Science and Education at the Centre for Invasion Biology

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Abstract

South Africa has severe problems caused by biological invasions in terrestrial, freshwater and marine ecosystems, and a long history of managing biological invasions. However, appreciation and systematic study of the problems associated with invasive species are relatively recent. In 2004, the Centre for Invasion Biology (CIB) was established as one of the first six national Centres of Excellence funded by the South African government. The aim of the DST-NRF Centres of Excellence is to concentrate existing capacity and resources to enable researchers to collaborate across disciplines on long-term projects that are locally relevant and internationally competitive. Understanding the biological and ecological underpinnings of invasions is crucial, but much emphasis is placed on understanding the 'human dimensions' of invasions, and on seeking solutions for current problems, and techniques for preventing new invasions. Education is a critical component of this knowledge-building process, and the CIB infuses education for sustainable development into all of its activities. The Centre conducts education and outreach at the secondary school, under-graduate, post-graduate and post-doctoral levels, and in the workplace to develop capacity at all levels. The Centre's flagship outreach programme, Iimbovane, aims to increase environmental literacy and inspire secondary school learners to take up scientific careers through facilitating field and laboratory work that is embedded in the life science curriculum; the programme focuses on under-resourced schools. At tertiary level, the under-graduate training course in invasion biology presented at Stellenbosch University provides an introduction to the exciting and important field of invasion science for final-year Bachelor degree students. A distributed network of researchers located in universities and research

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institutions around South Africa also trains 50–60 post-graduate students, and hosts ten to twelve post-doctoral researchers each year, through whom much of the Centre's research is conducted. In the working world, members are involved both in citizen science programmes on invasive species and in collaborative work with partner organisations which implement invasive species management programmes, provide employment opportunities for graduates of the Centre, and form a source of working (part-time) graduate students.

1 Introduction

Biological invasions are a substantial component of global change and are widely recognized as a major and growing threat to global biodiversity and the sustained delivery of goods and services from ecosystems (Pyšek and Richardson 2010). Appreciation and systematic study of the problems associated with invasive species are relatively recent, however. The study of invasions originally focussed on biological and ecological issues, and invasions were widely seen as a grand natural experiment in biogeography to gain insights into the determinants of range limits and factors that control membership of communities and ecosystems. Understanding these biological and ecological underpinnings of invasions remains crucial, but increasing emphasis is being placed on understanding the 'human dimensions' of invasions, seeking solutions for current problems and techniques for preventing new invasions. Therefore, in recent decades, most research on invasive species has sought solutions to the many social, ecological and economic problems associated with invasions (Richardson et al. 2011).

Many countries, especially the more developed nations, have major programmes in place to manage biological invasions. These are typically multi-faceted and multi-level initiatives that seek to reduce the extent and impacts of currently invasive species, while simultaneously implementing measures to reduce the chance of new invasions. The initiation and growth of such programmes has contributed to the rapid growth of invasion science, which is currently one of the most popular and vibrant sub-disciplines of ecology and environmental management worldwide. Thousands of scientific papers are published on aspects of biological invasions every year and the field now has a growing number of specialist journals and features prominently in the programmes of academic conferences worldwide (Richardson 2011). As with climate change and other complex environmental problems, there is a crucial need to raise awareness of all aspects of the process, and to highlight options for management among the public.

South Africa has severe problems with biological invasions in its terrestrial, freshwater and marine ecosystems, but is also one of the countries with the longest history of managing biological invasions. Despite many challenges typical of developing countries, South Africa has invested substantially in infrastructure and capacity development for addressing problems associated with biological invasions.

In 2004, the DST-NRF Centre of Excellence for Invasion Biology (the Centre for Invasion Biology; hereafter the CIB or 'the Centre') was launched—one of the country's first six national Centres of Excellence as part of a programme funded by the national government to concentrate existing capacity and resources to enable researchers to collaborate across disciplines on long-term projects that are locally relevant and internationally competitive (van Wilgen et al. 2014).

The CIB is a distributed network of researchers, students and partners managed from a primary hub at Stellenbosch University, with a secondary hub of researchers and support staff at the University of Pretoria. The aim of the Pretoria (or 'northern') hub is to coordinate activities of the northern partners where necessary to complete particular projects, and to support long-term biodiversity research in that area. In addition to the two hubs, CIB researchers are staff members of a range of academic and other research-oriented organisations and the network as a whole covers more than ten academic institutions and all of the country's provinces which have a university or large research organisation. This distributed network broadens the reach of the CIB beyond the higher education institutions, where most research is generated, and the CIB builds external partnerships to inform decision-makers in a range of organisations about biological invasions and their social and ecological impacts. Partners range from conservation agencies (e.g. South African National Parks, CapeNature), R&D organisations (e.g. the Council for Scientific and Industrial Research, CSIR) to large municipalities (eThekwini Municipality in Durban, City of Cape Town), which are users of the information generated. In addition, the CIB has a productive partnership with the South African National Biodiversity Institute (SANBI) that allows staff of the two organisations to work together on a range of activities from student co-supervision to joint implementation of invasive species legislation.

The aim to engage in research that is locally relevant and internationally competitive in order to enhance the pursuit of research excellence and capacity development has been augmented since the establishment of the CIB with the aim of maximising research impact on industry, business and society. The CIB's key performance areas (KPAs) include research, education and training, networking, knowledge brokerage and service provision. These five KPAs represent different ways of achieving impact in the research sphere—that is, they are elements of the research impact 'process'. This chapter will show how the CIB's key activities go beyond community involvement to community participation in research itself. Much of the CIB's research is conducted through post-graduate students and post-doctoral associates. Along with research excellence and education and training, DST-NRF Centres of Excellence are required to undertake networking, information brokerage and service provision, thereby maximising the impact of the CIB's work on different sectors of society and economy.

While the CIB's internationally competitive research and capacity building activities address impact at the academic level, the other KPAs are intended to ensure impact on other areas of society. Networking, information brokerage and service provision involve working with decision-makers to increase knowledge about biological invasions and seek to make invasion-related information resources

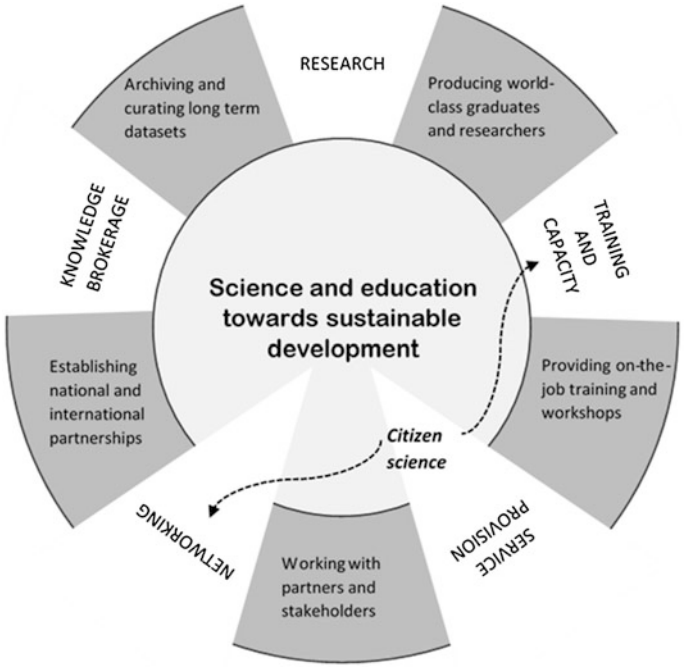

Fig. 1 The Centre for Invasion Biology's key performance areas and major activities contributing to education

readily available to broader society. Thus, the CIB sees all its key activities as hinging on education in different sectors (Fig. 1). For example, under its service provision activities, the CIB provides policy advice and consultancy services at reasonable cost to decision-makers in government, non-government organisations (NGOs) and the private sector. The long-term working relationships built between researchers and these institutions through service provision allow mutual learning to take place, thereby advancing the field.

Education in schools: The Iimbovane Outreach Project

Biodiversity and the conservation thereof are important for the maintenance of ecosystem function and delivery of environmental goods such as food and potable water. However, mounting evidence shows that the rate at which we are losing biodiversity and degrading ecosystems is unprecedented. One of the strategies that can help reduce the loss of biodiversity is increased public education and understanding of the consequences of biological invasions. While the scientific community has a reasonable understanding of threats to biodiversity, most South Africans are not familiar with biodiversity, its loss and the consequences of biological invasions. If we want the public to support conservation and management efforts, we must be purposeful in increasing environmental literacy and putting initiatives in place that educate citizens about the environment. The landscapes

where poorer urban communities are located are often heavily invaded and transformed by invasive alien plants, with virtually no natural indigenous plant diversity (City of Cape Town 2013). As a result, residents may have no direct contact with indigenous biodiversity (City of Cape Town 2013; Elmqvist et al. 2013; Miller 2005; Turner et al. 2004).

Only in the last decade has the basic education sector in South Africa become actively engaged in biodiversity education. Before 2006, biodiversity was not included in the formal school curriculum. This changed with the National Curriculum Statement for Grade 10–12 Life Sciences which now includes two chapters dealing with biodiversity, environmental change and the impacts of human activities on biodiversity. Many educators have had no formal training in the relatively young fields of biodiversity science and invasion science. Due to a lack of training in or direct experience with biodiversity, most educators struggle to develop practical projects in this subject area. Consequently, learners do not get the necessary content knowledge, or accumulate the critical thinking and practical skills needed to master life science as a subject, and therefore seldom consider taking up a career in science. With growing class sizes, a lack of access to transport and financial constraints, educators tend to move away from asking learners to collect specimens in the field. Instead, learners are told how specimens are collected, rather than being allowed to explore the process for themselves through direct experience. In most South African schools, these problems are exacerbated by the lack of access to scientific equipment such as microscopes and information and communication technology (ICT). These growing pressures on the delivery of high quality education are happening at a time when there is a growing demand for learners with critical thinking skills who are aware of human impacts on their environment and the need for sustainable solutions. The Department of Science and Technology's Ten-Year Innovation Plan articulates the need for knowledge workers who are equipped to participate in South Africa's developing knowledge economy (Department of Science and Technology 2008).

1.1 Serving the Education Need

The CIB runs an innovative, long-term project, Iimbovane, that combines science outreach and biodiversity monitoring, as well as ongoing relationships with partner organisations that contribute to its mandate. The Iimbovane Outreach Project grew out of the dual challenges to educate society about biodiversity and deepen public understanding of the consequences of biological invasions. The project provides support to learners and educators encountering biodiversity science at the secondary school level. Iimbovane, meaning 'ants' in isiXhosa, a widely-spoken South African language, focuses on ants as a model group for teaching biodiversity and invasion science. The project uses an experiential learning approach whereby participants accumulate knowledge and skills through direct involvement with the model group (ants). Participating learners and educators assist with the collection of

ant samples and relevant environmental data at monitoring sites in their school grounds (typically highly disturbed environments) and in matched reference sites in nearby protected areas. The project uses a simple sampling protocol: arrays of pitfall traps to collect ant species with matched vegetation samples to collect species richness and abundance information. An important advantage of this collection method is the diversity of groups that the learners discover when they remove the traps after a few days. Seeing the variety of insects encourages learners to ask questions about biodiversity.

Ants were selected as a focal group because of the group's high level of diversity in South Africa and the ease of collecting specimens using pitfall traps and low-cost equipment, making this protocol repeatable for educators who wish to repeat the project for teaching purposes. In addition, the project maintains an ant identification key based on the ant species identified in the project. The identification guide, together with classroom technology, such as laptop computers, microscopes and data projectors are handed to each school that participates in the project, making it possible for learners and educators to see and work with both biological samples and data using ICT. Project activities with learners take place during school contact hours, while educators receive training and provide feedback to the project team at separate workshops. During these workshops the project staff, together with educators, develop lesson plans and assessment activities that can be used in the classroom. The activities and products are therefore not an extra-curricular burden for the educators, but compliment their teaching.

1.2 Educational Advantages of Iimbovane

The value of education projects such as the Iimbovane Outreach Project lies mainly in their contribution to science and biodiversity education at school level. The project improves educator capacity in the field of biodiversity; educators benefit from project workshops by gaining in-depth knowledge on biodiversity, environmental change and human impacts, curriculum areas that are challenging for them. Iimbovane Outreach Project support enables them to teach biodiversity in a more confident and thoughtful manner. The project addresses the formal requirements of the South African National Curriculum for the Life Sciences, which requires that learners develop an understanding of science and how it is undertaken and applied in society. The project consists of a 'doing' phase when students carry out the fieldwork in school grounds and a 'reflective' phase during which the data collected are assimilated and applied (Fig. 2). By providing educational resources to the educators and working with learners in the field and laboratory, Iimbovane supports these curriculum aims and engages learners directly with the scientific process. The learners are thereby exposed directly to science and the scientific process in a real setting, rather than from textbooks in a classroom setting. Learners also see what the career of a researcher involves. Most learners participating in the Iimbovane

Fig. 2 The Centre for Invasion Biology's Iimbovane Outreach Project consists of a 'doing' phase during which participating learners plant pitfall traps to collect ants while interacting with scientists, followed by a 'reflective' phase during which learners analyse and interpret the data they have collected

Outreach Project do not receive this exposure any other way, at home or in their communities.

Direct contact with scientists working on the Iimbovane project gives learners a wider experience and understanding of what it means to practice science (Braschler 2009; Braschler et al. 2010). Scientific fieldwork also provides an opportunity for learners to work as a team and to work purposefully outdoors, learning to appreciate the natural world and link theory with observation. Perhaps one of the most significant advantages in terms of education and awareness is the learners' realisation that areas around their schools are in a poor environmental condition. Learners then become aware of pollution, habitat destruction and the extent of invasive alien species in their local environments (Ballouard et al. 2011).

Experiences of participating learners

> I really found the field work 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 are 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 realize how precious those animals are and also how human activities can affect animals' habitats. (Learner from Sarepta Secondary School)

Education at tertiary level

Education at tertiary institutions is traditionally delivered in modular units that encompass broad to specialist themes as students progress through their courses. A close rapport between course material and cutting-edge research is one that is strived for in many tertiary education programmes globally. In this respect, a semester course on invasion science at Stellenbosch University was initiated in 2014. The course was initiated and is delivered annually by members of the CIB's research team, typically by four lecturers and several guest lecturers who introduce a diversity of topics and their specialist knowledge. The course provides an introduction to the exciting and important field of invasion science for senior under-graduate (final year Bachelor degree) students.

The employment sphere

Biological invasions are widely recognised as one of the major threats to both the conservation of biodiversity and the maintenance of ecosystem services worldwide. In many parts of the world, the most challenging and time-consuming tasks of land managers and conservation biologists are those relating to controlling alien species and preventing impacts, and, increasingly, repairing systems already damaged by aliens. The interaction between invasions and other drivers of global change creates fascinating areas for research at many organisational levels, e.g. from genes to ecosystems. Invasions also represent a major challenge to the goal of sustainable development, as they affect the operations of a broad swathe of society from rural communities to major shipping companies. As such, invasion science demands insights from a wide range of disciplines. Furthermore, as an applied biodiversity field, invasion biology prepares graduates and young researchers effectively for employment. Graduates of the CIB work in a range of organisations from universities to government bodies, and private consultancies to parastatal biodiversity-focused organisations. Between 2004 and 2014, the CIB produced 211 graduates and supported 37 post-doctoral associates. Of these, most have found positions within their chosen field or continued to another advanced degree or post-doctoral position in South Africa or abroad. Alumni work in provincial environmental departments, national parks and nature reserves, South African and international universities, environmental observation networks and other research and policy-making organisations (such as the South African National Biodiversity Institute) (Table 1).

On-the-job training, or training towards advanced degrees for people already working full time, is an emerging focus for the education sector in South Africa. South Africa's government, through its Ten-Year Innovation Plan, is committed to producing 6000 PhD graduates per annum by 2025 (Department of Science and

Table 1 Examples of organisations employing recent graduates of the Centre for Invasion Biology

National government departments (e.g. Department of Environmental Affairs, Department of Agriculture, Forestry and Fisheries)
Provincial nature conservation and land management agencies (e.g. CapeNature)
Local authorities, including metropolitan municipalities such as the City of Cape Town
BirdLife South Africa (an affiliate of BirdLife International)
Blue Science (environmental consultancy focussing on water issues)
Coastal Environmental Services (consultancy focusing on environmental impact assessment)
Council for Scientific and Industrial Research (CSIR; a government-sponsored science council conducting directed and multidisciplinary research, innovation and development)
Fruit Fly Africa (industry-owned service organisation using sterile insect technique for area-wide fruit fly control)
National Research Foundation (NRF; independent government agency mandated to promote and support research)
South African Broadcasting Corporation (SABC; the national broadcaster of South Africa)
South African Environmental Observation Network (SAEON; an environmental observation network that delivers data for scientific research and informs decision-making)
South African Institute for Aquatic Biodiversity (SAIAB; a national research facility dedicated to the study of aquatic biodiversity)
South African National Biodiversity Institute (SANBI; government agency coordinating research, monitoring and reporting on the state of biodiversity)
South African National Seed Organization (SANSO; sectoral industry body that represents the South African seed industry)

Technology 2008). In 2009 South Africa produced 1380 doctoral graduates (Mouton 2011) indicating that a three- to four-fold increase in graduation rate will be required to meet the 2025 target. At the same time, many universities are experiencing a dearth of qualified applicants, and already more than 80 % of South African PhD students study part time (Mouton 2011). These students are typically more mature, experienced, and may be active in broader fields that their study itself addresses; however, they may need refresher courses to enable them to perform in their degree programme. Although there are significant obstacles to increasing part-time PhD enrolments in South Africa, including the lack of provision for part-time registrations in some universities and supervision capacity, efforts are being made to address these shortcomings (e.g. African Doctoral Academy, http://www0.sun.ac.za/ada/).

Service provision and networking

The CIB's managed network affords opportunities to extend our education work into our partner institutions. There are three main ways in which the CIB brings education into the working day of our partners: (a) through issue-based workshops (Novoa et al. 2015), (b) through field-work and research collaborations (Measey et al. 2014), and (c) through formal registration for post-graduate degrees.

Stakeholder workshops are a powerful tool for understanding the perceptions of the broad array of role players who are involved with invasive species problems. These meetings regularly include individuals from our partner network, as well as private land owners and lobby groups, and can contribute to developing research programmes and management strategies to address 'conflict species'—invasive organisms that are both beneficial and detrimental. Many alien species are conflict-generating, as they were introduced for a particular use and then established self-sustaining and expanding populations beyond the area of introduction, where they may have both positive and negative impacts. For example, South Africa has a major problem with invasive alien trees, many of which were introduced and widely disseminated as forestry plants, ornamentals or amenity trees (van Wilgen and Richardson 2012). The CIB has held several workshops to bring stakeholders together to seek the best solutions for dealing with conflict invasive tree species and other groups of organisms, such as cacti used in ornamental horticulture. These workshops have proved to be opportunities for stakeholders to share their values and experiences, and measurable changes of attitude have been documented (e.g. Novoa et al. 2015).

Workshops are also rich environments for ascertaining the level of understanding that participants have of invasive species and invaded systems, and therefore to set the agenda for ideas that need to be taught, identify common misconceptions and highlight communication gaps. For example, invasive mesquite (*Prosopis*) species and their hybrids were was thought to be widely used by farmers and rural dwellers in South Africa for fuel and as building material, until workshop discussions showed that mesquite is in fact considered to be inferior for these purposes (see Shackleton et al. 2015). In this respect, workshops are a learning experience for all involved, although at the outset it is not easy to predict who will be the educated or the educators. However, it is usually the case that all participants leave a workshop with an appreciation of invasive species from another standpoint.

The detection of a new species of invasive frog in a national park in 2010 (Fogell et al. 2013; Measey and Davies 2011) led to the development of a control programme and its inclusion in SANParks' Annual Plan of Operations (de Villiers et al. 2015). Control activities are now carried out by national park staff with the assistance of interns from local universities and under the guidance of CIB researchers. These activities take place annually over three days. The briefing for the field operation is carried out jointly by CIB and SANParks staff and includes information on the cause of the invasion, as well as an explanation behind the management decision and control programme. At least one intern usually takes the subject on as a project that will count toward a formal part of his or her degree. The outcome of these interactions with partner institutions has led to a better understanding of common invasive species problems, as well as increasing the support for invasion biology research in these organisations, and registration of members of staff for part-time degrees.

Currently, around 10 % of CIB post-graduate students also work for partner organisations. Although the student-supervisor role is formalised within the university context, links between higher education institutions and their partner

organisations provide many opportunities for co-supervision of students by scientist and managers working outside academia, as well as exchange of information between the CIB and the partner institute. In some cases this has resulted in three-way partnerships between the CIB and two partner organisations, with positive results for all parties. Because post-graduate degrees typically take two to three years, the graduates often stay in their former positions, and there is often a long-term positive feedback toward supervising more students and strengthening ties between partners and the CIB.

The role that citizen science can play in science education

Citizen science, or the involvement of citizens in research, has grown exponentially in the last fifteen years. While public involvement in science has well-established roots, the ease of connection between scientists and the public (i.e. via the internet) and the widespread digitisation of media have opened up significant opportunities for scientists and participating citizens alike (e.g. Silvertown 2009). Principally, citizen science has enabled data to be collected on a scale that was previously unfeasible at the regional, continental or even global scale (Bonney et al. 2009). South Africa has produced a number of regional atlas projects covering the region (South Africa, Lesotho and Swaziland) which have citizen science as a key part of data collection (e.g. Bates et al. 2014; Mecenero et al. 2013; Minter et al. 2004). The CIB has been a key participant in several of these projects, which have established South Africa as a global hotspot of citizen science. These projects have, in turn, called for more information on the distribution of invasive species in South Africa to be collected, and have generated important data about the distribution and dispersal of alien species. Citizen science has also been of great importance in generating data for invasion biologists in the USA (Crall et al. 2010).

Finding ways to engage efficiently with large numbers of contributors is particularly important in citizen science projects because engaging on an individual level would be expensive and onerous. One solution relies on crowd-sourcing to provide feedback as well as enhance the roles of citizens and scientists alike (Silvertown et al. 2015). A common way of soliciting information from citizen scientists is to call for the submission of electronic photographs of organisms or landscapes such as on iSpot (http://www.ispotnature.org/communities/southern-africa), but the identification of these photographs is difficult and tedious. Crowd-sourcing appears to be an excellent solution, and 80–90 % of identifications can be made through this form of social network. In addition, the original contributor receives feedback on his/her original submission, together with comments from experts in the network. The citizen scientist can then use the identification information to learn more about the distribution and biology of the organism of interest. He or she may in turn become an expert in identification of this or other taxa. Silvertown et al. (2013) offer some important considerations for those planning to employ citizen science towards a project, including the clarity of learning objectives and target audience, the project duration and legacy, as well as the scientific rationale behind the project.

Many citizen science projects have specific education targets built into their design (Silvertown 2009). Citizens are encouraged to engage not only in data collection, but to build their knowledge with tests and quizzes. For example, participants in the North American amphibian monitoring program had to learn the calls of native frog species in their area of North America. They then had to pass an online test in order to take part as a data-collecting member of the project. Data from this project have since been used to answer hypothesis-driven questions concerning the conservation of amphibians in the eastern USA (Cosentino et al. 2014).

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