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**

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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.

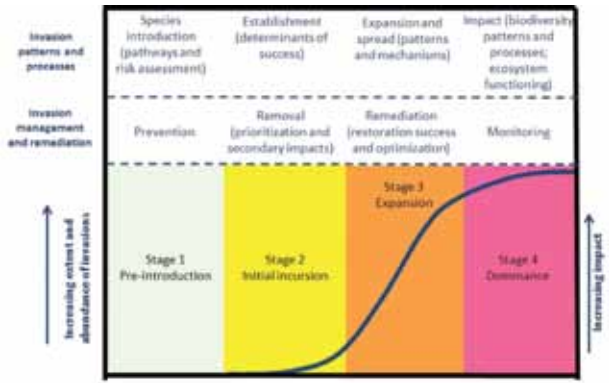
Many of the most damaging invasive species in most taxonomic groups were initially intentionally moved to the areas where they now cause problems. In many cases, such invasive species are still viewed as beneficial in at least parts of areas where they are invasive, and by some sectors of society.

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