conservation efforts. Conflicts include direct competition for land (human utilisation vs. conservation) and countless 'biodiversity versus X' permutations, where 'X' can be any human interest. A substantial proportion of conservation budgets are spent on addressing such conflicts or seeking ways to avoid or deal with such conflicts. Conflicts centred on alien species present a particularly vexing category of conservation problem.

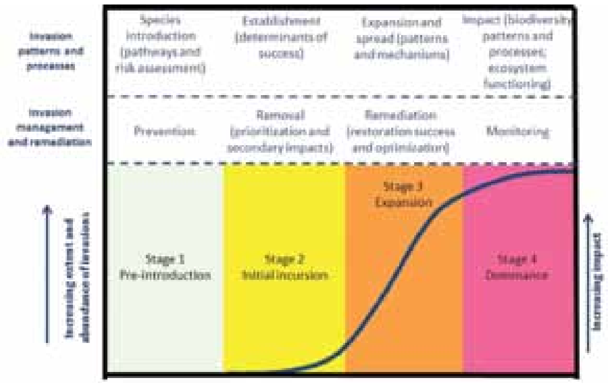
Many of the most damaging invasive species in most taxonomic groups were initially intentionally moved to the areas where they now cause problems. In many cases, such invasive species are still viewed as beneficial in at least parts of areas where they are invasive, and by some sectors of society.

There are many examples of such conflicts in South Africa. These include plant species introduced for food, fibre, ornamentation, or for many other purposes but which now run rampant as invaders of our natural ecosystems. Authorities also battle to come up with strategies to manage invasive birds, fishes and mammals that some people want to have in parts of the environment.

The ideal outcome is for all parties to agree on win-win solutions, where the species in question can still deliver benefits but not cause harm. The road to such solutions involves open discussions between all stakeholders and, inevitably, trade-offs and compromises.

Elements of invasion science

Effective management of biological invasions requires a multi-faceted and multi-pronged approach. Insights are needed to prevent the introduction of high-risk species (stage 1), to carry effective management of emerging invasions (before they become widespread and have major impacts (stage 2), to deal with invaders that are already too widespread to eradicate (stage 3), and to manage widespread invaders and heavily invaded ecosystems (stage 4). The figure shows the many facets of research undertaken at the DST-NRF Centre for Invasion Biology.



The stages of invasion. Image: van Wilgen et al. (2014) *South African Journal of Science* 110(7/8), Art. #a0074, 12 pages. http://dx.doi.org/10.1590/sajs.2014/a0074

The life stages of the invasive ladybird, Harmonia axyridis. *The eggs (A) take 3-4 days to hatch once they are laid. Ladybirds stay in the larval stage (B) for around 3 weeks, after which they form a pupa (C). Adults emerge from their pupae 4-5 days later, and take around a week to become mature adults (D). Research on the thermal adaptation of the invasive ladybird Harmonia axyridis includes several life stages A. eggs, B. larva, C. pupa and D. adults, in order to make reliable predictions of its responses to climate change.* Image: Ingrid A Minnaar.

Ladybirds:
successful invaders in small packages

In a warming world, can an invasive ladybird take the heat? **Susana Clusella-Trullas**, **Michael Logan** and **Ingrid A Minnaar** ask the question.

Some invasive species are more successful and harmful than others. Pinpointing which species deserve the most attention remains a great challenge, especially given the complexity of biological systems. Scientists have devised several classification schemes based on the rate of spread and environmental impacts to figure out which species can be considered the worst invaders. This information can also be used to predict future impacts given scenarios of environmental change, such as global warming and habitat degradation. Among insects, the harlequin ladybird (*Harmonia axyridis*) is high on the list of successful invaders, with considerable risk to native diversity.

Invasive ladybirds

This small colourful beetle (see photo), native to Asia, triumphs as an invader by spreading fast and outcompeting indigenous ladybird species.

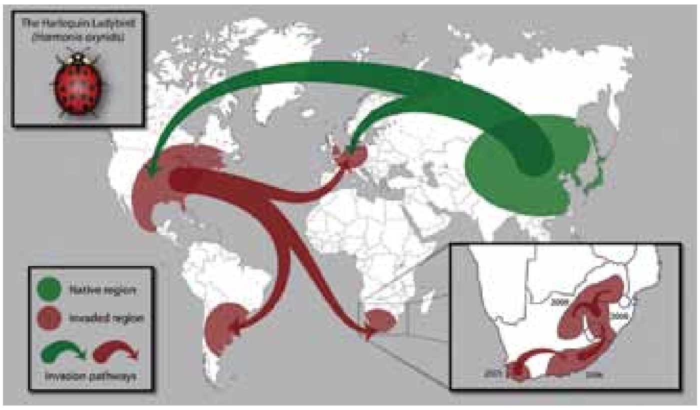
Its success is partly attributed to key characteristics that enable it to establish and spread rapidly in new environments. Individuals are large in body size relative to other aphid-eating ladybirds and can lay huge numbers of eggs over the course of their long lifespans. They are voracious predators with a broad diet preference, including feeding on their own eggs and siblings when food is scarce. They can also feed on the young of other ladybirds while simultaneously protecting their own progeny with chemical warfare. To make matters even worse, they may serve as vectors of disease because their immune systems appear superior to those of native ladybirds. The harlequin ladybird has become a nuisance in most places where it has been introduced by accident or intentionally as a biocontrol agent. It has negative effects on agriculture, human settlements and native ladybird diversity and abundance. It has now spread in four continents, and Africa is the most recent stop on its global conquest (see Box 1).

Spread in South Africa

In 2004, the harlequin ladybird was recorded on a farm near Stellenbosch. Museum records later showed that specimens of these ladybirds had already been deposited as early as 2001. The species probably arrived in South Africa even earlier than this. The early discoveries of harlequin ladybirds in the Western Cape were just the beginning. Their numbers have

Box 1

In a study published in 2010, Eric Lombaert and colleagues showed the spread of the harlequin ladybird across the globe. Native to Asia, it first appeared on the Eastern Seaboard of North America in 1988. From there it spread to three additional continents – to Europe, South America, and Africa in 2004 (with some evidence that a second colonisation of Europe from Asia occurred in 2001). Within South Africa (inset), ladybird records suggest that the beetle initially spread from Stellenbosch to the Eastern Cape, KwaZulu-Natal, the Free-State, and Gauteng by 2006. In 2009, it spread north into Mpumalanga and south-west into the hot and dry Northern Cape and North-West provinces.



This map shows the way in which the harlequin ladybird spread across the globe. Image: Corneile Minnaar

increased and their populations have spread rapidly over the past decade. They are currently found in all provinces of South Africa, from sea level to mountain tops.

Despite their clear establishment and spread in South Africa, little is known about the ecology and evolution of the harlequin ladybird in the region. If we are to predict the future impacts and distributions of this invasive species, we must begin to examine the interactions between native and invasive ladybird populations and the ways in which these interactions change as the environment shifts around them.

The harlequin ladybird's global presence illustrates its ability to tolerate a wide range of climates: hot, cold, wet and dry. As the climate in South Africa becomes hotter and drier as a result of climate change, invasive ladybirds may gain an advantage over native species because of their adaptability. Three major mechanisms can contribute to being adaptable to climate shifts. First, ladybirds may use behaviour such as moving to more adequate climatic areas or regulate their body temperature by shuttling more efficiently or precisely among hot and cold patches. Second, they may have flexible physiological responses that compensate for extreme weather events such as heat waves or cold snaps associated with climate change. Finally, ladybirds could also adapt to a changing climate over the course of several generations through evolution. Here in the CLIME Lab at the Centre for Invasion Biology at Stellenbosch University, we are actively studying the effects of climate change on the interaction between native and invasive ladybirds by exploring these three facets.

Behaviour and acclimation are the first lines of defence

In many parts of the globe, extreme weather events like heat waves are on the rise. These events can be extremely stressful to small 'cold-blooded' animals like insects whose body temperatures track ambient temperatures. However, insects have evolved several ways of dealing with rapid changes in temperature.

The first line of defence is usually a behavioural one. When temperatures spike, insects will move into a sheltered, shady patch of the habitat (to the underside of a leaf or underground) to prevent overheating. This kind of behaviour is known as 'behavioural thermoregulation' and is extremely common among species that do not produce their own internal heat (like mammals and birds). Behavioural thermoregulation increases insects' chances of surviving when the weather changes.

In order to assess how well the harlequin ladybird can overcome temperature variation using behaviour, we simulated their natural environment in the laboratory. This is not a simple task because the small size of insects means that they experience temperature at extremely fine spatial scales. We therefore mimicked the mosaic of the environment using small arenas with multiple 'warm' and 'hot' patches and examined their behaviour when facing good versus bad climate scenarios. These 'mini' landscapes can be altered to change the structure of the habitat or include natural complexity such as competitors, predators, and resource variation. We found that ladybirds adjust their behaviour depending on the quality of the thermal environment.

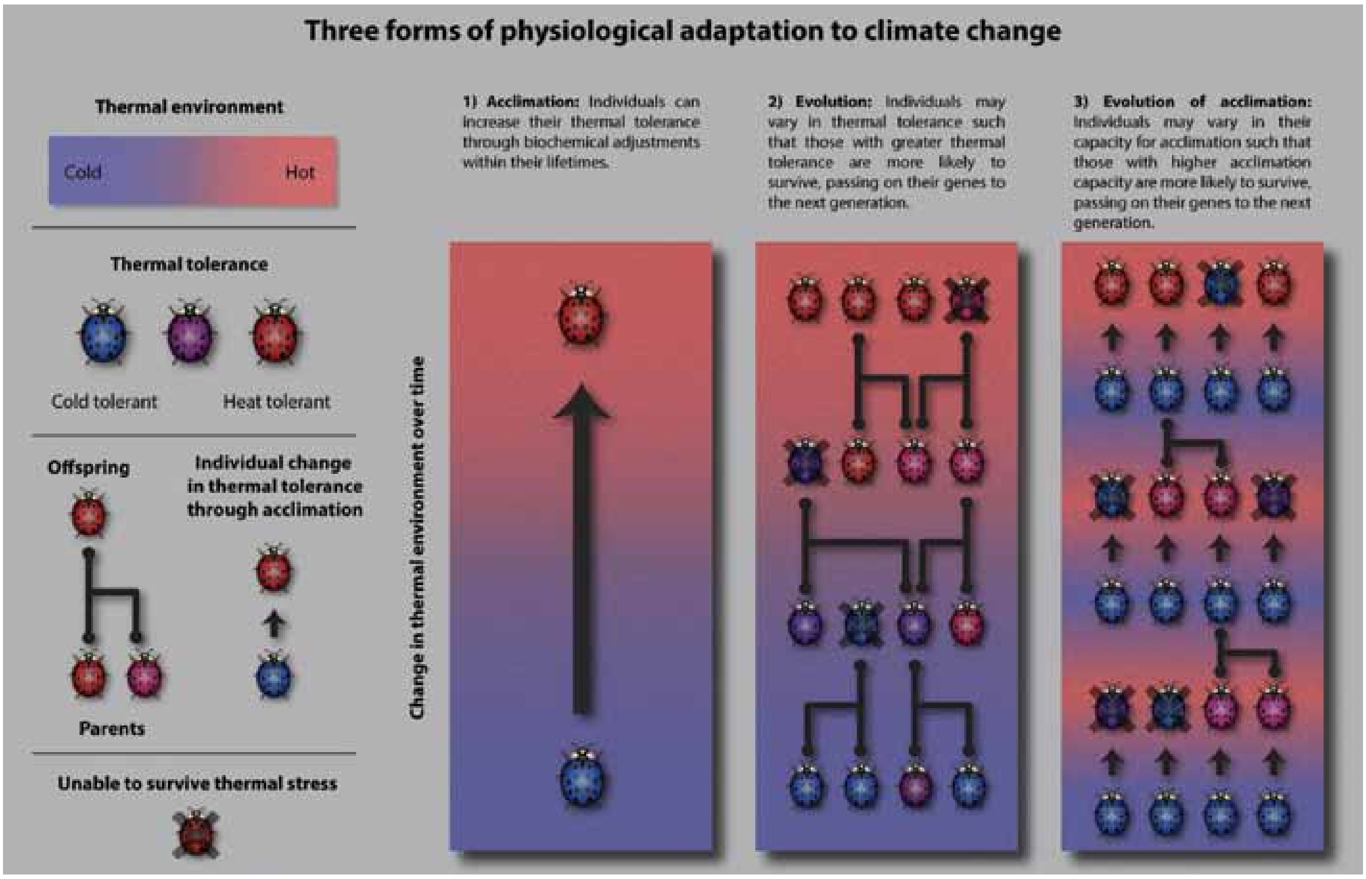
But sometimes thermoregulation is not enough. When the change in temperature is very rapid or the temperature hits extremes, insects may not have enough time to find a safe refuge. To survive these sorts of extreme events, individuals must *acclimate*. Acclimation is a direct physiological response to changing environmental conditions (see first panel in Box 2). For example, when an insect's body temperature rises sharply, certain genes are turned on that code for proteins whose specific job is to travel around the body repairing heat-induced tissue damage. These 'heat shock proteins' can persist within the animal's body for many days or even weeks, increasing its capacity to withstand additional heat waves.

Acclimatory responses to climate variation are thought to be short-term adaptive responses and are different from evolution because they occur within the lifespan of individuals. Our research examines these flexible responses across a wide range of traits, such as the highest and lowest temperature tolerated before the ladybird can no longer move away from a predator, the temperature selected by an individual when offered a broad temperature gradient, and changes in walking speed at different temperatures. We are combining these data to predict the short-term responses of harlequin ladybirds to temperature variation, and to predict their further spread into novel environments. We are also comparing native to invasive species – for example, can the harlequin ladybird acclimate to extremes faster or better than native ladybirds? Are larvae, pupae and adult ladybirds equally vulnerable to temperature variation? These questions are central to understanding the effects of climate change on biological invasions, and their answers will go a long way towards enabling us to accurately predict the future spread of the harlequin ladybird into other areas of southern Africa. However, behaviour and acclimation are only the first lines of defence against a changing climate. What about evolution?

Rapid evolution: will it tip the balance?

Since Charles Darwin first put forth his theory of evolution by natural selection in 1859, most scientists have considered evolution to be such a painfully slow process that we could only observe it indirectly (for example, by studying the fossil record). Selection experiments have now shown that,

Box 2



e.g., fruit fly body size and wing shape evolve rapidly and these changes can be observed in the lab after only a few generations (weeks to months).

In fact, many studies have successfully demonstrated evolution (even speciation) on extremely short time scales. It turns out we *can* observe evolution in real time. Remarkably, when a population contains genetic variation for some characteristic (say, the temperature at which they run fastest), and natural selection favours higher or lower values of that characteristic, observable evolution can happen after only a single generation!

The upshot of all this is that evolutionary change is likely to play a large role in determining the winners and losers in a warmer world. The species that can evolve the fastest will experience a smaller cost from changing conditions. This may give them the upper hand in competitive interactions with other species. If invasive species have particularly high evolutionary capacities, trouble is on the horizon.

Among individuals in a population, the degree to which variation in a trait is determined by genetics, independent of the environment, is referred to as the 'heritability' of the trait. All else remaining equal, the higher the heritability, the faster the trait can evolve.

Our research programme aims to generate breeding colonies of both the harlequin ladybird and the native lunate ladybird (*Cheilomenes lunata*) to study the genetics of several physiological traits in these species. The traits we are focusing on are thought to control the responses of insects to climate change, so understanding their evolutionary potential is important. In addition to measuring their heritabilities, we are also asking whether these traits are genetically correlated in ways that enhance or prevent evolutionary change. If harlequin ladybirds evolve more rapidly, it could mean that climate change will increase the extinction risk of native species by tipping the competitive balance in favour of the invasive species. In an interesting twist, it is not just the fixed thermal tolerance of a population that can evolve. Acclimation capacity itself can evolve when individuals vary in their ability to acclimate (see Box 2).

The general success of invasive species provides a hint that they may be more resilient to climate change than native species. At the CLIME lab we will continue to study the various mechanisms of adaptation to climate—behaviour, acclimation, and evolution—to better understand the impact of invasive species on South African ecosystems. **Q**

Susana Clusella-Trullas is a Senior Lecturer in the Department of Botany and Zoology and a core-team member of the Centre for Invasion Biology, Stellenbosch University. She heads the CLIME lab and combines theory, laboratory and fieldwork to examine physiological responses of organisms to changing environmental conditions. Her interests include the interactive effects of climate change and biological invasions on biodiversity. Further details on her research can be found at http://www.clusellatrullas.blogspot.com/.

Michael Logan is a Fellow of the United States National Science Foundation and a postdoctoral researcher in the CLIME lab at Stellenbosch University. Michael's research focuses on the genetics of thermal adaptation, and the evolution of tropical animals in response to climate change. For more information, visit www.evolutioninthetropics.com.

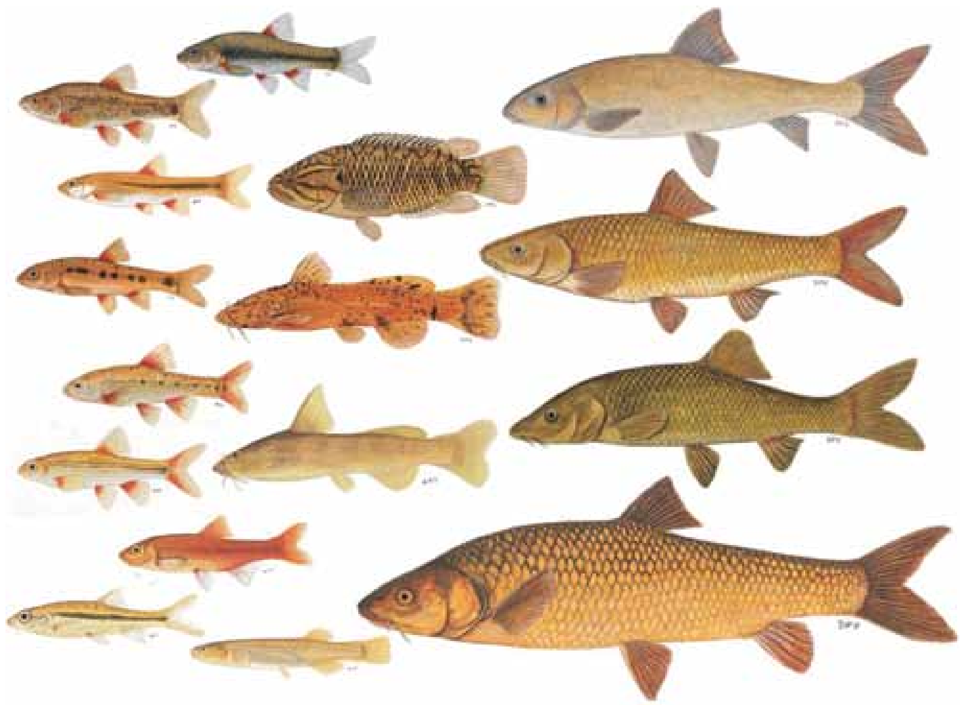
Ingrid A Minnaar is a member of the CLIME lab, and a PhD student in the Centre of Invasion Biology at the Department of Botany and Zoology, Stellenbosch University. Her PhD focuses on determining traits that enhance the successful invasion of insects, using invasive and native ladybirds in South Africa as model organisms.

Alien fish removals:

A new beginning for the Rondegat River

Olaf Weyl tells *Quest* how rivers are being rehabilitated after alien invasions.

The Cape Floristic Region of South Africa is a global biodiversity hotspot with an exceptional degree of biodiversity and endemism. Better known for its rich plant communities, the region is also home to 17 fish species which occur nowhere else on earth. Most are restricted to a single river or tributary within a river, which makes them particularly vulnerable to human impacts such as alien fish introductions, habitat destruction, and pollution. Human impacts are particularly severe in lowland rivers which receive run-off from agricultural and urban areas or modified by canal and dam building. This has caused many of our indigenous fishes to now only occur in small headwater streams located high up in mountain catchments where these impacts are absent. More than half of the endemic fishes in South Africa are considered to be in imminent danger of extinction and have been IUCN Red-listed



A collage showing the indigenous fish of the Cape Floristic Region. Image: Olaf Weyl

Top: Rhodes University Department of Ichthyology and Fisheries Science BSc Honours class of 2015 assisting with electrofishing surveys to determine Clanwilliam rock catfish abundance. Image: Olaf Weyl

Rivers such as the Rondegat River in the Cape Floristic Region are conservation priorities for conservation practitioners such as Dean Impson, an aquatic scientist at CapeNature, seen here snorkelling to check on indigenous fish recovery in the Rondegat River. Image: Olaf Weyl

Melanie Duthie of CapeNature checking rotenone drip rates during the treatment of the Rondegat River to remove smallmouth bass. Image: Olaf Weyl

*Clanwilliam rock catfish (*Austroglanis gilli*).* Image: Olaf Weyl/SAIAB

*A school of fiery redfin minnows (*Pseudobarbus phlegethon*).* Image: Olaf Weyl

as Endangered and Critically Endangered. The rivers in the Cape Floristic Region are key areas for conservation of biodiversity and in headwater refuges the main threat to the native fishes are alien fish introductions.

Sport fishing

Indigenous fish in the Cape Floristic Region are typically small, insectivorous species. As a result, they were considered unsuitable as sportfish and more aggressive, predatory fishes were introduced to provide opportunities for angling. The most widespread in headwater streams in the Cape Floristic Region are the smallmouth bass (*Micropterus dolomieu*) and rainbow trout (*Oncorhynchus mykiss*).

Research by Bruce Ellender, at the South African Institute for Aquatic Biodiversity (SAIAB) has shown that the impact of these introduced fish on native fish is particularly severe because the native fish did not evolve to cope with these large predators. As a result, they were either unable to compete with these new arrivals for food or were eaten, because they did not recognise the predators as a threat. For this reason most native fish now only occur in river reaches where alien fish have been unable to invade because of barriers such as waterfalls. To preserve the unique endemic fish fauna, removal of alien fish from conservation areas is therefore a priority for conservationists such as Dean Impson from CapeNature, who are in charge of conserving our natural heritage.

Eradicating alien fish

In February 2012, after years of careful planning by Dean's team at

SAIAB and CIB researcher Bruce Ellender with a smallmouth bass. Smallmouth bass were introduced into South African Rivers to provide opportunities for angling. Image: Olaf Weyl

CapeNature, South Africa's first non-native fish eradication using rotenone took place in the Rondegat River, a small headwater stream that had been invaded by smallmouth bass. Rotenone is a botanical compound found in the roots of the Derris plant from South America. When added to water it is a highly specific toxin that affects oxygen uptake in organisms that use gills to breathe (e.g. fish). Rotenone is, however, a very unstable compound that degrades rapidly after application. For this reason it is often used for fish control because the water is safe for fishes within a few days after treatment.

In the Rondegat River native fishes such as the fiery redfin minnow (*Pseudobarbus phlegethon*) and Clanwillam rock catfish (*Austroglanis gilli*) had been completely removed by smallmouth bass predation.

It was hoped that removing the bass would result in the recovery of native fish populations, which were still abundant in the stream above

Clanwilliam yellowfish (Labeobarbus capensis). Image: Olaf Weyl

GoPro camera used for underwater video analysis. Clanwilliam redfin minnows (Barbus calidus) in the background. Image: Olaf Weyl

Rhodes University students Nomonde Ndlangisa and Elethu Duna assisting with snorkel surveys. Image: Olaf Weyl

a small waterfall that marked the upper distribution limit of the bass. More than 470 smallmouth bass were removed during the treatment and the only native fish found during the first treatment were 139 Clanwilliam yellowfish that were too large to be eaten by the bass. Later, a team of researchers from the South African Institute for Aquatic Biodiversity found that the treatment of the river had been successful in removing smallmouth bass and that there was an almost instantaneous increase of fish diversity following the removal of the bass.

Monitoring of the recovery of the native fish communities required the use of a variety of methods. Diurnal fishes which are active during the day, such as fiery redfin minnows and Clanwilliam yellowfish, are best detected using snorkel surveys or with underwater video.

Nocturnal fish, such as the Clanwilliam rock catfish, hide under rocks during the day and can only be counted using electrofishing. Electrofishing uses an electrical current to stun the fish. After a short recovery period, the fish recovers and can be released back into the water. These monitoring surveys demonstrated that native fishes quickly recolonised sections of the river when smallmouth bass were removed. The success of the Rondegat River rehabilitation, where native fishes had been absent from the lower sections for more than 50 years, but returned almost immediately following the successful removal of alien fish, is anticipated to encourage more endemic fish restorations in South Africa. **Q**

Dr Olaf LF Weyl is Principal Scientist at the SAIAB and a core team member of the C•I•B. His research career started with field research on Lake Chicamba in central Mozambique. After obtaining his PhD from Rhodes University in 1999, he worked as an advisor to the Department of Fisheries in Malawi (1998-2002) and as Senior Lecturer in the Department of Ichthyology and Fisheries Science at Rhodes University (2003-2009) before joining the South African Institute for Aquatic Biodiversity (SAIAB) in 2009. His current research is geared towards providing information for the conservation and sustainable utilisation of African aquatic environments. To this end he has worked on freshwater ecosystems in Mozambique, Malawi, Namibia, Botswana, Zambia and South Africa.

Iimbovane learner begins her future in science

Leonne Adams was introduced to invasion science during a visit to her school by the Iimbovane Outreach Project. This sparked Leonne's interest in science, so much so, that she enrolled for a degree in biological sciences. *Quest* asked her a few questions about her studies.

Where did you go to school?

Gerrit du Plessis Secondary School, Riversdale.

What are you studying?

I am doing a Bachelor of Science in Biological Sciences (Human Life Sciences) at Stellenbosch University.

Tell us about your interest in science

My interests lie in nature and in the body, particularly human tissues. I would like to go into forensics. My first experience of real science was during our schools involvement with the Iimbovane Outreach Project. The project showed me as a Grade 10 learner what science is about, from working outside in the field, doing laboratory work and microscope work and how to explain one's findings. The Iimbovane Outreach Project played a part in my choice for tertiary studies. I always knew that I wanted to study further after school, but I was not familiar with the different courses offered. Being based at Stellenbosch University during one of the Iimbovane Outreach Project workshops, I was exposed to the university and what it offers. It made me feel self-assured about coming to Stellenbosch University.

Do you have any advice for school learners that are considering a career in science?

If you want something enough, you will get it. Show interest, go the extra mile and grab every opportunity, so that you can make an informed decision. Talk to people in the field, read up on different research fields and participate in volunteer work.

Disruptive interactions
predator-prey relationships in invasions

Mhairi E Alexander explains the way that normal predator-prey relationships can be affected by the arrival of alien species.

All organisms must eat in order to survive, and for predators this involves killing and eating prey. For the individuals that are involved there are obvious consequences, such as survival or death. However, these relationships also scale up and play a critical role in how populations and communities are structured. Predator-prey relationships are therefore critically important ecological interactions.

The arrival of a new, alien species into a system can have the potential to disrupt these interactions, and much research is focused on understanding why this might happen. Natural systems in South Africa are not immune to the impacts of biological invasions. Current research on the role of invasive species in predator-prey interactions shows them to be of key importance across a range of different environments. But how do invasive species affect these predator-prey relationships? And, importantly, what are the consequences?

Redfin minnows, Pseudobarbus afer, in their natural habitat. Image: Dr Darragh Woodfod

The European paper wasp Polistes dominula on its nest (left) and the German wasp Vespula germanica (right). Image: Wikimedia Commons

Native predator good – alien predator bad?

In any predator-prey interaction, the prey either 'live' or 'die' and this outcome doesn't depend on whether the predator is native or alien. What is often important in the alien-native interactions, however, is the rate at which predation occurs. Invasive species are often 'better' predators, consuming more prey than native counterparts at a much faster rate – and this can of course have serious consequences for the prey species and their long-term survival.

South Africa has experienced a number of fish introductions and many of them are large predatory species that have become established in headwater streams. Where they are found, native aquatic invertebrates and small fishes, like the endemic redfin minnow (*Pseudobarbus afer*), are often absent. Laboratory feeding trials have shown that invasive fish, such as largemouth bass (*Micropterus salmoides*) and sharptooth catfish (*Clarias gariepinus*), consume a greater number of prey at a faster rate in comparison to native fish across a range of prey densities. Researchers therefore suggest that the negative impact, which is consistently observed across invaded river systems in South Africa, is driven considerably by this increased predatory ability of the invasive fishes.

But why are these invasive fish better predators than the natives? In general, predators are adapted for catching and consuming prey, while prey are adapted for escaping from such threats. And in fact in South Africa's headwater streams, many of the small fish move into central channels at night, where they remain suspended in midwater. This is known to be an effective strategy against predation by native eels that move along the sides of the streams, searching in crevices and vegetation for food. These small fish however then become vulnerable to predation by the invasive predators that swim through these channels searching for a meal.

This is an example of an evolved antipredatory response towards a native threat that isn't appropriate in the face of an invasive predator. It also highlights clearly a type of impact invasive species can have on predator-prey interactions. However, these documented effects came from studies on existing invasions where impact had already occurred. But what about those species with the potential to invade where impact hasn't been documented? Ideally environmental managers have to predict the impact of a damaging invasive predator before the impact happens and often knowledge can be gained through studying invasion history of a species from other parts of the world where there has already been a negative effect. An example is that of the European shore crab which has a serious impact on prey communities globally, and work is being done now to prevent the same occurring in South Africa (see box).

The domino effect

When alien predators are introduced to a new area they can have more than just direct impacts on focal prey species. Invaders can also create a domino effect by causing an indirect increase or decrease of an associated species (which can be an animal or a plant, or both). These processes, called trophic cascades, can have significant impacts on a range of species. They also occur among native species. However, the effects of an invader on such phenomena are often hard to predict and can have serious, negative consequences.

Feral cats, for example, are considered to be among the global Top 100 Worst Invasive Species (http://www.issg.org/worst100_species.html) and in South Africa they have effects on small indigenous vertebrates such as birds, reptiles and mammals. This often results in the decline of indigenous species with impacts tending to be greatest on endemic birds on islands.

On Dassen Island, 10 km off the West Coast of South Africa, feral cats were found to severely alter the numbers of nestling seabird chicks through predation, resulting in decreases in adult populations. Research has shown that seabirds can drastically alter the composition of flora on breeding islands by providing nutrients for plant growth with their excrement. Once these colonies are decimated, interruption to this nutrient cycling can dramatically change plant communities. As a result of this trophically cascading threat, a feral cat eradication programme was started in the 1980s and had successfully exterminated the invasive species by 2008.

Such indirect impacts of introduced species can also affect society, and invasive predators can cause serious problems for the economy. For instance, there are a number of industries in South Africa that are dependent on pollination by bees and other insects, e.g. the wine trade. However, this is under threat with the arrival of two voracious predators, the European paper wasp (*Polistes dominula*) and the German wasp (*Vespula germanica*). Through predation on bees and insect larvae, these wasps are placing serious pressure on the native pollinators. Their invasion is showing no signs of slowing down. There is therefore great concern that with an increase in predation by wasps, and a decrease in pollinator prey, there may be a serious impact on the wine industry that requires the services of these native pollinators as part of the crop cycle. As such, in South Africa's Western Cape, there is a concerted effort to contain the spread of these invasive predatory insects (http://www.capetowninvasives.org.za/project/animals).

It's not all about invasive *predators*

Although there tends to be a greater emphasis on invasive predators, alien species can also arrive in a new region as prey. The majority of scientific studies tend to focus more on predatory invasive species as they generally have a greater, more conspicuous impact. However, what this neglects is that an invader may also become an important food source to native predators. An interesting question is therefore what happens when native predators are faced with a new type of invasive prey?

Well, firstly, there may be a number of challenges to overcome for a native predator if it is to effectively consume an invasive prey species. However, an invader might not fall within the feeding capabilities of a native predator and it might continue to focus its feeding on native species. This reduces predation pressure of the invasive species and can allow it to spread. In marine systems in South Africa the invasive barnacle (*Balanus glandula*) is continuing its spread along the coast, and studies on predation by native whelks have shown them to actively avoid eating this invasive prey, preferring to consume the native barnacle. It is suggested that this is because the native has thinner shells and more easily accessed flesh.

The European shore crab: an incoming predatory threat?

A young European shore crab showing the characteristic green colour.

Image: Wikimedia Commons

The rocky intertidal shore of South Africa's West Coast is home to a great diversity of species owing to the cool, productive upwelled waters. However, one important group of taxa that is poorly represented in this zone are predators. This is in contrast to many global rocky shore regions and is often related to an unsuitable and harsh environment. There is therefore an 'empty niche' that is not filled by any native predator and we are potentially playing a waiting game where an invasive species may arrive and cause devastation.

This may have already occurred through the introduction of the European shore crab (*Carcinus maenas*) to South Africa via ballast water transfers from large ocean-going vessels. Owing to these introductions, the shore crab has now established populations in Table Bay and Hout Bay harbours. This species is another top global invader with a devastating impact history whereby it alters community make-up and structure through heavy predation on species such as mussels and whelks in regions of invasion. There is therefore great concern that this species might have similar effcts on the already marginalised native species if it were to make its way out of these harbours.

The worry is so great that an eradication programme is underway to investigate the feasibility of removing this species from Hout Bay. Only time will tell if this programme will be successful. In the meantime this preatory niche remains unfilled and much focus of marine invasive screening is on identifying those species that might be voracious predators with the capacity to cause serious impacts on South African intertidal rocky shores.

The native predatory whelk, Trochia cingulata, *feeding on an invasive mussel.*
Image: Dr Tammy Robinson

However, invasive prey may even become the preferred resource and a native predator that is able to consume a new dominant prey type will be at an advantage to those that cannot.

The mussel invasions that have occurred in South Africa (detailed in Dr Tammy Robinson's article on the patterns and trends of marine invasions) are an example of a case where there have been significant changes to prey availability. Historically, native predatory whelks have preferentially consumed the once abundant native ribbed mussel (*Aulacomya atra*). However, these whelks are now presented with a very different foraging landscape owing to the Mediterranean mussel invasion. The whelks have subsequently adapted to the new dominant invasive prey and consume them in greater numbers in lab feeding experiments, even when they are offered in combination with their previous favourite, the native ribbed mussel.

What is also interesting is that this experience with one invasive mussel has seemed to make them even more capable of feeding on a second newly-invasive mussel species, *Semimytilus algosus* that, introduced from Chile, has only recently become established.

The importance of invasions in predatory interactions

It is clear that invasive species play an important role in community dynamics and the functioning of ecological systems. This is not lost in the context of predator-prey interactions and invasive species can pose a threat to not only native prey populations but can play an important role as a basal prey resource with far-reaching effects on the associated species.

In South Africa, invasive species also play an important role in predator-prey relationships, with research showing them to be drivers of species loss when they occur as predators, as well as having an important role as a prey resource. Ultimately, all predator-prey interactions are about life and death but it really does appear that what is doing the killing and what is being eaten have important consequences for the county's natural systems. **Q**

Originally from Scotland, Mhairi Alexander completed her PhD in 2012 at Queen's University Belfast in Northern Ireland. Her thesis investigated the predatory strength of a native amphipod species that is ubiquitous on intertidal rocky shores around the UK and Europe. She moved to South Africa at the beginning of 2013 to work at the C•I•B at Stellenbosch University on predicting impacts of invasive species through resource use quantification. Although a lot of her work to date has been in marine systems, she now also studies freshwater invasions in South Africa in collaboration with researchers at the South African Institute for Aquatic Biodiversity in Grahamstown.

Grasslands of Lesotho helped to inspire a career in invasion science

Growing up in the grasslands of the mountain Kingdom of Lesotho, Dr Sebataolo Rahlao has travelled a long road to academic and personal success in invasion science. *Quest* asked him a few questions about his career in invasion science.

What is your current position?

I am the Director of Invasives Monitoring and Reporting at the South African National Biodiversity Institute (SANBI).

What did you study?

I started my academic career at the National University of Lesotho, where I successfully completed a BSc with my majors in biology and physical geography. I then decided to trade the mountains for the sea, and enrolled for an honours degree at the University of Cape Town (UCT). I continued with my studies at UCT and graduated with an MSc in Conservation Ecology. From there I moved to the Stellenbosch winelands to pursue a PhD at the DST-NRF Centre of Excellence for Invasion Biology (C·I·B), where the focus of my thesis was on the vulnerability of ecosystems to grass invasions (using *Pennisetum setaceum* as a model) under different scenarios of global change.

Why did you choose to follow a career in invasion science?

Initially, I wanted to specialise in environmental science and enrolled for a BSc Hons at UCT. It was during this year that I became familiar with the Centre of Excellence at the Percy Fitzpatrick Institute at UCT. I met with Prof. Morne du Plessis, the then Director, and told him about my interest in their MSc Conservation Biology course. I was told the course was very intensive and that I would need to work ten times harder than in my Honours course. This was the motivation I needed, and decided to give it my best shot. During the course of that year, I was introduced to invasion science by Prof. David Richardson, Director of the C·I·B, and Dr Guy Preston, Director of the Working for Water programme. I found invasion science fascinating and decided to specialise in it. The following year I enrolled for a PhD with Prof. Karen Esler at the C·I·B.

Sebataolo Rahlao. Image: Sebataolo Rahlao

What does your position as Director of Invasives Monitoring and Reporting involve?

In my position, I have to provide leadership in the development of a programme that monitors and reports on invasive alien species in South Africa. I regularly report to the Minister of Environmental Affairs on the status of invasive alien species in South Africa. A large part of my work also involves maintaining strategic partnerships to strengthen the use of scientific evidence for the management of invasive alien species.

What are the most important lessons you've learnt during your career?

It is of utmost importance to understand the people you work with and treat them with respect. Confidence and competence will get you far in life – spend time and any resources you have to develop that combination! In some instances one needs to work ten times harder to be successful in your career.

What do you do to unwind?

I am up for a good hike and love to travel.

Meet molecular systematics laboratory manager Tlou Manyelo

During her time at the Science Centre, Tlou taught school learners about the wonders of science.

Tlou Manyelo. Image: Tlou Manyelo

Tlou Manyelo is the laboratory manager at the Leslie Hill Molecular Systematics Laboratory at the South African National Biodiversity Institute (SANBI), in Cape Town.

Her work as laboratory manager is to oversee the processing and curation of biological samples of various SANBI projects. She is responsible for making sure that all the data accompanying the samples are archived and made available to researchers who are interested. Tlou is involved in various interesting projects. For example, her current project is not for the faint-hearted and looks at the evolutionary relationships between viper species from all over Africa.

Tlou started her career in science by completing an undergraduate and an honours degree in zoology, at the University of Limpopo. Her first position was as senior laboratory assistant at the University of Limpopo, in their Botany Department. However, after a few years in the laboratory, Tlou decided to share her passion for science outside of academia and joined the university's Science Centre. In 2010, Tlou joined the DST-NRF Centre of Excellence for Invasion Biology (C•I•B) as technical officer, which took her back to the field and laboratory.

Tlou took her career further by recently completing a masters degree in botany, which focused on the evolutionary relationships between different species of snoutbean (genus *Rhynchosia)*, in South Africa. Tlou believes that there is no sector of research should be taken as a single entity. *'Research may not have a direct influence immediately, but every bit of information generated could help us to understand and ultimately to conserve our environment. For example, genetic information could help us identify threatened species.'*

Monitoring invasive species from icy islands to arid lands

Tshililo Ramswiela is a research technician with the South African Environmental Observation Network (SAEON) and is based at SAEON's Arid Lands node in Kimberley. *Quest* asked him a few questions about his career.

What did you study?

I completed a Bachelor of Environmental Management at the University of Venda, and then decided to enrol for a master's degree at the DST-NRF Centre of Excellence for Invasion Biology (C•I•B), Stellenbosch University. At the C•I•B, I was introduced to the field of invasion science. My study looked at the spread of alien and invasive plants across Marion Island, which gave me the opportunity of a life-time – to visit the sub-Antarctic region and Marion Island.

What is important about your work and the work of SAEON?

For us to make decisions about our environment and its management, we need to have reliable scientific data. Threats caused by invasive species are ever increasing and yet we do not know much about how invaders affect native species and how they will be affected by climate change. In my work, we do long-term environmental monitoring, which means we collect data on environmental conditions, for example weather data, veld conditions and vegetation surveys. My work includes recording observations in the field, collection of biological material, processing and identification of samples, and data analysis.

What do you enjoy most about your work as a research technician for SAEON?

My work brings me to places where very few people have the privilege to set foot. Exploring the vast Northern Cape and Karoo region is undoubtedly an experience to cherish, especially Namaqualand during the flowering season.

What have been some of the highlights of your studies and your time at SAEON?

Going to the sub-Antarctic region and Marion Island was certainly the highlight of my university career. So far, in my career with SAEON, the highlight was conducting research in our biggest protected area, the Kruger National Park.

Not many youngsters look at science as a career path, what led you down this path?

Science is very broad and it has many fields to explore. I started out with a background in environmental management and then specialised for two years in invasion science. In my work as a research technician I deal with invasive species on a daily basis. I see science as an adventure, an opportunity to discover new things while having fun at the same time.

Tshililo Ramswiela during one of his research visits to Marion Island. Image: Tshililo Ramswiela

What do you do when you kick off your shoes to relax?

I enjoy watching a good documentary, reading any material, and I have a passion for sports.


A well-managed pine plantation (in the background) next to indigenous forest in a nature reserve (Buffelskloof Private Nature Reserve, Mpumalanga). Image: Mathieu Rouget

Land-use planning & biological invasions

Mathieu Rouget considers how careful planning can reduce problems with invasions.

The South African population increased by 1.3% in 2013 – another 70 000 people added to the population each year if this rate of increase continues. This growing population will need more land for agriculture, settlements, transport and other forms of infrastructure. New roads will be built, crop fields will expand and new residential areas will be planned. Much of this change in land use will affect wild space – natural areas. People also require natural areas to provide important services such as water purification and recreation. Keeping the balance between infrastructure development and nature is complex, and many factors need to be considered. This is what we call land use planning – the allocation of land to specific activities, including agriculture, settlement, transport, factories and open spaces.

Human activities can result in the movement (intentionally or accidentally) of plants and animals to areas where they would not occur naturally. Over millennia, plants and animals have been introduced to many parts of the world. In South Africa, many species of pines, eucalyptus and wattles have been introduced to provide wood for timber and pulp. Sometimes introduced species can spread and become invasive, especially after changes in land use or disturbance. For example, as agricultural areas have been abandoned in the KwaZulu-Natal midlands, wattle has spread. Pines planted for commercial use have spread into the mountains of the Western Cape.

There is a link between human activities, land-use planning and biological invasions. This article focuses on the linkages between land-use planning and plant invasions, using examples from South Africa. It shows how the lack of appropriate land-use planning can lead to plant invasions and how the current distribution of invaded areas can inform future land use and human activities. The specific focus is on impacts on natural resources, including biodiversity.

Inadequate land-use planning in the past – an important factor in plant invasions

Plant invasions often represent the legacy of the past. Previous agricultural practices, or past socio-economic needs, largely explain the patterns of plant invasions. Examples include prickly pear (*Opuntia ficus-indica*), originally introduced to provide fodder for animals and now a major invader of rangelands, and certain Australian wattles, introduced to South Africa to stabilise sand dunes and now highly invasive in many habitats.

The lack of strong environmental regulations and land-use planning guidelines in the past has resulted in many unsustainable developments. During the expansion of forestry plantations in the 1950s, many mountainous areas were planted with gums or pines in places that were too steep for harvesting or where the climate was unsuitable, and as a result these plantations were abandoned. Because the trees were never harvested, they started to spread into the surrounding natural grasslands in the Drakensberg or fynbos in the Cape, where they invaded mountain catchments, which are the main water-source areas for our country. Because pines and eucalyptus use more water than natural vegetation, this resulted in a decrease of water flow, which was up to 40% in some catchments. Appropriate land-use planning would have looked at whether or not the area was suitable for these plantations and steep areas, climatically unsuitable areas or riparian (land next to rivers) areas would have been left unplanted.

If well planned and well managed, the impacts of large-scale forestry plantations on natural resources can be

Clearing invaded areas in the upper catchment to restore grassland and plant avocado orchards (Koedoe's river valley, Limpopo). Image: Mathieu Rouget

minimised. At the planning stage, avoiding sensitive areas (such as riparian areas) or areas with high invasion risk will reduce the impacts. Once plantations are established, proper management (including clearing of self-sown saplings and fire control) can reduce plant invasions.

Planning for agricultural expansion – the case of ZZ2

What we already know about the extent – including the potential future extent – of plant invasions can help us to make decisions around land-use planning and management. These decisions can be made at the level of local farms, but also nationally.

ZZ2 is one of the largest farming enterprises in the country, with the main farming operations located in the Koedoe's river valley in the Limpopo province. ZZ2 manages over 40 000 ha of land in a small water catchment and currently farms 10 000 ha. Most of the upper catchment is invaded by a mixture of wattles, eucalyptus and pines as a result of past failed farming efforts, which has led to the land being abandoned.

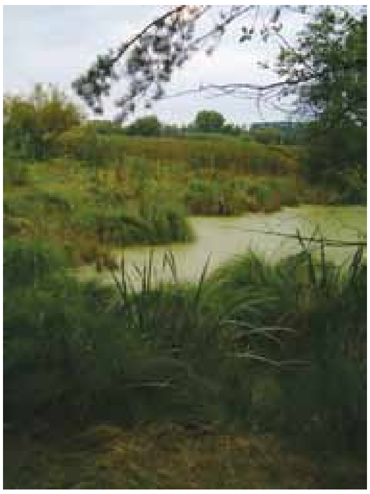
To keep up with increasing demand for avocados, ZZ2 started to expand their orchards in the upper parts of the catchment to benefit from the cooler climates in these areas. Given a choice of densely invaded areas, marginal lands, and natural vegetation (composed of bushveld, grassland and forest), most farmers would have avoided invaded areas to expand their activities. In other words, they would have farmed the more easily cleared natural vegetation. However, wise planning from ZZ2 led to the expansion of avocado orchards in densely invaded areas. ZZ2 invested heavily in clearing the upper catchment by mechanically removing alien trees to restore indigenous grasslands and plant new orchards. Although hundreds of hectares were cleared, only a portion was used for avocado orchards, and the remaining area was restored to grassland.

The long-term benefits of ZZ2 investment are still to be seen, but one would expect improvements in the ecosystem services, biodiversity and agriculture production of the upper catchment. With reduction in the density and extent of alien trees, ecosystem functioning will improve, resulting in greater water supply (especially during the dry period) downstream. The ecological and economic benefits of such clearing operation are being monitored to determine the long-term effects.

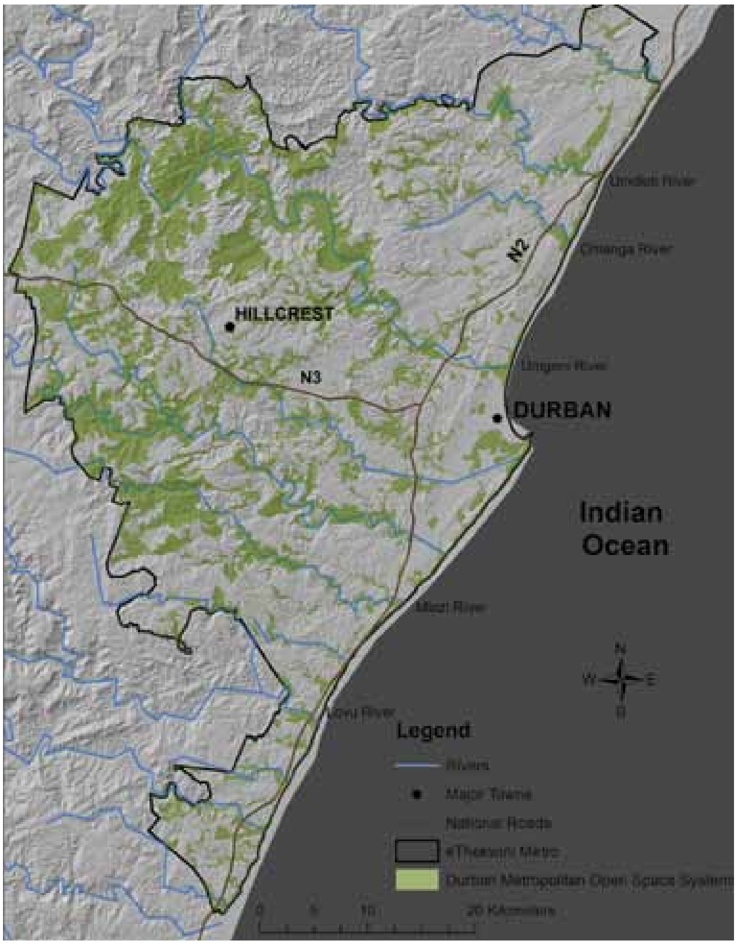
Sound land-use planning involves careful consideration of the short-term and long-term benefits of any land-use change. The ZZ2 case study shows that investing in clearing upper catchments of invasive species can result in a win-win situation for agriculture, ecosystem functioning and biodiversity and that agriculture and biodiversity conservation can mutually benefit from each other. Without ZZ2 intervention, the catchment would still be invaded, with reduced water flow and negative impacts on biodiversity and farming activities.

Ecosystem services

Ecosystem services are the benefits that people get from undisturbed, or little disturbed, ecosystems. Examples are clean drinking water and decomposition of wastes. The Millenium Ecosystem Assessment in the early 2000s grouped ecosystem services into four broad categories: provisioning – such as the production of food and water; regulating – such as the control of climate and disease; supporting – such as nutrient cycles and crop pollination; and cultural – such as spiritual and recreational benefits.



Wetlands are important in assimilating wastes. Image: Wikimedia Commons



The DMOSS area. Image: Mathieu Rouget

Restoring degraded areas in the Greater Durban Metropolitan Area

Urban areas in Africa are growing rapidly, posing considerable challenges for sustainable land-use planning. Economic development requires new infrastructure. Adequate services are also needed. The provision of this infrastructure and services needs careful plannning – particularly land-use planning.

The eThekwini Municipality is responsible for managing and regulating development through land-use planning in the city of Durban and its surrounding areas. Land-use planning is particularly important as the city is located in a global biodiversity hotspot, the Maputaland-Pondoland-Albany hotspot – which is home to plants that are found nowhere else in the world.

Cities are also known as hotspots for biological invasions. Many species are transported and introduced through air, sea and road traffic. Plant trade for streets and gardens is significant and an urban environment provides many pathways and areas for successful establishment of alien species (e.g. road verges for alien plants). It is therefore not surprising that urban areas are generally more invaded than other parts of the landscape. The eThekwini Municipality faces considerable challenges with plant invasions. With strong development imperatives and a limited budget, what measures can a local government put in place for sound environmental planning and alien plant management?

The municipal Department of Environmental Planning and Climate Protection has developed a unique system to control future infrastructure development and conserve biodiversity. Named the Durban Metropolitan Open Space System (DMOSS), this land-use planning tool identifies important and biodiversity-sensitive areas in order to maintain them in a natural state. The DMOSS guides land-use development applications towards areas that have already been converted (i.e. with little natural habitat remaining) and minimises the impact of urban expansion on the remaining biodiversity in the municipality.

The DMOSS includes a comprehensive map of invaded areas and is regularly updated. Degraded areas that are also severely invaded (where most of the original natural ecosystem is gone) may be prioritised for infrastructure development if the terrain is suitable and if there are no other environmental constraints. However, areas that are only moderately invaded should preferably be targeted for alien plant control by the municipality as these still support high levels of biodiversity. Given its limited budget for alien plant control, research is currently taking place to identify areas where alien invasive plants should be cleared. Taking into account biodiversity importance, land tenure and ownership and degree of invasion, key areas are targeted and management plans established in partnership with private land owners, non-profit organisations, provincial and national departments.

The way forward – integrated land-use planning

These three case studies show that the development of any infrastructure or change in land use cannot take place in isolation and that proper consideration should be given to the environment. This is what we call integrated land-use planning. Over the last few decades, the South African National Biodiversity Institute has been working hard to develop planning tools which integrate land use and biodiversity.

Several provinces, notably KwaZulu-Natal, the Western Cape and Mpumalanga, have developed provincial maps that identify important areas for biodiversity. These maps are used to guide conservation efforts, inform development applications and to minimise the impacts of land use on biodiversity. Where information on plant invasions exists, this is used to direct alien plant clearing or select important biodiversity areas which are still free of invasive plant species.

These provincial assessments are conducted using Geographic Information Systems (GIS) and complex decision-making software. This software – used extensively in research in South Africa and elsewhere – combines mathematical theory, geography, land practices, ecology and socio-economic data to select the most suitable area for a given land use.

The interface between environmental conservation, land-use development and alien plant invasions provides exciting research opportunities. These often require complex partnership arrangements between science and practice. Two are currently in place in Cape Town, with the C•I•B and the City of Cape Town, and in Durban – the Durban Research Action Partnership, with UKZN and the eThekwini Municipality. Such collaboration will provide innovative solutions to tomorrow's environmental challenges. **Q**

Originally from France, Mathieu Rouget completed his PhD on alien plant invasions and conservation planning in 2002 at the University of Cape Town. He has worked for several academic and governmental organisations, including the South African National Biodiversity Institute. He currently holds the DST-NRF Research Chair in Land-Use Planning and Management at the University of KwaZulu-Natal. His work focuses on the interface between science and practice, linking biodiversity and land-use development.

Fishing for invasive species


Alexis and penguin friends. Image: Alexis Olds

She walked with penguins, fished for invasive alien fish and she sees every experience as a learning experience. Alexis Olds, an Ecological Coordinator with CapeNature Scientific Services, understands that you need to spend time outside if you want to understand nature.

Alexis was first introduced to invasive alien species during her BSc (Hons) in Conservation and Biodiversity. However, it was during her postgraduate studies at the DST-NRF Centre of Excellence for Invasion Biology (C·I·B) that Alexis was lured to the world of ichthyology. She enrolled for a master's degree with C·I·B core team member, Dr Olaf Weyl, at the South African Institute of Aquatic Biodiversity (SAIAB). The focus of her research was to determine the extent of invasion of four freshwater alien fish species (Mozambique tilapia, mosquito fish, largemouth bass and common carp) in the Wilderness Lake system in the Western Cape. Alongside the sampling of the fish (native and alien), she also looked at the establishment success of these alien species – what environmental factors helped or curbed their establishment.

Her career started when she was offered an estuarine internship with the South African Environmental Observation Network (SAEON). From there she joined CapeNature as Programme Manager for their Marine Protected Areas, Islands and Estuaries Programme and moved on to become the Ecological Coordinator for the De Hoop Nature Reserve, De Mond Nature Reserve and Dyer Island. In her position as Ecological Coordinator, she facilitates and coordinates the collection and interpretation of biodiversity data, and ultimately informs biodiversity management planning and decision-making for the reserves that she manages. She works closely with reserve staff and scientists to make sure that the necessary research and monitoring gets done.

From a very early age Alexis knew that she wanted to work outdoors, in nature and with animals. *'Passion led me down this path. Not pursuing a career in biology never crossed my mind, and the scientific field provides endless opportunities to make a meaningful difference,'* says Alexis. Her position as programme manager often takes her for long hours out of the office and into the field. Alexis explains, *'You need to be able to handle long hours in the field, in sometimes terrible conditions and still keep your sense of humour. Being a field scientist can be a tough job, you need to leave your inhibitions at the door and be willing to work hard'.*

Introducing invasive plants for biofuel: weighing up the pros and cons


Ryan Blanchard. Image: Ryan Blanchard

Ryan Blanchard is a researcher at the Council for Scientific and Industrial Research (CSIR) in Stellenbosch. His research interest focuses on the invasion potential of plants that are used for the production of biofuel. *Quest* asked him a few questions about the importance of his work.

What did you study?
I completed my Bachelors, Honours and Master's degrees at the University of Cape Town. For my PhD I was awarded a studentship from the CSIR and registered at DST-NRF Centre of Excellence for Invasion Biology (Stellenbosch University).

What is important about your work?
My research on biofuels is important in a developing-world context where governments are aiming to increase the socio-economic status of the rural poor by increasing agricultural production. Growing biofuels is one of the mechanisms identified by governments to reach this goal. My research will help decision-makers to consider the consequences of using plants that could have negative impacts on the environment, despite their economic benefits. For example, many of the plants that are used to produce biofuels are invasive in many parts of the world. By following guidelines from my research, it should be possible to mitigate or avoid their potential impacts.

Not many youngsters look at invasion science as a career, what led you down this path?
For me, there was initially an aspect of fun and passion. It was during my undergraduate studies that I learnt how invasive alien species survive in new areas that they invade and how they are able to replace native species. I was really fascinated because this phenomenon was not limited to one habitat or one group of species. Also, many of our current problems are caused by the historical movement of species to new locations. Despite new information about the pathways and impacts of invasive alien plants, species are still being moved around for several reasons. In my view, there are still many opportunities to improve our current invasive alien species policies to avoid future negative impacts. My initial interest in science coupled with a desire to learn about how systems work and to be able to ask questions about these systems was rather intriguing.

The most important lessons you've learnt during your career?
It is important to surround yourself with peers who share a common interest in your work. Never be afraid to ask for help, but always show that you have put the effort in to get as far as you can. It is important to manage your time and to be aware of the core things that you need to learn to complete your research.

On a lighter note, what do you do to unwind?
I like to cycle and I love the ocean. My dad runs a boating company and I help on weekends when needed. This gives me the chance to go to out sea, which can be very relaxing.

Natural fires & plant invaders *what is the link?*

Brian van Wilgen explains the link between invasive alien plants and ecosystems where fire is a natural feature.

Fires are a natural feature of many of South Africa's ecosystems, and they occur regularly in the dry season in fynbos shrublands, grasslands and savannas across the country. Plant species that occur naturally in fire-prone ecosystems are adapted to survive fires, either by re-sprouting after fire, or by germinating from seeds that survive the fire. Not only are plants adapted to survive fires, they also often require fires to complete their life cycles, or to remove competition from other plants. In other words, the vegetation is not only fire-adapted, it is often fire-dependent. Examples of fire-adapted species include proteas in fynbos that age and die without fire, and many other fynbos plant species whose seeds are stimulated to germinate by smoke from fires. In savannas, the balance between grasses and trees is maintained by fire, and it has been clearly demonstrated that exclusion of fires for long periods leads to the elimination of grass and dominance by trees and shrubs – so-called 'bush encroachment'. Managers of natural ecosystems and rangelands therefore recognise the vital role played by fires, and they use fire to maintain these ecosystems.

How fires start

For a fire to start, three conditions must occur together – there must be (i) sufficient fuel in a continuous fuel bed to allow fires to spread, (ii) warm, dry weather, and (iii) a source of ignition. In savannas, grasslands and fynbos, a mixture of dead and live plant material (fuel) that will support a spreading fire normally develops quite quickly. Such vegetation does not normally burn in the wet season (as plants are green and the vegetation is moist), but in the dry season all that is needed is a source of ignition, and big fires can occur. In the days before human populations reached their present high levels, fires were started by lightning. Nowadays, however, most fires are started by humans, either accidentally or deliberately. Fire managers have simultaneously to achieve two goals. First, they have to ensure the safety of people during veldfires, and to protect property and assets at risk from fires. Secondly, they need to ensure that fires continue to play their vital role in maintaining healthy and productive ecosystems, and trading off the needs of ecosystems with the imperative for safety is one of the biggest challenges to fire management.

Pine trees grow to a much larger size than the fynbos shrubs that they replace, increasing fuel loads and the intensity of fires, leading to damaging fires of unnaturally high intensity. Image: Brian van Wilgen

What is the influence of invasive alien plants?

Invasive alien plants obviously don't affect either the weather or the frequency and distribution of ignitions, but they often drastically change the structure of the vegetation, changing both the amount and the type of fuel available to support fires. As a result, they can introduce fires into areas where fires did not occur historically, and by increasing the mass of plant material in fire-prone ecosystems, they can make fires more intense. For example, the invasion of fynbos shrublands by alien pines (*Pinus* species) and hakeas (*Hakea* species) can substantially increase the above-ground plant mass, increasing the amount of fuel available to burn, and make fires more intense and more difficult to control.

The greater intensity of the fire also damages the soil. While soils are not negatively affected by fires in un-invaded fynbos, the higher fire intensity on invaded areas leads to the development of water-repellent layers in the soil. This in turn leads to severe erosion during the following rainy season, degrading catchment areas and leading to flood damage. Houses that are situated next to invaded fynbos are at higher risk of destruction during wildfires, because of the increases in fire intensity associated with higher fuel loads.

In the arid karoo shrublands, which hardly ever burn because there is too little fuel, invasion by an alien perennial grass could change the vegetation sufficiently to allow fires to burn. Experimental studies have shown that, should this happen, very few of the karoo shrubs would be able to survive, and this would ultimately affect the core natural resources that support the karoo economy.

Invasive alien plants and fire management

Invasive alien plants also complicate fire management because, like the plants in the ecosystems they invade, they too are often fire-adapted (see Box 1). Invasive alien plants also have a competitive advantage over native plant species, because they typically are not accompanied by the host of pathogens and insect enemies that help to keep them in check in their home ranges. This means that fires will simply result in the further spread of some invasive alien plants, if the invasive plants themselves are not felled prior to burning.

Invasion of many ecosystems by fire-adapted alien trees and shrubs is an enormous threat to the conservation of these ecosystems. An example is provided by invasive Australian wattles that produce an abundance of seeds that accumulate in the soil. These seeds are stimulated to germinate en masse by fires in fynbos, grassland and savannas, which means that burning can dramatically increase the number of plants. Felling followed by burning can be used to deplete soil-stored seed banks, but is not effective over large areas because repeated and intensive follow-up weeding of new seedlings is needed.

The introduction of alien grasses into fire-free karoo shrublands can result in fires which damage the fire-sensitive plants, ultimately reducing the livestock carrying capacity of these farmlands. Image: Brian van Wilgen

Aftermath of an intense fire in an area invaded by triffid weed in Phinda reserve, northern KwaZulu-Natal. The weeds have effectively been cleared, and the area has been opened up to a degree that will facilitate follow-up weeding. Image: Brian van Wilgen

There may be some good news, however, as the introduction of biological control to reduce the seed output of Australian wattles may be changing this picture. The introduction of a suite of seed-feeding weevils and gall-forming flies and wasps (which prevent seed production by inducing the formation of galls instead of seed pods), has significantly reduced the seed output of many Australian wattle species. This in turn has increased the prospects for effective control by combining mechanical felling, fire and seed reduction.

Fires to manage invasive alien plants

Fires can also be used to assist the management of alien plants in some cases. For example, triffid weed (*Chromolaena odorata*) invades many of the savanna parks in northern KwaZulu-Natal, and it is a priority species for control. Clearing this species manually can be expensive, but high-intensity fires, if we are able to apply them safely, can clear these plants very effectively. The follow-up operations to remove regrowth are much less expensive, so large areas can be cleared effectively by combining fire and follow-up weeding. This has been demonstrated in the Phinda reserve near Mkhuze. In this area, fire scientists are conducting trials that involve aerial ignition of fires from helicopters. These trials have shown that spiral ignition patterns can produce relatively intense fires under safe burning conditions, and the practice holds much promise for improving effective control of triffid weed.

In conclusion

Fires are both inevitable and necessary in many of our ecosystems, but fires and invasive alien plants interact in many and complex ways that can substantially increase the difficulty of managing fires. Invasive alien plants make the fire control problem worse, and they aggravate the effects of what would otherwise be an ecologically beneficial process. Because invasive alien plants are spread by fires, fire also increases their impacts on water resources, rangeland productivity, and biodiversity in fire-prone fynbos, grasslands and savannas. It is thus important to increase attempts to remove invasive alien plants from fire-prone ecosystems, as well as to prevent their introduction and spread in areas that are currently not invaded. Q

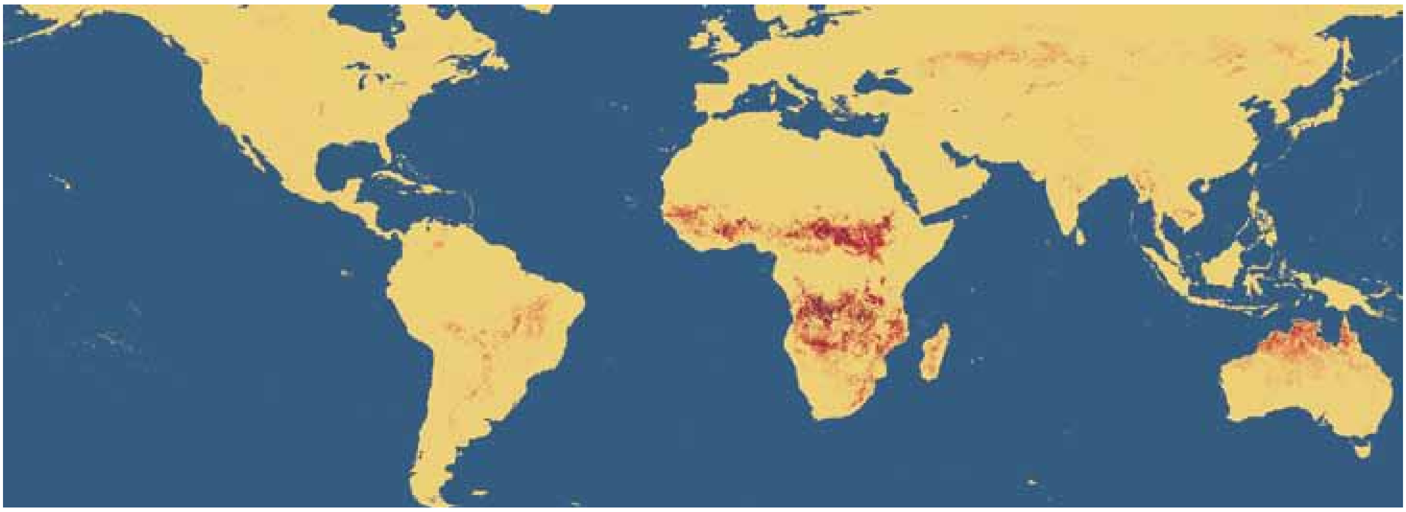
Brian van Wilgen is Professor in the Centre for Invasion Biology at Stellenbosch University, and he has four decades of experience as an applied ecologist in southern Africa. He has worked in a range of organisations, where he has used ecological understanding to develop practical solutions to the problems of ecosystem conservation, management and sustainable use. His research has focused largely on two fields – the ecology of vegetation fires and the use of fire in ecosystem management, and the ecology and management of invasive alien plants.

Fire and invasive pines

Pine stands adjacent to fynbos seen after the recent fires in Noordhoek, Western Cape. Image: Bridget Farham

Mountain slopes near Stellenbosch, showing the effects of fire in an area that was invaded by alien pine trees. The imprints of burnt logs can be clearly seen, and will lead to soil damage and erosion in the rainy season. Image: Brian van Wilgen

The pine trees and hakea shrubs that invade fynbos shrublands are killed by fires and spread over considerable distances by means of winged seeds that germinate in the post-fire environment. Control is possible through pre-fire felling (after which seeds are released) and burning after 1 – 2 years (which kills any resultant seedlings before they can mature). The control is effective, but because of the difficulties in reaching invasions in remote and rugged terrain, progress with mechanical clearing of these trees and shrubs has been limited. In the case of hakeas, biological control in the form of a seed-feeding weevil and a seed-feeding moth has been in place for several decades, and this has led to some progress in their control. No biological control agents are currently available for pines, however, due to concerns about the impact they may have on the forest industry (potential seed-attacking insects may spread diseases such as pitch canker). Finding a sustainable solution to the fire-driven pine invasion problem is possibly the most important challenge facing managers of fynbos ecosystems.



Invasive grasses:

Africa burns and why this matters for grasses

Above: Many ecosystems across the world experience fire, but the frequency with which they burn can vary from as often as once a year to as infrequently as once every few decades. The parts of the world that burn most often are the grass-dominated savannas. This picture shows that African savannas, in particular, burn very frequently (indicated by darker reds) and the area that burns frequently is much larger in Africa than on any other continent. Image: Vernon Visser

Vernon Visser and **Susan Canavan** describe the current situation with invasive grasses in South Africa and what fire has to do with this.

When most South Africans think about invasive species the first thing that comes to mind is a pine tree or a wattle tree. The idea that grasses can be problematic invasive species probably seems absurd. Yet if we venture beyond our shores we find that this is precisely the case in many other parts of the world. Grasses are among the most abundant and damaging invaders of natural areas in regions such as the Americas, Australasia and Pacific islands like Hawaii. They can radically increase fire severity and frequency, resulting in complete ecosystem change (Box 1).

Why African grasses?

What is perhaps of most interest is that many of the invasive grasses worldwide are African species. Africa appears to be relatively little affected by invasive grasses, but African grasses are causing problems elsewhere in the world. Why might this be the case?

The most obvious reason is perhaps that fewer grass species have been introduced into Africa than elsewhere in the world. Grasses are best known for their uses in agriculture (cereals, fodder for animals, etc.) and therefore we might expect that similar species and numbers of species have been introduced all around the world for agricultural purposes. Indeed, when we investigated the uses of alien grasses introduced into South Africa we found that most of these species are used in agriculture. This is no different to the situation in, for example, the USA, Australia and Chile. In fact, almost exactly the same set of species, and numbers of species, have been introduced into South Africa and these other countries for agricultural purposes. Many of these introduced grasses originate from Eurasia and include some

Box 1: The alien grass-fire cycle

The alien grass-fire cycle refers to the invasion of fire-adapted alien grasses into ecosystems that previously experienced few or no fires. These grasses tend to be tall bunch grasses that produce highly flammable aboveground biomass in the form of leaves and stems that have a high surface-to-volume ratio and thus rapidly dry out when they die back. These grasses are also able to rapidly recover after fires because their leaves are 'easy' to replace and the plant meristems are located below ground. Once these grasses are introduced into habitats that were previously fire-free (or at least experienced infrequent fires) they rapidly promote fires because of these features. Native vegetation is unable to survive this sudden increase in fire frequency and the fire-adapted alien grasses spread into habitat that is opened up by fire.

Classic examples of the alien grass-fire cycle include invasions of Gamba grass (*Andropogon gayanus*) in Australia, buffel grass (*Cenchrus ciliaris*) in the arid west of the USA, and molasses grass (*Melinis minutiflora*) in much of South and Central America. All three of these species are native to Africa.

Gamba grass invasion in Australia. On the left is an example of a native eucalypt woodland in northern Australia. The image on the right shows what an invaded woodland looks like after the eucalypt trees have been killed by fire. Image: Wikimedia Commons

Buffel grass invasion in Hawaii, USA. On the left is an example of native vegetation (Panoramio: http://www.panoramio.com/photo/30980166). The picture on the right shows part of the island completely overrun by buffel grass. Image: Wikimedia Commons

Avena barbata

Avena fatua

Brachypodium distachyion

Briza maxima

Briza minor

Bromus catharticus

Hordeum murinum

Poa annua

Vulpia myuros

Grasses invasive in the fynbos biome. Image: Wikimedia Commons

Box 2: Invasive grasses in South Africa

Probably the worst invasive grass in South Africa is the Spanish reed (*Arundo donax*), a plant which you most likely would not even recognise as a grass. This plant is largely restricted to rivers and wetlands, which might leave you thinking it is not that much of a problem. That would be incorrect because this species has spread to nearly every river system in South Africa and is choking out native vegetation for many thousands of kilometres along riverbanks.

Alien grasses are becoming increasingly problematic in the fynbos biome. Here grasses, mostly of European origin, dominate large areas of lowland fynbos, particularly in disturbed habitats (e.g. through too frequent fires or soil nutrient enrichment through air pollution or nitrogen fixation by alien legume plants).

Fountain grass (*Pennisetum setaceum*) is native to the arid mountains of northern Africa. It has pretty 'fluffy' inflorescences, which make it popular as a garden plant. It has also been extensively planted for mine dump rehabilitation. However, this species is becoming increasingly abundant across much of the western parts of South Africa. In the arid Succulent and Nama Karoo it is frequently seen spreading along riverbanks and roadsides. It is thought that this species is being spread by mowing road verges. The biggest worry with fountain grass is that it starts to invade natural vegetation in the arid parts of the country and introduces fire into these biomes, which are not normally exposed to fire.

*Spanish reed (*Arundo donax*) invading along a riverbank.* Image: Wikimedia Commons

Fountain grass spreading along roadsides in the Western Cape. Image: Wikimedia Commons

of our best-known crops, including wheat and rice. What does set South Africa apart from these countries though, is that many South African species have been moved around the world for use as pasture grasses. So what is it about African grasses that makes people want to use them as animal feed?

The main reason African grasses are so popular for animal feed seems to be that many of them respond very well to grazing. Unlike grasses in much of the Americas and Australia, African grasses have evolved with large herds of grazing animals. African grasses are so popular as pasture grasses that Australia even had a government-sponsored programme to introduce alien grasses, with most species originating from Africa. Although African grasses are such popular pasture species worldwide, their success as invasive species is probably for a different reason – fire!


Growing bamboo culms.


Collection of bamboo culms of different sizes ready for processing.


Charcoal made from bamboo culms.


Harvesting of sugar cane for uses such as biofuel production.

Emerging uses for grasses. Image: Wikimedia Commons

Box 3: Emerging uses for grasses

Agroforestry

With increasing rates of deforestation and rising prices for wood, statured grasses such as bamboos are becoming a good alternative to traditional hardwoods. The lignified stalk or culm has a similar texture to wood, but with the added benefit of being lighter and having higher tensile strength than steel. Rapid growth rates, some of the fastest in the plant kingdom, mean that some bamboo species can produce more cubic meters of material than any hardwood tree and almost all softwood trees. In Asia, where there are many native bamboo species, bamboos are commonly used instead of wood for building houses, making tools, utensils, etc. These useful qualities have meant that there is a growing demand for Asian bamboo species, which are being cultivated *en masse* around the world as a substitute for wood.

Carbon mitigation

Other emerging uses for statured grasses, for both bamboos and similar reeds and canes, include their use to offset carbon emissions through mass planting. This is done because many of these species sequester a significant amount of carbon, while also serving as a valuable harvest crop.

Biofuels

Rapid growth, a perennial nature and low management requirements of many statured grasses such as *Arundo donax* (Spanish reed) have made them a popular choice for biofuel production. The production of biofuels is a growing industry that aims to replace traditional oil consumption with geologically-recent carbon energy to reduce greenhouse gas emissions. This is done by harvesting plants, algae or bacteria, which are processed and converted into a convenient energy form such as ethanol. Unfortunately, many of the species suited for biofuel production also have many weedy attributes such as rapid growth rates and high dispersal capacity. This conflict of interests has led to arguments about the feasibility of this industry: the environmental costs of invasion in the long term may outweigh the economic benefits in some cases.

Fire on the African savanna

African savannas are unique in that they burn frequently, as often as once a year (see title photo). The reason is partly to do with the monsoonal climates experienced over much of Africa and because grasses here are uniquely adapted to burn. Grasses here generally grow faster, produce more flammable biomass and survive fires better than grasses elsewhere in the world. When African fire-adapted grasses were introduced into the Americas and Australia they were able to outcompete the native grasses there because they encouraged more regular fires and were able to survive these fires, unlike the native species. Paradoxically, when grasses from elsewhere in the world were introduced into Africa, they were unable to cope with the regular fires that occur here.

You might now be thinking that we live on a continent that is immune to grass invasions. And yes, you are probably justified in thinking this, to a degree. It seems unlikely that African savannas and grasslands will experience the same radical vegetation changes that have occurred elsewhere in the world as a result of anything to do with fire. However, we do have reasons to be concerned (Box 2).

Summing up

Grasses are becoming increasingly popular as ornamental plants and people are growing an ever wider range of grasses in their gardens. Grasses are also being proposed as biofuel feedstocks, and for use in carbon mitigation schemes (Box 3). The grasses being used for these purposes are very different to those used for animal feed and few have been introduced up until now.

We are also seeing an increasing number of grasses being introduced from regions such as Australia and South America, places which previously contributed very little to our introduced grass flora. These regions have very similar climates to South Africa and therefore the likelihood of a newly introduced grass species being able to survive in South Africa is all the greater.

The wildcard for predicting future grass invasions though is global environmental change. Rising carbon dioxide levels and changing temperature and rainfall regimes may tip the balance in favour of invasive grasses in South Africa, but exactly where and when is difficult to predict. It is with this in mind that recently a National Working Group on Alien Grasses was established whose purpose is to monitor the situation with invasive grasses in South Africa. The hope is that through the group's efforts we will be able to identify emerging grass invasions early enough, and thereby prevent grass invasions of the same magnitude as have occurred elsewhere in the world. **Q**

Vernon Visser is a postdoctoral researcher at the Centre for Invasion Biology. Among other research areas, he works on understanding and predicting alien grass distributions. He is also leader of the National Alien Grass Working Group, which was established to assess and monitor grass invasions in South Africa.

Susan Canavan completed her BSc and Hons in Ecology and Economics at the University of Guelph in Canada. She is currently working on her MSc in Botany at Stellenbosch University's Centre for Invasion Biology. Her research looks at the risks and benefits of introduced bamboo species.

Ant invasions

Natasha Mothapo and **Theresa Wossler** tell us about invasive ants in South Africa.

Ants dominate most ecosystems, are highly adaptable and can live in a wide range of environments and form 15 - 20% of the biomass of land animals. They play a very important role in the ecosystem, particularly through their symbiotic relationships with other organisms such as other arthropods (e.g. insects and spiders), plants, and fungi. Furthermore, they influence the surrounding vegetation through seed dispersal and various other ecosystem services.

Ants are social insects and form colonies characterised by one or several reproductive queens, some males which are produced seasonally (drones), and female workers. Some species also have a special 'caste' of workers that are adapted for defence, a soldier caste. Some ant species can disperse large distances and a single fertilised female can establish a very large colony in just a few years.

Invasive ants

Among the animal invaders, social insects such as ants, bees and wasps are important in terms of their distribution, ecological and economic damage. Invasive ants that are frequently associated with human presence are known as 'tramp' ants. Five ant species have made it to the list of 100 worst invasive species in the world. These include yellow crazy ant (*Anoplolepis gracilipes*), red imported fire ant (*Solenopsis invicta*), Argentine ant (*Linepithema humile*), African big-headed ant (*Pheidole megacephala* which is native to South Africa), and the little fire ant (*Wasmannia auropunctata*). These ant species are successful because they prefer human-modified habitats such as our homes, gardens

Top and above: Argentine ants. Image: Nanike Esterhuizen and Eiriki Sunamura

A dead lizard being dragged away by yellow crazy ants in India.
Image: Wikimedia Commons

Red imported fire ants. Image: Wikimedia Commons

Why are some invasive ants so successful?

Ants live in large colonies and are highly adaptable. The queen can establish a colony on her own, and because she can fly, she can establish colonies at a great distance.

They are good competitors, efficient at finding and collecting food. They work cooperatively and rely on large numbers to outcompete native species.

They have a broad dietary spectrum that allows them to use a wide range of food resources.

We have made their life easier due to the high resource availability in our living environments. They can overwinter in our homes because it is warm and food is abundant.

What is a unicolony?

Unicoloniality is the term given to a social structure common in invasive ant species where aggression and territorial boundaries between colonies are absent. Ants from different nests freely mix, resulting in the formation of spatially vast supercolonies. Currently, the Argentine ant has the largest supercolony that spans across four continents (North America, Europe, Asia and Australia). This is one of the largest cooperative units known to man, paralleled only by human colonisation of the world.

and agricultural environments. These areas provide ants with abundant food and water resources and ample places to nest. Invasive ants tend to have very loose nesting habits, nesting in pot plants, under rocks and rubbish piles. This makes them easy to move around and they have used this to hitchhike across the world.

Change in social organisation

Aggression between ant colony members is usually very high, because colonies need to protect themselves from each other and from predators. This type of social structure is called multicoloniality. Invasive ants bring a new twist by changing their social structure in introduced environments to what is called unicoloniality. In this social structure, colonies are not aggressive towards each other and individuals from different colonies can freely mix. They can form colonies that span large geographic scales, known as supercolonies. This means that ants in Gauteng can be placed together with ants from Stellenbosch, and they would recognise each other as colony mates and not show aggression.

All invasive ant species share characteristics that are thought to contribute to their success, such as having multiple reproductive queens in a colony, which promotes rapid colony growth, a broad and generalist diet and the ability to survive in human impacted environments such as gardens and vineyards. When ants are introduced to a new area they are freed from their natural enemies, which allows colonies to reach extremely large sizes, and as a result exert pressure on native ants by competing with them for food and nesting sites. The large numbers of invasive ants makes them better competitors, resulting in the displacement of native ants.

Species	Description	Origin	Introduced range	Earliest records	Distribution in SA
Argentine ant (*Linepithema humile*)	Brown black	Argentina, Brazil	Africa, Asia, Europe, North America, oceanic tropical islands	1893	Gauteng, Eastern Cape, Western Cape, Northern Cape, North West, Free State
White-footed ant (*Technomyrmex diffilis*)	Jet black with pale legs	Madagascar	North America, South East Asia, oceanic tropical islands	Unknown	Western Cape, KwaZulu-Natal
Destroyer ant (*Monomorium destructor*)	Bi-colour (light brown body and dark brown black abdomen)	North Africa, Middle East and Asia	Africa, Australia, Panama, oceanic tropical islands	1862	Western Cape, KwaZulu-Natal
Tropical fire ant (*Solenopsis geminata*)	Yellow to light brown, hairy ant, polymorphic	South America	Africa, North America, Asia and Australia	Unknown	KwaZulu-Natal
Yellow crazy ant (*Anoplolepis gracillipes*)	Yellowish to reddish brown, long legs, slender body and large eyes	Africa or Asia?	Africa, Australia, oceanic tropical islands	Unknown	Gansbaai, Table Bay, Knysna

A table summarising ant invasions in South Africa.

Argentine ants in South Africa

The Argentine ant is the most widespread ant species in South Africa. It is thought to have been introduced during the Anglo-Boer War with horse fodder from Argentina. It has since successfully established in six of South Africa's nine provinces. Argentine ants mostly invade urban and agricultural land, but can also spread into natural environments. Their aggressiveness coupled with their large numbers, can reduce the abundance and diversity of other non-ant ground-living invertebrate species and other small mammals, reptiles and birds.

In the Cape Floristic Region, a globally renowned biodiversity hotspot, Argentine ants disrupt important plant-ant mutualisms, known as myrmecochory. A total of 29 families and 78 genera of fynbos plants have been identified as containing species that are ant dispersed. Over half the species of the plant family Proteaceae (53% or 1 300 species) in the Cape Floristic Region are reliant on ants for seed dispersal. Indigenous ants receive food rewards (elaiosome) attached to the seeds when they move them underground. In this way, when the indigenous ants feed on seeds, they also help them to disperse and protect them from fire and predation.

Argentine ants displace important seed-dispersing ants through competition for food and nesting space, only moving smaller seeds shorter distances, and they do not bury them underground. Argentine ants rob nectar from proteas, and compete with honeybees for this resource, and also aggressively drive other flower-visiting pollinators from the flowers. In this way, they may threaten the survival of some protea species that are a key feature of this biodiversity hotspot.

In agricultural systems, Argentine ants are economic pests. They help aphids and scale insects to survive and grow, leading to outbreaks of these pest species on crop plants, especially fruit trees. Aphids and scale insects can reduce plant fitness and fruit quality, as well as spread disease. Furthermore, Argentine ants can directly damage soft fruits. These damages can translate to millions of Rand in costs.

Other invasive ants and their status in South Africa

There have been very few scientific studies on invasive ants in South Africa, and studies on the current distribution and potential impacts of these species are imperative. Currently we have five alien ant species recorded in South Africa. Besides Argentine ants there is the white-footed ant (*Technomyrmex diffilis*) known as an agricultural pest in vineyards and households. On the other hand, the impacts of the destroyer ant (*Monomorium destructor*), tropical fire ant (*Solenopsis geminata*) and yellow crazy ant (*Anoplolepis gracillipes*) have not been demonstrated, despite their long history of presence in the country. This is surprising for these renowned invasive species, suggesting that the presence records need to be checked. **Q**

Theresa Wossler has been working with social insects for approximately 30 years and is currently focusing on different aspects of social insect invasion ecology, namely invasive ants, honey bee social parasitism and diseases. She is the editor of the journal African Zoology.

Natasha Mothapo is currently a postdoctoral fellow through the C•I•B. She has studied the colony structure and ecological impacts of the invasive Argentine ant in South Africa for both her Masters and Doctoral degrees. She is ant crazy.

Invasive species in *pollination networks*

Steve Johnson shows us that we need to study birds and bees, and even moths, to understand how plant invasions work.

In this age of efficient transport across land, sea and air, the Earth has become a global village. Travel and trade between countries has led to the introduction of countless plant and animal species into regions where they had never occurred naturally before. Most of these alien species do not survive outside the pampered confines of human settlements, but some eventually become naturalised and even invasive, and some transform natural ecosystems. This process of invasion begins when alien species become incorporated into the various ecological networks that sustain life. This article discusses pollination networks, the web of interactions between plants and their animal pollinators.

Bees and pollination networks

Pollination (the transfer of pollen between flowers) is needed for most plants to produce seeds and reproduce. In turn, flowers provide the food needed by many groups of insects, including bees, most butterflies and moths, and many flies and beetles, as well as vertebrates such as nectar-feeding birds and bats.

Should we be concerned that invasive species will disrupt pollination networks in South Africa? One way of answering this question is to look at what has happened to pollination networks in other places when alien plants and pollinators have been introduced. A compelling example is that of the honeybee (*Apis mellifera*). This species, native to Africa and Europe, has been domesticated for thousands of years and is the most widely utilised pollinator of crop plants. It was introduced into North and South America where it had never occurred naturally, and being a super-generalist that can obtain food from a very wide range of flowers, it did not take long for the species to become naturalised. It has now seriously disrupted natural ecosystems in countries such as Argentina. The first introductions were of the European subspecies of the honeybee, but later introductions of the far more aggressive African subspecies gave rise to the much-hyped phenomenon of the 'killer bees' (or 'Africanised honeybees') of South and Central America.

The South American tree tobacco (*Nicotiana glauca*) is invasive in South Africa where it is pollinated by sunbirds that exhibit unusual hovering behaviour to reach the nectar. Image: Anton Pauw

Opposite page: Carpenter bees (genus *Xylocopa*) in South Africa perform a similar pollination role to bumblebees (genus *Bombus*) in Europe. If *Bombus* species were to be introduced to South Africa, they would compete with carpenter bees for access to rewards from large flowers such as this *Brunsvigia radulosa*. Image: Steve Johnson

Invasion meltdown

An important group of social bees that do not occur naturally in South Africa are bumblebees (genus *Bombus*). They are found naturally in the northern hemisphere and in some parts of South America. Like honeybees, bumblebees are super-generalist insects and, after being introduced to New Zealand and Tasmania, they rapidly became naturalised. They have disrupted many natural pollination mutualisms, but more alarming is their effectiveness in pollinating large-flowered invasive plant species from the northern hemisphere, such as the notorious *Rhododendron ponticum* and Paterson's curse (*Echium plantagineum*). This is what biologists call an 'invasion meltdown', and it happens when invasive species promote the success of other invasive species. Given the ecological concerns raised worldwide, it is unlikely that the South African government would sanction the introduction of bumblebees to this country. There is, however, a danger that bumblebees may be introduced to South Africa by a misguided individual, as was apparently the case in Tasmania. Not only could this lead to an invasion meltdown by promoting the spread of invasive plant species that originate from the native range of bumblebees, but it could also seriously jeopardise our local carpenter bees (genus *Xylocopa*), which are about the same size as bumblebees and occupy a similar ecological niche of feeding from large, deep-tubed flowers. Carpenter bees are solitary and more specialised than bumblebees and likely to come off second-best when faced with competition for nectar resources from bumblebees. Bumblebees may also compete with our native honeybees, with negative consequences for honey production, crop pollination and pollination of native plant species.

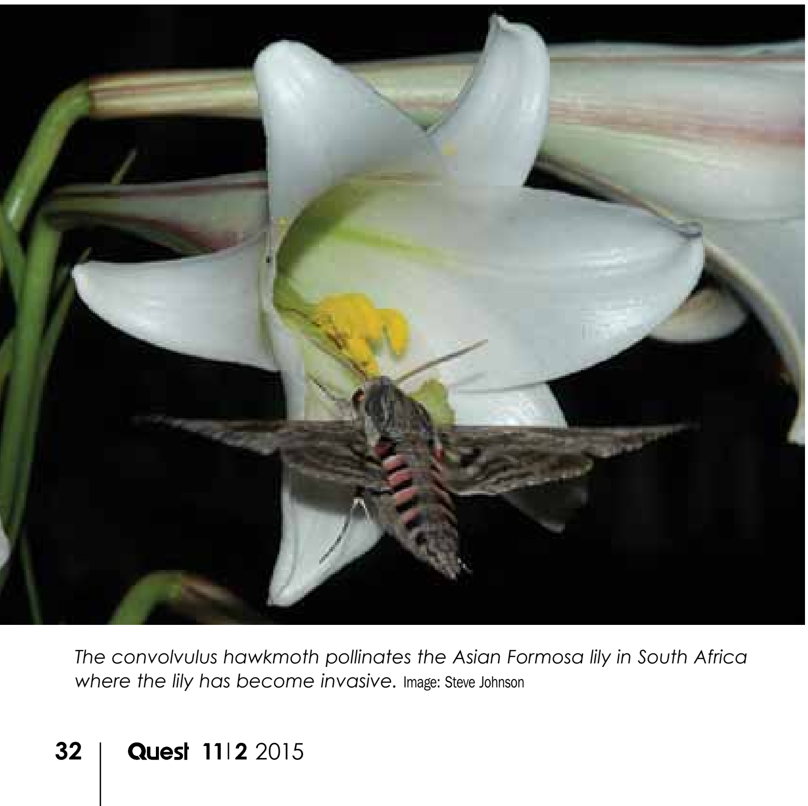
Invasive plants and local pollinators

To become invasive, introduced (alien) plants must have an assured means of reproduction. Many alien plants are capable of producing seeds through self-pollination and thus do not have to rely on local pollinators for reproduction. Another way of assuring reproduction is for these alien plants to become incorporated into local pollination networks. Pollinators in the introduced region become substitutes for the original pollinators in the native range of the plant species. An example is the small tree tobacco (*Nicotiana glauca*) which is pollinated by hovering hummingbirds in its native South America. Some

The convolvulus hawkmoth pollinates Macowan's crinum lily which is indigenous to South Africa. Image: Steve Johnson

scientists would have predicted that this tree would not invade in South Africa because our local sunbirds usually prefer to perch while feeding on flowers, but in fact local malachite sunbirds do visit and pollinate the tree tobacco, and are so eager to reach the nectar that they show the uncharacteristic behaviour of hovering to do so.

Another example of this is the vine (*Ipomoea alba*) whose long-tubed flowers have been seen to be pollinated by the convolvulus hawkmoth (*Agrius convolvuli*) in South Africa. This local hawkmoth substitutes for the hawkmoths that pollinate the vine in its original range in South America. Another invasive species pollinated by the convolvulus



The convolvulus hawkmoth pollinates the Asian Formosa lily in South Africa where the lily has become invasive. Image: Steve Johnson

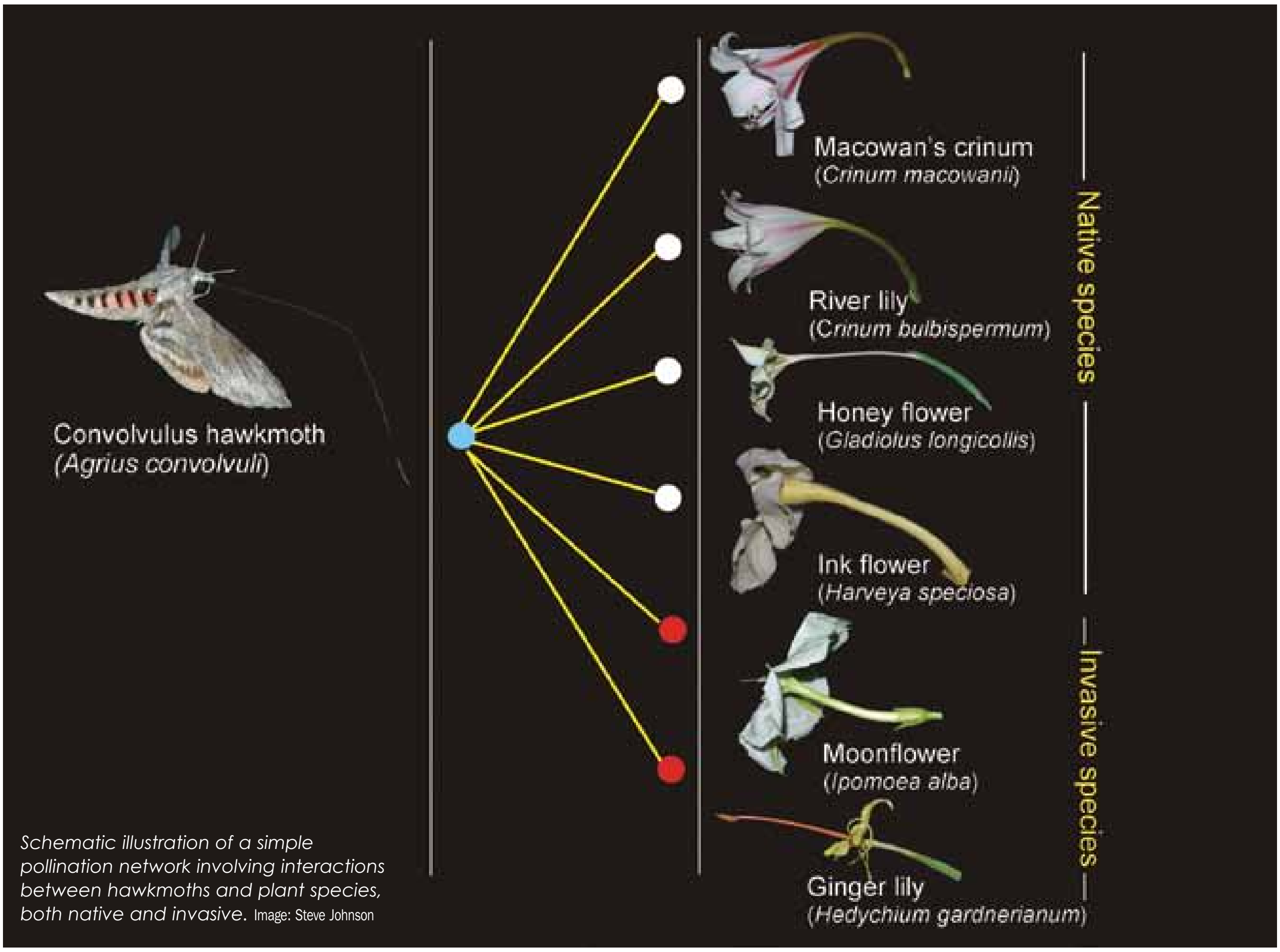
hawkmoth in South Africa is the Asian Formosa lily (*Lilium formosanum*). This lily may be adapted for pollination by the convolvulus hawkmoth, which occurs naturally in Asia, so allowing the Formosa lily to become easily incorporated into the South African hawkmoth pollination network.

What happens to local pollination networks when alien plant species are introduced? If no local pollinators are suitable, then plants are unlikely to become incorporated into these networks and become invasive (unless, of course, they are capable of self-fertilisation or extensive vegetative reproduction, as in the case of water hyacinth (*Eichhornia crassipes*). However, as revealed in the above examples, in many cases local pollinators, including honeybees, will visit and pollinate the flowers of invasive species. Alien plant species can compete with local plants in terms of pollinator attraction. They may act as 'magnet species' that increase pollinator abundance in invaded communities, but do so by drawing pollinators away from other native plant communities.

Some bee-keepers are actually in favour of alien plant species such as Australian bluegums that produce copious amounts of nectar, as they boost honey production. This is not necessarily a problem if the interaction is mainly between managed hives and stands of bluegums, as long as there are other ecological filters that prevent invasion by these introduced plant species. If, however, the activities of honeybees on flowers of alien plants causes these plants to become invasive, then the cost to the country will obviously soon exceed the benefits in terms of honey production.

Safe and unsafe plant introductions

How then do we determine which plant species are safe for introduction and which are not? Plant species that can self-fertilise or reproduce by cloning are obviously risky because they do not need to become incorporated into pollination networks. Some plants, such as the common European dandelion (Taraxacum officinale) and the much more dangerous triffid weed (Chromolaena odorata), have an



Schematic illustration of a simple pollination network involving interactions between hawkmoths and plant species, both native and invasive. Image: Steve Johnson

unusual form of reproduction known as apomixis, which allows them to produce seeds by cloning. in other words they don't need pollinators. For plants that do need pollinators, you can try to predict whether a local pollinator is likely to substitute for the pollinators in the introduced plant's native range. This is not always easy to do, as in the case of the tree tobacco that substituted its hummingbird pollinators for sunbirds that unexpectedly hover while feeding on flowers.

It is also important to consider the possibility of an invasion meltdown. *Rhododendron ponticum* (common rhododendron, a major invader in the UK), which is currently cultivated in South Africa, could become seriously invasive if bumblebees were to be introduced here.

Invasive plants that are cross-pollinated by local insects will continue to develop new genetic combinations, which may accelerate the process of invasion. For example, the purple loosestrife (*Lythrum salicaria*) is a European plant species that has become invasive in North America. It is cross-pollinated by the native bumblebees of North America and, through the new genetic combinations that arise from sexual reproduction, has undergone rapid evolution and is now spreading into new territory in Canada.

Controlling invasive aliens

The fight to combat invasive organisms is a tough battle in terms of both the manpower needed to control their spread and the difficulties in making scientific predictions about which species are likely to do so in the future. One of the biggest challenges, however, is to make the public aware that the beautiful plants in their garden may actually be dangerous, and that cute fuzzy pollinators such as bumblebees may actually be harmful if introduced. One of the main roles of science is to encourage us to think objectively about problems, and not to be seduced by the apparent beauty in a plant or animal. It is not too late to stop future biological invasions by identifying plants and animals that have just begun to become incorporated into natural ecosystems or that have the potential to do so. **Q**

Pollination networks

Network analysis was originally developed in biology for the study of food webs, but can be applied to the study of mutualistic interactions. Networks are usually drawn as nodes representing species connected by lines representing interactions. Pollination networks describe the pattern of interactions between plants and flower-visiting animals in local biological communities. Plants or animals that interact with many other organisms are generalists, while those that interact with just a few are specialists.

Pollinators that perform a similar role are considered to belong to the same functional group. Many plant species are specialised for pollination by a particular animal functional group. A general property of pollination networks is that the animals that pollinate flowers are mostly generalists, while flowers are more specialised. For example, some plants have flowers that are specialised for pollination by hawkmoths (the functional group in this case), but the hawkmoths themselves may visit dozens of different plant species. There are some examples of reciprocally specialised mutualisms, such as those between figs and their specific wasp pollinators, but these are relatively rare in nature.

It is also important to realise that not all interactions between flowers and flower-visiting animals are mutualisms. Bees will often rob flowers of their nectar by biting through the side of the corolla without pollinating the flower, and plants, in turn, may use mimicry to trick insects into visiting flowers without actually providing a reward of pollen or nectar.

Steve Johnson holds the NRF-DST South African Research Chair in Evolutionary Biology and is currently a professor at the Pietermaritzburg campus of the University of KwaZulu-Natal. He is a leading international expert in the field of plant pollination biology .

The notorious cane toad. Image: A Turner and SJ Davies

John Measey and **Sarah Davies** discuss the emerging problems associated with invasive amphibians.

Hopping invaders

Many of us share our environment with a number of wild animals, and among the vertebrates, the amphibians (Class: Amphibia) may be the most numerous. In South Africa, amphibians are only represented by frogs (Order: Anura), but worldwide there are two other groups, the tailed salamanders (Order: Caudata), and the limbless caecilians (Order: Gymnophiona). Together, there are more than 7 300 species, with the frogs making up 88%. Considering the total number of species, only a handful of these have been moved outside of their native ranges (147 frogs; 37 salamanders, 2.5%), and an even smaller number (1.4%) are thought to have successfully established invasive populations. These invasions have not been equally distributed across the world, with Australia, Europe, USA and many of the Caribbean islands receiving far more introductions than elsewhere. But what's the fuss about? How could invasive amphibians possibly become a problem, and why would people want to move them in the first place?

Moving amphibians

The pathways which have led to amphibian introductions include unintentional movement, similar to many of the other invasive plants and animals. Have you ever bought a pot plant, only to find when you get home that there's a frog in it? Or

Distorted Earth. This image shows a 'cartogram' where the size of each country is proportional to the number of known amphibian invasions it has received. Note how most of Africa has shrunk to almost nothing, while Europe, USA and many of the Caribbean islands are larger than they would normally appear. Image: John Measey pulled a bunch of bananas apart to find a frog sheltering inside? Some frogs (especially the toads: Family Bufonidae) regularly inhabit areas that we light up at night, feeding on the insects that are attracted to our lights. Before day breaks, they'll be looking for places to hide from the sun and readily enter into dark boxes. If such boxes happen to be at a port, they could be picked up, placed on boats and shipped around the world. When the containers are opened up again, the animals can find themselves on another continent, and if it isn't too cold (and if they arrived with a mate) you can imagine how it is possible for them to start an invasive population. But perhaps the most unexpected pathways of amphibian invasions are the deliberate movement and introductions of frogs for a whole host of reasons.

The cane toad (*Rhinella marina*) is probably the best-known invasive amphibian in the world, and certainly the most studied. Originating in Central and South America, cane toads have been introduced to at least 90 different sugarcane growing areas in the Caribbean, Australia and Pacific since the 1930s. It was thought that the toads would control a number of beetle pests that were causing problems for sugarcane growers. The rest, as they say, is history. With so much help from those who introduced them, cane toads have quickly established invasive populations in many of the sites in which they've been introduced. The largest area invaded is Australia, where the toads are still spreading across the world's largest island. The cane toad isn't alone in its attempted use as a cane-beetle predator. The islands of Reunion and Mauritius (east of Madagascar) imported guttural toads (*Amietophrynus gutturalis*, which also occur naturally in South Africa) which have since become a real problem all over these islands. One of the hazards that the toads bring is their parotid glands (these contain bufotoxins that the toads excrete whenever they are threatened), which poison any potential predators and have caused serious declines for anything that wants to eat them.

You may well have heard of frogs legs as being a delicacy of the French, but there are plenty of people who

The American bullfrog. Image: Wilkimedia commons

want to eat them, enough for there to be a global market in frogs legs. Clearly, it makes sense to grow your meat as locally as possible, so in the 1990s a trend started for farming frogs, and the species selected for this enterprise had many of the attributes we associate with invasive species: they had a cosmopolitan diet, grew fast, and were able to live in many climates. Although not the only species to be part of this aquaculture trade, the American bullfrog (*Lithobates catesbeiana*) has become invasive in 31 countries. Science has also had a role to play in the pathways of invasive frog introductions, and the subject of this story involves a frog which should be very familiar to many readers: the platanna or African clawed frog (*Xenopus laevis*: see Box 1). Interestingly, these animals became so easy to breed and keep in captivity that they became extremely popular in the pet trade, and this has resulted in more introductions and the establishment of invasive populations.

Invasive impacts

You might think that we know enough about the problems of invasive amphibians that their movement would be prohibited, but this is not the case. For example, within the USA, between 2001 and 2009, 20 million American bullfrogs and 1.25 million platannas were traded. During the same period, the USA exported 12 000 and 120 000 of the same two species, and the trade in amphibians is growing as the demand for rare or unusual pets increases. As the trade grows the numbers of amphibians that are likely to escape increases and so the number of invasive populations increases. But what impacts do these invasive frogs make when they establish a new population?

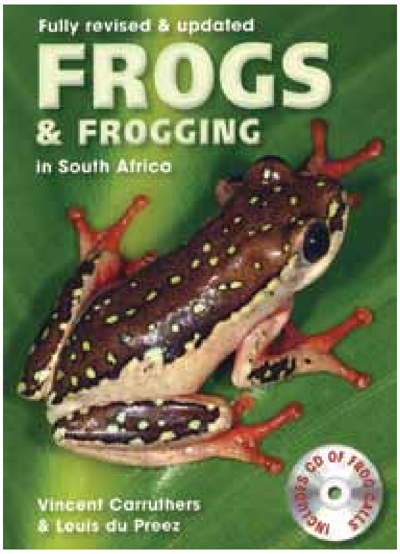
Invasive frogs can affect the environment into which they are introduced in many ways. Frogs are prodigious predators, as anyone who has tried to keep a frog in captivity will know. Even a very small frog can happily eat ten or fifteen insects per day! Therefore, when there are many frogs in an area there can be a major impact on insect populations. Frogs also eat other frogs, and this could result in native frogs becoming rarer or even going extinct, particularly if the invading species is large, like the American bullfrog.

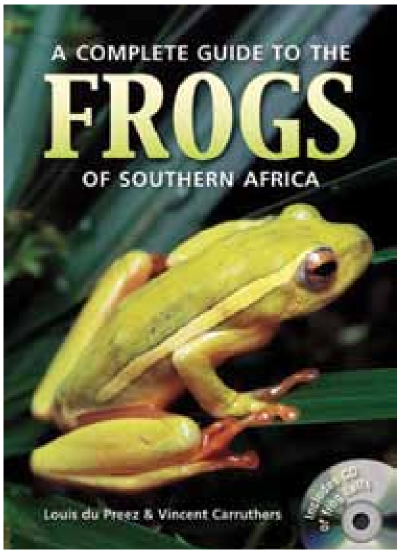
Opportunity cost

One interesting impact of frog extinctions is called 'opportunity cost'. This means that if a species is already extinct, or very rare and difficult to find, we will not be able to find out whether there are possible economic and social uses of these animals. Thus, humans will lose an opportunity they would have had if the species had survived or been protected. Some frogs have already given scientists natural compounds or templates for making synthetic chemicals that could help in treating cancer and other diseases. This is why it is important to support nature conservation efforts in your area, and be aware of the global threats to frogs, such as the loss of wetlands and climate change.

When animals or plants enter a new environment they can transport disease-causing organisms with them, such as bacteria, viruses or fungi. This may be what happened when the platanna was introduced to North America. Native frogs may have been infected by a fungus carried by the introduced frogs, causing them to become sick and die in large numbers.

Some introduced frogs become extremely abundant, and this can affect other aspects of the ecology in the area where they are introduced. For example, coqui frogs (*Eleutherodactylus coqui*) are very abundant in forests on Puerto Rico island and can consume up to 115 000 insects per night. The waste from these frogs, as well as their decomposing bodies when they die, provides nutrients, such as nitrogen and carbon, for plants and decomposer organisms. Researchers found that if the frogs were kept out of an area, the rate of nutrient cycling in the forest slowed down, and some plants grew more slowly.





Two useful books on frogs.

What can you do?

If you're interested in finding out more about South Africa's frogs and those from other countries, there are many excellent resources you can use to learn more. Field guides are available in many libraries and bookshops (see the book covers). You can get to know the frogs in your area by looking in the vegetation around ponds and dams, especially during summer. Even if you cannot see them, you may be able to hear them calling. The field guides shown are great because they include CDs with the calls of each species, so that you can become familiar with them and identify them without even seeing them. Many people think that the frog sounds they hear at night are made by insects or birds, when many of them are the mating calls of nocturnal frogs. South Africa has 125 species of frogs and it's possible to become familiar with most or all of their calls.

If you have a water body near your home, you can monitor the frog

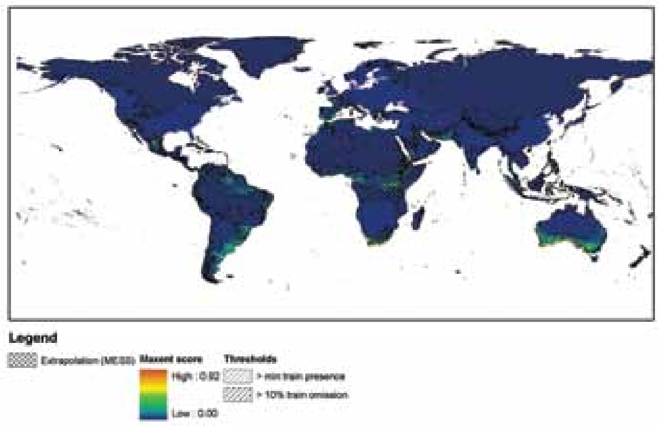
Box 1: Common platanna

The platanna or African clawed frog (*Xenopus laevis*) first became of interest to the wider scientific community in the 1930s. Endocrinologists found that hormones present in the urine of pregnant women stimulated female platannas to lay eggs. As platannas bred throughout the year and were easily maintained in the laboratory, this was found to be a suitable animal for pregnancy tests. And so began a massive trade in live animals from South Africa to pregnancy clinics around the globe.

Once again, the properties that made this species useful in the laboratory (large size (producing lots of eggs), hardy (to many environments), resistant to disease) also made the species ideal for invasions so that when colonies escaped, or were released, they quickly started invasive populations. Being primarily aquatic, the platannas have been shown to have a negative effect on local amphibians, eating their eggs and tadpoles as well as adults. The impact on freshwater invertebrates is not well known, but it has been suggested that this species is capable of changing the ecology of the ponds it invades.

Some of the first invasive populations were in the USA and UK, and date back to the period when this species was regularly used in pregnancy testing. However, invasions have continued right up to the present, and invasive populations of this species are now found on four continents. Worse, this species is known to harbour a fungal pathogen (*Bd*), known to have grave adverse effects on many other amphibian species. Whether or not this pathogen originally came from South Africa, the invasive populations now act as a reservoir.

*A global invader: the African clawed frog or platanna (*Xenopus laevis*).*
Image: John Measey



Global distribution model. Scientists have projected the climate of the platanna to see where in the world it may spread. Note how suitable climates cover much of Australia, Europe, Mexico and South America.

Groups of amphibians	Numbers of frogs (Anura)	Numbers of salamanders (Caudata)	Numbers of caecilians (Gymnophiona)
Number of species which have been introduced worldwide	125	37	0
Number of species which have become established outside their natural range	85	19	0
Number of species indigenous to South Africa#	119	0	0
South African endemic species	66	0	0
Domestic exotics*	3	0	0
Invasive alien species from outside SA	0	0	0
South African species that are invasive elsewhere in the world	2	0	0

New species are still being described in South Africa, so this number is rising.
*Species which are native to South Africa, but have been moved by humans outside of their natural range.

A table showing the numbers of invasive amphibians globally and in South Africa.

populations there each summer, and try to identify all the species that are calling there. The story of a frog that likes to breed in farm dams and garden ponds is told in Box 2. You will find that frogs call most when the weather is warm and moist and not too windy, and most frogs are nocturnal. However, in the Western Cape and Northern Cape many species breed in winter instead of summer, and these species are adapted to cold weather.

Note: you need a permit to keep a South African frog as a pet.

iSpot is a website devoted to recording people's encounters with nature (http://www.ispotnature.org/communities/southern-africa). Once you have registered on iSpot, you can send your photos of animals you see and experts can help you identify them. You can also find out what observations others have made and whether your observation is new or unusual. **Q**

John Measey has been working with amphibians for more than 20 years and is currently the IUCN's chair of the Amphibian Specialist Group in southern Africa. John has worked on invasions of the platanna on three continents, and his students now study local invasions in South Africa. He is a senior researcher at the C•I•B hub at Stellenbosch University.

Sarah Davies works with the C•I•B team at Stellenbosch University. She completed her PhD in 2014 on the invasion of the painted reed frog in the Western Cape of South Africa, and thinks that amphibians are the coolest vertebrates in the world.

Box 2: The painted reed frog

The South African Frog Atlas (http://adu.org.za/frog_atlas.php) was compiled by many herpetologists and volunteers going out and listening for frogs around their homes, and in more remote areas. Eighty seven percent of the quarter degree squares (QDS) in South Africa were visited and the frogs recorded there. (A QDS is the area covered by a 1:50 000 topographical map, so you can imagine that this involved a lot of field work.) During the Frog Atlas process, when they were comparing the field results with specimens that were kept in museums, scientists noticed that some species were becoming more widespread than they had been in the past. For example, the painted reed frog (*Hyperolius marmoratus*), a species from the eastern parts of the country, was found living in the Stellenbosch area, and scientists at CapeNature and Stellenbosch University began to study its spread. When Sarah Davies was conducting research for her PhD, she noticed that most of the painted reed frogs in the Western Cape live in dams and ponds that have been built by farmers and land-owners to provide water for irrigation.

A dam in which painted reed frogs were found. Image: AA Turner

Frogs can move between these water bodies by hopping, if the distances are small, or via vehicles, goods or plants that are being transported across larger distances. If drivers don't check their vehicles and cargo, there could be a couple of small frogs sitting on or in their vehicle and they may be taken to another pond where they could mate and lay eggs. After two years, these could have developed into a whole new generation of adult frogs, and a few individuals could, in turn, spread to a neighbouring pond. In this way, painted reed frogs have spread to over 3 000 km^2 of the Western Cape Province. This is a very rapid rate of spread if you consider that species usually spread very slowly – for example many species went extinct at the end of the last ice age because they could not track the climate changes fast enough. In this case of human-mediated biological invasion, only fifteen years were needed for the frog to extend its range westwards by over 600 km.

A painted reed frog. Image: AA Turner

The house crow – a common bird in Asia. Image: Wikimedia Commons

Winged invaders: Bird introductions

Lorinda Hart and **Colleen Downs** consider the example of the rose-ringed parakeet.

The common myna – an abundant invasive species. Image: Lorinda Hart

Invasion biology has become an important area of biological research, especially in the light of global climate change. The invasion of alien species is recognised as one of the leading causes of extinction of indigenous animal species, particularly birds. The negative impacts of alien birds could include damage to property and crops, noise and nuisance, and the spread of disease to humans and native species. One example is feral pigeons found in cities. They nest and roost on buildings in large flocks and spread harmful bacteria in their faeces and in some cases parasites from their feathers. Some people also develop an allergy to their feather and scale dust.

Certain invasive bird species also hybridise with native species. An example is mallard ducks breeding with our indigenous duck species. As a result our 'pure' ducks are at risk of being replaced by mallard-indigenous duck hybrids. But how do invasive bird populations begin?

How are birds introduced?

Birds are kept as pets and ornamental captives and because they can fly, they have a high escape risk. In South Africa many bird species have escaped from captivity or have been intentionally released into the wild by well-meaning people. Some of these birds have been able to survive, establish

The popular rose-ringed parakeet. Image: Sophia Turner

breeding colonies and spread in their new environment. This is how species such as the common myna and the mallard duck became known as invasive species. Of the ten invasive bird species that live in the wild in South Africa, six are believed to have been deliberately introduced, e.g. chukar partridges and common starlings, three escaped captivity, e.g. mallard ducks and one, the house crow, was most likely a ship stowaway. It is also believed that these ship-hitching birds spread from Durban to Cape Town in this way.

Some bird species cannot survive or breed in South Africa and are of less concern. For example, in the late 1800s British colonials tried to deliberately introduce game birds (pheasant and quail) for hunting and song birds (thrushes and nightingales) which reminded them of England, but these introductions were mostly unsuccessful.

Birds are able to cover great distances and cross geographic barriers, allowing them to expand their ranges relatively quickly. This means that they can spread quickly once they are introduced to a new place. The common starlings did just that. They spread from 18 birds released in Cape Town, crossing over the mountains 30 years later and have since spread to KwaZulu-Natal and Mpumalanga, showing no signs of stopping.

As with all alien species introductions, the successful invasion of alien bird species worldwide could be because of the capabilities of the birds themselves (e.g. they could be well-suited to the climate of the region where they are introduced), the environments they find themselves in (the forest they were introduced to contained very similar nesting sites and food to the region they came from overseas), or specific chance factors at the time of introduction (e.g. enough birds were released at the same time to ensure successful breeding), or any combination of these. Identifying common traits which have led to the successful invasion of a certain species, such as the common myna is difficult because there is very little literature available on invasive birds in South Africa, and not enough is known about how these species affect our local fauna and flora. It is important to identify invasive traits because as the pet trade expands with demands to import new and exotic species, screening for 'invasive traits' could prevent new problem species from being brought into the country.

The chukar partridge – an introduced game bird. Image: Wikimedia Commons

The human link

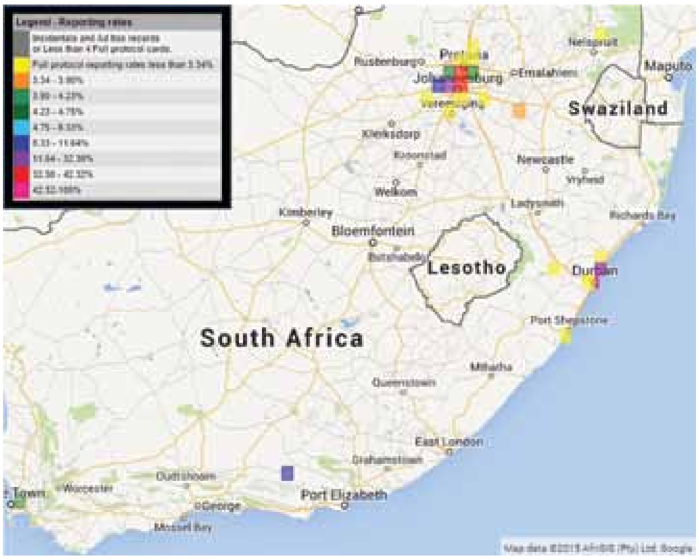
Invasions have been strongly linked to human disturbance and urbanisation, especially with the success of invasive bird species. Humans have altered nearly 50% of the Earth's land surface, and continue to do so, so there is plenty of human-modified habitat available. As the cities become larger and denser, natural habitats and ecosystems become scarce. Urban areas have a wide variety of different bird habitats and are highly fragmented because of the construction of buildings and houses. Most bird species cannot live in these areas and need natural areas for nesting and feeding, but a few species are able to exploit new niches created by human activity or expanding existing niches (such as gardens and

Species	Scientific name	Place of origin	Control
Chukar partridge	*Alectoris chukar*	Eurasia	None
Common peacock	*Pavo cristatus*	Indian subcontinent	None
Rose-ringed parakeet	*Psittacula krameri*	Central and north Africa, Asia and Indian subcontinent	None
Common chaffinch	*Fringilla coelebs*	Europe, north Africa and western Asia	None
Rock dove/feral pigeon	*Columba livia*	Europe, north Africa and south Asia	No official control programme, some industrial areas control locally
House crow	*Corvus splendens*	India and surrounds	Poison largely successful
Common starling	*Sturnus vulgaris*	Temperate Europe and western Asia	None
Common myna	*Acridotheres tristis*	Asia	None, some breeding pairs locally removed
Mallard duck	*Anas platyrhynchos*	Most of the northern hemisphere	Programmes in place, largely using poison
House sparrow	*Passer domesticus*	Europe, Asia and Mediterranean	None

A table showing invasive birds in South Africa and current control strategies, identified from the book Alien and Invasive Animals: a South African Perspective *by Mike Picker and Charles Griffiths (Struik Nature, 2011).*

buildings). Introduced species are also more likely to be found in urban areas due to the abundance of food and nesting sites. Feral pigeons and common mynas are good examples of species that benefit from humans, as they feed on scraps in the streets or are fed and have many buildings to nest and roost on.

Box 1: Citizen scientists facilitate research



This map shows the current distribution of rose-ringed parakeets in South Africa. It was generated on Google maps by the *Southern African Bird Atlas Project (SABAP, http://sabap2.adu.org.za).* This project relies on citizen scientists and researchers who submit sighting records of birds observed in different areas. The different coloured squares show the different reporting rates of a species in different areas. Rose-ringed parakeets currently have strongholds in Durban and Johannesburg and are spreading outwards from these areas. They are also being observed in smaller groups in the Cape and near Port Elizabeth for example. This public platform allows the spread and decline of certain species to be monitored and is a wonderful example where technology, enthusiastic observers and scientific research can work together to benefit conservation. To learn more visit http://sabap2.adu.org.za.

Exotic parrots

More recently exotic parrot species have been setting off researchers' warning bells, with reports of feral birds on the increase. One species of particular concern, which has become a successful invader in South Africa, is the rose-ringed parakeet. It is native to southern Asia and sub-Saharan Africa, but today it is the most widespread invasive parrot worldwide, with established feral populations in at least 35 countries on five continents. Parrots are popular pets as they are colourful and charismatic. As with other caged birds, escapes and releases are quite common. Their popularity also makes it difficult for nature conservation officials to trap or remove them, because the public enjoys seeing them around. Today there are several exotic parrot species in the wild in South Africa (see Symes 2014 review for further reading). Not all of these will become invasive as their numbers may be too low or they could be a long-lived species with very specific breeding requirements and take a long time to produce offspring, so their population will grow very slowly.

In South Africa, rose-ringed parakeets have established breeding colonies in Gauteng and KwaZulu-Natal. First sightings in South Africa were noted in 1972 and initial breeding records date back to the 1980s in Gauteng. These birds were considered rare and were most likely escapees from cages. While they were also seen to breed in Cape Town in the 1950s, these populations did not persist. Today, in South Africa, they are considered fairly common in areas where they occur and in 2005 it was estimated that the population in Durban was about 700 – 1 000 individuals. It is likely to have increased since then, and so the current rose-ringed parakeet population size and trends in South Africa need to be determined. Researchers at the University of KwaZulu-Natal are busy setting up research projects on this species.

Overseas their populations are expanding exponentially and it is suspected that once the South African population is sufficiently large, similar trends will be experienced here. In general, invasive bird species have a lag period, which can last for decades, after which there is a population explosion. This was true for the common myna whose population appeared unchanged for 30 years, after which it soon became one of the worst invasive bird species in South Africa. Numerous efforts to eradicate invasive species have been largely unsuccessful due to this phenomenon, and early detection has been suggested as a key step in any control strategy. Based on a recent study and data from the *Southern African Bird Atlas Project (SABAP)*, rose-ringed parakeets largely occur in urban areas. There are already indications that this species is spreading into neighbouring suburbs and these birds have once again been sighted in the Cape and in other areas.

Rose-ringed parakeets are generalist birds, occurring in a wide range of habitats and feeding on a variety of food items. This means that they are not very fussy and easily adjust to new and different environments. Researchers from the University of KwaZulu-Natal have found that these parakeets are able to conserve energy in extremely cold situations and show no sign of hypothermia at 5°C, despite being a tropical species. This physiological capability has no doubt facilitated its spread across the world. It is important that we understand the threats these birds could pose to our ecosystems. In South Africa these birds have been seen to evict black-collared barbets and golden-tailed woodpeckers from their nests, but whether or not they are having a significant effect on these species has not yet been quantified. Where food and nest sites are not limiting, these birds have the capacity to reproduce successfully and rapidly. When their population gets big enough they spread from urban areas to more rural areas and can damage crops and disrupt natural ecosystems. Although this species is widely studied on a global scale, very little work has been done in South Africa. There is currently no management plan to control rose-ringed parakeets, although discussions are currently underway to determine which methods would be most suitable. Public education should also be undertaken to create awareness of the potential threat these parakeets pose to indigenous species. **Q**

Dr Lorinda A Hart is a post-doctoral research fellow at the University of KwaZulu-Natal under the supervision of Prof. Colleen Downs and Dr Mark Brown. She has broad research interests and is especially interested in ecophysiology, and urban and invasive ecology. Her PhD focused on avian and bat frugivores which fed on invasive fruits commonly found in South Africa, particularly KwaZulu-Natal. The effect that frugivores have on invasive seed germination and the energetic rewards gained by the frugivores that feed on these fruits was also quantified. After her PhD she conducted public surveys and determined the current rose-ringed parakeet distribution in the in the greater Durban Metropolitan area of eThekwini. She is currently involved in several projects on a range of species including fruit bats, birds of prey, woolly-necked storks and a variety of seabirds from the Seychelles.

Prof. Colleen T Downs has been at the University of KwaZulu-Natal since 1994. Her research interests are broad and multidisciplinary. They include the conservation, ecology, physiology and behaviour of terrestrial vertebrates in unpredictable environments. This includes ecosystem health in KwaZulu-Natal incorporating conservation, general biology and persistence of mammal, herpetological and bird species with changing land use (including urban ecology). This includes several species such as Cape parrots, bushbuck, oribi, pelicans, Cape vultures, Nile crocodiles, fruit bats, raptors, small carnivores and feral cats. Another interest is science education (particularly problems experienced by Biology students and development of strategies to address these). Her other contribution has been in the development of research capacity, particularly at both undergraduate and postgraduate levels.

Further reading

Hart LA and Downs CT 2014 Public surveys of rose-ringed parakeets, *Psittacula krameri*, in the Durban Metropolitan area, South Africa. African Zoology, 49:283-289.

Picker M and Griffiths C 2011 Alien and Invasive Animals: A South African Perspective. Struik Nature, Cape Town.

Symes CT 2014 Founder populations and the current status of exotic parrots in South Africa. Ostrich 85:1-10.

From hydrologist to invasion biologist

Farai Tererai is the Deputy Director: Planning, Monitoring and Evaluation for the Working for Wetlands programme within the Department of Environmental Affairs (DEA). As a former hydrologist, Farai find himself now battling invasive alien species in our wetlands. *Quest* asked him a few questions about his career in invasion science.

What did you study?

All my studies were in the broad discipline of environmental science. My undergraduate and honours degrees were in Geography. I studied both physical and human geography, but I discovered that I was more interested in physical geography, which was the focus of my Masters degree. After working as a hydrologist for a few years I enrolled for a PhD at the DST-NRF (C•I•B) Centre of Excellence for Invasion Biology at Stellenbosch University.

What are your current duties?

The Working for Wetlands programme's mandate is to protect wetlands, to promote their wise use and rehabilitation of those wetlands that are degraded. My job involves the development of monitoring and evaluation systems, standards, and best practices, and providing planning support to our national projects.

Describe the career path that led you to your current position

During my work as a hydrologist I gained experience in various fields. I moved into monitoring and evaluation for a non-governmental organisation called GOAL-Ireland where I helped to develop and implement monitoring and evaluation systems for their development projects. After my PhD I worked for the Agricultural Research Council (ARC) on a short-term research contract modelling the potential distribution an invasive alien shrub, Crofton weed (*Ageratina adenophora*). I then joined the University of Cape Town as a postdoctoral research fellow in the African Climate and Development Initiative (ACDI) and then joined the Working for Wetlands Programme.

Farai Tererai. Image: Farai Tererai

What do you enjoy about your work?

I enjoy my position because it gives me the opportunity to do fieldwork, to examine the biological diversity of wetlands, and, more importantly, it allows me to pull together all my interests and previous experience – hydrology, riparian ecology, and invasion ecology.

What do you do to unwind?

I am fond of swimming and hike regularly. I am also a keen reader and enjoy spiritual books.

Getting the message across: The Iimbovane Outreach Project

Members of the Iimbovane project team teaching learners about ant morphology during classroom lessons. Image: Iimbovane Outreach Project

Learners attending Iimbovane learner workshops using microscopes to identify invertebrate samples. Image: Iimbovane Outreach Project

Learners attending Iimbovane learner workshops are introduced to invertebrates in different ecosystems. Here they are exploring aquatic invertebrates sampled from a nearby river. Image: Iimbovane Outreach Project

Dorette du Plessis and **Sophia Turner** tell us how ants are being used to teach learners about biodiversity

South Africa is globally renowned for its rich diversity of plant and animal life. Among the variety of ecosystems, South Africa has three internationally-recognised biodiversity hotspots: the Maputo-Pondoland Albany, the Fynbos and the Succulent Karoo biomes. For national and international scientists, the country provides many opportunities to study and observe different ecosystems. However, in a country where resources are scarce and science education is a privilege, we as scientists need to take science to the public.

Communicating science

Education, particularly environmental education, is essential if we want to protect biodiversity. While the scientific community has an understanding of the threats to biodiversity, the vast majority of South Africans are not familiar with biodiversity, biodiversity loss and the pressures on our ecosystems. If we want the public to support conservation efforts, we need to put initiatives in place to educate the public about the environment. The participation of the public in research activities is one way of increasing awareness of and appreciation for biodiversity. This is known as citizen science, and gives members of the public or non-scientists opportunities to get directly involved with scientific research and to help create knowledge.

School-ground science

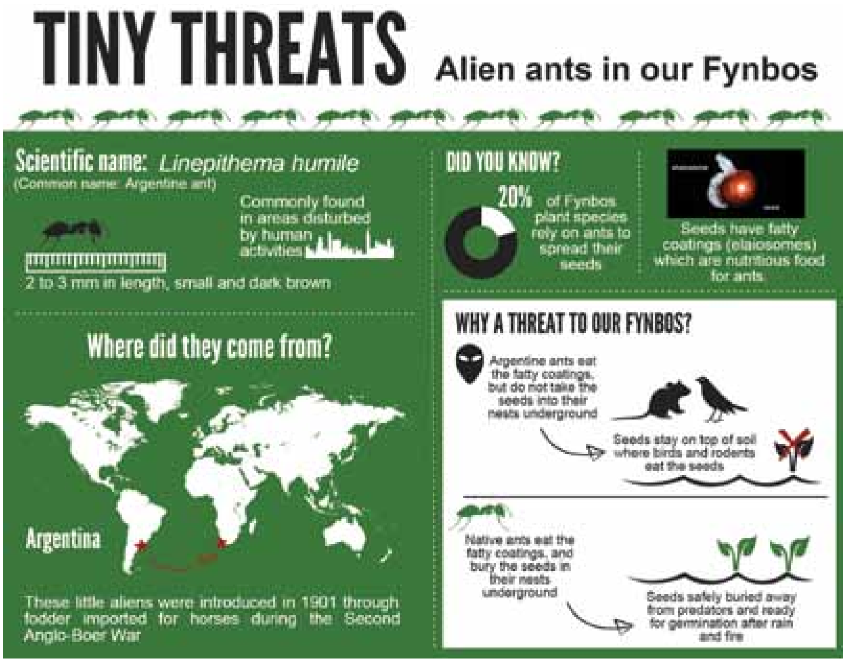
In 2006, the DST-NRF Centre of Excellence for Invasion Biology (C·I·B) decided to take biodiversity science to the people through the development of a science outreach project: The Iimbovane Outreach Project.

In essence, Iimbovane (meaning 'ants' in isiXhosa) takes biodiversity to schools in the Western Cape, particularly to schools in communities with little or no previous exposure to biodiversity science. The Iimbovane Outreach Project gives learners a chance to participate in a scientific project, the results of which are used to monitor changes in biodiversity, specifically ant diversity. Learners and educators from partnership schools receive training and tools to collect their own biodiversity data in the field and to use the data collected in the classroom. Learners collect ants at sampling areas located in modified and pristine areas. The modified areas are on the school grounds and show learners how the disturbance of a habitat affects ant communities when comparing their results to that of a pristine site, which is in a nearby nature reserve or national park. By using areas with different levels of disturbance and observing the effects on the ant diversity, learners get a better understanding of biodiversity and biodiversity loss.

The presence of the invasive alien Argentine ant (*Linepithema humile*) in ant communities on school grounds teaches learners about invasive alien species and their effects on local biodiversity (see Box 1 and infographic). The learners' experience with sampling and data collection is supported by lessons presented by the project team. These lessons align with the national Life Science curriculum focusing on biodiversity, critical thinking and scientific inquiry. The tools provided to the partnership schools include a high-quality microscope, a computer, a data projector, an ant reference collection, and an electronic guide to identify the ants.

Impact of science outreach

The value of science outreach projects such as Iimbovane, lies mainly in its contribution to science and biodiversity education at school level. The project uses an 'experiential learning' approach, which integrates the appreciation of biodiversity and the knowledge of how science works into the lives of learners who are not regularly exposed to science. Through the course of



Box 1. Tiny threats – alien ants in our fynbos

The Argentine ant (*Linepithema humile*) is a tiny black-brown ant from South America, which has already established itself in many parts of the world. This little invader usually occurs in areas that have been disturbed by human activities, for example, gardens, parking lots, etc. and is often present in many of the school grounds that the Iimbovane Outreach Project monitors.

So how do Argentine ants threaten our ecosystems? Many plant species in fynbos ecosystems rely on native or indigenous ants to spread their seeds (this is known as myrmechochory). An indigenous plant has an oily nutrient-rich layer around their seeds, which attracts ants. Indigenous ants take the seeds of these plants into their nests underground, where the seeds are protected from rodents and fires. Argentine ants, however, only eat the oily layer without taking the seeds underground, leaving the seeds exposed on the surface of the soil. (See more information in the article on ant invasions by Natasha Mothapo and Theresa Wossler.)

their participation, the learners get to experience all the steps of the scientific method. They ask questions about biodiversity, answer the questions through data they collect, and learn to interpret graphs and calculate diversity measures. Besides creating awareness of biodiversity, Iimbovane makes learners aware of conservation and wider environmental issues such as climate change and sustainable development. Learners also get to see what the job of a researcher, particularly a biologist, involves. After participating in Iimbovane, these learners bring biodiversity knowledge into their families and communities.

The impact of the Iimbovane Outreach Project on participating learners is evident.

'I really found the fieldwork informative because I saw what hard work it is to collect many different specimens and to do research. One of my favourite things during the week was the lab work and the microscope work. Our school does not have many microscopes and we do not get to work with them often, which is why it was so interesting to work with them last week. I also want to do forensic science and I love the possibility of just being in a lab and doing experiments all day. The week was very, very informative and I have learned new skills because I am not an outdoorsy person but I learned that I can do it and I can survive the elements and work under different types of conditions. I've also learned so many things in the lab like learning how to identify different insects and use the microscope to do so.' (Learner from Malibu High School)

'I've learnt that ants are very important to us even if they're small and that we must value biodiversity.' (Learner from Vusisizwe Secondary School)

'The workshop was extremely helpful - working with actual microscopes was great. The fieldwork was awesome, as it made me realise how precious those animals are and also how human activities can affect animals' habitats.' (Learner from Sarepta Secondary School) Q

Dorette du Plessis is the outreach manager of the C·I·B and manages the Iimbovane Outreach Project. Sophia Turner is the technical officer for the Iimbovane Outreach Project. She assists with schools outreach visits, field sampling and the processing of ant samples for the project.

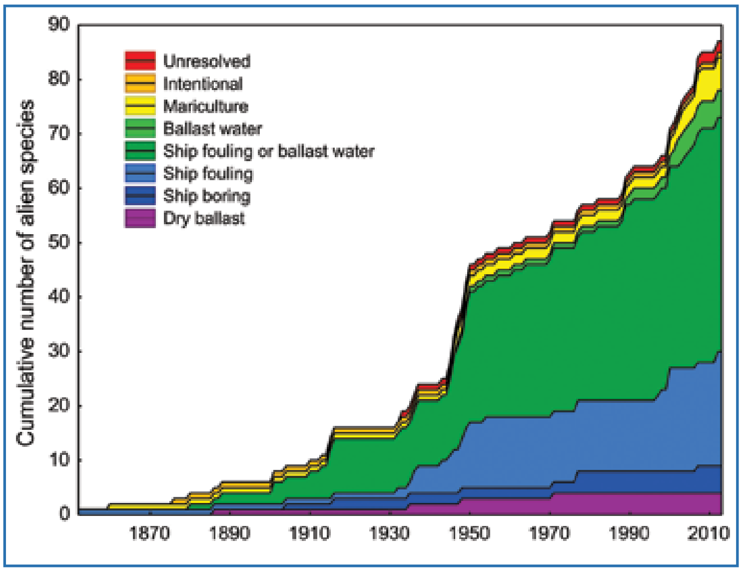
Learners planting pitfall traps to collect ants and conducting vegetation surveys as part of their participation in the Iimbovane Outreach Project.
Image: Iimbovane Outreach Project

The Iimbovane project team teaching learners how to draw graphs and interpret biodiversity data.
Image: Iimbovane Outreach Project

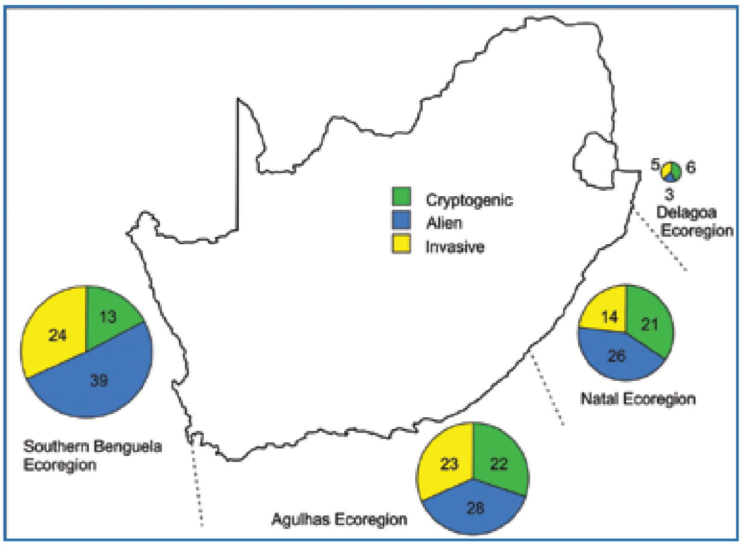
Marine invasions in South Africa: patterns and trends

Tammy Robinson looks at the way that marine organisms arrived in South Africa.

Marine organisms (mainly invertebrates and algae) have been moved around the globe, both intentionally and accidentally, since people first began navigating the seas. As such the mechanisms through which species are introduced (also called vectors) have changed as oceanic transport has developed through time. This has led to different types of species being introduced at different stages through history.



The number of marine alien species recorded in South African waters through time. Introductions are separated by the mechanism by which they are thought to have been introduced. Image: Tammy Robinson



The relative number of cryptogenic, alien and invasive species known from the four South African marine ecoregions. Note that the different size of the pies is indicative of differences in the total number of these species known from the different ecoregions. Image: Tammy Robinson

The early wooden-hulled vessels were home to a suite of specialised wood-boring species like shipworms and small crustaceans known as gribbles. These species not only damaged the ships themselves but also rapidly infested the wooden piers and pilings in the harbours that the ships visited. Because they caused damage and cost harbours and ship owners lots of money, these wood-borers were among the first alien species to be noticed by people. Of the 87 marine alien species known from South African shores today, five are thought to have been introduced in this way. It's interesting to note that we don't always know exactly when species were introduced and so scientists report the dates when alien species are first recognised. This is why the number of alien boring species known from our shores went from four to five in 2008 when a tiny protist (*Mirofolliculina limnoriae*) was recorded for the first time by Professor Charles Griffiths of the University of Cape Town and the Centre for Invasion Biology, despite all boring species most likely having arrived more than 100 years ago.

To adjust buoyancy and increase stability, early wooden ships often took on dry ballast. This solid material was usually taken from areas near harbours and consisted of coastal sand and rocks that were loaded into vessels at ports of departure. Intertidal animals were often attached to the ballast rocks, while coastal plants, seeds and insects were also accidentally loaded during the ballasting process. Many of these species survived in the damp ballast holds, only to be dumped onto new shorelines once the ships arrived at their destinations. The relatively low number of alien species introduced to South African waters by ship boring and solid ballast is indicative of the relatively few ships that called in our ports in early times when compared with the large number of modern vessels that use our harbours today.

As wooden vessels travelled slowly they were ideal habitats for a wide variety of fouling organisms. Fouling biota are species that normally live permanently attached to rocks (i.e. they are sessile) but are able to attach other hard substrata like the bottoms of ships. Typical fouling species include mussels, barnacles and tubeworms. Modern steel ships continue to carry fouling species, but as they are generally larger, travel more rapidly, and are painted with anti-fouling paint designed specifically to discourage fouling organisms, the numbers and types of fouling species have changed through time. It's notable that the number of species introduced to South Africa through fouling increased rapidly after the 1930s and then again after the early 2000s. While the first increase probably reflects increased shipping traffic the second probably reflects the banning of toxic anti-fouling paints. These paints were good at preventing fouling but proved to be so toxic that they were banned though an international convention. While this was good for preventing poisoning of coastal waters, it has meant that more fouling species are now being spread across the world's oceans.

Dry ballast was first replaced by water ballast in the late 1800s and was completely phased out by the 1950s. The conversion to ballast water saw a decline in dry ballast introductions but spurred a new wave of invasions. Also, ballast water is usually loaded in shallow port areas with lots of sediment. This results in sediment layers building up on the floor of the ballast tanks that can support a group of sand-burrowing species, such as clams and worms that would not previously have been translocated. Although many sessile alien organisms are thought to have arrived through ship fouling, it is often difficult to distinguish this vector from that of ballast water because sessile species can also be introduced as free swimming larvae. This pattern is reflected in most alien species known from South Africa being thought to have arrived by one of these two vectors.

Besides introducing alien species through different shipping-associated vectors, people sometimes intentionally introduce organisms. Most often such species are introduced for mariculture purposes, i.e. they are taken into a new region so that they can be farmed. Examples of mariculture species in South Africa include mussels, oysters and abalone. While some alien mariculture species remain confined to farms, in some cases they can escape and spread into surrounding natural habitats. Sometimes mariculture species can bring along 'hitchhikers'. These associated organisms can then spread from farms and go on to negatively impact the receiving environment. To date two species originally introduced for mariculture (i.e. the oyster *Crassostrea gigas* and the common carp *Cyprinus carpio*) have become invasive, while four associated species have established in our waters. This should warn us about the risks associated with culturing alien species.

Interesting patterns emerge when the numbers of cryptogenic (i.e. those species that can't definitively be called alien or indigenous because we don't know enough about where they naturally occur), invasive alien marine species are considered across the four marine ecoregions of our coast. It's notable that the highest number of invasive alien species are known from our cold west coast and decrease with an eastward movement. The reason for this pattern is unclear, but it could be the combined effect of the very long shipping history of the Southern Benguela ecoregion (i.e. west coast), the fact that mariculture is focused on this coast, and a higher sampling effort in this well-studied region. The relatively low number of cryptogenic species on the west coast might also reflect that this area has been very well studied by marine biologists. Here researchers have a good knowledge of indigenous species, enabling them to better distinguish between indigenous and alien organisms and so reducing the number of species designated as cryptogenic. The very low number of marine invasive alien species in the Delagoa ecoregion (the area just south of the Mozambique boarder) is thought to be due to the lack of any harbours and the small size of this ecoregion, but it must be acknowledged that this region is less well studied than the rest of the coast.

While the last 20 years has seen much progress in the field, marine invasion biology is in its infancy in South Africa. It is clear that there is much work that needs to be done and this offers exciting opportunities to future researchers. **Q**

Dr Tammy Robinson is a marine biologist in the Department of Botany and Zoology at Stellenbosch University and a core team member at the DST-NRF Centre of Excellence for Invasion Biology. Her research focuses on understanding the impacts of marine invasive species along the South African coast.

Unexpected outcomes from the invasion of the Mediterranean mussel *Mytilus galloprovincialis*

In the late 1970s a new species of mussel was noticed on the rocky shores of Saldanha Bay. Genetic studies confirmed that it was the alien mussel *Mytilus galloprovincialis* that originates from the Mediterranean Sea. As with many species, the vector of introduction is uncertain but is thought to be hull fouling or ballast water. This mussel rapidly spread along the coast, inducing changes as it went. Before this invasion rocky shores were open habitat, typified by the presence of large grazing *Scutellastra granularis* limpets. However, as the mussel spread it out-competed the limpets on most shores and coated the rocks in thick mussel beds. This change from bare rocks with limpets to complex mussel beds totally altered rocky communities, a clear negative impact associated with this invasion. At first glance we would expect the limpet populations to be threatened by this process, but the opposite happened. In fact, many more limpets are now present on these shores but they are much, much smaller, with each limpet living on its own small mussel. Another unexpected consequence of this invasion involves the African black oystercatcher *Haematopus moquini*. This endemic coastal bird was listed as endangered by the IUCN prior to the mussel invasion. However, the increase in mussels meant an increased food supply for these birds, enabling them to increase their population size to a point that they have been removed from the endangered species list. This example demonstrates that while invasions can have detrimental impacts on natural systems, they can sometimes have unexpected consequences too.

The invasive mussel Mytilus galloprovincialis *coats rocky shores from the border with Namibia to East London on the east coast.* Image: Sophia Turner

Managing invasions before they become widespread

John Wilson and **Sarah Davies** discuss the challenges.

*A) A small nest of the European paper wasp (*Polistes dominula*). The wasps have a painful sting, and frequently nest in people's houses. This invasion is causing havoc across the northern suburbs of Cape Town and in Stellenbosch, and the wasps are expanding their range rapidly. B) Two specialised wasp control teams have been established in Cape Town focusing on the removal of European paper wasp nests. In their first season they removed over 6 000 nests from private residences across the northern suburbs. Residents requiring assistance with wasp removal are urged to report a sighting on the City of Cape Town's Spotter Network, or send an email to invasive.species@capetown.gov.za. It is still too early to tell whether we can eradicate this species from South Africa, but immediate action can stop them becoming a permanent and painful fixture of South African summers.* Image: Ulrike Irlich, City of Cape Town (top: wasp nest) and Ntsikelelo Baba (bottom: wasp control team)

Invasive species can be managed in many different ways, but of course if we can prevent species being introduced, then there will be no invasions. Prevention can be achieved by banning imports of certain species, or ensuring that ships, cargo and passengers are inspected and cleaned before they arrive. Using laws and regulations in this way does, however, come at a cost to personal freedom. There has to be a good reason why someone is not allowed to keep a particular species of animal as a pet or grow a particular crop. Therefore for prevention to be effective, detailed scientific evidence is needed to support a decision to ban a species, and the risks posed must be publicised so that business owners and travellers know what to look for and why they should be careful. But even if regulations are based on sound evidence, are well publicised, and are respected, accidents will happen. Preventing future invasive species at the border is sometimes simply impractical or too costly, and of course it will not stop species that are already in the country from invading. Therefore, South Africa set up a national invasive alien vegetation clearing programme, the Working for Water Programme, which has been very successful in creating jobs removing invasive trees from water catchments (thereby protecting and restoring our precious water resources). The focus of the Working for Water Programme has naturally been on tackling existing problems. But there are many potential future invasive species out there. In 2010, South Africa had about 8 750 introduced plant species. Out of these, 660 were recorded as naturalised and 198 were listed as invasive in the National Environmental Management: Biodiversity Act. Only 64 were being actively controlled or managed in some way by Working for Water. Most introduced plant species will never cause significant problems, but even if a small fraction does, the costs to the country will be massive. This is why it is important to try to deal with invasions before they become widespread.

Contingency planning

One of the most important elements in the pro-active management of biological invasions is contingency planning. This involves setting out clear plans and strategies that are to be implemented when a particular event occurs. For example, all the major ports in South Africa have an oil-spill contingency plan so that as soon as a spill occurs, the plan goes into action to stop the flow of oil, contain the spread and begin cleaning it up. In the same way, contingency plans can be made for invasive organisms. Rather than waiting until an invasive species is widespread and causing massive impacts before management starts, a management programme (based on the contingency plans) can be immediately implemented once a species is detected in the country. Early Detection and Rapid Response (EDRR) is part of this process. Resources are allocated to detecting and identifying particular species or

problems before they become widespread. This can be done by people who are specially trained to look for particular invaders, or by engaging with the wider public through publicity campaigns and hot-lines like iSpot, where the public is involved in reporting and learning about new species they see growing or living around them (http://www.ispotnature.org/communities/southern-africa). The 'rapid response' part of EDRR involves having enough skilled people and resources to immediately clear, capture or contain the alien invasive organisms once they have been detected. For a South African example see the City of Cape Town's EDRR unit http://www.capetowninvasives.org.za/edrr.

In cases where a species has a restricted distribution it might be possible to clear or remove every single individual (including all seeds and/or eggs) from South Africa. If we can prevent such species from being introduced again in future, i.e. eradicate them, then there will be one less invasive species to worry about. A good example of eradication is the removal of feral cats from South Africa's Marion Island (Marion Island is part of the Prince Edward Islands group and lies 1 400 km south of Port Elizabeth in the Southern Ocean). For many other examples of eradication, go to http://diise.islandconservation.org/.

Detecting new invasions

A lot of work and money is needed to detect and document new invasions, provide reliable assessments of species already in the country or that might be introduced, and coordinate management between the various people involved. To achieve this, the South African National Biodiversity Institute (SANBI), through funding from the Department of Environmental Affairs, set up an Invasive Species Programme in 2008 (see http://www.sanbi.org/biodiversity-science/state-biodiversity/biodiversity-monitoring-assessment/invasive-aliens-early-det, for more details read http://dx.doi.org/10.1590/sajs.2013/20120111). The aim of the Invasive Species Programme is to make

*Kudzu vine (*Pueraria montana*), the light green plant with the large leaves shown here growing over and covering several trees and bushes in Mpumalanga, is considered one of the worst invasive species in the USA. It is originally from Asia and was introduced to South Africa in the 1920s to a single farm. Thankfully, it hasn't yet spread widely and is currently restricted to a few small populations in a couple of provinces, but it is starting to move. Kudzu vine poses a major threat to South Africa's biodiversity and infrastructure, and as such, it has been declared a national eradication target. It will take time and persistence to remove all the plants, but SANBI's Invasive Species Programme is committed to ensuring that the on-going environmental devastation caused by kudzu vine in the southern states of the USA is not replicated in southern Africa.*
Image: Dr Sjirk Geerts, Cape Peninsula University of Technology

sure that we understand and manage not just the current widespread invaders but also species that might be future threats. If we can stop the next Port Jackson willow or lantana before they become widespread then we will have made a major impact. And if we can be persistent and consistent enough to eradicate such species from South Africa, then we will have permanently reduced the size of the future invasion problem.

In summary, while much can be done to prevent new introductions, it is impossible to stop all invasions from happening, and many future invaders have probably already been introduced. But if we are pro-active in managing species before they become widespread we can limit the next wave of invasions. The future might not be invasive free, but it is certainly looking much brighter than the past! Q

John Wilson is the science lead for the South African National Biodiversity Institute's Invasive Species Programme. He is interested in efforts to improve the pro-active management of biological invasions. He is based at the Centre for Invasion Biology, Stellenbosch University.

Sarah Davies works with the C•I•B team at Stellenbosch University. She is interested in all aspects of invasion biology, their social consequences and how people can manage them. She also works on frogs that are expanding their distributions in South Africa.

Ailanthus altissima, commonly known as the tree of heaven, is a deciduous tree that originates from China. Introduced as an attractive ornamental tree, the species has been planted throughout South Africa, and they have spread from these plantings in an uncontrolled manner. Image: Ulrike Irlich

Cities invaded

Invasive species thrive in the hustle and bustle of cities. **Mirijam Gaertner**, **Ulrike Irlich**, **Vernon Visser**, **Gareth Walker** and **Phil McLean** examine the issues.

Why are invasive non-native species abundant in cities?

People collect non-native species for a range of reasons – some are serious plant or animal collectors, while others just like a variety of plants in their gardens. Cities are by definition places where large numbers of people live in close proximity, and they tend to accumulate a variety of new species in large numbers, and this (large numbers of people, a proportion of who collect a large variety of non-native species in a relatively small area) explains why such species are abundant in cities. The growth in the number and size of cities worldwide has also contributed to the problem and South African cities are no exception.

Cape Town is an example of a city where invasive species are a large and growing problem. Cape Town has a population of 3.8 million people, and it is growing more rapidly than any other city in southern Africa. Cape Town is also a focal point of the national economy and international tourism, providing avenues and opportunities for the introduction and spread of non-native species within the city and surrounding landscapes. The problems in Cape Town are particularly acute, because it is located in the Cape Floristic Region (an area of extremely high biodiversity). The city's boundaries contain 18 nature reserves, including Table Mountain National Park. Thus the risk posed to native biodiversity by non-native species that escape is extremely high.

What's the issue? Why bother?

Invasive species can displace native species and, in the worst-case scenario, completely dominate areas. From their strongholds within city environments invasive species can spread into surrounding natural areas, where they can pose significant threats to native species. Almost two-thirds of known invasive alien plants have originated from gardens. Non-native animals kept as pets (e.g. cats and many bird and fish species) can establish feral populations and become invasive if they manage to escape or are deliberately released. Escaped non-native fish and domestic cats can have significant impacts on wildlife.

In Cape Town, there are a number of examples that illustrate these problems. Pine trees (*Pinus* species), established to provide timber and to 'improve' the bare mountain slopes, and Australian wattles (*Acacia* species), planted mainly for dune stabilisation, have spread widely into natural vegetation. Invasive pines and wattles pose serious risks to humans because they increase the severity of wild fires near residential areas (see van Wilgen this issue). Another concern is that criminals use dense wattle stands to hide in. Another non-native species, the tree of heaven (*Ailanthus altissima*, planted as an ornamental street tree) is highly invasive in the urban environment, and it damages buildings and roads.

Floating water weeds (such as water hyacinth, *Eichhornia*

*Left: Non-native eucalypt species are seen as 'culturally native' in parts of South Africa. Right top: Non-native mallard ducks have established feral populations across Cape Town and are now interbreeding with indigenous ducks. Right middle: Invasive pine trees provide shade and are regarded by some people as more attractive than fynbos shrublands but they are well known for replacing native fynbos species. Right bottom: Common myna (*Acridotheres tristis*), a highly invasive bird species that is considered a serious threat to native bird species.* Image: Sophia Turner, Ulrike Irlich, Lisel McGregor, Dick Daniels (http://carolinabirds.org/)

crassipes and parrot's feather, *Myriophyllum aquaticum*) were introduced as decorative pond plants, and have spread to block waterways and negatively affect water quality. Some non-native species can also cause serious health problems. Pampas grass (*Cortaderia selloana*, a popular garden plant) and beefwood (*Casuarina equisetifolia*, widely-used as a windbreak and for shade) can both cause allergic reactions, especially to people susceptible to hay fever and asthma. Syringa (*Melia azedarach*), oleander (*Nerium oleander*) and thorn apples (*Datura ferox* and *D. stramonium*) all have potentially lethal parts (berries, leaves or seeds). In addition to plants, non-native animals such as the European paper wasp (*Polistes dominula*) and the German wasp (*Vespula germanica*) can also be problematic. These two aggressive wasp species are a serious nuisance, as well as a potential health hazard for people who are allergic to them. Another urban invader is the house crow, which thrives in an urban environment, living on refuse and becoming a nuisance and health hazard.

So let's get rid of them!

Unfortunately it's not so easy, as some species pose conflicts.

People often have strongly differing views when it comes to non-native species, and these divergent views sometimes lead to conflicts. Trees are particularly controversial, as many citizens regard the trees as attractive and ecologically beneficial, complicating the efforts to control those that are invasive. People can also establish cultural connections with non-native trees. Because they are so long-lived, non-native tress can become associated with a place and be regarded as culturally important by some city inhabitants (e.g. non-native eucalypt species are seen as 'culturally native' in parts of South Africa). Examples include Jacaranda trees (*Jacaranda mimosa*) in Pretoria and English oaks (*Quercus robur*) in Stellenbosch. Some harmful species are also simultaneously beneficial to certain groups of people or industries. For example, invasive pine trees are well known for replacing native fynbos species but they also provide shade and timber, and are regarded by some people as more attractive than fynbos shrublands. Non-native mallard ducks are another example. They were introduced via the pet trade and have established feral populations across Cape Town and now interbreed with indigenous ducks, contaminating the gene pool of these native species. People are very fond of the ducks and it is common for families to spend time at ponds, feeding these ducks. Of particular concern is the interbreeding with the indigenous yellow-billed duck. In both the cases of alien trees and ducks in the city of Cape Town, control programmes have been seriously complicated by large numbers of people expressing strong opposition to the control.

NEM:BA alien and invasive species regulations

In October 2014 the Alien and Invasive Species regulations of the National Environmental Management: Biodiversity Act (NEM:BA) became law. These regulations are aimed at preventing the introduction and further spread of invasive and potentially invasive species. In practice the regulations consist of a list of invasive organisms (plants, animals and microbes) and a list of species prohibited from being imported into the country. The list of invasive organisms groups species into four different categories, with specific management and control requirements for each category (Table 1). All landowners (private, business and government) in South Africa are required to comply with these requirements under the Act. The City of Cape Town, as a major landowner within the municipal boundaries of Cape Town, is no exception to this and is already in the process of implementing the NEM:BA regulations. As a first step the City needs to know what listed species are on municipal land. To this end the City is using its spotter network (on www.capetowninvasives.org.za) to record data on listed non-native species. This distribution information is then being used to support control operations aimed at (1) eradicating all category 1a species, and (2) developing a management plan for future invasive species control. The presence and density of invasive species that occur on all City-owned land is being mapped and appropriate control measures put in place to reduce the impact of such invasive species. The City of Cape Town is leading the way in this regard and it is hoped that these experiences can be used to develop guidelines for other municipalities to become compliant with the new regulations.

For more information on the NEM:BA AIS regulations visit: http://www.invasives.org.za/legislation.html

Table 1: Categories used to define legal requirements for listed invasive organisms in South Africa

Categories	Legal requirements
Category 1a	Invasive species that must be eradicated if possible (or controlled if not). Trade, planting or propagation is prohibited.
Category 1b	Invasive species that must be controlled and, where possible, eradicated. Trade, planting or propagation is prohibited.
Category 2	Invasive and potentially invasive species for which a permit is required to carry out a restricted activity. This category includes commercially important species such as pines, wattles and gum trees.
Category 3	Invasive species that need not be controlled or removed (sometimes just for particular areas or provinces). However, no further planting, propagation or trade is permitted.

The way forward: management and policies

All landowners, including municipalities such as the City of Cape Town, are obligated by South African environmental legislation (NEM:BA) to manage certain invasive species that are listed under the Act. This is especially important in Cape Town, given the juxtaposition of protected and urban areas (Box).

Cape Town's invasive species control programmes dates back to the 1940s. In 2008 the City established an Invasive Species Management Unit, with an annual budget of R1 million and a dedicated team. Since then, the programme has grown to include areas managed by multiple departments within the city. The City now manages 55 teams, averaging 10 workers each, drawn from impoverished communities. These teams are tasked with the control of invasive plants and animals in terrestrial and aquatic ecosystems. They are also responsible for the early detection of emerging invasive species and implementing control measures as quickly as possible to control and if possible eradicate them. Although originally funded by the City's ratepayers, additional and substantial funding has been obtained from the Working for Water programme and other sources, increasing the available funds to more than R20 million in 2014. Nature reserves are given first priority, followed by areas where invasive plants are a fire hazard or provide shelter for criminals and areas in which there are small populations of an invasive species which can be easily controlled.

Another approach being piloted by the City is the promotion of indigenous plant species over non-native ones. This approach is undertaken in tandem with alien species control operations so that people have viable alternatives for providing variety in their gardens, shade or screening. This positive aspect of the city's operations also helps to reduce any negative perceptions associated with control operations.

How can you get involved?

The City of Cape Town has several organisations that provide opportunities for you to get involved. You can join your local 'Friends' or NGO groups, generally associated with nearby nature reserves or conservation areas, to assist with indigenous plant monitoring and emerging weed detection. Alternatively, you can join your local hack group to assist with invasive plant clearing. You can also log records of invasive species on iSpot (www.ispotnature.org) or become a member of Cape Town's Spotter Network on www.capetowninvasives.org.za. You can join the Facebook page Cape Town Invasive Species for more information about invasive species in and around Cape Town. You can also take active measures like not planting invasive species in your garden, or being more careful about how you dump garden waste, so as not to spread unwanted species. Other cities in South Africa have similar initiatives (see for example http://www.durbaninvasives.org.za/). Q

Mirijam Gaertner is a restoration ecologist. Her research focuses on impacts and legacies of alien plant invasions and resilience of native ecosystems. She is specifically interested in the impacts of invasive alien plant species on fynbos ecosystems and has tested different restoration strategies aiming to both reduce the abundance of alien species and re-introduce native species. Since 2013 Mirijam has been coordinating the research component of Cape Town's Invasive Species Unit.

Ulrike Irlich is the Programme Manager for Monitoring and Evaluation in the Invasive Species Unit of the City of Cape Town. As part of the programme she also manages emerging weeds and target species programmes. She is also studying for a PhD, focusing on urban invasions and the management of invasive species in an urban environment.

Vernon Visser is a postdoctoral researcher at the Centre for Invasion Biology, Stellenbosch University. He is currently working on a project together with Stellenbosch Municipality and Stellenbosch University to help these two organisations become compliant with the new NEM:BA Alien and Invasive Species regulations.

Gareth Walker is a conservation ecologist with a special interest in invasion biology. He is currently enrolled at Stellenbosch University as a master's student focusing on the urban invasive species Ailanthus altissima. *His main focus includes the accurate mapping of* A. altissima *throughout South Africa and specifically in Cape Town as well as the implementation of successful management plans promoting the eradication of the species.*

Phil McLean is an invasive species specialist with extensive knowledge on the identification and treatment of invasive plants in South Africa. He is currently engaged with his master's degree through the C•I•B. at Stellenbosch University looking at the challenges faced by smaller municipalities in complying with their NEM:BA requirements.

Dave Richardson. Image: Jaco le Roux

From forestry to invasion science

Dave Richardson is currently Director of the DST-NRF Centre for Invasion Biology. *Quest* asked him about his career.

Where did you go to university and what degrees/qualifications do you have?

I have a BSc in Forest Science and Nature Conservation from Stellenbosch University and Masters and PhD degrees in Botany from the University of Cape Town.

Describe the career path that led you to your current role. Where have you worked before this position?

During my final year of forestry studies at Stellenbosch University I applied for a position as researcher at the Jonkershoek Forestry Research Centre. I worked there for 10 years, during which time I completed my Masters and PhD degrees on the work I was doing on the ecology of tree invasions in fynbos. I then worked for 13 years at the University of Cape Town at the Institute for Plant Conservation. In 2004 I moved to Stellenbosch University to be part of the DST-NRF Centre of Excellence for Invasion Biology (C•I•B). In 2011 I was appointed Director of the C•I•B.

What are your current duties?

As Director of the C•I•B, I'm responsible for managing a team of researchers and administrative staff at the Stellenbosch HQ, and for the functioning and performance of the national C•I•B operation which involves researchers and students at many South African universities. I am also a Professor in the Department of Botany and Zoology at Stellenbosch University.

Tell us about your interest in invasion science. Why did you choose to follow a career in invasion science?

I got involved in invasion science by accident. While studying forestry I envisaged going into a career in commercial forestry. A job opportunity at Jonkershoek, to work on invasive plants in catchments, provided a good excuse to keep living in Stellenbosch after my studies. The start of my job at Jonkershoek fortuitously coincided with the launch of an international programme on biological invasions in which South Africa played an important part. My work on invasive trees in fynbos fed into this programme and I soon became fascinated with the new field of invasion ecology.

Why is research such as yours important for South Africa? What is important about your work?

Invasive species are trashing South African ecosystems at an alarming rate. Trashed ecosystems cannot deliver the services such as clean water and healthy soils, that we need to build a prosperous country. We need innovative ways of dealing with the massive problems we have now and to reduce the likelihood of new invaders taking hold. I believe that the C•I•B is making a real difference in these areas.

What were the skills you had to have to do the work your work?

The work for my Masters and PhD involved the population ecology of invasive tree species, that is, how the tree populations grow or shrink over time and what causes these changes. This involved combining methods in plant ecology, remote sensing (using satellite imagery and aerial photographs to examine and reconstruct plant invasions) and computer modelling (to forecast population changes after many generations). These skills have served me well in my career, but I've needed to learn many new skills and have needed to collaborate with colleagues in many different disciplines to deal with the growing challenges involved in understanding and managing invasions. I've also had to learn about managing a large research programme – one of South Africa's national Centres of Excellence – which seeks to focus and strengthen national skills and resources to deal with an issue of growing importance to the country.

Not many youngsters look at science as a career path, what led you down this path? What attracted you to it?

I love the challenge of tackling complex problems using the tools and methods of science – and problems don't come much more complex than those relating to biological invasions.

What do you enjoy most about your work; what makes it all worthwhile?

Unravelling the many factors that determine why some species are so successful as invaders is like building a complex jigsaw puzzle. I love the detective work that is required in the many studies that I am involved in. I have collaborated with hundreds of colleagues from all corners of the world and have many great friends as part of my work. I really enjoy the challenges involved in managing a large team of people with diverse skills and backgrounds.

The most important lessons you've learnt during my career are?

Opportunities arise in unexpected places and at unexpected times. Always be ready to seize these.

What interests/hobbies do you have?

I love music, reading, hiking, natural history and enjoying fine food and wine with family and friends.

Top: Pines are often introduced as a source of timber in South Africa, but they also need a lot of water, increase fire hazards, and harm the native vegetation.

Risk assessment
a key tool for reducing the incidence and impacts of invasions

Sabrina Kumschick takes a look at the interface between science and practice in the biology of invasions.

Most alien species are introduced to a new area because they provide some sort of benefit for at least part of society. Mammals, reptiles and birds are often introduced as pets, attractive plants as garden plants, and trees to provide building material. Alien species are also crucial for the survival of humankind, considering that most crops and livestock used worldwide are not native to most parts of the planet where they are grown. However, we need to keep in mind that some alien species are not beneficial to the environment and economy where they are introduced, and in some cases the damage they do is greater than the benefit they were introduced for.

For example, the giant African landsnail (*Achatina fulica*), originally occurred on the coast of East Africa, but as it is a good source of protein, it was introduced around the world as a food source. However some snails escaped from their breeding farms and are now living in the wild and causing severe problems in the ecosystems where they occur. For example, they can be hazardous to drivers, causing cars to skid. They also alter soil properties due to the composition of their shells, which can lead to different plants growing where they are present. Potentially even worse, however, is another snail, the rosy wolf snail (*Euglandina rosea*) which was introduced to control its 'big brother'. It is highly predatory and, like many humans, eats snails. But of course it doesn't mind whether the snail it eats is a giant African landsnail or an indigenous snail. It eats whatever snail it can find and has led to the extinction of several native snails on the Pacific islands. Unfortunately, there is clear evidence that it effectively controls populations of the giant African land snail.

The giant African land snail – not only used as a food source, but also popular as pets. Image: Sabrina Kumschick

Using risk assessment

Assessing the risk of an alien species becoming problematic is a way to prevent such damage from occurring. Risk assessment can advise on which species to stop before problems become too big to handle. If people had carefully studied the generalist diet of the rosy wolf snail before introducing it, it would have been obvious that its introduction might lead to severe negative consequences for the endemic local snails. Risk assessment is important for predicting which species may become invasive and cause problems for humans or local biodiversity.

Risk assessment tools look at a specific event that is considered to be risky or uncertain, for example the rosy wolf snail (or any other alien species) becoming a problematic invader, and assess the likelihood of such event occurring, and the consequences should they occur.

Let's take the hypothetical example of a polar bear being introduced to South Africa: The likelihood of a polar bear establishing and thriving in South Africa is low. Polar bears live in Arctic conditions. Most of South Africa is warm and temperate. So the chance of the polar bear becoming invasive in South Africa is close to zero. However, if you look at the consequences if the polar bear were to become established in South Africa, namely the negative impacts

A kangaroo is better adapted to the South African climate than a polar bear, but the consequences for local fauna and humans could be huge due to the polar bear's appetite, should a polar bear be introduced and establish. All these factors need to be taken into account when determining the risk of these species becoming problematic invaders in South Africa. Image: Wikimedia Commons

the polar bear could cause, the picture changes. Being top predators, they could have a huge impact on our fauna, especially on our seals, and of course on humans.

Protocols for risk assessment have been developed to help separate benign from the harmful alien species *before* they become problematic. For example, when considering importing new alien species, risk assessments would recommend that the benign species be allowed in, whereas the potentially harmful ones would be prohibited.

The risk assessment tools used most often rely on scoring systems that ask a set of questions linked with the likelihood of the species becoming invasive and the consequences if it does. The questions that are asked are about the species' behaviour in other areas where it has been introduced (its 'invasion history'), the species' biological and ecological features, the suitability of the new environment and climate into which the species might be introduced, and any undesirable characteristics that the species might have – such as toxicity for plants. Each answer is linked to a score that reflects how much the given factor is thought to influence a species' success in its new range. The polar bear would, for example, get a low risk score in a South African context because of the poor match between the climatic features of its native range and those that exist in South Africa.

However, if a similar exercise were carried out for a kangaroo, for example, this species would get a high score for suitable climate, since Australia has a very similar climate to South Africa.

The sum of scores leads to a decision on a species' risk – if the score is higher than a certain threshold, a species is considered as potentially harmful and rejected, if it is lower than the threshold defined it is probably safe for import and could be allowed in (sometimes subject to certain conditions).

Risk assessment methods developed to date are not without flaws, and incorrect decisions do occur. The nature of the incorrect decision influences the costs associated with it, and which stakeholders are involved (see the box). Apart from a few incorrect decisions, risk assessment tools have proved to be hugely beneficial in other countries. Preventing the introduction and spread of harmful invaders through risk assessments would protect South Africa's native species from the negative effects of new harmful alien species. Furthermore, they can save a lot of money as management actions are much more effective and cheaper when the alien species is tackled before it has become widespread and caused substantial damage. **Q**

Sabrina Kumschick is a core team member at the Centre for Invasion Biology and works on risk assessments of alien species. She is interested in what makes some species more problematic than others and how to predict impact.

Examples of questions used to assess the risk of alien plants

The questions are taken from the Australian Weed Risk Assessment scheme, one of the most widely used schemes applied to alien plants.

- Has the species become naturalised where grown?
- Is it a domesticated plant, which has been introduced from another region, and is it growing, reproducing and maintaining itself in the introduced range?
- Broad climate suitability (environmental versatility) – Score 'yes' for this question if the species is known to grow in a broad range of climate types. Use the map of climatic regions available in a comprehensive atlas.
- Produces spines, thorns or burrs – the plant possesses a structure known to cause fouling, discomfort or pain to animals or man. If it is thornless subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a thorny form.
- Unpalatable to grazing animals – consider the plant with respect to areas where the plant has the potential to grow and if the herbivores present could keep it under control. This feature may be found at any stage of the lifecycle of the plant and/or over periods of the growing season.
- Well controlled by herbicides – documented evidence is required for effective chemical control of the plant. This control must be acceptable in the situations in which it is likely to be found. The chemical management should be safe for other desirable plants that are likely to be present. This information will be poorly documented for most non-agricultural plants.

False negatives and false positives in risk assessment

False positives

Generally, a false positive occurs when something is shown to be true or positive when it is actually false or negative – positive in our case means that an alien species is harmful. False positives will lead to alien species being managed or rejected for entry when they pose little risk, leading to a loss in income or undue restriction regarding its use. For example, if a beautiful, orange flowering tree species is not allowed to be imported even if it is actually safe, the nursery industry would suffer from losing out on potential sales of the species.

False negatives

A false negative occurs when something is shown to be negative but is actually positive. False negatives in the case of alien species risk assessments will lead to a species not being managed or being accepted for entry when it poses a substantial risk. This leads to new invasions and negative impacts, which can result in high costs caused by the alien species. A hypothetical rainbow-coloured daisy may not be identified as posing a high risk when evaluated and could be accepted for importation and sold in nurseries. It may, however, then escape from gardens and invade natural areas, supressing native species. In this case, the nursery industry would have made profits on its sales, while the costs of subsequent invasions and impacts caused by the species would be borne by society at large.

It is therefore important when developing risk assessments and thresholds for import to keep false negatives to a minimum, while false positives do not usually have a large effect.

Stakeholder involvement: Making strategies workable

Involving stakeholders in formulating workable strategies for managing invasive species. **Ana Novoa** and **Ross Shackleton** share lessons from two very different plant groups – cacti and mesquite.

American Giant: One of the spineless cultivars of Opuntia ficus-indica *(cactus pear).* Image: A Novoa

Open discussions between stakeholders who benefit from cactus species in South Africa and stakeholders who want to reduce their negative impacts. Image: A Novoa

Humans have moved species to areas outside their native ranges for millennia, and alien species are now common components of most ecosystems. Agriculture, forestry, pet and horticulture trade in most parts of the world are largely based on alien species. Some examples of valuable alien species that have been introduced globally are tomatoes, native to the South American Andes, chickens from Asia, and roses which are native to Asia, Europe, North America and northwest Africa.

Only a very small proportion of alien species become invasive. These invasive species have major ecological and socioeconomic impacts in their new areas. For example, famine weed (*Parthenium hysterophorus*), native to southern United States, has been accidentally introduced to South Africa and it has become an environmental and agricultural pest. It grows on all soil types and in a wide range of habitats. Famine weed suppresses native vegetation and crop yields and contaminates crop seed, meat from livestock that has eaten the weed is not fit for consumption, and regular contact with the plant produces allergic dermatitis and asthma in humans. Another example of a harmful invasive species is the Asian fruit fly. The Asian fruit fly was accidentally introduced to Africa around 2003, and soon after the first introductions, it spread rapidly throughout the continent, carried in infested fruits. Currently, it is the world's worst destructive pest of fruit and vegetables, affecting the livelihoods of many farmers.

Costs, benefits and conflicts of interest

Despite the previously mentioned examples of 'desirable' and 'undesirable' alien species there are many that involve both benefits and costs. These can raise substantial conflicts of interests around their use and management. For example, alien conifers were introduced from Europe and North America over 300 years ago and have been widely planted in South Africa. These trees bring many benefits to the South African economy by providing timber and jobs. People also like them for aesthetic reasons. However, these trees cause several unintended problems: dense stands of invasive trees reduce water supply, grazing potential and lead to the loss of South Africa's natural habitats and species. These wide ranges of positive and negative impacts have created a conflict of interests between foresters (who make money from plantations), the public (who like the trees for aesthetic reasons, or whose land is negatively affected by them) and conservationists (who want to conserve biodiversity).

As a consequence of these kinds of conflicts, there has been increasing interest in assessing the perceptions of different stakeholders involved with alien species. However, in most cases there is still a lack of collaboration between different parties, such as scientific researchers, the commercial sector (e.g. nurseries, pet shops, landscapers, and farmers), invasive species managers, policy makers and the public. This can result in the failure to develop and implement successful management strategies for invasive species.

In this article we explore approaches for facilitating interactions between stakeholders involved with alien species. We use the family Cactaceae (cacti) and the genus *Prosopis* (mesquite) in South Africa as study cases to find solutions for this problem.

Cacti

The problem

Cactaceae is a family of 1919 plant species that are almost all native to the Americas. The first alien cactus species arrived in South Africa early in the 18th century. Over the following two centuries many species were introduced to produce fruit for human consumption and fodder for livestock and are still being used for this today. Over the last 60 years, hundreds of new species were introduced to South Africa, almost exclusively for ornamental purposes. Food-science researchers (specialising in a wide range of crops) are also looking to develop the agro-industry around cactus in South Africa. Their fruit can be processed into jams, marmalades, juices, syrups, and cladodes (the fleshy leaf-like structures) can be consumed as vegetables, pickles and flour.

However, many of the introduced species have naturalised and 35 cactus species are currently listed by the government as invasive in South Africa. The negative impacts of invasive

Dense stands of Prosopis *species (mesquite) fringe water courses in many parts of the arid interior of South Africa.* Image: R Shackleton

A survey was done across the invasive range of mesquite in South Africa to determine the perceptions of stakeholders regarding the benefits and costs associated with the species. Image: R Shackleton

cacti on South African biodiversity, ecosystem functioning, resource availability, national economy and human health have been recognised for well over a century. These benefits and costs have resulted in numerous conflicts.

The solution

To address the conflicts surrounding cacti in South Africa, we identified relevant stakeholders (nursery owners, farmers, land managers, scientists) and assessed their perceptions through questionnaires. We found that those stakeholders who were positively affected by cactus species were not aware of some of the negative environmental and socio-economic impacts of cactus invasions, while those stakeholders who wanted to reduce the negative impacts of cactus species in South Africa were not fully aware of their positive impacts.

We then tried to enhance the interaction between stakeholder groups through open dialogue and discussions in a one-day workshop organised by the Centre for Invasion Biology. Surprisingly, one session of interaction and dialogue between stakeholders was enough to increase

Cactus pear vs prickly pear

The fruit of the prickly pear. Image: Wikimedia Commons

The prickly pear (*Opuntia ficus-indica*) was introduced from Mexico to South Africa early in the 18th century. Since then, many stakeholders benefitted from the species: households sell prickly pear jam in local markets, traditional medicines are used both domestically and sold, fruits are a source of income and nutrition for many local communities, and it is used as an important agro-forestry species for fruit consumption and animal fodder. However, in the 1980s prickly pear became invasive, displacing native vegetation and crops, negatively affecting livestock and humans (injured by its spines), and creating a conflict of interests between positively affected stakeholders and those stakeholders who wanted to reduce its negative impacts. This conflict of interests was soon addressed, thanks to the existence of a non-invasive alternative: the cactus pear. In the 20th century, an American nursery owner (Luther Burbank) developed spineless cultivars of *Opuntia ficus-indica*. Due to their lack of spines, these cultivars (known as cactus pear) are not invasive. Therefore, stakeholders positively affected by the prickly pear, could use a non-invasive alternative, the cactus pear. Nowadays, cactus pear is being widely used in South Africa and all over the world as an important agro-industrial crop. However, more awareness and transfer of knowledge are needed to stop the use of spiny *Opuntia* species in South Africa.

their 'cactus knowledge' and improve the willingness of all stakeholders to collaborate on cactus management actions.

After this first interaction, we arranged open discussions to help in identifying key barriers to cactus management in South Africa. Some of the identified barriers (e.g. 'lack of funding' or 'lack of prioritisation of control efforts') are common to all invasive species management. However, other barriers come from particular parties' interest, such as 'some invaded areas are not easy to access' identified by managers from South African National Parks (SANParks). It was only by involving all parties in the workshop that we could identify all the barriers to successful management. These discussions also allowed us to openly discuss potential solutions for each barrier and develop regulations to guide the management of harmful invasive cacti. As a result, management objectives were broadly supported by all stakeholders.

Mesquite

The problem

Prosopis species (mesquite) were introduced to South Africa from the Americas to provide fire wood, fodder and shade to farmers and rural communities in arid parts of the country. These trees still provide these benefits, but with time and increased invasion in the mid-1900s, numerous negative impacts on humans and the environment were observed. These include: reduced water supply and impacts on natural grazing lands, loss of biodiversity, decreased property values, and breakage of infrastructure due to the strong roots. The wide range of positive and negative effects of mesquite stands had led to conflicts between those who want to use and promote mesquite trees (e.g. some farmers and NGOs) and those who want to reduce the negative impacts of mesquite (some farmers and conservation managers). But before alternative management approaches can be adopted (biological control) it was important to get a better understanding of stakeholder perceptions, wants and needs.

The solution

As explained in the previous example, we assessed the perceptions of stakeholders to get a better understanding of the issues regarding mesquite in South Africa. We found that some groups use and benefit from mesquite (farmers use the trees to provide fodder while poor communities harvest trees for fuel wood). However, other groups are predominantly negatively impacted by it (e.g. urban dwellers). People from urban areas (suffering impacts on their infrastructure and aesthetics) face different impacts as a result of mesquite invasions to people in rural areas (who experience loss of land). We also found that for all stakeholders the costs of mesquite were greater than the benefits, warranting the need for improved management.

Through workshops with different stakeholders, we are getting a better understanding of the factors that prevent effective management of mesquite. This work has highlighted the fact that different groups are facing different problems and have different perspectives on what is needed to manage mesquite. For example, Working for Water Programme managers highlighted the high expense of clearing mesquite and the fact that government departments are not working together as the biggest barriers to effective management, whereas researchers suggested that contrasting interests, lack of knowledge and poor prioritisation are the major issues.

What did we learn from *Prosopis* and Cactaceae?

Invasive species are a major driver of global change, affecting numerous groups of people in positive and negative ways. This situation can make understanding the roles of invasions difficult for society. Moreover, it can complicate the choice and/or application of different policy decisions and management options.

The case studies described (and others) have shown that we need to consult all interested parties to understand all dimensions of the problem, to identify misconceptions and gaps in knowledge, to understand how this knowledge can be transferred to the population, to solve conflicts of interests around alien species, and to build consensus and integrate different perspectives to arrive at sustainable strategies for managing invasive species. **Q**

Ana Novoa is a postdoctoral researcher at the Centre for Invasion Biology (C•I•B). She works on understanding the history of introduction, ecology, distribution, and management of succulent plants in South Africa.

Ross Shackleton is a final year doctoral student at the C•I•B. Ross is looking into the impacts and management of Prosopis *invasions in South Africa as part of his PhD.*

From insects to invasion science

Mark Robertson is currently an Associate Professor in the Department of Zoology and Entomology at University of Pretoria. *Quest* asked him about his career.

Where did you go to university and what degrees/qualifications do you have?

I studied at Rhodes University and obtained a BSc, majoring in Zoology, Botany and Entomology. I then did a BSc honours degree in Zoology, followed by a PhD in Botany and Entomology.

Describe the career path that led you to your current role? Where have you worked before this position?

During my studies I worked on various contracts for the Agricultural Research Council based in Grahamstown. I also travelled to many countries in Africa to do paid field work. After my PhD I moved to Pretoria to take up a job as lecturer at University of Pretoria.

What are your current duties?

I have several duties including research, lecturing, and supervision of postgraduate students.

Tell us about your interest in invasion science. Why did you choose to follow a career in invasion science?

I have had a keen interest in plants and animals for as long as I can remember. By travelling to different places during my studies I became interested in the diversity of species in these areas and the reasons that they occur there. I also observed that many places had the same plants in common and that people must have introduced these species. I became interested in invasive organisms because of the potential threats they pose to the natural areas that I like to spend time exploring. I found that invasion science offers an interesting combination of theoretical issues and practical management problems that need to be researched.

Why is research such as yours important for South Africa? What is important about your work?

All organisms, including humans, rely on functioning ecosystems and biodiversity to survive. Invasive organisms can have many negative impacts on natural systems. For example, invasive insects can cause major economic impacts on agriculture, particularly for crop production. My research investigates how to manage invasive organisms and to understand some of the risks and impacts that they have on natural systems in order to limit the negative impacts that they can have.

What were the skills you had to have to do the work your work?

A good understanding of ecology, the ability to analyse data, write computer programs, scientific papers and work with other people.

Mark Robertson. Image: Mark Robertson

Not many youngsters look at science as a career path, what led you down this path? What attracted you to it?

I grew up in a small town in the eastern Free State and spent a lot of time walking and amusing myself in the veld. I have always been keen on hiking, rock climbing and camping. My dad played quite a big role in my interest in spending time outdoors. I became really interested in nature by doing these outdoor activities. I really enjoyed biology at school and realised that it was possible to make a career of it. My parents were very supportive and said that I should follow a career that interested me.

What do you enjoy most about your work; what makes it all worthwhile?

I really enjoy discussing interesting ideas with people and enjoy the excitement that comes from answering research questions about the natural world. I enjoy teaching and working with young people. I enjoy the diversity of plants and animals that I work with and the interesting places that I work in. My motivation is the enjoyment of my research and I have learned that hard work and discipline are vital, even when you enjoy your work.

What do you do to unwind?

I like to go running, canoeing, spend time in the mountains and most of all, flying my paraglider.

A career in invasion science

Invasive alien species are considered one of the foremost threats to our biodiversity and ecosystems, and to keep invasive alien species in check, we need the knowledge and know-how of dedicated individuals. One such individual is Ulrike Irlich, currently the Programme Manager for Monitoring and Evaluation in the Invasive Species Unit of the City of Cape Town.

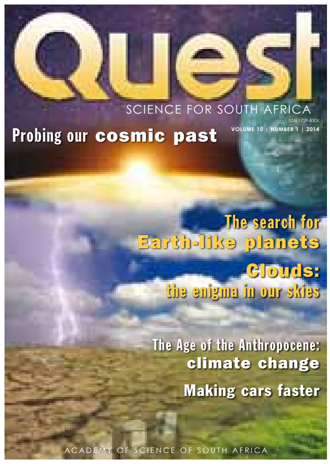
After matriculating in 1999, an interest in nature led Ulrike to a BSc in Biodiversity and Ecology at Stellenbosch University. Ulrike soon decided she was ready for the challenge of postgraduate studies and continued with an Honours and then Masters degrees in zoology at Stellenbosch University. Although she considered a PhD, Ulrike wanted to find her feet and interests in the working environment. Her career started off with an internship at the Zoological Society of London (UK) collecting data for a research project on pheasants. Coming back to South Africa, she held several positions at universities and NGOs where she learned the skills to equip herself for her current position. After a contract with the Wilderness Foundation as Stewardship Officer, Ulrike was appointed as Programme Manager for Monitoring and Evaluation in the Invasive Species Unit of the City of Cape Town.

Ulrike currently oversees the species programme, a programme that focuses on the control of emerging weeds and problem species across the City of Cape Town. Her day-to-day activities include awareness campaigns, the management of teams that do invasive species removal, research, monitoring and evaluation. For her position as programme manager, Ulrike developed a specific set of skills needed for success: good writing, communication, time management, conflict management and mentoring. Because the focus of her programme is on invasive species, she has to have a working knowledge of the identification of different invasive species as well as knowledge about their impact and management.

Ulrike and her team are doing valuable work in combating invasive alien species. Emerging weeds are species that are in the process of becoming invasive or potential threats. If one removes them as soon as possible, the cost of control is far less than if one left them to spread further. Ulrike explains, *'In Cape Town we have identified about 20 plant species that are emerging, or that are on our watch list, and we control them and raise awareness on these species. While some of the plants have been in Cape Town for quite some time already, we believe that in Cape Town we can bring them under complete control. For example, red valerian, has been in Cape Town for many years and was widely planted as a garden plant. A few years ago this species jumped the garden fence and is now spreading into Table Mountain National Park. Red valerian is a fire retardant species, so could potentially be very detrimental for the fire-driven fynbos'.*

Ulrike Irlich. Image: Ulrike Irlich

Despite having a lot on her plate, Ulrike has recently enrolled for a PhD at the DST-NRF Centre of Excellence for Invasion Biology, Stellenbosch University and her advice to youngsters *'Take every opportunity you get, and make the best of it! Even if you don't enjoy what you are doing, you don't know what doors it will open next!'.*



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From mathematics to invasion science

Cang Hui is currently a professor in the Department of Mathematical Sciences at Stellenbosch University. *Quest* asked him about his career.

Where did you go to university and what degrees/qualifications do you have?

I did my studies at Xi'an Jiaotong University and postgraduate studies at Lanzhou University, both in China. My degrees (BSc, MSc and PhD) are all in the field of applied mathematics, related to biomathematics.

Describe the career path that led you to your current role. Where did you work before this?

I came to Stellenbosch University immediately after my PhD in 2004. From 2004 to 2007, I was a postdoctoral associate in the Department of Conservation Ecology and Entomology, funded by the Centre for Invasion Biology (C•I•B). I was a staff researcher at the C•I•B from 2008 to 2013. I was promoted to full professor in 2014 in the Department of Mathematical Sciences, which coincided with my appointment by the NRF to the Tier 1 South African Research Chair (SARChI) in Mathematical and Theoretical Physical Biosciences, co-hosted by the African Institute for Mathematical Sciences (AIMS) in Cape Town.

What are your current duties?

I'm working on the interface between mathematics and biology. My duty is mainly research and postgraduate training.

Tell us about your interest in invasion science. Why did you choose to follow a career in invasion science?

I want to understand how a complex adaptive system (CAS) emerges and functions. Ecological systems are ideal natural models for CAS. To understand the function and structure of ecological systems, we cannot rely on observations alone. Instead, we also need to see how the system responds to intrusion, perturbation and disturbance. Invasive species are natural/human-driven forces that can serve the purpose for understanding the robustness and function of the recipient ecological system, like viruses to an immune system, meteors to a planetary system. Invasion science is a trans-disciplinary research field, requiring team works from scientists in all fields of natural and social sciences. I like the multi-disciplinary philosophy in invasion science.

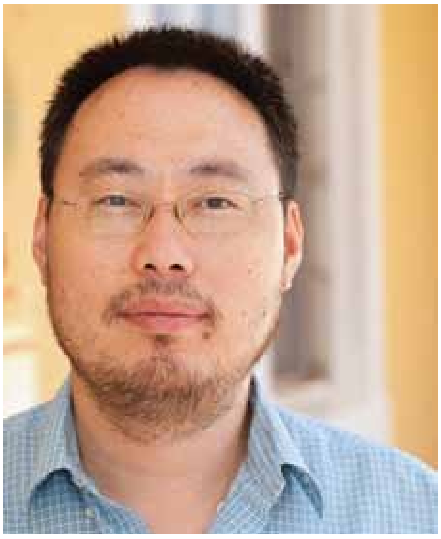
Why is research such as yours important for South Africa? What is important about your work?

Training applied mathematical students to work on real world issues and training ecological students to embrace numerical approaches are important steps to make South Africa's young scientists more globally competitive. I think my research first benefits South African students by equipping them to work at the forefront of scientific research. Graduates with competent skills will serve the country, especially in the emerging field of bio- and eco-informatics, helping to explore/manage/industrialise the potential of renewable natural resources and putting the country onto a green and sustainable trajectory.

My work is curiosity driven, intellectually interesting and challenging. Many results from my research have been picked up by scientists locally and globally for more efficiently monitoring and managing endangered and invasive species when facing global changes.

What were the skills you had to have to do the work your work?

A good understand of the system (e.g. ecology), together with competence in mathematics and computer science.



Cang Hui. Image: Cang Hui

Not many youngsters look at science as a career path, what led you down this path? What attracted you to it?

I have never wanted to do anything else other than science, as long as I can remember. Science is humanity's crown jewels. I don't think we need any persuasion in this regard.

What do you enjoy most about your work; what makes it all worthwhile?

To steadily understand how a system works. So, the joy is comprehension, motivated by curiosity. Thomas Edison said 'Genius is one percent inspiration and ninety-nine percent perspiration' – in other words it is all about hard work.

What do you do to unwind?

I love tennis.

Everyday products originating in outer space

What do jewellery, the petroleum industry, cellphones, batteries and camera lenses have in common? Apart from being used regularly by millions across the globe, they are all made from various heavy elements such as platinum, gold, silver, uranium and lanthanum that originate in outer space.

These heavy elements are produced when massive stars explode and matter, which makes up much of our planet, is hurled into space. Powerful explosions or supernovae provide the prefect astrophysical conditions for the production of approximately 70% of all heavy elements we observe here on earth and across the universe, says Dr Vincent Kheswa who recently obtained his doctorate in Physics at Stellenbosch University.

Kheswa's study focused on lanthanum and more specifically on how a specific lanthanum isotope (138La) an atom with the same number of protons but different number of neutrons is produced. He says the astrophysical conditions, under which this isotope is formed, has long puzzled scientists. Kheswa says that apart from camera lenses and battery-electrodes, lanthanum is being used in hydrogen storage. He adds that a better understanding how 138La is formed could also help us determine the age of the universe.

Collaborating with researchers from iThemba LABS and the Universities of Oslo and Brussels, Kheswa performed an experiment where particles were smashed together to create the rare 138La nuclei. Nuclei are the very dense regions of protons and neutrons at the centre of an atom. The decay products from these nuclear reactions were then studied using different advanced detector systems. Kheswa says scientists use accelerator laboratories to study nuclear physics properties, which lie at the heart of elemental formation. He adds that each measurement provides pieces of the puzzle to unravel the secrets of the production of elements and provides constraints on the hot and dense environments necessary for efficient production.

Kheswa says his measurement 'suggests that the interaction with neutrinos, which are very small and elusive but very abundant particles during a supernova explosion, remains the main reaction that produces 138La in the cosmos and not photodisintegration which is the process whereby protons and neutrons are ejected by the continuous absorption of high-energy photons'.

'This finding provides important insight into the production of heavy elements and places stringent constraints on the astrophysical environments that must exist in the cosmos to produce heavy elements.'

'In particular, the confirmation of neutrinos being almost exclusively responsible for the production of 138La will no doubt serve as a driving force for more research into this rare process.'

Kheswa says the wealth of information garnered from this experiment significantly improves our understanding of the astrophysical processes involved in the production of many heavy elements found on earth and elsewhere in the universe. He adds that it also helps scientists explain the ability of nuclei to absorb and emit light that influence overall reaction rates in astrophysical environments during a supernova.

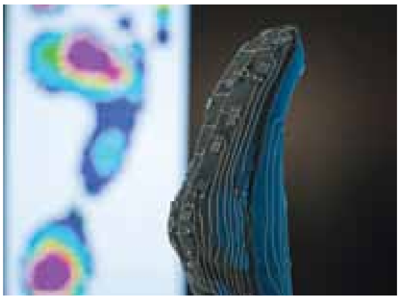
'This study provides more information on the underlying nuclear structure of nuclei which describes how reactions proceed and in which astrophysical environments they take place,' says Kheswa.

Pressure-monitoring stockings to prevent wounds in diabetics

Diabetics often have little feeling in their feet and don't perceive the body's pressure or temperature signals there. This can result in unnoticed wounds that then develop into abscesses. Many diabetics have to have toes or feet amputated. Now, a novel kind of pressure stocking developed by Fraunhofer researchers is set to help protect against wounds via an integrated sensor system that sends a warning when pressure is too high.

In total, 40 very fine, dielectric elastomer sensors measure compression load and distribution for diabetes patients – taking over the job usually performed by the nerves in their feet.

The sensors are made from a soft and very stretchy elastomer silicone film that is easy to integrate into textiles. This film is coated on both sides with highly flexible electrodes of graphite or carbon black. When the film deforms because of compression or stretching, its thickness decreases and its surface area simultaneously increases. An application-specific integrated circuit (ASIC) chip built into the system collects the measurement data and the controller transmits them wirelessly to a smartphone or tablet, which then informs the diabetes patient that it is time to change foot position or weight distribution.



A sock for diabetics. Image: Fraunhofer-Gesellschaft

Study links war, global warming for first time – in Syria

Researchers have published the first major study to draw a link between global warming and ongoing civil unrest or war. The study suggests a link between global warming-related climate trends and severe drought in the Fertile Crescent region that preceded civil unrest in Syria. However, the report also points to farming practices as a factor exacerbating the dry conditions.

A study suggests a link between global warming-related climate trends and severe drought in the region, preceding civil unrest in Syria. The Fertile Crescent is a quarter-moon-shaped zone of relatively moist and fertile land that includes what are today large parts of Iraq and Syria.

Syria's ongoing internal conflict began in 2011, following three years of the most severe drought recorded in the region, scientists said. Farming practices prior to the drought probably contributed to groundwater depletion, and the drought was followed by agricultural collapse and internal displacement of up to 1.5 million people who moved from rural farmland to urban centres, according to the researchers. They add that the results suggest links between drought, global warming-related climate trends, and the Syrian unrest.

World Science: http://www.world-science.net.

Mysteries of 'molecular machines' revealed

Scientists are making it easier for pharmaceutical companies and researchers to see the detailed inner workings of molecular machines.

To understand how a machine works you have to be able to see how it is put together and how all its parts fit together. This is where the Los Alamos scientists come in. These molecular machines are very small: a million of them placed side by side would take up less than an inch of space. Researchers can see them however, using X-rays, crystals and computers. Researchers produce billions of copies of a protein machine, dissolve them in water, and grow crystals of the protein, like growing sugar crystals except that the machines are larger than a sugar molecule.

Then they shine a beam of X-rays at a crystal and measure the brightness of each of the thousands of diffracted X-ray spots that are produced. Then researchers use the powerful Phenix software, developed by scientists at Los Alamos, Lawrence Berkeley National Laboratory, Duke and Cambridge universities, to analyse the diffraction spots and produce a three-dimensional picture of a single protein machine. This picture tells the researchers exactly how the protein machine is put together.

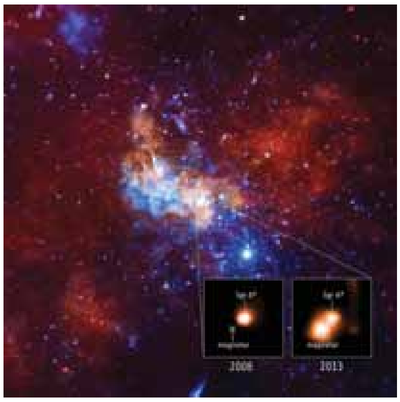
Source: Los Alamos

Magnetar near supermassive black hole delivers surprises

Since its discovery two years ago when it gave off a burst of X-rays, astronomers have been actively monitoring the magnetar, dubbed SGR 1745-2900, with Chandra and the European Space Agency's XMM-Newton. The main image of the graphic shows the region around the Milky Way's black hole in X-rays from Chandra (red, green and blue are the low, medium and high-energy X-rays, respectively). The inset contains Chandra's close-up look at the area right around the black hole, showing a combined image obtained between 2005 and 2008 (left) when the magnetar was not detected, during a quiescent period, and an observation in 2013 (right) when it was caught as a bright point source during the X-ray outburst that led to its discovery.

The team first considered whether 'starquakes' are able to explain this unusual behaviour. When neutron stars, including magnetars, form, they can develop a tough crust on the outside of the condensed star. Occasionally, this outer crust will crack, similar to how the Earth's surface can fracture during an earthquake. Although starquakes can explain the change in brightness and cooling seen in many magnetars, the authors found that this mechanism by itself was unable to explain the slow drop in X-ray brightness and the hot crustal temperature. Fading in X-ray brightness and surface cooling occur too quickly in the starquake model.

The researchers suggest that bombardment of the surface of the magnetar by charged particles trapped in twisted bundles of magnetic fields above the surface may provide the additional heating of the magnetar's surface, and account for the slow decline in X-rays. These twisted bundles of magnetic fields can be generated when the neutron star forms.



The region around the Milky Way's black hole in X-rays from Chandra.
Image: NASA/CXC/INAF/F. Coti Zelati et al.

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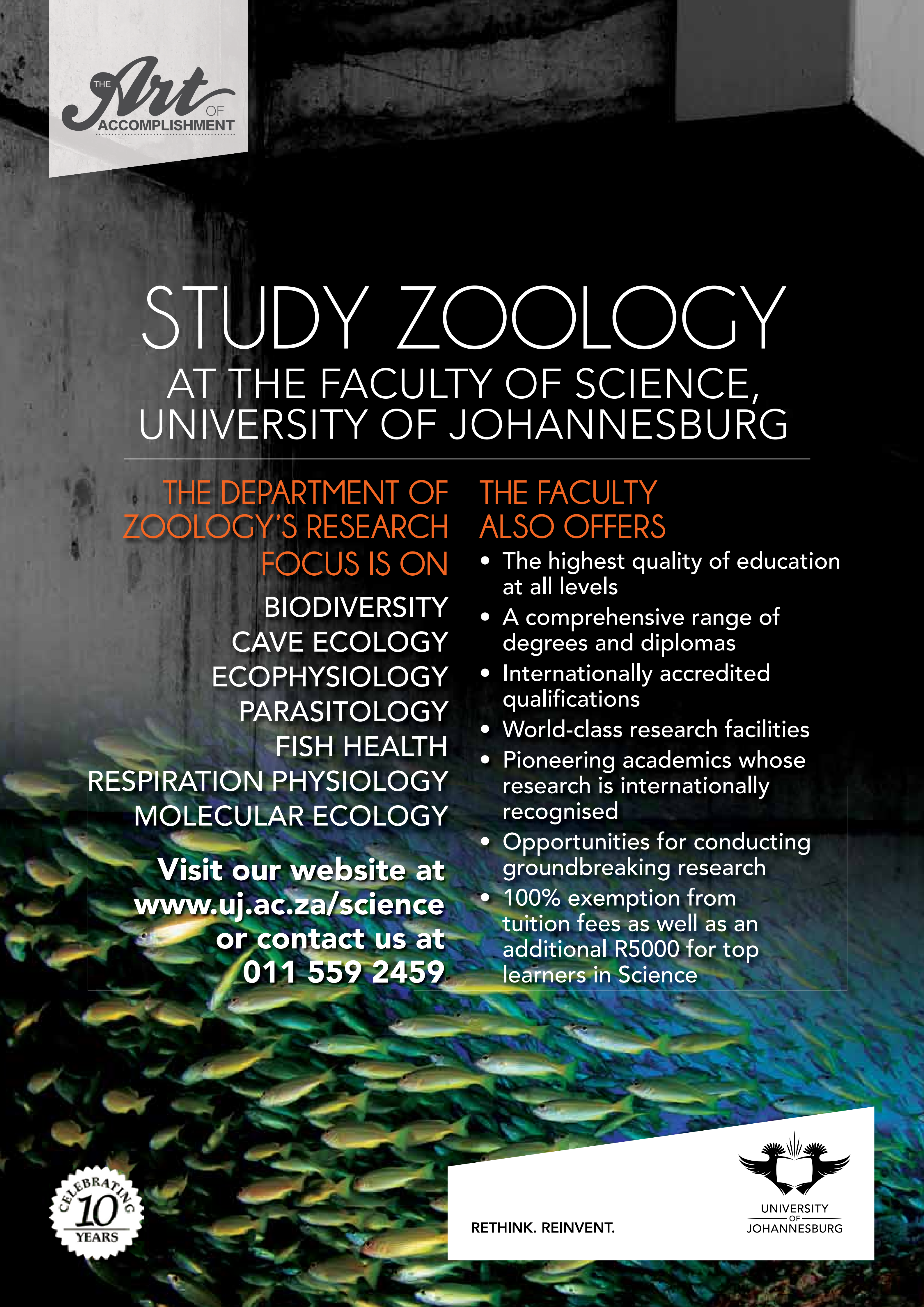
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