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# A proposed national strategic framework for the management of Cactaceae in South Africa

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Background: South Africa has a long history of managing biological invasions. The rapid increase in the scale and complexity of problems associated with invasions calls for new, more strategic management approaches. This paper explores strategic management approaches for cactus invasions in South Africa. Cacti (Cactaceae) have had a long history of socio-economic benefits, considerable negative environmental and socio-economic impacts, and a wide range of management interventions in South Africa.

Objectives: To guide the future management of cactus invasions, a national strategic framework was developed by the South African Cactus Working Group. The overarching aim of this framework is to reduce the negative impacts of cacti to a point where their benefits significantly outweigh the losses.

Method: Four strategic objectives were proposed: (1) all invasive and potentially invasive cactus species should be prevented from entering the country, (2) new incursions of cactus species must be rapidly detected and eradicated, (3) the impacts of invasive cacti must be reduced and contained and (4) socio-economically useful cacti (both invasive and non-invasive species) must be utilised sustainably to minimise the risk of further negative impacts.

Results: There are currently 35 listed invasive cactus species in the country; 10 species are targeted for eradication and 12 are under partial or complete biological control. We discuss approaches for the management of cactus species, their introduction and spread pathways and spatial prioritisation of control efforts.

Conclusion: A thorough understanding of context-specific invasion processes and stakeholder support is needed when implementing strategies for a group of invasive species.

Introduction

Biological invasions need to be appropriately managed to prevent and reduce negative environmental and socio-economic impacts (Simberloff et al. 2013). However, in most cases, the effort required to manage all invasions far exceeds the available resources. Moreover, such management options can create conflicts between stakeholder groups both directly (by taking away a desired resource) and indirectly (e.g. opposition to the release of chemicals) (Zengeya et al. 2017). Such conflicts can impede management interventions. Management must, therefore, be strategic such that (1) interventions are appropriate and sufficient to meet the goals of management and (2) management efforts are spatially and temporally consistent and coordinated.

A useful approach to strategic planning for biological invasions is to jointly consider groups of species with similar management requirements (van Wilgen et al. 2011). Grouping species for management identifies not only common goals but also common stakeholders. This allows for the simplification of decision-making processes. Such strategies require a good understanding of the target species (i.e. which species need to be managed and how), their pathways (i.e. the routes and vectors of introduction and spread) and the spatial distribution of impacts (i.e. areas containing resources that are susceptible to threats by invasions) (Visser et al. 2017). Effective management interventions should be planned in this context and should incorporate pathway-, species- and area-based approaches (Wilson et al. 2017).

This article explores strategic management planning using the family Cactaceae in South Africa as a case study. Cacti form a distinct taxonomic group that, with a few exceptions, share similar

physiological traits, habitat preferences, spread pathways and negative impacts (Novoa et al. 2015b, 2016b) and, importantly, are also managed in similar ways (Walters et al. 2011). The aim of this article is to explore the process of developing a national strategic framework for a group of invasive species. This strategic planning process relies heavily on a good understanding of invasion processes specific to the target group and effective stakeholder engagement.

The history and status of Cactaceae in South Africa

Cacti are among the most widespread and dominant groups of invasive plants in South Africa (Nel et al. 2004; van Wilgen et al. 2012), with 35 species already listed as invaders under the *National Environmental Management: Biodiversity Act* no. 10 of 2004 (NEM:BA). This is a result of their long history of introduction and utilisation in South Africa for agriculture and ornamental horticulture (Walters et al. 2011). Benefits of cacti in South Africa are derived from a range of socio-economically important activities, such as the horticulture trade, and commercial and subsistence agriculture. Their impacts are mainly related to costs associated with losses of biodiversity, ecological functioning and agricultural productivity. The country's arid interior offers favourable conditions for the establishment of drought-adapted species, such as cacti. Consequently, South Africa is a global hotspot of cactus invasions, with one of the highest diversities of naturalised cactus species outside the family's native range (Novoa et al. 2015b).

There is also a long history of cactus management in South Africa (Zimmermann, Moran & Hoffmann 2004). The genus *Opuntia* was among the first invasive taxa to be regulated (under the *Agricultural Pests Act* no. 11 of 1911), and South Africa's first biological control programme was implemented against the invasive cactus *Opuntia monacantha* in 1913 (Zimmermann et al. 2004). Since then, 15 additional cactus species have been targeted for biological control (Klein 2011; Paterson et al. 2011), and several widespread cacti are controlled through physical and chemical clearing, as part of the Working for Water programme (van Wilgen et al. 2012). Ten cactus species are listed as category 1a invasive species under NEM:BA and have thus been targeted for eradication (Wilson et al. 2013). However, the coordination and prioritisation of these cactus control programmes at a national level has yet to be implemented.

Management decisions need to be based on a clear understanding of the underlying invasion processes involved. Here we discuss the distribution and abundance, the benefits and impacts, and the pathways of cacti in South Africa to provide suitable context for management planning.

Distribution and abundance

An estimated 400 cacti taxa have been introduced to South Africa (Walters et al. 2011), many of which are currently present in gardens and private collections. Thirty-five cactus taxa are invasive in South Africa (Figure 1). Distributions per taxon vary; some occur country-wide (e.g. *Opuntia ficus-indica* is widely cultivated for fodder and fruit and has naturalised at many of these sites), while other taxa are confined to relatively small ranges (e.g. *Opuntia pubescens* has naturalised at a single site in a botanical garden) or occur in low numbers at several isolated localities (e.g. *Opuntia microdasys*, a popular garden ornamental, has naturalised at over 50 sites). However, introductions have occurred continuously for several decades without formal risk assessment, and some invasive cacti have shown long lag phases (>50 years between introduction and the start of invasive spread; Walters et al. 2011). It is therefore likely that a large invasion debt (sensu Rouget et al. 2016) has accumulated, which must be considered when formulating long-term management plans.

Benefits and impacts

Cacti have many important socio-economic benefits in South Africa. Around 300 species of cacti are imported to South Africa annually for ornamental horticultural purposes (Novoa et al. 2017). Cacti are highly valued for their use as ornamentals and are widely popular in gardens and as curiosity plants for collectors. Several cactus species are also used for commercial and subsistence agriculture where they are farmed for food, fruit and livestock fodder. These drought-resistant crops enable significant increases in the productivity of marginal land (Brutsch & Zimmermann 1993). These industries (i.e. horticultural and agricultural) are noteworthy contributors to the economy and food security of a developing country such as South Africa.

Cacti also have substantial negative environmental and socio-economic impacts (Barbera, Inglese & Pimienta 1995; Novoa et al. 2016b). Their ability to spread vegetatively results in the formation of large, dense invasive stands (in some cases up to 100% canopy cover) that exclude other vegetation and animals. Spines and glochids which are present on most species are damaging to small wildlife and livestock that have not coevolved with cacti (Walters et al. 2011). This translates into costly negative impacts, particularly to agricultural systems. Invasions of rangelands result in reductions in productivity and capacity of commercial and subsistence grazing (Lloyd & Reeves 2014). Added to these impacts are the considerable costs involved in controlling cactus invasions. Although the full cost of the impacts of cactus invasions in South Africa has not yet been quantified, control efforts between 1995 and 2008 cost nearly ZAR100 million (in 2008 equivalent Rand; van Wilgen et al. 2012).

Pathways

There are several main pathways along which cacti are introduced and spread (intentionally or unintentionally) around South Africa (Table 1). Most introduction pathways are related to utilisation of cacti (e.g. for ornamental horticulture, food production and livestock fodder) and involve intentional introductions. Local scale spread is often unintentional, for
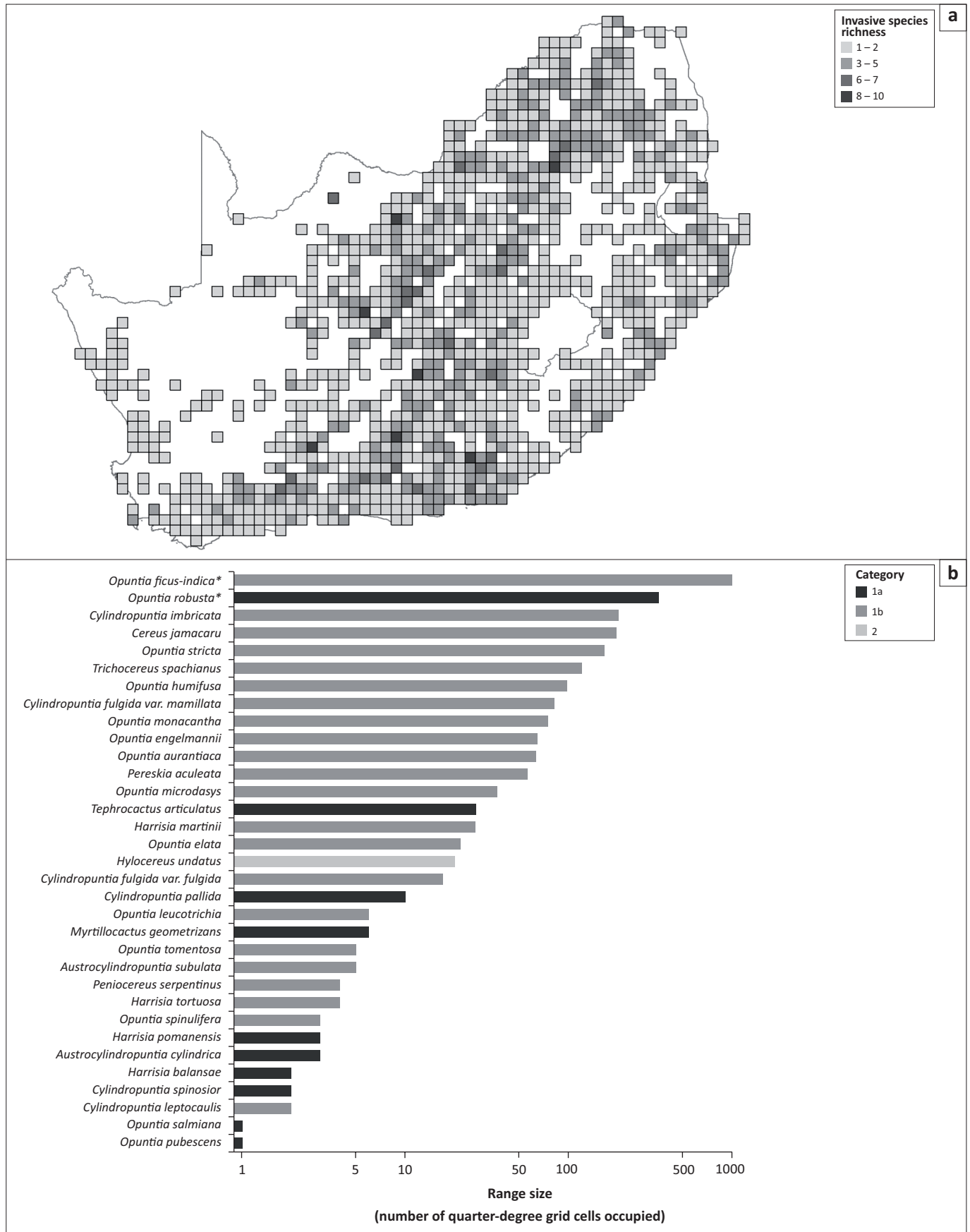
FIGURE 1: The current extent of cactus invasions in South Africa, showing (a) the distribution and species richness of listed invasive cacti per quarter degree grid cell (QDGC) and (b) range sizes of invasive cacti in South Africa.

TABLE 1: Invasion pathways for cacti at different scales and recommended management interventions to limit introduction and spread of invasive species. Pathways are listed in descending order of ease of management.

Pathway	International scale	Regional scale	Local scale	Management interventions
Horticulture (legal)	Permitted import of seeds by wholesalers	Distribution of plants to towns through nursery industry	Informal trade at garden clubs, markets	Correct listing of prohibited species
				Engagement with nursery stakeholders
				Enforcement of regulations
Food production	Import of spineless *Opuntia* cladodes	Distribution of *Opuntia* fruits for sale in supermarkets	Escape from cultivation and reversion to spiny forms	Biological and chemical control of escaped spiny plants
Livestock farming (fodder)	Not applicable	Farmers share plant material for fodder production	Movement of plant material by animals.	Increased public awareness
				Enforcement of regulations
				Livestock exclusion in invaded areas
Horticulture (illegal)	Import of seeds and live plants through online trade without permit	Illegal sale of plants in the nursery trade	Informal trade at garden clubs, markets	At-border screening of imports
			Exchange of plants among gardeners and succulent enthusiasts	Post-border inspections of nurseries and enforcement of regulations
				Improved public awareness of illegal cacti
Animal dispersal	Not applicable	Long-distance dispersal of seeds by birds	Movement of plant material and seeds by animals, for example, elephants and baboons	Contain spread by detecting and removing outlier populations
Abiotic dispersal	Not applicable	Not applicable	Dispersal of seeds by water and wind	Contain spread by detecting and removing outlier infestations

example, via animal-mediated dispersal or escape from cultivation. These pathways and their associated vectors need to be managed to limit the movement and subsequent invasions by invasive and potentially invasive species.

Almost all contemporary introductions of cacti are via the horticultural trade to meet a growing demand for ornamental cacti. The horticulture pathway has contributed the most invasive cacti to South Africa (Walters et al. 2011). Legal importation of cacti is conducted by a small number of nursery wholesalers in South Africa (Novoa et al. 2017). However, most of the approximately 300 ornamental cactus species imported by wholesalers are unlikely to become invasive (Novoa et al. 2015b). Those that are potentially invasive make up a small proportion of the horticulture trade, which means that prohibition of trade in selected species or genera is unlikely to have a large enough impact on the horticulture industry to cause resistance.

Illegal horticultural introductions of invasive species are more challenging to manage. Most cacti are imported as seed, which makes detection of illegal imports difficult. Screening seed imports by seed size has recently been proposed as an accurate method of discriminating invasive and potentially invasive from non-invasive cacti: larger seed size is correlated with invasiveness (Novoa et al. 2016c). However, we believe that illegal imports make up a small proportion of the total horticultural trade in cacti. A major threat is the local dissemination of invasive species already present in the country. While registered nurseries and growers generally avoid trade in listed invasive species, there is a large, unregulated trade in cacti which are sold and exchanged informally (personal observation).

A source of local scale spread of invasive cacti is the utilisation of certain opuntioid cacti for food production and livestock fodder. In the majority of cases, spineless cultivars are used although there is a risk of reversion to spiny populations

(Flepu et al. n.d.), which increases the likelihood of escape and invasion. Escape from cultivation is facilitated primarily by animal dispersal of seeds and plant material through fruit consumption and vegetative propagation (Dean & Milton 2000; Foxcroft & Rejmánek 2007).

The South African Cactus Working Group

In response to the need for strategic cactus management, a national working group (the South African Cactus Working Group; SACWG – see Appendix 1) was established in 2013 to develop and coordinate the implementation of a national management strategy for invasive cacti. The working group consists of representatives from all relevant organisations in South Africa involved in research, policy or management of cactus invasions. The primary benefit of the working group is its use as a forum to exchange ideas and current knowledge and to inform ongoing research and interventions. This enhances collaboration and cooperation among government departments and organisations and provides a more conducive environment for strategic decision-making. For instance, a recent proposal by the Department of Environmental Affairs to prohibit the entire Cactaceae family (with considerable socio-economic repercussions) was retracted in favour of a more nuanced and risk-appropriate listing proposed by the SACWG through a strategic decision-making process (Novoa et al. 2015a). This ability for cohesive, expert-driven decision-making based on current evidence makes the cactus working group a suitable entity for national scale strategic planning.

Stakeholder engagement

Although strategic decision-making is overseen by the SACWG, which represents organisations that are mandated to regulate and control cacti, the outcomes will clearly affect multiple external stakeholders (Figure 2). Proposing control
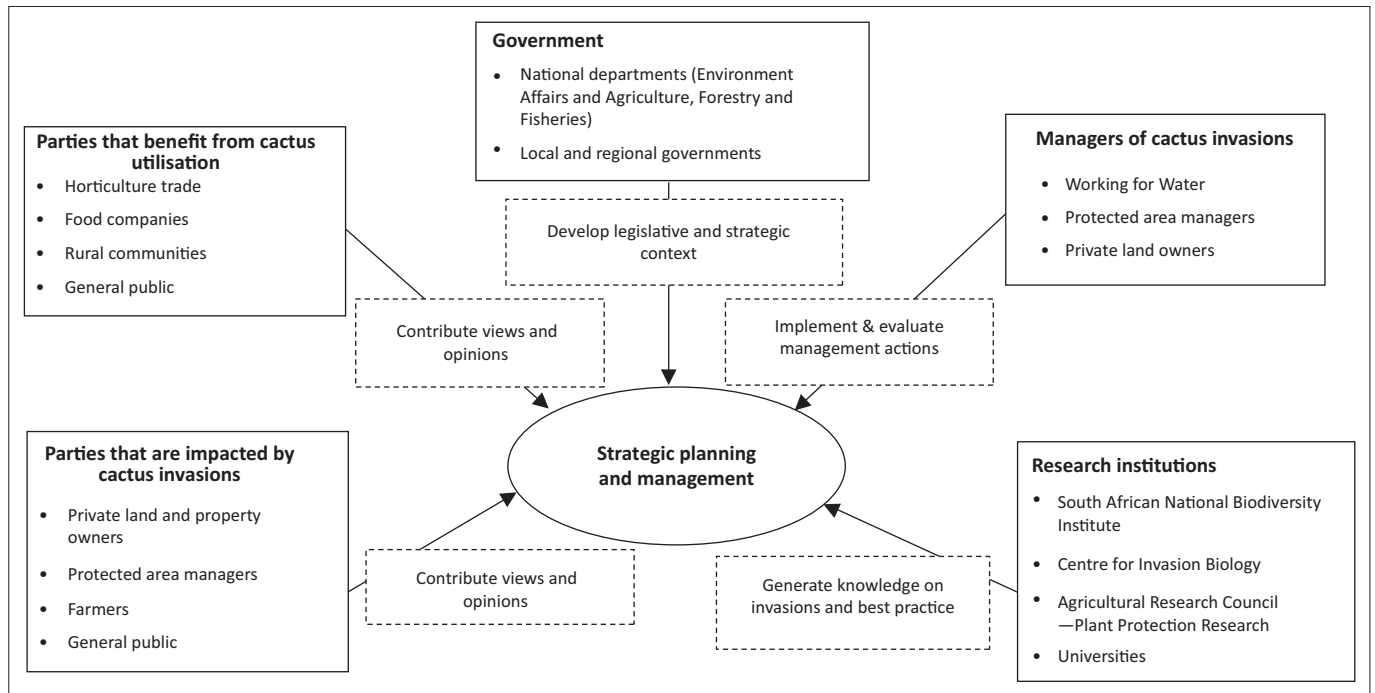
FIGURE 2: Stakeholder groups and their representative organisations involved in strategic planning and management of cactus invasions in South Africa.

or regulation of non-native species with benefits can create conflicts of interest that hinder management success (Estévez et al. 2015). Overcoming these conflicts can be difficult, especially where livelihoods are at stake, as described by Beinart (2003) for prickly pear in South Africa. The challenge is to garner wide stakeholder support for management interventions when values around certain invasive species may differ. Effective stakeholder engagement during the strategic planning process is therefore essential (García-Llorente et al. 2011).

To achieve such engagement in South Africa, all the stakeholders were invited to participate in a workshop with the aim of increasing awareness of different viewpoints and values associated with cactus impacts and benefits (Novoa et al. 2016a). Following this workshop, there was somewhat of a convergence of stakeholder perceptions, which facilitated a smoother decision-making process. This was encouraging, as altering behaviours to support strategic management of cacti (e.g. not propagating and selling invasive cacti) involves a change in perceptions and values associated with invasions (Selge, Fischer & van der Wal 2011).

Strategic framework

A national strategic framework (Figure 3) was constructed by the SACWG over four consecutive workshops during 2013–2015, taking all the stakeholders' opinions into account. The overarching vision of the strategy is to reduce the negative impacts of cacti to a point where the benefits of having them in the country would significantly outweigh the losses. To achieve this vision, we considered that four strategic objectives need to be met based on the approach by van Wilgen et al. (2011): (1) all invasive and potentially invasive cactus species are prevented from entering the country,

(2) new incursions are detected and eradicated, (3) the invasive impacts of species are reduced and contained and (4) socio-economically useful cacti are utilised sustainably.

A species-based approach

The next step was to determine what management action should be taken for each species. To do this, we developed a protocol with five endpoints (Table 2; Figure 4): (1) Do nothing (i.e. no regulation of species needed unless further evidence to the contrary), (2) Prevention (i.e. prohibition and preventing entry of potentially invasive species into the country), (3) Eradication (i.e. eradication of new incursions), (4) Containment (i.e. stopping or slowing the spread of invasive species) and (5) Impact reduction (i.e. maintaining invasive populations at densities with tolerable impacts). Before implementing the strategies outlined in the framework, species-based management goals must be assigned to the each taxon (i.e. all species in the Cactaceae family) using the decision protocol in Figure 4.

Unlike within other taxonomic groups (e.g. Australian acacias, van Wilgen et al. 2011), within the family Cactaceae, all species considered as useful by the legal trade are not invasive or harmful – that is, the species used in agriculture are the non-invasive spineless cultivars of *O. ficus-indica* and *Opuntia robusta*, and no invasive species are considered as useful by the international legal trade (Novoa et al. n.d.). Therefore, the decision protocol in Figure 4 will result in 'do nothing' for useful species. However, this might need to be amended in the future.

Preventing introductions of high risk species is an important and often highly cost-effective step in reducing the potential impacts of invasions. Risk assessment is needed to distinguish
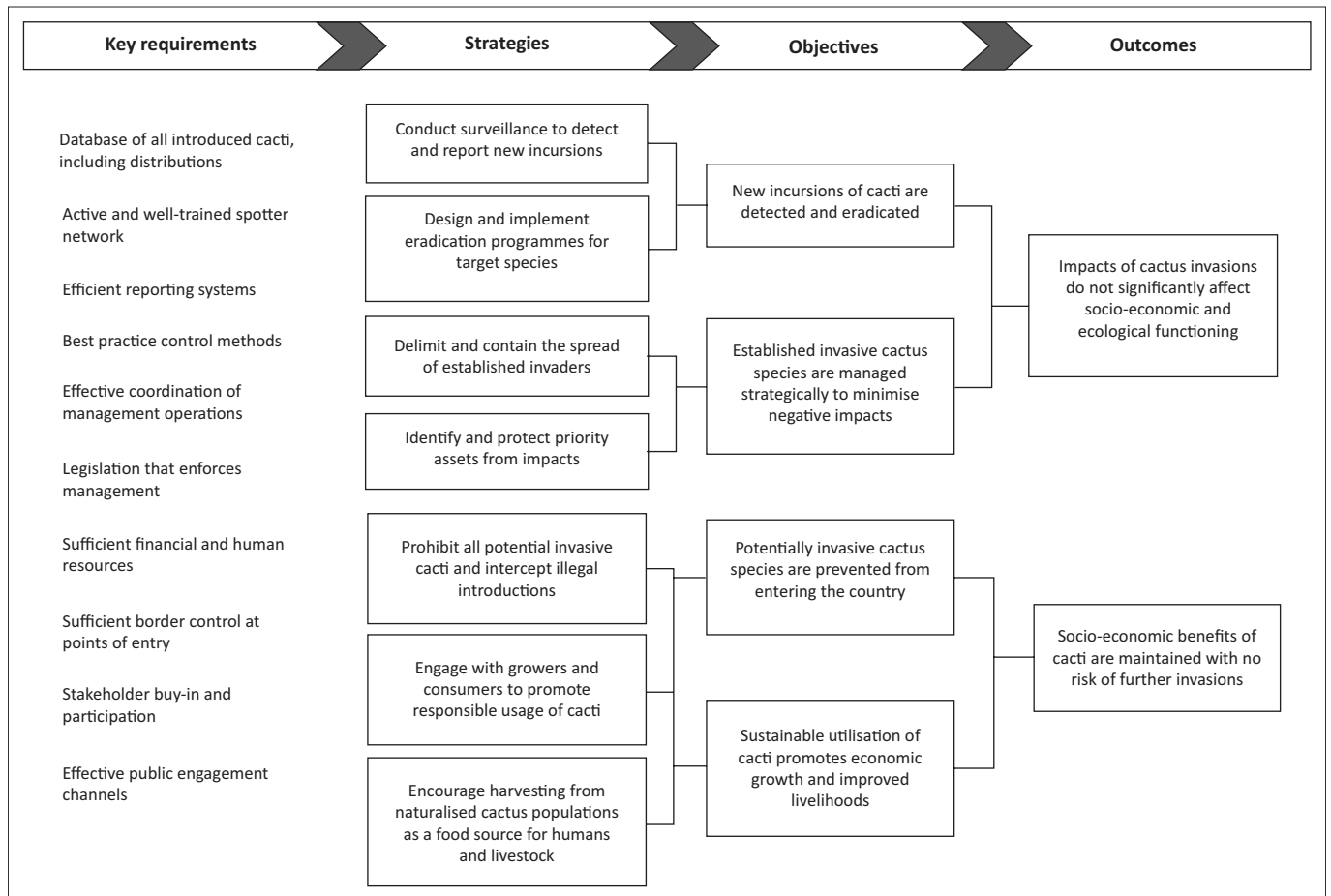
FIGURE 3: National strategic framework and key requirements for the management of cactus invasions in South Africa.

TABLE 2: Implementation of species-based management of cacti in South Africa.

Species-based goal/endpoint	Implementation	Actions to date in South Africa	Reference
Do nothing	Species with low risk of invasiveness are not regulated	Risk assessment of Cactaceae	Novoa et al. 2015b
Prevention	Species with high risk of invasiveness or invasive elsewhere are prohibited	Risk assessment of Cactaceae	Novoa et al. 2015b
		Four invasive genera prohibited under NEM:BA regulations	
Eradication	New incursions of cacti and naturalised species with limited distributions are eradicated from the country	New incursions detected and recorded in SAPIA	Henderson 2007
		Ten cactus species currently being assessed for eradication feasibility	Wilson et al. 2013
Containment	The spread of species with high risk of range expansion is stopped or slowed	No formal assessment of containment feasibility for cacti to date	
		Use of biological control to prevent seed set in some species	Paterson et al. 2011
Impact reduction	Populations of widespread invasive species are reduced to tolerable levels	Biological control of 16 cactus species	Paterson et al. 2011
		Strategies for integrated management of cacti in protected areas developed	Lotter and Hoffmann 1998

NEM:BA, *National Environmental Management: Biodiversity Act*; SAPIA, Southern African Plant Invaders Atlas.

species that pose significant invasive threats from those species that are safe to utilise. All invasive or potentially harmful species should be prohibited. A global assessment of the Cactaceae by Novoa and colleagues (2015b) has shown that invasiveness in cacti is correlated with growth form (i.e. morphological traits that increase the ability to propagate, e.g. segmented stems) and native range size (Novoa et al. 2015b), and most invasive species in the family belong to 13 genera (out of 130), particularly in the Opuntioideae subfamily. Species-specific preventative measures, such as prohibition, should thus be targeted at those species identified as potential invaders. Species from four genera (*Cylindropuntia*, *Harrisia*, *Opuntia* and *Pereskia*) are currently on the NEM:BA prohibited list (i.e. they may not be introduced to South Africa) because of the prevalence of globally invasive taxa in these groups.

Given the potentially large invasion debt of cacti in South Africa, new instances of naturalisation are likely to occur. New incursions of cacti should be eradicated where feasible. Feasibility of eradication is assessed on an individual species basis and broadly depends on reproductive and dispersal characteristics and the eradication effort required relative to available resources (Panetta 2015). Approaches for evaluating the feasibility of eradication of invasive taxa in South Africa have been developed (Jacobs, Richardson & Wilson 2014; Kaplan et al. 2012) and can be adapted for application to
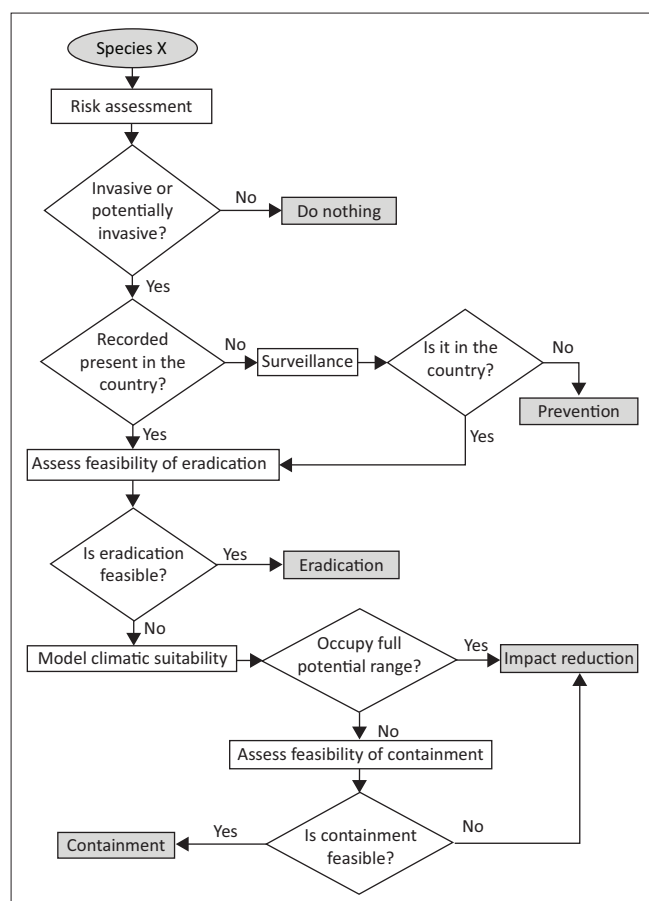
FIGURE 4: Decision framework for setting species-based management goals for invasive cactus species.

TABLE 3: Effectiveness of control of listed invasive cacti in South Africa.

Variables	NEM:BA category			Total
	1a	**1b**	**2**	
Taxa with registered herbicides	0	8	0	8
Taxa under complete biological control	0	7	0	7
Taxa under partial biological control	3	8	0	11
Taxa where the only current management option is physical removal	7	2	1	10
Total Taxa listed	**10**	**25**	**1**	**36**

NEM:BA, *National Environmental Management: Biodiversity Act.*

cactus taxa. Although cacti do not form long-lived seed banks, their propensity for vegetative propagation is likely to complicate eradication efforts; small pieces of plant material can break off, spread and root easily (Bobich & Nobel 2001), forming new and often inconspicuous plants. Species considered as feasible eradication targets should have few, localised populations (e.g. *O. pubescens*; Cindi & Jaca 2016) and highly effective control treatments available.

Species for which eradication is not feasible should be controlled by containment of spread and reduction of negative impacts. Feasibility of containment is also assessed on a species-by-species basis. Containment is considered only for those species that do not occupy their full potential invasive range in South Africa (based on bioclimatic models) and which have the ability to spread. Preventing further range expansion of cacti or slowing the spread would involve stopping seed production through biological control, and setting up barrier zones around existing infestations and regular monitoring of these zones to detect and remove extra-limital incursions (Sharov & Liebhold 1998). As with eradication, containment of a species relies on complete removal of populations to limit further spread and should be considered only for species for which there are effective control methods (Table 3). To date, there have been no attempts to contain cacti in South Africa, although there have

been instances where fruit production has been successfully hindered by biological control agents (Paterson et al. 2011).

Impact reduction is an appropriate goal for widespread, dominant cactus species. Thresholds for impact tolerance may vary by land use type because of relative susceptibility to impacts. For example, protected areas and rangelands will likely have a much lower tolerance to impacts than transformed or urban areas. Consequently, populations will require different management interventions to reduce densities to the required maintenance levels, although further research is needed to determine optimal maintenance levels under different land use scenarios.

A highly effective management tool for reducing the impacts of cacti is biological control (McFadyen 1998). Twelve cactus species are currently under complete or partial control in South Africa by three groups of biological control agents: cochineal insects (*Dactylopius* sp.), a mealybug (*Hypogeococcus festerianus*) and cactus moth (*Cactoblastis cactorum*) (Table 3). In some cases, novel associations between biocontrol agents and host species can result in almost complete extirpation of populations, such as with *Cylindropuntia fulgida* where augmented release of control agents resulted in a kill rate of up to 99% (T. Xivuri et al., unpublished data). At least eight cactus invaders are now at full maintenance levels (with no or very limited control measures required) because of successful biological control which necessitates a residue population of the weed for the survival of the biological control agents. Under such levels of biological control, beneficial species such as *O. ficus-indica* and *O. robusta*, which are used as fodder sources, could potentially be delisted from the regulations as they no longer pose significant threats. In cases where biological control is less effective, an integrated management approach combining biological, chemical and mechanical control should be implemented. For example, biological control of *Opuntia aurantiaca* is less effective in higher rainfall areas (Moran & Zimmermann 1991), necessitating integrated management interventions. Investment in biological control will be a key element of any strategy to deal with cactus invasions (Zachariades et al. 2017).

A pathway-based approach

Introduction and spread pathways must be identified and prioritised to prevent and contain the impacts of cacti (Table 1). The most difficult pathways to manage are those

that involve abiotic and animal vectors of spread. Migrating animals, such as birds, or floodwaters can disperse cactus propagules over long distances (Walters et al. 2011). These are fairly stochastic processes and should therefore be managed on a case-by-case basis. This will most likely involve species-based containment or impact reduction approaches, although certain vectors, such as livestock animals and transport vehicles, should be inspected and controlled in high risk areas.

Human-mediated pathways (including both intentional and unintentional introductions) can be managed more strategically. The two broad human-mediated pathways of intentional cactus introductions and dissemination in South Africa are horticulture and agriculture (including legal and illegal trade). To ensure that no prohibited cacti are introduced intentionally by growers through the legal cactus trade, the existing permit-regulation process needs to be well managed. However, intentional illegal trade of cacti is facilitated mainly by international online trading (such as Ebay.com) where suppliers are not necessarily held to the same import regulations as 'legal' importers (Humair et al. 2015). Moreover, unintentional introductions of invasive cacti may still occur, for instance, because of misidentification or incorrect labelling of seed imports.

We believe that legal horticultural trade of cacti would be relatively easy to regulate through increased awareness of prohibited and regulated cacti among importers and their international suppliers (Novoa et al. 2017), and enforcement of compliance where necessary. Illegal trade of cacti can be best managed through at-border screening of seed imports, increased public awareness of the risks of cactus invasions and the promotion of safer, non-invasive cacti and succulents for gardening and landscaping. Managing escape from cultivation and subsequent spread of impacts of cacti requires responsible utilisation. Engaging with livestock farmers and growers of cacti to increase awareness of the threats posed by cactus invasions and ways to prevent them, such as animal exclusion from invaded areas, is recommended. The movement of cacti across the land borders between South Africa and other African countries is a potential threat, although cactus biological control agents can also move in this way (Faulkner et al. 2017).

An area-based approach

Because of lack of funding and capacity for managing invasions, often species cannot be managed across their entire invasive range, particularly those species that are very widespread. An alternative is to spatially prioritise management efforts to areas where the majority of impacts or potential impacts are likely to occur (Downey et al. 2010). These priority areas contain ecologically or socio-economically important assets that are at highest risk from impacts by cactus invasions. These include protected areas and livestock production regions (Figure 5). Criteria for prioritisation of certain areas would include level of conservation concern (e.g. a formally protected area vs. a
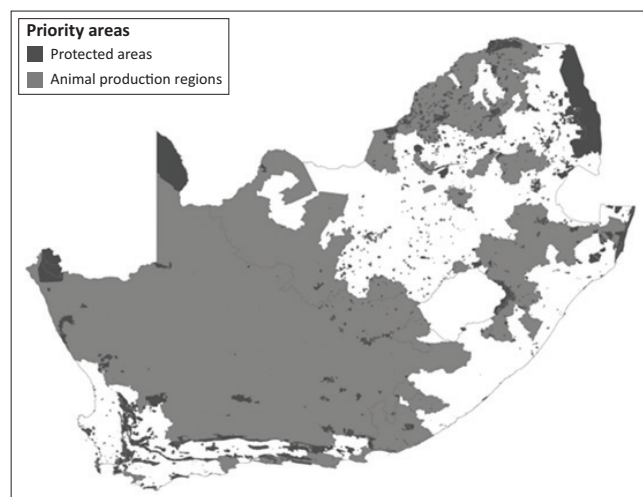
Source: Data sourced from Department of Agriculture, Forestry and Fisheries.
FIGURE 5: Priority areas for cactus management in South Africa based on assets most vulnerable to the negative impacts of cactus invasions.

critical biodiversity area), grazing capacity or agricultural productivity, and eco-tourism value. These criteria should be rated and ranked following a multi-criteria decision analysis framework (e.g. Forsyth et al. 2012).

For simplicity of management, prioritisation should occur at the scale of land ownership, for example, individual farms or nature reserves. Further research on fine-scale impacts and local invasion hotspots would assist in refining priority areas to enable better allocation of resources. If available resources are insufficient, further prioritisation and trade-offs will need to be made to ensure that strategic objectives are being met at a national scale (van Wilgen et al. 2016).

The way forward

Strategic management needs to incorporate a means of monitoring and assessing the efficacy of strategies towards achieving the desired outcomes. An effective monitoring programme should assess the accuracy of the problem definition, audit the achievement of goals and provide feedback to evaluate policy (Rogers & Biggs 1999). Although targets and endpoints are not explicitly defined here, we propose a set of indicators that can be used to evaluate progress towards achieving strategic objectives (Table 4).

For management to be adaptive, strategies must be based on clear evidence. To this end, the SACWG must ensure that management operations that are encompassed by this framework are well documented and aligned with current knowledge of cacti and best practice. This requires effective cooperation and collaboration among the partner organisations within the SACWG. Likewise, collaboration with relevant international experts is essential. Accordingly, several members of the SACWG are represented on an international cactus working group (http://academic.sun. ac.za/cib/projects/cactuswg/index.asp), which has recently been initiated to collate information on cactus invasions and their management globally.

TABLE 4: Indicators of progress towards achieving the national strategic objectives for cactus management in South Africa.

Management objective	Indicator	Action
Prevention of invasive cactus species	Number of new imports of potentially invasive species	Refine risk assessments based on current data
Sustainable utilisation of cacti	Number of instances where nursery industry does not comply with invasive species policy	Audit nursery compliance with NEM:BA Alien and Invasive Species regulations
Eradication of new incursions	New incursions of cacti detected before naturalisation or spread occurs	Active surveillance of cactus invasion hotspots
	Successful eradication of cactus species	Monitor progress of eradication programmes
Reduction of impacts of widespread invasive cacti	Stakeholder support for control of invasive cacti	Engage stakeholders in the management of invasive cacti
	Effective control methods are available for invasive species	Develop and test biological and chemical control for all listed invasive species
	Stable and decreasing population densities	Monitor changes in population densities over time at fixed points

NEM:BA, *National Environmental Management: Biodiversity Act.*

Importantly, this strategy requires ownership in order to ensure implementation and continuity over time. Ownership of the strategy should lie with the South African National Department of Environmental Affairs that represents NEM:BA and the Alien and Invasive Species Regulations.

General conclusions

Strategic management of invasions requires integration of pathway-, area- and species-based interventions. To explicitly incorporate these approaches into strategic planning and management objectives, a good understanding of invasion processes is necessary. We demonstrated this for cacti which have benefited from both a well documented history of management and a large body of research in South Africa. Unfortunately, this is not the case for many other groups of invasive species requiring management. In instances where data and knowledge are insufficient, the formation of taxon-specific working groups, such as the SACWG, is recommended to bring together stakeholders to build the expertise and knowledge necessary for strategic planning at a national level. Coordination and buy-in from stakeholders is essential for successful management of invasive species, especially at a national scale. We believe that future management of cacti in South Africa will be greatly enhanced through the adoption of this proposed strategic framework and with continual coordination and engagement between SACWG stakeholders. More work is needed to improve the framing of issues and problems relating to invasive cacti with ongoing consultation with all stakeholders to identify innovative solutions (Zengeya et al. 2017).

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

H.Kaplan led the development of the strategic framework with A.N. and J.R.U.W. H.Kaplan and A.N. wrote the article. All other authors contributed to the strategic framework and the article during workshops held by the SACWG. H.Klein H.G.Z. and P.M. made inputs regarding biological, chemical and integrated control of cacti. P.I. and D.M.R. provided guidance on conceptualisation of the strategic framework. L.H. provided distribution and abundance data for cacti.

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Appendix 1

Background, role, and composition of the South African Cactus Working Group (SACWG)

The *National Environmental Management: Biodiversity Act* (10 of 2004) requires the South African National Biodiversity Institute (SANBI) to regularly monitor and report on the status of listed invasive species in South Africa.

Towards this end, SANBI initiated a South African National Cactus Working Group (SACWG) to strategically monitor and coordinate management of cactus species in South Africa. The role of the SACWG is to:

1. Develop a national cactus management strategy;
2. Co-ordinate nationally work done on cactus;
3. Assess the risks and management feasibility of cacti;
4. Ensure best practice control methods are used against target cactus species;
5. Improve co-ordination and communication among research institutes, invasive species managers and relevant government departments; and
6. Engage with external stakeholders.

Representatives from all relevant organisations involved in the management or research of cactus and invasive species policy-makers are included in the working group (Table 1).

The SACWG convened in June 2012 to constitute itself. They will continue to meet biannually with SANBI serving as secretariat.

TABLE1-A1: Member organisations of the South African Cactus Working Group.

Organisation	Relevant expertise	Web link
Department of Environmental Affairs – Environmental Programmes	Design and implementation of policies on alien and invasive species in terms of the *National Environmental Management: Biodiversity Act* no. 10 of 2004	https://www.environment.gov.za/branches/environmental_programmes
Department of Agriculture, Forestry and Fisheries – Directorate of Land Use and Soil Management	Design and implementation of policies on alien and invasive species in terms of the *Conservation of Agricultural Resources Act* no. 43 of 1983	http://www.daff.gov.za/ http://www.daff.gov.za/daffweb3/Branches/Forestry-Natural-Resources-Management/LUSAM
South African National Biodiversity Institute: Invasive Species Programme	Detection and assessment of invasive species for eradication	http://www.sanbi.org/biodiversity-science/state-biodiversity/biodiversity-monitoring-assessment/invasive-aliens-early-det
DST-NRF Centre for Invasion Biology	Conduct research and development and training in biodiversity science especially as it applies to understanding the impacts of, and managing and preventing biological invasions	http://academic.sun.ac.za/cib/
Agricultural Research Council – Plant Protection Research Institute	Research on the ecology and control of invasive alien plants in South Africa with emphasis on non-native problem plants in conservation and pasture situations.	http://www.arc.agric.za/arc-ppri/Pages/ARC-PPRI-Homepage.aspx
South African National Parks	Management of invasive species in protected areas in South Africa	https://www.sanparks.org/

Source: Photo by L. Otto, 2013

FIGURE 1-A1: Attendees of the South African Cactus Working Group Meeting of 25 April 2013.