A new national unit for invasive species detection, assessment and eradication planning

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DATES:
Received: 22 June 2012
Revised: 19 Dec. 2012
Accepted: 08 Jan. 2013

KEYWORDS:
biological invasions; early detection and rapid response (EDRR); biosecurity; post-border risk assessment; invasion debt; South Africa

HOW TO CITE:
Wilson JRU, Ivey P, Manyama P, Nänni I. A new national unit for invasive species detection, assessment and eradication planning. S Afr J Sci. 2013;109(5/6), Art. #0111, 13 pages. http://dx.doi.org/10.1590/sajs.2013/20120111

Even with no new introductions, the number of biological invasions in South Africa will increase as introduced species naturalise and become invasive. As of 2010 South Africa had ~8750 introduced plant taxa, 660 recorded as naturalised, 198 included in invasive species legislation, but only 64 subject to regular control (i.e. only widespread invaders are managed post-border). There is only one documented example of a successful eradication programme in continental South Africa – against the Mediterranean snail (*Otala punctata*) in Cape Town. Here we describe the establishment in 2008 of a unit funded by the Working for Water Programme as part of the South African National Biodiversity Institute's Invasive Species Programme (SANBI ISP) designed to (1) detect and document new invasions, (2) provide reliable and transparent post-border risk assessments and (3) provide the cross-institutional coordination needed to successfully implement national eradication plans. As of the end of 2012, the ISP had an annual budget of R36 million, employed 33 staff working across all nine provinces, supported 10 postgraduate students, hosted 35 interns (including those as part of a drive to collect DNA barcodes for all invasive taxa) and created over 50 000 days of work as part of government poverty alleviation programmes. The unit has worked towards full risk assessments for 39 plant taxa and has developed eradication plans for seven species; the unit is now helping implement these plans. By focusing on science-based management and policy, we argue that SANBI ISP can play a leading role in preventing introduced species from becoming widespread invaders.

Introduction

Biological invasions are a major threat to biodiversity and economic livelihoods in South Africa. Invasive plants cost South Africa an estimated R6.5 billion every year,[1] but if left unmanaged overall impacts on ecosystem services are likely to rise by an order of magnitude.[2] As part of national legislation,[3] South Africa is developing a national strategy to combat this threat, with three main methods for limiting impacts: prevent introductions, eradicate taxa that do get in and strategically manage established infestations (through containment, impact reduction, or value addition) (Figure 1).[4]

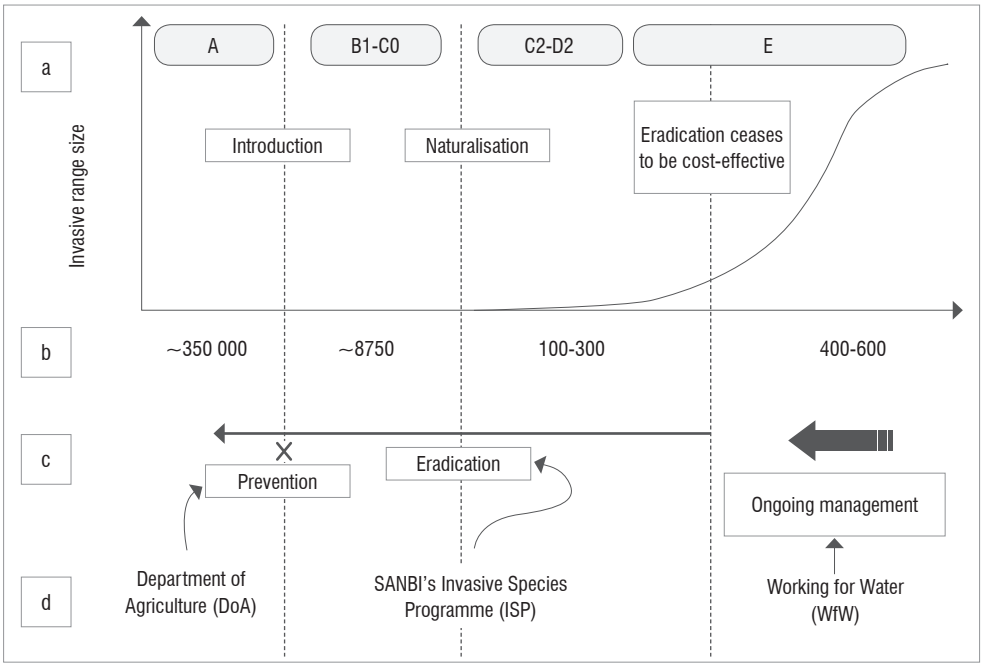


Figure 1: There was a strategic gap in the management of invasive plants in South Africa that is now being filled by the South African National Biodiversity Institute's Invasive Species Programme. Schematic of the progression of an invasion with relevant categories (a),[5] estimates of the number of plant species in South Africa recorded in each group (b), the three major strategies for dealing with biological invasions (c) and the organisations responsible for managing alien plants at each stage (d).

In South Africa, the Department of Agriculture manages quarantine services and conducts pre-border risk assessments in collaboration with the National Plant Protection Organisation. Under particular circumstances the costs of prevention can be higher than eradication or management,[6] but, in general, far too little is spent on

quarantine.[7] This is likely also the case for South Africa, although we do not have the figures for how much is actually spent (or indeed whether current procedures are effective). However, the number of introductions is often documented. For example, the reptile pet trade has grown exponentially over the last 30 years, with more species being introduced from more countries in much greater numbers.[8] Although there are few instances of reptiles naturalising to date, it is likely that some of these taxa will become invasive in the future.[9]

The management of established invaders in South Africa has varied based on the taxon, the invasion location, and which stakeholders are involved. But the management of widely established invasive plants has been led by the Working for Water Programme (WfW) since its establishment in 1995.[10] By 2008 WfW had spent R3.2 billion, reducing the extent of invaded areas for some species and limiting the spread of many others.[10] South Africa has also been actively involved in biological control of weeds since 1913,[11] with the WfW programme providing increasing resources since 1996. Biocontrol agents are established on 48 invasive alien plant species, of which 10 species are completely controlled, and another 18 species are under a substantial degree of control.[11] These biocontrol agents are estimated to save South Africa several billion rand each year by reducing the negative impacts invasive plants have on ecosystem services.[1]

Despite these efforts to control a few widespread invaders, many other species are not managed. Some species are already widespread but for whatever reason have not yet been widely controlled or included in regulations (Figure 2). Other species are relatively limited in distribution as a result of the small number of sites of introduction[12] but could have major future impacts. Similarly, many naturalised species have not started spreading, perhaps because of a lag phase.[13] And finally, many introduced species will only naturalise in the future[14]; for example, estimates from South Australia place the time from introduction to naturalisation of woody perennials to be more than 100 years.[15]

For plants, around 64 taxa are subject to regular control by the WfW programme, but 198 plant taxa are listed as invasive aliens[17] and 238 are listed under draft regulations.[3] So about 140 species are already defined as invaders where more control effort is required. As of August 2010, the Southern African Plant Invaders Atlas (SAPIA) documented 660 plant taxa as having at least naturalised in the region.[16] So more than 400 species have been flagged as naturalised or invasive but are not listed in regulations, although more than half of these are recorded from one or two quarter-degree grid cells only (Figure 2). Finally, the total number of introduced plant taxa in South Africa is estimated at 750 non-native tree species and 8000 non-native shrubby and herbaceous species, many of which could naturalise in the future.[18] The dedication

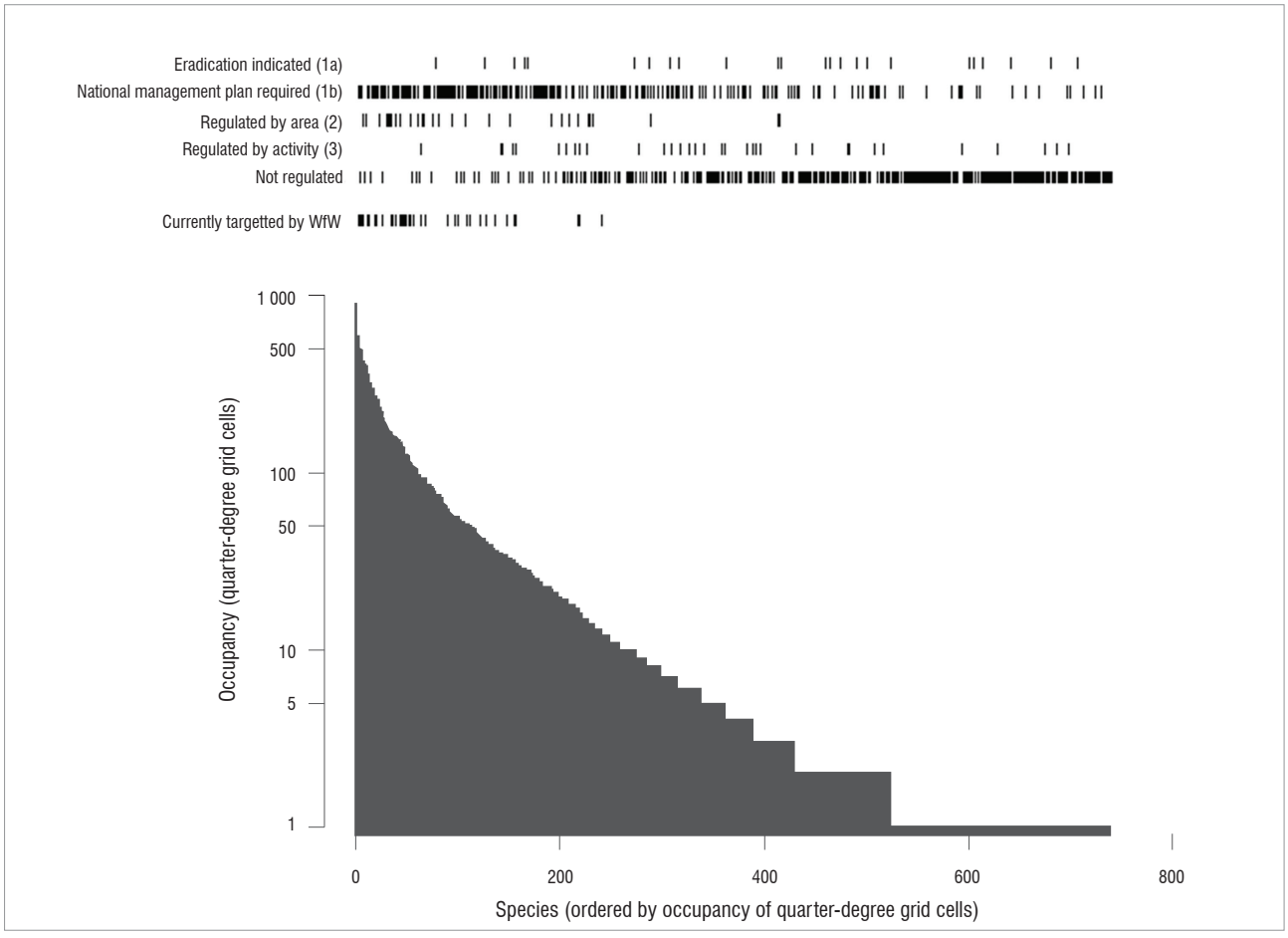


Figure 2: The different legislative categories and the management targets for the Working for Water (WfW) Programme correspond poorly to estimates of the extent of invasions. Specifically some species are found at many sites, but are indicated for eradication (1a species to the left of the graph); other prohibited species are only recorded in one area, but eradication is not considered (1b species to the right of the graph); and some species are widespread invaders that are not regulated at all (species to the left of the graph). Occupancy is based on the Southern African Plant Invader Atlas database[16] (accessed August 2010, 2 years after the programme was started) restricted to records from South Africa and records where the species identity was known. The legislative categories shown are as per the *National Environmental Management: Biodiversity Act (10/2004): Draft Alien and Invasive Species Regulations 2009*.[3]

of specific resources to provide comprehensive risk assessments and control for these taxa has, until recently, been lacking (Figure 1).

In this paper we introduce a new programme in the context of past approaches to detect, evaluate and eradicate invasive organisms. Finally, we discuss lessons learned and progress made to date.

A South African Programme

In March 2008 the South African National Biodiversity Institute (SANBI) was contracted by the WfW Programme of the Department of Water Affairs and Forestry to develop, in partnership with other stakeholders, a programme focusing on 'emerging' plant invaders. In the initial 3-year funding cycle the programme was called the Early Detection and Rapid Response (EDRR) Programme for Invasive Alien Plants.

During the development of the programme, the terms 'emerging' and 'early detection and rapid response' caused considerable confusion among key stakeholders. For example, it was not clear whether EDRR should work on regional priorities (e.g. controlling species that are new to a particular area but already widespread elsewhere in the country[4]). As a result, EDRR was initially tasked with assessing the feasibility of containment. However, it quickly became clear that responding to stakeholder concerns and working on large-scale containment exercises would use the majority of the resources allocated to EDRR, such that the management goal of eradication would again be sidelined (compare Box 1 and Box 2). The programme needed to focus on achieving this specific management goal, whereas the term 'EDRR' is a management approach that can apply to any stage of the invasion process at any spatial scale. The programme therefore dropped the name EDRR in favour of SANBI Invasive Species Programme (SANBI ISP).

SANBI ISP has grown steadily and by the end of 2012 had an annual budget of R36 million with a presence in all nine provinces. SANBI ISP now employs 33 staff, has supported 10 postgraduate students, hosted 35 interns, and created over 50 000 person days, of which the majority were employed through the Natural Resource Management Programme poverty alleviation programme.

Box 1: Assessing invasiveness and eradication costs

Acacia paradoxa in South Africa

Three of the top ten most prominent invasive alien plant taxa in South Africa are Australian acacias[9]; a further eight acacias are in the top one hundred most widely distributed invasive plant taxa.[69] Given the difficulties controlling large persistent seedbanks,[40] and the long-term ecosystem level effects of acacia invasions,[70] there have been calls that more should be done proactively to prevent future acacia invasions, including attempting eradication.[4,40]

Acacia paradoxa has invaded only one site in South Africa – the northern slopes of Table Mountain. It was probably first planted in the late 1800s as a small hedge by the forester who lived in the King's Blockhouse on Devil's Peak. Until recently, the plants appear to have been ignored with recent reports suggesting the population had probably disappeared.[53] After the population was rediscovered in the late 1980s, large plants were cleared and the species was incorporated into general invasive plant management. However, the interval between clearing in that area (3–5 years) was much longer than the juvenile period (1–2 years), and so seed production was not halted.[55]

A detailed assessment and survey of the population in 2008 found more than ten thousand plants spread over ~295 ha with plants forming dense monospecific thickets in patches.[55] Fortunately, this was the only known population in the country, plants had not spread far from the initial point of introduction, and the seedbank was confined almost exclusively to below the canopy. Modelling work and field observations suggested, however, that if left unmanaged the species could expand substantially in range and impact the environment in ways similar to other Australian acacias.[55,61] This work demonstrated both that the species posed a substantial threat, and that eradication was feasible (Figure 3).

Using the initial survey as a starting point, annual search-and-destroy operations in collaboration with the South African National Parks (who manage the area) and WfW-SANBI have been ongoing since 2009. The aim is to systematically survey the affected area during the flowering season (i.e. August–October) and prevent new seed-set. In 2010, surveys found about a hundred new adult plants and the total extent was revised slightly upwards to 310 ha, but there is no evidence that the population extent is larger than this. Later in 2010 and during the start of 2011, seedling patches emerging after the initial clearing (and a subsequent wildfire) were cleared. Over 600 000 seedlings were hand-pulled on a contract costing R400 000. As such, the exercise is much more expensive than general clearing operations (which will still continue in the area separate to the *A. paradoxa* work), but this approach was estimated to be much more cost effective than if either no action was taken or containment were attempted (Figure 4).[61] The total cost over the next 20 years is estimated to be R5.4 million (net present value in 2012) if control is successful, but the duration of the eradication is still to be properly estimated. The management approach and measures to reduce the seedbank will be adapted in the light of progress and exploration of new methods.[64]

A dense thicket of *Acacia paradoxa* on the slopes of Table Mountain in 2008 (photo: Rafael Zenni). The implementation of a national eradication plan for this species is a collaboration between WfW, SANBI and South African National Parks.

Without a specific focus on eradication, *A. paradoxa* would have continued to slowly spread through the park (and possibly further afield). However, it is likely that eradication will now be achieved as the necessary resources are in place and there is willingness from all parties involved.[41] The main question remaining is whether our persistence lasts longer than the seedbank, but given the status of Table Mountain as a World Heritage Site, control should continue in perpetuity.

Box 2: The need for early detection and rapid response at a regional scale

Pom-pom weed management in South Africa

Alien plant clearing operations in South Africa have largely been area-based,[4] and, with the exception of classical biological control,[71] there are few species-specific control programmes or national management plans, such as the Australian Weeds of National Significance initiative.[72] In its initial phase, SANBI ISP was tasked with developing and implementing a national plan for a highly visible species that has been spreading rapidly from a localised source: pom-pom weed (*Campuloclinium macrocephalum*). Our remit was to manage outlying populations and work towards a national containment strategy for the species.

Campuloclinium macrocephalum (pom-pom weed) in South Africa is no longer an eradication target and a national management plan integrating local land managers is required.

Pom-pom weed is a South American asteraceous herb that was probably introduced into South Africa in the 1950s as a garden ornamental. It was first recorded as a naturalised weed in the 1960s and was still at low levels well into the 1990s, but over the past 20 years it has spread throughout the grassland biome. Between 2008 and 2010, rapid response teams were contracted to clear all known populations during the flowering season (September–March) at a cost of over R5 million. While this endeavour created work for over 500 people during the flowering season, and reduced populations, there are no documented examples of medium-sized populations (>1 ha) having been extirpated, and, given the rise in sightings,[73] it is clear that the species has continued to spread during this time.

The pom-pom weed case is instructive for several reasons. Firstly, pom-pom weed could probably have been eradicated if action had been taken when it was first detected. Secondly, based on the difficulties of managing control teams across a wide area, a national management plan needs to involve local or regional early detection and rapid response teams that could quickly implement physical control of incipient outlying populations in combination with re-distributing effective biocontrol agents.[74] But finally, pom-pom weed is a lesson for why eradication requires a national focus (Figure 2). The budget spent on pom-pom weed clearing contracts alone was approximately 20% of the total programme's budget, with annual expenditure similar to that predicted for the eradication of other species (Table 1). The focus on pom-pom weed has meant fewer species have been evaluated or targeted for eradication.

In conclusion, for South Africa to implement early detection and rapid response effectively there needs to be capacity and expertise at regional levels and species-specific national strategies with specific and measurable goals. There should also be structures in place to prevent such initiatives from detracting from eradication attempts. Ironically, the diversion of attention onto pom-pom weed might mean the next pom-pom weed can no longer be eradicated.

Proposed mandate and process

SANBI ISP has developed the following mandate, with a work flow as proposed in Figure 3:

- Detection of new invaders: coordinate surveillance for and manage records of new instances of naturalisation
- Post-border risk assessment: evaluate species in enough detail to make a decision as to whether regulation is required and, if so, in what form
- Eradication planning: estimate the feasibility of eradicating species and either develop and implement an eradication plan or recommend a revision in listing

In the rest of the paper we discuss progress on these three core areas of work.

The focus for SANBI ISP is continental South Africa; a separate process of evaluation and eradication is already ongoing for the sub-Antarctic Islands of Prince Edward, Marion and Gough.[19]

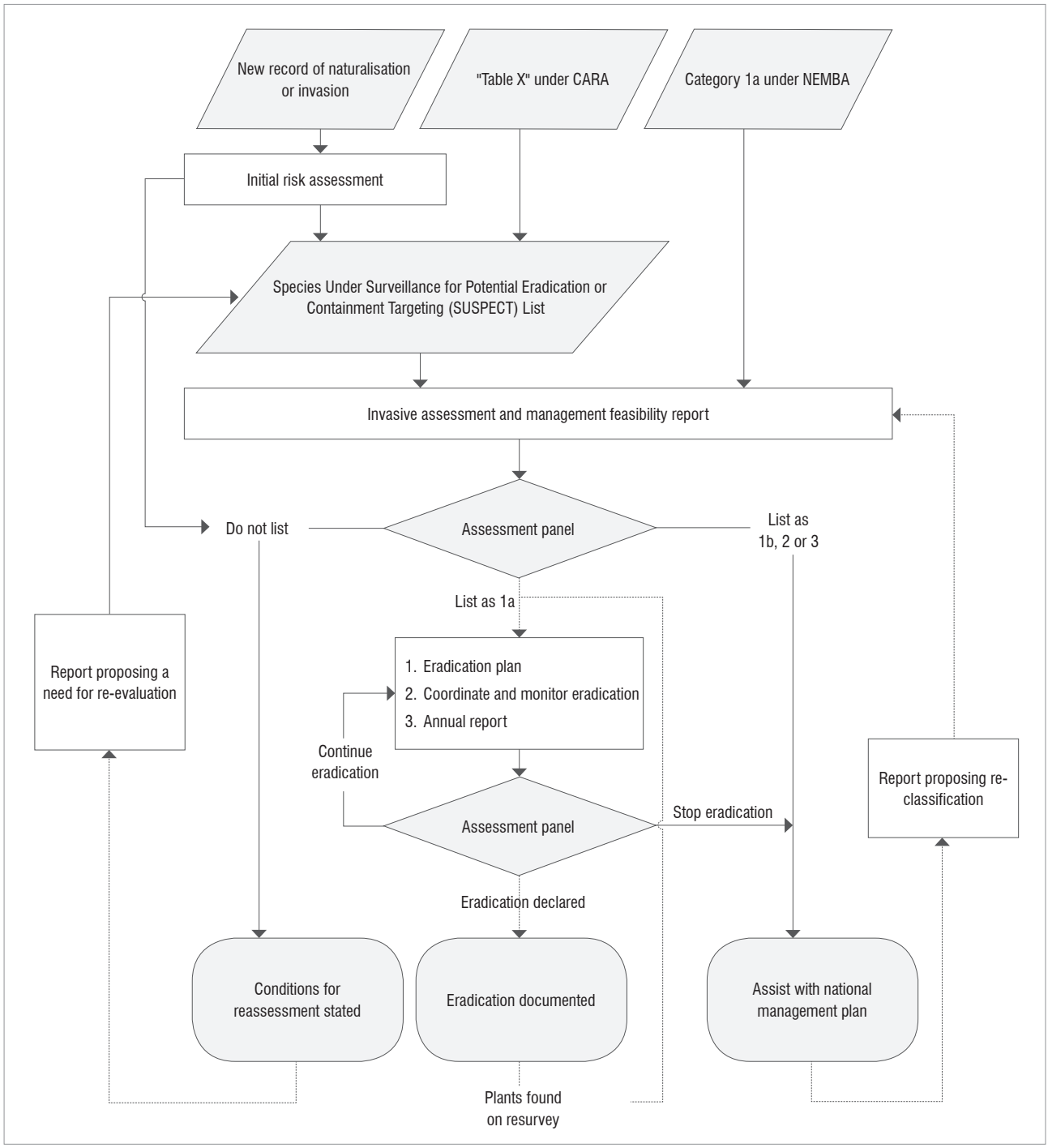
Detecting new invaders

There are several strategic approaches for invasive alien species detection (e.g. site-specific surveys, species-specific surveys and random surveys[20]). For commercial agricultural pests in South Africa there has been both area-specific monitoring (e.g. field inspectors employed to survey farms for pests) and species-specific monitoring (e.g. approximately R2 million per annum is spent on detecting and controlling incursions of the fruit-fly *Bactrocera invadens* from neighbouring countries) (Venter JH 2011, personal communication, Nov 22). But most documented cases of naturalisation or invasion have come from a few interested scientists not employed specifically to look at the issue of invasions.[8,21–24] For example, Giliomee[23] documented a rate of approximately one new insect establishing in South Africa per year over the past decade, while Herbert[24] estimated that there has been one new introduced terrestrial mollusc establishing every 5 years (28 in total since the 1850s).

A recent assessment of marine and estuarine biological introductions showed just how poor our overall knowledge of particular groups is. Through reviewing historical literature, and some limited additional focused survey work, Mead et al.[22] quadrupled the number of known marine introductions to 86 and highlighted several cryptogenic species. In comparison, the naturalised plant flora is well known and documented thanks largely to Lesley Henderson and the SAPIA project.[16] SAPIA was founded on general roadside surveys for invasive alien plants and has grown to be the primary repository for new plant naturalisation records.

Detection efforts by SANBI ISP to date have largely been based on revisiting historical records in SAPIA, but site-specific (e.g. historical arboreta) and species-specific surveys (see Box 1 and Box 2) have been initiated. SAPIA itself has shifted emphasis, and is focusing more on new instances of naturalisation, linking directly with SANBI ISP. For example, 54 new species were recorded as naturalised between April 2010 and March 2013 (Henderson L 2011, unpublished SAPIA annual progress report, March, ibid 2012, ibid 2013). These records are highlighted through SAPIA's quarterly newsletters,[25] increasing the potential to discover other naturalised populations of these species.

The SANBI ISP is using other strategies to engage with the broader community,[26] including distributing pamphlets on all target species (see Supplementary figure 1 online), and providing a dedicated email address for new records (alienplants@sanbi.org.za). Shortfalls of this approach are that hotlines and leaflets lack direct engagement,[27] and that effectiveness is much easier to measure in terms of the amount of information distributed (i.e. number of leaflets) than of impact on the behaviour of the recipients (i.e. the change in the rate with which sightings are reported). This shortfall



CARA, Conservation of Agricultural Resources Act of 1983 *amended 2001; NEMBA,* National Environmental Management: Biodiversity Act (10/2004): Draft Alien and Invasive Species Regulations 2009.

Figure 3: A proposed process for managing new plant invaders. The categories listed are as per the *National Environmental Management: Biodiversity Act (10/2004): Draft Alien and Invasive Species Regulations 2009*[3]. A separate process of evaluation, not described here, is required pre-border and is part of prevention. The success of the programme can be measured by how species are fed through each step of this process.

is partly overcome by linking detection directly to management, and by basing SANBI ISP employees throughout the country with an explicit mandate to develop professional networks of spotters and engage with the broader public. For example, local managers in the southern Cape involved in the eradication of *Acacia stricta* reported several populations that had not been previously identified.[28]

While the SAPIA database continues to provide significant value, SANBI ISP has also focused on improving identification and data management.[29] Of the 198 species listed under the *Conservation of Agricultural Resources Act, 2001* (CARA), as of 2009, 40 did not have herbarium records recorded in the Pretoria Herbarium Computerised Information System (PRECIS), either because specimens were not collected or data had not yet been uploaded. This omission can have direct costs for management. For example, the biological control of Cactaceae has historically been hampered by a lack of accurate taxonomic knowledge that has only been resolved more recently using phylogeographic tools.[30] To address these concerns, three taxonomists and three taxonomy assistants have been employed, and resources provided for the additional 1386 herbarium

samples collected to date. Moreover, the programme has been involved with a drive for the DNA barcoding of introduced taxa. This resulted in 23 postgraduate interns being employed for 6 months in 2011 and 2012 working around the country on different fauna and flora.

Post-border risk assessment

After detection, the decision to prioritise resources and act against a species needs to be based on an evaluation of invasion risk. There are a variety of tools available for pre-border assessments,[31] although arguably such assessments are no better than simply considering prior invasion history and the quality of climate match.[32] Given the uncertainties inherent in the invasion process it has been suggested that risk assessments should become adaptive.[32] Many introduced plants initially have significant value for particular stakeholders and costs are disparate, only accumulating later.[4] Therefore the net value of an introduced taxon can change substantially over time.[33] As such, post-border risk assessments should be done in consultation with relevant stakeholders.

If legislative processes are cumbersome and a particular stakeholder is keen to engage, non-binding agreements can be useful in curbing the threat of invasions. For example, many members of the horticultural industry were involved in developing the St Louis Declaration of 2001[34] (see also Burt et al.[35]). Stakeholders can also be directly involved in the legislative process. For example, the horticultural industry in New Zealand is an active participant in the development and assessment of regulations as part of the National Pest Plant Accord.[36] There is no such similar high-level legislative consultation in South Africa, but comment on proposed regulations is sought. WfW does, however, run a Nurseries Partnership Programme which, amongst other roles, aims to enhance the level of awareness within the nursery industry and the general public of invasive alien plants, their potential impacts and relevant current legislation.

Legislation is a growing component of invasive species management internationally, with 55% of countries signatory to the 1992 Convention on Biological Diversity having invasive alien species relevant national legislation in 2010.[37] Current South African legislation regarding invasive alien plants forms part of the *Conservation of Agricultural Resources Act, 1983*. Regulations 15 and 16 under this act, which concern problem plants, were amended in March 2001; while new regulations have been debated and published in draft,[3] they have yet to be formally published and there are few legal measures in place for controlling problem species that have not previously been regulated under CARA.

As part of CARA, the Agricultural Research Council – Plant Protection Research Institute developed a 12-criteria risk assessment flow diagram for evaluating plant species for regulation. However, the process has not to our knowledge been published and it relies heavily on the expertise of individual assessors, which means it is very difficult to justify the regulatory decisions. As a result, conflicts of interest have arisen when regulated species have an economic value. For example, *Paulownia tomentosa* shows signs of invasion, but a local lobby group has advocated the development of plantations of the species for the production of timber, biofuels and wood pellets for power generation. Consequently, the species was not listed on the CARA regulations but is included on the *National Environmental Management: Biodiversity Act (10/2004): Draft Alien and Invasive Species Regulations, 2009* (NEMBA 2009 draft AIS regulations).[3] Similarly, many species proposed under CARA were removed at a later stage. The act of 2001 lists 198 plant taxa, but a further 101 were included in an unofficial Table X. This table is a list of introduced taxa that posed an identified risk to South Africa's agriculture (or biodiversity), but that either had not been fully assessed or a decision had not been agreed upon by stakeholders. An ongoing concern is that taxa in Table X are not formally assessed, nor are the requirements to keep them on the list stipulated – in essence, the commercial exploitation of taxa in Table X is questioned without any supporting justification.

There are, therefore, three main categories of species that require evaluation (Figure 3):

1. New records of plant introductions or naturalisations
2. Plant taxa that are considered a threat but are not regulated because of lack of information or a conflict of interest (including species originally contained in Table X under CARA; see Supplementary table 1 online, and www.sanbi.org.za/programmes/threats/invasive-species-programme/lists)
3. Plant taxa where nationwide eradication is indicated in national legislation (species listed nationally as category 1a under the NEMBA 2009 draft AIS regulations, see Supplementary table 2 online, and www.sanbi.org.za/programmes/threats/invasive-species-programme/lists)[3]

The number of new naturalisations sensu Pyšek et al.[38] is, of course, not known, and will depend on the effectiveness of detection mechanisms and the number of species that are introduced.

The second category is based on Table X under CARA. To provide some assurances for this list, we propose that all taxa on Table X be added to a new list: the 'Species Under Surveillance – Possible Eradication or Containment Targets' (SUSPECT) list. While the list will have no direct legal inference, it should include species where there is sufficient documented evidence to warrant in-depth investigation. We propose that new additions to the SUSPECT list (in particular new instances of naturalisation) must be accompanied by (1) an initial risk assessment as per article 21 of the NEMBA 2009 draft AIS regulations, (2) a specimen lodged in a South African collection, (3) a short background dossier on life-form and invasive tendencies elsewhere in the world lodged with SANBI and (4) a detailed project plan including information on current regional distribution in South Africa, local-scale distribution for one or more naturalised populations, an assessment of management options and an outline of proposed research. As per chapter 6 of the NEMBA 2009 draft AIS regulations, SANBI will then facilitate an invasive assessment and management feasibility report for each species on the SUSPECT list, and provide recommendations for how the species should be dealt with. These invasive assessment reports would then be assessed by an independent advisory panel, and would form part of the public consultation process.

The third category is a legislative definition. The main problem here is that the NEMBA AIS listing process was not complete as of May 2013. Issues of overlap with CARA and the categories for listing had not been entirely resolved, but we strongly recommend that a category that explicitly calls for nationwide eradication should be included.

Eradication planning

Eradication is the elimination of every single individual (including all seeds and vegetative propagules) of a species from an area to which re-colonisation is unlikely to occur.[39] As a management goal, eradication is one of the few activities regarding invasive species that can lead to permanent improvement in biodiversity indicators,[37] but it has not been considered and implemented as often as it could be.[40,41]

Simberloff[42] outlined five main features of successful eradications: (1) invasions are detected early, and there is little delay before action is taken, (2) sufficient resources are allocated from start to finish, (3) a person or agency has the authority to enforce cooperation, (4) enough research is conducted to identify when, where and how management will be most effective and (5) the project has an energetic, optimistic, and persistent leader.

We know of several plant eradication attempts in South Africa, all initiated by the government, but none of which led to eradication. Intensive programmes were initiated in the early 1960s to remove camel thorn (*Alhagi camelorum*) from irrigation schemes. However, the systemic herbicides available at the time dealt poorly with the extensive underground root systems.[43,44] Satansbos (*Solanum elaeagnifolium)* was first recorded in 1952,[45] but only in 1968 was legislation enacted and an eradication programme initiated.[46] Despite some local successes, by 1972 the eradication campaign was cancelled with the total infested area having reached an estimated 14 500 ha.[47] This failure was ascribed to inadequate biological knowledge, ineffective herbicides and application techniques, and a lack of cooperation from many farmers.[46] The most extensive eradication campaign in South Africa was against

jointed cactus (*Opuntia aurantiaca*).[48] This plant was highlighted as a potential eradication target as early as 1892,[49] but eradication attempts only started much later. Despite legislative backing (e.g. the *Jointed Cactus Eradication Act of 1934*), thousands of labourers and millions of rand spent on herbicides, apparently not a single farm was cleared.[48] More recent efforts (since 1978) to eradicate *Cylindropuntia fulgida* have similarly failed, again probably because of a slow initial response, the lack of efficient follow-up, and ultimately inadequate funding (Zimmermann H 2011, personal communication, Oct 31).

Animal eradication from South Africa has not been much more successful. Eradication of the Himalayan tahr (*Hemitragus jemlahicus*) from Table Mountain (Cape Town) was initiated in 1973, but, despite concerted control efforts during 2004, there have recently been several confirmed sightings (see http://za.ispot.org.uk/node/129992). We are aware of only two successful animal eradications resulting from active eradication programmes. Domestic cats were declared eradicated from Marion Island in 1992 after a substantial 19-year project,[50] and the Mediterranean snail (*Otala punctata* misapplied as *O. lactea*) was eradicated from Cape Town between 1987 and 1989 at an estimated treatment cost of R215 000 (in 1988 prices) for an infestation of ~4 ha.[51] In both cases the resources committed were substantial, follow-up surveys were conducted for many years after the initial effort and there was a dedicated and enthusiastic project leader. As a comparison to the *O. punctata* case, the vermiculate snail (*Eobania vermiculata*) was found in Port Elizabeth (Eastern Cape) in 1987 but eradication efforts were not as aggressive and subsequently failed; the species is now well established at several sites.[51]

Eradication as a management goal for animal invasions has had somewhat of a resurgence recently. Indian house crows (*Corvus splendens*) are being targeted in Cape Town, eThekwini-Durban and Richard's Bay, rabbits (*Oryctolagus cuniculus*) are being removed from Robben Island (Western Cape), and feral pig (*Sus scrofa*) populations are being monitored in the Western Cape – although all of these projects are yet to fully determine whether eradication is likely to succeed. All these projects are striving to be transparent, humane and sensitive to public concerns – a lack of public acceptance for vertebrate control can stop an eradication programme.

Despite the number of failures, there are arguably many instances of successful eradication which have not been properly documented: e.g. red-eared slider terrapins (*Trachemys scripta elegans*) in Cape Town,[52] the decollate snail (*Rumina decolata*)[24] and some invasions from forestry trial plantings.[53] But these are likely interventions that occurred before the species was found at multiple sites or in large numbers.

The failure to eradicate anything more than a few individuals in continental South Africa is, we argue, because (1) new invaders are usually of relatively minor concern at a local scale and just one of many potential targets for resources, (2) invasions often cross administrative boundaries so national priorities might be of less concern locally and vice versa and (3) general clearing operations result in some initial reduction in plant densities but are insufficient to achieve eradication from a particular area.[54–56] We propose that the solution to these concerns is to appoint a national body to oversee and prioritise eradication. Specifically, we propose that eradication planning should be a core part of the mandate of SANBI ISP.

The first challenge faced by SANBI ISP was to demonstrate that eradication is achievable. We attempted to prioritise action based on various criteria (such as number of records in SAPIA and expert opinion). However, invasive taxa in South Africa studied in enough detail to facilitate prioritisation, were too widespread for eradication.[57–59] Therefore, the programme took a pragmatic approach. We targeted species brought to our attention by field experts (e.g. *Opuntia salmiana*), where a project had already been initiated (e.g. *Acacia paradoxa*, Box 1), or where the plants were known to be major invaders elsewhere in the world (e.g. kudzu vine, *Pueraria montana*).

Opuntia salmiana was first detected in 1988 by a Department of Agriculture weed extension officer who recognised the threat of another cactus invasion, and initiated an eradication programme (Farrell E 1989, Department of Agriculture, Land Use and Soil Management unpublished report, May). A lack of resources, and the retirement of the champion, meant the project was shelved. Thankfully, while the infestation has become denser in the two decades since the last eradication attempt, it is confined to two properties so eradication might still be feasible.

Pueraria montana (kudzu vine), was first recorded as invasive in the 1960s by government foresters. As kudzu vine is one of the most widespread and persistent invaders in the USA, probably in part because plants were originally widely redistributed for erosion control and as fodder supplements,[60] the Department of Forestry was concerned enough to invest in an eradication programme. Substantial efforts were made to control the species during the 1970s and early 1980s, but the project ultimately failed (Zimmermann H 2011, personal communication, Oct 31), again because of a lack of persistence in terms of effort and funding, and continuity (in this case the land was taken over by private forestry companies). Recent surveys suggest the original infestations are still present and have not dramatically increased in area. While several additional populations have been identified at different sites around the country, eradication is therefore still probably economically viable.

In all these cases, the feasibility and cost of eradication needs to be determined in the context of other management options.[59,61] For example, if eradication can be quickly assessed and rejected, then other control options, e.g. containment or early adoption of biocontrol, can be prioritised and overall management costs reduced.[62] To assess the cost of standard clearing versus eradication, we first regressed the number of person days spent clearing particular invasive alien plants over the lifetime of WfW[10] against an estimate of area infested from a recent mapping exercise.[63] This exercise showed a tight correlation between the spatial extent of WfW targets and effort spent clearing (Figure 4). We then compared the estimates of effort required for existing eradication programme costs based on detailed mapping exercises for *A. implexa*, *A. paradoxa* and *A. stricta* (Table 1). The eradication costs varied widely, and are largely a function of the biology and location of the invasions – *A. implexa* does not have a large seedbank, only reproduces after several years, and is only found on easily accessible sites, whereas *A. paradoxa* has an extensive seedbank, reproduces at a small size when it is still difficult to detect, and much of the invaded site is steep and covered in native vegetation; *A. stricta* is highly visible along easily accessible forestry plantation roads and has a substantial seedbank. However, in general, eradication requires more effort than normal clearing operations – eradication arguably requires more detailed data so that progress can be assessed and the system managed adaptively, while more intensive management is often required to completely prevent reproduction.[64]

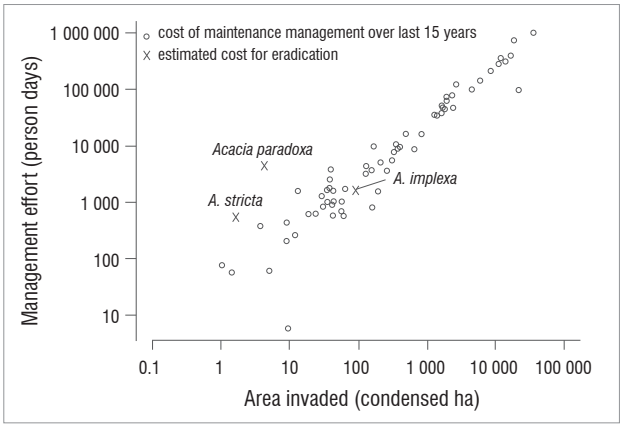


Figure 4: The relationship between the effort spent by the Working for Water Programme (WfW) on alien plant clearing and the size of the infestation (in terms of total condensed canopy). Examples of ongoing eradications of three acacia species are shown. Note the time to eradication will likely be greater than 15 years for these species, and this control represents an additional cost to the area. The measure of condensed canopy area is based on regional extrapolations from a few study sites for the WfW data, and on maps of individual plants for the eradication attempts.

Table 1: Species currently targeted by the South African National Biodiversity Institute's Invasive Species Programme. The information provided is up to date as of May 2013 (including populations identified after a particular reference has been published).

Botanical name	Legal status†	Project status	Number of confirmed naturalised populations and size of infestations (based on an approximate convex hull unless specified)	Estimated costs in terms of net present value in 2012 (initial assessment (IA); full assessment (FA); eradication)	Reference
Acacia fimbriata A.Cunn. ex Don	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	2: both populations in Grahamstown, one of 200 adult trees over ~1 ha, the other of >13 adult trees	IA+FA+ eradication: <R250k over next 25 years	
Acacia implexa Benth.	CARA category 1	Eradication attempt in progress	3: total of 30 000 plants over ~600 ha (convex polygon of individual populations) or ~96 ha (condensed canopy cover): Wolseley – 3556 plants, ~200 ha; Tokai – 1639 plants, ~192 ha; Stellenbosch – 22 978 plants, 99% in ~208 ha on Papegaaiberg	IA+FA: R116k Eradication: R2.2M over next 15 years	75
Acacia paradoxa DC.	CARA category 1	Eradication attempt in progress	1: Table Mountain National Park, ~12 000 plants over ~350 ha (convex polygon) or 0.7 ha (condensed canopy cover)	IA+FA: R200k Eradication: R5.4M over next 20 years	55,61
Acacia retinodes Schltdl.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	1: Tokai, all adults already removed, ~100 seedlings emerged over a small area <1 ha	IA+FA+ eradication: <R50k over next 25 years	
Acacia stricta (Andrews) Willd.	Proposed category 1a under NEMBA	Eradication attempt in progress	9: total of ~20 000 plants over ~110 ha (convex polygon of individual populations) or ~1.7 ha (condensed canopy cover) – all within a 50-km radius of Knysna in the Western Cape	IA+FA: R285k Eradication: R1M over next 25 years	28
Acacia viscidula Benth.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	1: Newlands Forest, <100 adult plants over ~5 ha	IA+FA+ eradication: <R250k over next 25 years	
Anigozanthos flavidus DC. *Anigozanthos rufus* Labill. and hybrids between them	None – added to SUSPECT list	Risk assessment and delimitation	6: Cape Peninsula, Kleinmond, Honingklip farm, Blomkloof (<20 ha each)	IA: R10k Initial management of three populations: R55k	76
Asphodelus fistulosus L.	None – added to SUSPECT list	Risk assessment and delimitation	5: West coast, all populations <100 m^2, disturbed roadsides in deep sandy soils	IA: <R100k	77
Banksia ericifolia L.f.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	5: Waterford, Agulhas National Park, ~10 000 plants over 150 ha with monocultures in ~5 ha; other populations nearby (furthest in McGregor), but none more than a few hundred adult plants	IA+FA: <R100k Initial management towards eradication: ~R80k	13
Berberis julianae Schneid.	None – added to SUSPECT list	Risk assessment and delimitation	>6: North West (Potchefstroom), Free State (Golden Gate Highlands Nature Reserve and Platberg Nature Reserve), and KwaZulu-Natal (Underberg) with high possibilities in Lesotho and the Western Cape	IA+FA 2012–2015: ~R400k	
Campuloclinium macrocephalum DC.	CARA category 1	Containment, biological control research and implementation	Not known precisely but likely >10 000; records from ~100 distinct quarter-degree cells (SAPIA Jan 2012) in five provinces. Found along road verges and transport routes	Containment activities 2012–2013: ~R10M (see Box 2)	
Crotalaria agatiflora Schweinf.	Proposed category 1a under NEMBA	Risk assessment, delimitation and eradication planning	~122: ~100 in Gauteng, 12 in Mpumalanga, 6 in KwaZulu-Natal, 4 in Limpopo. Populations range from 1–40 seedlings to 150–300 big plants. Found along road verges, riparian areas, dump sites and abandoned sites	IA+FA: >R200k Initial management 2012–2013: ~R42k	
Cylindropuntia fulgida (Engelm.) F.M. Knuth *var. mamillata* (Schott ex Engelm.) Backeb.	CARA category 1 (listed as *Cylindropuntia fulgida*, i.e. all varieties)	Delimitation and containment	116: 109 in Northern Cape over 27 514 ha, 7 in Eastern Cape over 338 ha, some reports from the Western Cape to be confirmed	Surveys and containment activities up to March 2013: R870k	
Cylindropuntia pallida (Rose) F.M.Knuth	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	7: Eastern Cape over 585 ha, other reports to be confirmed including five reports from the Northern Cape	IA+FA+ initial management: R75k	
Diplocyclos palmatus (L.) C.Jeffrey	Proposed category 1a under NEMBA	Risk assessment and delimitation	12: all populations in KwaZulu-Natal in Pietermaritzburg and Kloof	IA: <R20k	
Epipremnun aureum (Linden & Andre)	None – added to SUSPECT list	Risk assessment and delimitation	6: all in KwaZulu-Natal, small populations 0.01–0.04 ha, from improper dumping of garden refuse	IA: <50k	
Furcraea foetida (L.) Haw.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	75: 50 in KwaZulu-Natal, 10 in Eastern Cape, 10 in Western Cape and 5 in Mpumalanga. Populations range from one individual plant to 3000 plants with numerous bulbils	Initial management in KwaZulu-Natal 2012–2013: R163k	
Genista monspessulana (L.) O.Bolós & Vigo	Proposed category 1a under NEMBA	Eradication attempt in progress	3: Tokai – 400 plants, 0.71 ha; Klein Constantia – 5100 plants, 0.6 ha; Ceres – 1460 plants 0.57 ha	IA+FA: <R100k Eradication: R80k over next 10 years	78
Harrisia balansae (K. Schumann) N.P. Taylor & Zappi	None – added to SUSPECT list	Risk assessment and delimitation	3: over about four farms in Groot Marico, North West Province	IA+FA: <R20k Initial management 2012–2013: R42k	

Continued on next page

Botanical name	Legal status†	Project status	Number of confirmed naturalised populations and size of infestations (based on an approximate convex hull unless specified)	Estimated costs in terms of net present value in 2012 (initial assessment (IA); full assessment (FA); eradication)	Reference
Harrisia pomanensis (F. A. C. Weber) Britton & Rose	None added to SUSPECT list	Risk assessment and delimitation	8: populations are on 8 farms between Maastroom & Alldays, in Limpopo Province	IA+FA: ~R30k	
Hydrilla verticillata (L. f.) Royle	Proposed category 1a under NEMBA	Monitoring and containment, biological control assessment underway	1: 600 ha at height of infestation on Pongolapoort Dam (KwaZulu-Natal, Swaziland and South African border), the infestation has declined naturally since then	IA 2010–2013: R217k Biocontrol research and chemical trials 2010–2013: R269k	
Hydrocleys nymphoides (Humb. & Bonpl. Ex Wild)	Proposed category 1a under NEMBA	Risk assessment and delimitation	1: 0.5 ha infestation from a pond in St Joseph's College, Howick KwaZulu-Natal	IA: <R10k	
Hypericum pseudohenryi N.Robson	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	>100: spread over ~8000 km^2 in KwaZulu-Natal; uKhahlamba Drakensberg Park (Sani Pass, Lower Sani Pass, Kamberg, Giant's Castle, Monk's Cowl); Mount West; Karkloof; and scattered throughout KwaZulu-Natal Midlands; Hogsback in Eastern Cape	IA+FA+ initial management 2010–2013: R1.6M	
Iris pseudacorus L.	Proposed category 1a under NEMBA	Risk assessment, delimitation and eradication planning	11: 8 in Gauteng; 1 in Mpumalanga; 3 in KwaZulu-Natal. Found along watercourses	IA 2010–2013: <R20k	
Lythrum salicaria L.	CARA category 1	Eradication attempt in progress	7: along an ~8-km stretch of the Liesbeeck River in Cape Town; total infested area is ~2.4 ha	IA+FA: R133k Initial management 2010–2013: R302k	
Melaleuca hypericifolia Sm.	Proposed category 1a under NEMBA	Risk assessment, delimitation and eradication planning	2: Hout Bay population spread over 8 ha; Kleinmond ~100 plants over 0.5 ha	Initial management 2012–2013: R75k	
Melaleuca parvistaminea Byrnes	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	~2: Waterval Nature Reserve and Kluitjiekraal wetland. Total area affected is in the range 500–1000 ha	IA+FA: R150k Initial management 2010–2013: R750k Eradication: R1.6M over next 7 years	79
Melaleuca quinquenervia (Cav.) S.T.Blake	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	3: Wolseley – ~265 plants and 50 seedlings ~0.3 ha; Tokai Arboretum – ~9 trees from 12 planted individuals, ~0.1 ha; Kranzkloof Nature Reserve, Durban – only one confirmed individual but historical reports of a substantial infestation	IA+FA and initial management of Tulbagh population 2009–2013: ~R600k	
Mimosa albida Humb. & Bonpl. ex Willd.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	1: 61 plants along the Mkhomazi River near Richmond in the KwaZulu-Natal midlands	IA: R20k	
Opuntia salmiana J.Parm. ex Pfeiff.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	3: Brits area (Wagpos), North West Province, in total <5 ha. Found mostly under the canopy of trees and in tall grasses	IA 2010–2013: <R20k Initial management 2010–2013: R200k	
Paspalum quadrifarium Lam.	Proposed category 1a under NEMBA	Risk assessment and delimitation	1: Melmoth forest plantations, KwaZulu-Natal, 15 individuals clustered together in an impenetrable clump along a river, and some plants recruiting in shallow soil in the riverbed	IA: R20k	
Petiveria alliacea L.	None – added to SUSPECT list	Risk assessment, delimitation, and eradication planning	1: 869 plants across two city blocks in Durban	IA: R1.4k	80
Pueraria montana var. *lobata* (Willd.) Maesen & S.M.Almeida ex Sanjappa & Pradeep	Proposed category 1a under NEMBA	Eradication attempt in progress	4: 55 ha in Mpumalanga; 1 small population in Cedara, KwaZulu-Natal; 1 in Limpopo; and 1 in Mamelodi, Gauteng, ~1 ha	IA+FA: <R50k Initial management 2010–2013: R3.6M	
Rivina humilis L.	CARA category 1	Risk assessment and delimitation	>10: 10 in KwaZulu-Natal, some records from Gauteng and Eastern Cape	IA: <R20k	
Sagittaria latifolia Willd.	None – added to SUSPECT list	Risk assessment, delimitation, and eradication planning	1: small population in KwaZulu-Natal, ~0.02 ha	IA: R5k	
Sagittaria platyphylla (Engelm.) J. G. Sm.	None – added to SUSPECT list	Risk assessment, delimitation and eradication planning	10: in three provinces, all infestations 0.1–2 ha	IA+FA: R685k Initial management: R90k	
Spartinia alterniflora Loisel.	None – added to SUSPECT list	Eradication attempt in progress	1: Great Brak Estuary, Western Cape – 1 ha in the salt marsh, sand- and mudflat	IA+FA+ initial management 2007–2013: R128k	81
Tephrocactus articulatus (Pfeiff.) Backeb.	Proposed category 1a under NEMBA	Risk assessment, delimitation and eradication planning	>5: populations in Northern, Eastern and Western Cape Provinces	IA+FA: <R100k Initial management: R75k	
Triplaris americana L.	CARA category 1	Risk assessment, delimitation and eradication planning	Various: only detected in KwaZulu-Natal, <200 trees detected in total, with naturalised populations in five suburbs of Durban	IA+FA: R330k Initial management 2009–2013: R600k	

†*Species listed under the* Conservation of Agricultural Resources Act, of 1983, *amended 2001(CARA) were also included in the* National Environmental Management: Biodiversity Act 2009 Draft Alien Invasive Species Regulations *(NEMBA), but species recorded here as 'Proposed category 1a under NEMBA' were not previously listed under CARA. Under NEMBA 2009, category 1a species require compulsory control, i.e. eradication, whereas category 1b species are controlled as part of an invasive species control programme. The SUSPECT (Species Under Surveillance – Possible Eradication or Containment Targets) list refers to species that have been identified as potential risks but are not listed under either CARA or NEMBA (see Supplementary table 1 online).*

Finally, both for determining eradication cost-effectiveness and prioritising between eradication targets, the benefits to be gained through control need to be included. For example, *A. paradoxa* is invading and outcompeting natural vegetation on a World Heritage Site and so has by far the highest current biodiversity impact of any of the wattles assessed for eradication to date, although the population is relatively small and will be costly to manage.

Conclusions

Invasive taxa in South Africa are usually only managed once they are widespread. Incursions are detected too late, there is a substantial delay between the perception of a problem and both on-ground management and legislative change and eradication is not carried through to completion because of poor planning. Initial estimates of eradication costs relative to standard WfW operations vary markedly. It is costly to remove low density infestations that are hard to detect in areas with poor accessibility, but, in some cases, with greater precision and coordination, eradication need not be much more expensive than standard clearing.

As for species of conservation concern,[65] listing invasive species can have significant political and economic consequences, so risk assessments need to be transparent and evidence based (e.g. combining field data observations, research on species attributes and relevant literature; Figure 3). Data therefore needs to be stored in a way that can be used for legal cases when necessary. Any such data and decisions should be documented and published, and the decisions implemented. Given that legislation should link to management goals, such risk assessments will also need to consider on-ground management (e.g. eradication feasibility, Box 1).

For these reasons, SANBI ISP was set up to improve detection rates, perform post-border risk assessments and coordinate nationwide eradication attempts. Similar organisations have been proposed around the world (such as in Europe[66]), but we believe South Africa is the first country to have a unit specifically dedicated to these tasks. To date, full risk assessments are being developed for 39 species and eradication plans are being implemented against seven species (Table 1). But ultimately, the success of SANBI ISP depends on research, implementation, public engagement, and regulation being administered and conducted as a single iterative process. While such effort is difficult to coordinate[67] and raises many issues (see Box 3), we believe that by combining adaptive management and applied research, it is possible to reduce the number of

Box 3: Key issues in invasive species detection, evaluation and eradication planning

While progress has been achieved on a number of species (Table 1), the work to date has highlighted several key issues that need to be addressed. Here we outline a few of these with the aim of setting a preliminary research agenda (see also Panetta et al.[59]).

Detection

- A transparent watch list should be developed so that processes can be implemented to prevent high-risk species from being introduced, and to quickly detect those that are introduced.
- Information sources on species that are already in the country need to be assessed and collated to identify records that need verification and identify species that need further evaluation.
- Sites where there is a high likelihood of naturalisation need to be identified so that monitoring can be targeted.
- A process is needed to record, verify and act upon observations from the general and professional public to ensure observers feel valued and are more likely to submit records, thereby increasing the rates of detection.
- Systems are required to identify unknown taxa more quickly to reduce reaction time.
- It is often unclear whether a record is actually an alien. Standard processes are needed to resolve issues of origin (native or introduced), so that control and legislation can be implemented timeously.

Evaluation

- Species identified as requiring evaluation or eradication need to be prioritised for detection across the country.
- Standard metrics need to be set for reporting the abundance and extent of infestations.
- Standard protocols are required for determining the area that needs to be searched and how populations should be delimited at a landscape scale.
- Tools are required to estimate the rate of population growth and spread of newly introduced species in order to estimate the threat posed and where to search.
- The abiotic or biotic factors limiting population size and spread rates should be identified if future risks are to be predicted and any lag phases should be identified and quantified.
- A formalised process for assessing risk, which includes consultation with stakeholders, is needed.
- The regulatory process for listing or changing the status of listed species needs to be made explicit and timeous.
- Standard procedures are required to determine the relative invasiveness and stability of cultivars or hybrids in comparison to parental species, in particular to provide advice to horticulturalists.
- Procedures are needed for determining the potential for and detection of hybridisation between introduced taxa and native taxa.

Eradication

- Standard metrics for measuring progress towards eradication, with procedures to collect and collate relevant field data, are needed.
- A protocol is required to estimate the efficacy of management, specifically the rate of detection in relation to likelihood of reproduction between control operations.
- The likely maximum propagule persistence should be estimated to determine the duration of control operations.
- Standard procedures for estimating the time to eradication, which can be easily updated as new field observations are made, are needed.
- A process is needed for determining the costs of different actions and thereby the benefits of opting for a strategy of eradication.
- A strategy for deciding when to declare the eradication unsuccessful (and if so how the species will be controlled post-eradication attempt) should be determined early for each attempted eradication.
- It should be specified and made clear that the government should take financial responsibility for eradication attempts.
- A process for gaining access to private property, if it is required for eradication, needs to be set in place.
- The efficacy (financial and likelihood of success) of different management approaches needs to be assessed.
- A process is required to ensure herbicides are available timeously with due consideration for potential negative consequences. Similarly, a process is needed to ensure any animal eradication is conducted ethically.

new naturalisations and invasions; we are confident that in this way we can reduce (South) Africa's invasion debt (sensu Essl et al.[68]).

Acknowledgements

This work was funded by the South African Working for Water Programme of the Department of Environmental Affairs. J.R.U.W. acknowledges support from the DST-NRF Centre of Excellence for Invasion Biology. All current and past staff of SANBI ISP contributed valuable insights, discussion and enthusiasm. Sjirk Geerts, Di Spear and John Moore provided useful comments and Sjirk Geerts assisted with the analysis in Figure 4.

Authors' contributions

All authors contributed to the conceptual development of the paper; J.R.U.W. led the writing.

References

1. De Lange WJ, Van Wilgen BW. An economic assessment of the contribution of biological control to the management of invasive alien plants and to the protection of ecosystem services in South Africa. Biol Invasions. 2010;12(12):4113–4124. http://dx.doi.org/10.1007/s10530-010-9811-y
2. Van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manag. 2008;89(4):336–349. http://dx.doi.org/10.1016/j.jenvman.2007.06.015
3. South African Department of Environmental Affairs and Tourism. National Environmental Management: Biodiversity Act (10/2004): Draft Alien and Invasive Species Regulations, 2009. Pretoria: Government Gazette; 2009.
4. Van Wilgen BW, Dyer C, Hoffmann JH, Ivey P, Le Maitre DC, Moore JL, et al. National-scale strategic approaches for managing introduced plants: Insights from Australian acacias in South Africa. Divers Distrib. 2011;17(5):1060-1075. http://dx.doi.org/10.1111/j.1472-4642.2011.00785.x
5. Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, Jarošík V, et al. A proposed unified framework for biological invasions. Trends Ecol Evol. 2011;26:333–339. http://dx.doi.org/10.1016/j.tree.2011.03.023
6. Moore JL, Rout TM, Hauser CE, Moro D, Jones M, Wilcox C, et al. Protecting islands from pest invasion: Optimal allocation of biosecurity resources between quarantine and surveillance. Biol Conserv. 2010;143(5):1068–1078. http://dx.doi.org/10.1016/j.biocon.2010.01.019
7. Leung B, Lodge DM, Finnoff D, Shogren JF, Lewis MA, Lamberti G. An ounce of prevention or a pound of cure: Bioeconomic risk analysis of invasive species. P Roy Soc B Bio. 2002;269(1508):2407–2413. http://dx.doi.org/10.1098/rspb.2002.2179
8. Van Wilgen NJ, Wilson JRU, Elith J, Wintle BA, Richardson DM. Alien invaders and reptile traders: What drives the live animal trade in South Africa? Anim Conserv. 2010;13(S1):24–32.
9. Griffiths C, Picker M. Alien and invasive animals: A South African perspective. Cape Town: Struik Nature; 2011.
10. Van Wilgen BW, Forsyth GG, Le Maitre DC, Wannenburgh A, Kotzé JD, Van den Berg E, et al. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. Biol Conserv. 2012;148(1):28–38. http://dx.doi.org/10.1016/j.biocon.2011.12.035
11. Klein H. A catalogue of the insects, mites and pathogens that have been used or rejected, or are under consideration, for the biological control of invasive alien plants in South Africa. Afr Entomol. 2011;19(2):515–549. http://dx.doi.org/10.4001/003.019.0214
12. Procheş Ş, Wilson JRU, Richardson DM, Rejmánek M. Native and naturalized range size in *Pinus*: Relative importance of biogeography, introduction effort and species traits. Global Ecol Biogeogr. 2012;21(5):513–523. http://dx.doi.org/10.1111/j.1466-8238.2011.00703.x
13. Geerts S, Moodley D, Gaertner M, Le Roux JJ, McGeoch MA, Muofhe C, et al. The absence of fire can cause a lag phase – the invasion dynamics of *Banksia ericifolia* (Proteaceae). Austral Ecol. In press 2013.
14. Kowarik I. Time lags in biological invasions with regard to the success and failure of alien species. In: Pyšek P, Prach K, Rejmanek M, Wade M, editors. Plant invasions: General aspects and special problems. Amsterdam: SPB Academic Publishing; 1995. p. 15–38.
15. Caley P, Groves RH, Barker R. Estimating the invasion success of introduced plants. Divers Distrib. 2008;14(2):196–203. http://dx.doi.org/10.1111/j.1472-4642.2007.00440.x
16. Henderson L. Southern African plant invaders atlas (SAPIA). Appl Plant Sci. 1998;12:31–32.
17. Conservation of Agricultural Resources Act of 1983, No. R. 280, Department of Agriculture, editor, amended 2001.
18. Richardson DM, Wilson JR, Weyl OLF, Griffiths CL. South Africa: Invasions. In: Simberloff D, Rejmánek M, editors. Encyclopedia of biological invasions. Berkeley and Los Angeles: University of California Press; 2011. p. 643–651.
19. Department of Environmental Affairs and Tourism, South Africa. Environmental outlook: A report on the state of the environment. Pretoria: DEAT; 2006. p. 371.
20. Wittenberg R, Cock MJW, editors. Invasive alien species: A toolkit of best prevention and management practices. Wallingford, Oxon: CAB International; 2001. http://dx.doi.org/10.1079/9780851995694.0000
21. Plisko JD. Megadrile earthworm taxa introduced to South African soils (Oligochaeta: Acanthodrilidae, Eudrilidae, Glossoscolecidae, Lumbricidae, Megascolecidae, Ocnerodrilidae). Afr Invertebr. 2010;51(2):289–312. http://dx.doi.org/10.5733/afin.051.0204
22. Mead A, Carlton JT, Griffiths CL, Rius M. Revealing the scale of marine bioinvasions in developing regions: A South African re-assessment. Biol Invasions. 2011;13(9):1991–2008. http://dx.doi.org/10.1007/s10530-011-0016-9
23. Giliomee JH. Recent establishment of many alien insects in South Africa – A cause for concern. Afr Entomol. 2011;19(1):151–155. http://dx.doi.org/10.4001/003.019.0105
24. Herbert DG. The introduced terrestrial Mollusca of South Africa. SANBI Biodiversity Series 15. Pretoria: South African National Biodiversity Institute; 2010.
25. Agricultural Research Council. News articles: SAPIA News [homepage on the Internet]. No date [updated 2013 May; cited 2013 May 13]. Available from: http://www.arc.agric.za/home.asp?pid=1&toolid=2&sec=1001.
26. Morton J. National Weed Incursion Plan: Preparedness and response guidelines for weed managers. Brisbane: Department of Primary Industries and Fisheries; 2008.
27. Kruger H, Thompson L, Clarke R, Stenekes N, Carr A. Engaging in biosecurity: Gap analysis. Canberra: Australian Government: Bureau of Rural Sciences; 2009. p. 39.
28. Kaplan H. Assessing the invasiveness of *Acacia stricta* and *Acacia implexa*: Is eradication an option? [MSc thesis]. Stellenbosch: Stellenbosch University; 2012. p. 107.
29. McGeoch MA, Spear D, Kleynhans EJ, Marais E. Uncertainty in invasive alien species listing. Ecol Appl. 2012;22(3):959–971. http://dx.doi.org/10.1890/11-1252.1
30. Paterson ID, Hoffmann JH, Klein H, Mathenge CW, Neser S, Zimmermann HG. Biological control of Cactaceae in South Africa. Afr Entomol. 2011;19(2):230–246. http://dx.doi.org/10.4001/003.019.0221
31. Pheloung PC, Williams PA, Halloy SR. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. J Environ Manag. 1999;57(4):239–251. http://dx.doi.org/10.1006/jema.1999.0297
32. Hulme PE. Weed risk assessment: A way forward or a waste of time? J Appl Ecol. 2012;49:10–19. http://dx.doi.org/10.1111/j.1365-2664.2011.02069.x
33. Shackleton CM, McGarry D, Fourie S, Gambiza J, Shackleton SE, Fabricius C. Assessing the effects of invasive alien species on rural livelihoods: Case examples and a framework from South Africa. Hum Ecology. 2007;35(1):113-127. http://dx.doi.org/10.1007/s10745-006-9095-0
34. Fay K. The St Louis Declaration on Invasive Plant Species, a product of the workshop on linking ecology and horticulture to prevent plant invasions [homepage on the Internet]. c2003 [cited 2013 May 13]. Available from: http://www.fleppc.org/FNGA/St.Louis.htm

35. Burt JW, Muir AA, Piovia-Scott J, Veblen KE, Chang AL, Grossman JD, et al. Preventing horticultural introductions of invasive plants: Potential efficacy of voluntary initiatives. Biol Invasions. 2007;9:909–923. http://dx.doi.org/10.1007/s10530-007-9090-4

36. Newfield MJ, Champion PD. Risk assessment for the New Zealand National Pest Plant Accord: Which species should be banned from sale? Plant Protection Q. 2010;25(2):75–78.

37. McGeoch MA, Butchart SHM, Spear D, Marais E, Kleynhans EJ, Symes A, et al. Global indicators of biological invasion: Species numbers, biodiversity impact and policy responses. Divers Distrib. 2010;16(1):95–108. http://dx.doi.org/10.1111/j.1472-4642.2009.00633.x

38. Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J. Alien plants in checklists and floras: Towards better communication between taxonomists and ecologists. Taxon. 2004;53:131–143. http://dx.doi.org/10.2307/4135498

39. Myers JH, Savoie A, Van Randen E. Eradication and pest management. Ann Rev Entomol. 1998;43:471–491. http://dx.doi.org/10.1146/annurev.ento.43.1.471

40. Wilson JRU, Gairifo C, Gibson MR, Arianoutsou M, Bakar BB, Baret S, et al. Risk assessment, eradication, and biological control: Global efforts to limit Australian acacia invasions. Divers Distrib. 2011;17(5):1030–1046. http://dx.doi.org/10.1111/j.1472-4642.2011.00815.x

41. Simberloff D. We can eliminate invasions or live with them. Successful management projects. Biol Invasions. 2009;11:149–157. http://dx.doi.org/10.1007/s10530-008-9317-z

42. Simberloff D. Eradication – preventing invasions at the outset. Weed Sci. 2003;51(2):247–253. http://dx.doi.org/10.1614/0043-1745(2003)051[0247:EPIATO]2.0.CO;2

43. Erasmus DJ, Viljoen BD. Screening and sequential application of herbicides for the control of *Alhagi camelorum* Fisch. Report for the Department of Agriculture, Directorate Resource Conservation. Pretoria: ARC; 1993.

44. Jooste WJ. Experiments on the chemical control of *Alhagi camelorum* Fisch. S Afr J Agr Sci. 1965;8:287–288.

45. Henderson M, Anderson JG. Common weeds in South Africa. Pretoria: Botanical Research Institute, Department of Agricultural Technical Services; 1966. p. 276–277.

46. Wasermann VD, Zimmermann HG, Neser S. The weed silverleaf bitter apple ('Satansbos') (*Solanum elaeagnifolium* Cav.). Technical Communication No 214. Pretoria: Department of Agriculture and Water Supply; 1988. p. 1–10.

47. Hattingh ID. Verspreiding, bestryding en navorsing ten opsigte van *Solanum elaeagnifolium* Cav. [Distribution, control and research on *Solanum elaeagnifolium* Cav.] [unpublished report]. Pretoria: Department of Agricultural Technical Services; 1972. Afrikaans.

48. Moran VC, Annecke DP. Critical reviews of biological pest control in South Africa: 3. jointed cactus, *Opuntia aurantiaca* Lindley. J Entomol Soc S Afr. 1979;42(2):299–329.

49. Fischer A. New cactus (prickly pear). Agri J Cape of Good Hope. 1892;5:93–94.

50. Bester MN, Bloomer JP, Van Aarde RJ, Erasmus BH, Van Rensburg PJJ, Skinner JD, et al. A review of the successful eradication of feral cats from sub-Antarctic Marion Island, Southern Indian Ocean. S Afr J Wildlife Research. 2002;32(1):65–73.

51. Herbert DG, Sirgel WF. The recent introduction of two potentially pestiferous alien snails into South Africa and the outcomes of different pest management practices: An eradication and a colonization. S AfrJ Sci. 2001;97(7/8):301-304.

52. Picker M, Griffiths C. Alien and invasive animals: A South African perspective. Cape Town: Struik Nature; 2011.

53. Poynton RJ. Tree planting in southern Africa: vol. 3 other genera. Pretoria: Department of Agriculture, Forestry, and Fisheries; 2009.

54. Witkowski ETF, Garner RD. Seed production, seed bank dynamics, resprouting and long-term response to clearing of the alien invasive *Solanum mauritianum* in a temperate to subtropical riparian ecosystem. S Afr J Bot. 2008;74(3):476–484. http://dx.doi.org/10.1016/j.sajb.2008.01.173

55. Zenni R, Wilson JRU, Le Roux JJ, Richardson DM. Evaluating the invasiveness of *Acacia paradoxa* in South Africa. S Afr J Bot. 2009;75:485–496. http://dx.doi.org/10.1016/j.sajb.2009.04.001

56. Braack AM. An evaluation of the management of the invasive alien plant *Lilium formosanum* (Wallace) in the province of KwaZulu-Natal, South Africa [MSc thesis]. Bloemfontein: Centre for Environmental Management, University of the Free State; 2011. p. 62.

57. Mgidi TN, Le Maitre DC, Schonegevel L, Nel JL, Rouget M, Richardson DM. Alien plant invasions – incorporating emerging invaders in regional prioritization: A pragmatic approach for Southern Africa. J Environ Manage. 2007;84(2):173–187. http://dx.doi.org/10.1016/j.jenvman.2006.05.018

58. Nel JL, Richardson DM, Rouget M, Mgidi TN, Mdzeke N, Le Maitre DC, et al. A proposed classification of alien plant species in South Africa: Towards prioritizing species and areas for management action. S Afr J Sci. 2004;100:53–64.

59. Panetta FD, Csurhes S, Markula A, Hannan-Jones M. Predicting the cost of eradication for 41 Class 1 declared weeds in Queensland. Plant Protection Q. 2011;26(2):42–46.

60. Guertin P, Denight M, Gebhart DL, Nelson L. Invasive species biology, control and research: Part 1: Kudzu (*Pueraria montana*). Final report TR-08-10. Washington DC: US Army Corps of Engineers; 2008.

61. Moore JL, Runge MC, Webber BL, Wilson JRU. Contain or eradicate? Optimizing the management goal for Australian acacia invasions in the face of uncertainty. Divers Distrib. 2011;17(5):1047–1059. http://dx.doi.org/10.1111/j.1472-4642.2011.00809.x

62. Olckers T. Targeting emerging weeds for biological control in South Africa: The benefits of halting the spread of alien plants at an early stage of their invasion. S Afr J Sci. 2004;100(1):64–68.

63. Kotzé JDF, Beukes BH, Van den Berg EC, Newby TS. National Invasive Alien Plant Survey. Report number GW/A/2010/21. Pretoria: Agricultural Research Council Institute for Soil, Climate and Water; 2010.

64. Panetta FD, Cacho O, Hester S, Sims-Chilton N, Brooks S. Estimating and influencing the duration of weed eradication programmes. J Appl Ecol. 2011;48(4):980–988. http://dx.doi.org/10.1111/j.1365-2664.2011.02000.x

65. Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akcakaya HR, Leader-Williams N, et al.. Quantification of extinction risk: IUCN's system for classifying threatened species. Conserv Biol. 2008;22(6):1424–1442. http://dx.doi.org/10.1111/j.1523-1739.2008.01044.x

66. Hulme PE, Pyšek P, Nentwig W, Vilá M. Will threat of biological invasions unite the European Union? Science. 2009;324(5923):40–41. http://dx.doi.org/10.1126/science.1171111

67. Al-Khatib K, DiTomaso JM. Stages in the development of an Early Detection and Rapid Response (EDRR) program for invasive alien plants in California. In: Brunel S, Uludag A, Fernandez-Galiano E, Brundu G, editors. 2nd international workshop on invasive plants in the Mediterranean type regions of the world; 2010 August 2–6; Trabzon, Turkey. Trabzon: European Environment Agency; 2012. p. 168–174.

68. Essl F, Dullinger S, Rabitsch W, Hulme PE, Hulber K, Jarošík V, et al.. Socioeconomic legacy yields an invasion debt. Proc Natl Acad Sci USA. 2011;108(1):203–207. http://dx.doi.org/10.1073/pnas.1011728108

69. Wilson JR, Kaplan H, De Kock C, Mazibuko D, De Smidt J, Zenni RD, et al. Assessment and attempted eradication of Australian acacias in South Africa as part of an EDRR programme. In: Brunel S, Uludag A, Fernandez-Galiano E, Brundu G, editors. 2nd International workshop on invasive plants in the Mediterranean type regions of the world; 2010 August 2–6; Trabzon, Turkey. Trabzon: European Environment Agency; 2012. p. 206–212.

70. Le Maitre DC, Gaertner M, Marchante E, Ens EJ, Holmes PM, Pauchard A, et al. Impacts of invasive Australian acacias: Implications for management and restoration. Divers Distrib. 2011;17(5):1015–1029. http://dx.doi.org/10.1111/j.1472-4642.2011.00816.x

71. Zimmermann HG, Moran VC, Hoffmann JH. Biological control in the management of invasive alien plants in South Africa, and the role of the Working for Water programme. S Afr J Sci. 2004;100(1/2):34–40.

72. Thorp JR, Lynch R. The determination of weeds of national significance. Launceston: National Weeds Strategy Executive Committee; 2000.

73. Henderson L. Mapping of invasive alien plants: The contribution of the Southern African Plant Invaders Atlas (SAPIA) to biological weed control. Afr Entomol. 2011;19(2):498–503. http://dx.doi.org/10.1111/j.1472-4642.2011.00816.x

74. McConnachie AJ, Retief E, Henderson L, McKay F. The initiation of a biological control programme against pompom weed, *Campuloclinium macrocephalum* (Less.) DC. (Asteraceae), in South Africa. Afr Entomol. 2011;19(2):258–268. http://dx.doi.org/10.4001/003.019.0217

75. Kaplan H, Van Zyl HWF, Le Roux JJ, Richardson DM, Wilson JRU. Distribution and management of *Acacia implexa* (Benth.) in South Africa: A suitable target for eradication? S Afr J Bot. 2012;83:23–35. http://dx.doi.org/10.1016/j.sajb.2012.07.016

76. Le Roux JJ, Geerts S, Ivey P, Krausse S, Richardson DM, Suda J, et al.. Molecular systematics and ecology of invasive kangaroo paws in South Africa: Management implications for a horticulturally important genus. Biol Invasions. 2010;12:3989–4002.

77. Boatwright JS. *Asphodelus fistulosus* (Asphodelaceae, Asphodeloideae), a new naturalised alien species from the West Coast of South Africa. S Afr J Bot. 2012;79:48–50. http://dx.doi.org/10.1016/j.sajb.2013.03.019

78. Geerts S, Botha PW, Visser V, Richardson DM, Wilson JRU. Montpellier broom (*Genista monspessulana*) and Spanish broom (*Spartium junceum*) in South Africa: An assessment of invasiveness and options for management. S Afr J Bot. 2013;87:134–145. http://dx.doi.org/10.1016/j.sajb.2013.03.019

79. Jacobs L. Evaluating the invasiveness and feasibility of eradication for *Melaleuca parvistaminea* Byrnes (Myrtaceae) in South Africa [BSc Hons report]. Stellenbosch: Stellenbosch University; 2012. p. 46.

80. Cheek MD. Naturalisation note: *Petiveria alliacea* L. in KwaZulu-Natal, South Africa. Bothalia. 2013;43(1):97–100.

81. Adams JB, Grobler A, Rowe C, Riddin T, Bornman TG, Ayres DR. Plant traits and spread of the invasive salt marsh grass, *Spartina alterniflora* Loisel., in the Great Brak Estuary, South Africa. Afr J Mar Sci. 2012;34(3):313–322. http://dx.doi.org/10.2989/1814232X.2012.725279