An approach to the development of a national strategy for controlling invasive alien plant species: The case of Parthenium hysterophorus in South Africa

Invasive alien species require co-ordinated strategic management if negative impacts are to be effectively avoided. Here we describe a strategy for the management of Parthenium hysterophorus L. (Asteraceae) in South Africa. P. hysterophorus is an annual herb native to tropical America, which has become invasive in over 30 countries. The strategy sets goals for (1) the prevention of spread to new areas; (2) local eradication of isolated populations; (3) containment in areas where eradication is not possible; and (4) actions to protect assets where containment is no longer an option. We developed both a national strategy to set policy and to monitor progress towards goals at a national level and an implementation plan to set goals and timeframes for their achievement at local levels. It is not clear, at this stage, whether or not the goals of the strategy are achievable because implementation will face many challenges arising from ecological features of the target plant, social and cultural practices that will influence management, inadequate levels of funding and multiple political considerations. Our strategy proposes regular assessment using high-level indicators, a practice that is widely recognised as essential but seldom implemented at a national scale. Because the outcomes are uncertain, it is vital that regular monitoring of outcomes should be instituted from the start, so that both appropriate adjustments can be made to the strategy and lessons for the implementation of similar strategies elsewhere can be derived.

Introduction

Growing numbers of invasive alien species are establishing and spreading in many parts of the world, and these invasions are often accompanied by substantial negative impacts on ecosystems, the economy and human health (Pimentel 2011). In response to these threats, many countries have ratified the Convention on Biodiversity, which requires signatory nations to ‘prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species’. While most of the signatory countries have developed high-level strategies for dealing with invasive alien species in general, very few have developed detailed strategies for individual priority species. In most cases, preventing or containing the impacts of a single invasive alien species that dominates over large areas will almost certainly be beyond the means of individual landowners. In such cases, effective control, if it is possible, has to be co-ordinated by governments, often at a national scale. There is thus a distinct need for co-ordinated, strategic approaches that will increase the chances of achieving sustainable and effective control.

In Australia, a relatively small number of invasive alien plant species (20 in the year 2000 rising to 32 in 2014) has been designated as Weeds of National Significance (WONS, see Thorp and Lynch 2000). Grice, Clarkson & Calvert (2011) proposed the use of a geographically differentiated strategy for the management of the invasive wetland grass Hymenachne amplexicaulis (Rudge) Nees (Poaceae), one of Australia’s WONS. Their approach recognises that different objectives and methods would be appropriate for different parts of a species’ introduced range, or areas that it might yet invade. Based on the suitability of areas for invasion, and on the absence, presence or abundance of the species, they formulated four appropriate responses: Prevention of invasion for areas where the species was not yet present (given low priority in unsuitable habitats, and high priority elsewhere); local eradication where it was deemed feasible; containment where eradication was no longer possible, but where control was still feasible; and asset protection where containment was not feasible any more. On the basis of this classification, Grice et al. (2011) divided Australia into 21 management zones, each of which was assigned one of the four objectives, and they suggested that this approach could be usefully applied to other invasive species to more effectively...
address their broad-scale management. The effectiveness of this approach is yet to be assessed, and its widespread and effective implementation is likely to face a range of challenges, especially if the approach is to be adopted in developing countries where resources and management capacity are limited, and where perceptions of the importance of the problem differ.

Notwithstanding the challenges facing developing countries, South Africa has recently (2014) promulgated regulations (under the National Environmental Management: Biodiversity Act, Act 10 of 2004, hereafter NEM:BA) that provide for the establishment of national-level invasive species management programmes for priority invasive alien species. The regulations further require that an ‘invasive species control and eradication strategy’ should be drawn up to guide each management programme. A list of priority species has not yet been finalised, and this may take some time, but in view of the urgent need to develop guidelines and test approaches for such strategies, it was decided to develop a strategy for the invasive alien weed *Parthenium hysterophorus* L. (Asteraceae), known locally as famine weed (Macdonald 2014).

In this paper, we provide a brief description of the development of a strategy and implementation plan for the management of *P. hysterophorus* in South Africa, and we discuss the challenges for the expansion of the approach to other species and to other developing countries.

**Parthenium hysterophorus in South Africa**

*Parthenium hysterophorus* is an annual herb native to tropical America, and it has become invasive in at least 34 countries in Africa, Asia, Australia and the Middle East (Adkins & Shabbir 2014). The species was first recorded in South Africa in 1880 (Wood 1897) but remained an uncommon weed restricted to cultivated and disturbed areas for almost 100 years (Hilliard 1977). The presence and abundance of invasive alien plant species in South Africa is recorded within quarter-degree grid cells (cells of approximately 25 x 25 km) in the Southern African Plant Invaders Atlas (Henderson 2007). In 1980, *P. hysterophorus* was found in only three cells, but this had reached 15 cells by 2000, and then rose rapidly to 62 cells in 2007 and to 76 cells in 2014 (Figure 1). *Parthenium hysterophorus* causes severe allergic reactions (dermatitis, hay fever and asthma) in a large proportion of people who come into contact with it, as well as in livestock and wildlife (Towers & Mitchell 1983; Patel 2011). The potential for the species to have serious consequences for the agricultural economy, human health and biodiversity (Wise et al. 2007), coupled with its recent rapid expansion, have contributed to its preliminary selection as a priority species.

*Parthenium hysterophorus* currently occurs in four South African provinces in the northeast of the country, as well as in neighbouring Swaziland and Mozambique (Figure 1). Climatic suitability modelling (McConnachie et al. 2011) indicates that it could potentially spread to a much larger area (Figure 2). The biology of *P. hysterophorus* is characterised by rapid growth and flowering, and copious seed production. While the species is not aggressively competitive in healthy vegetation, it thrives in disturbed areas and is dispersed by a wide range of vectors, including water, animals, vehicles, tools and machinery. The species readily invades disturbed or overgrazed areas, and seed banks can persist in the soil for up to six years (Navie et al. 1998). Controlling *P. hysterophorus* in South Africa will not be an easy task, given the country’s wide network of tarred and dirt roads and tracks, high population density with low socio-economic status in many areas, communal grazing and poor rangeland management practices that together have created conditions that promote invasion. The most effective available management options include minimising spread, eliminating isolated outbreaks, maintaining rangelands in good condition (*P. hysterophorus* more readily invades degraded areas) and the use of introduced biological control agents. Minimising the spread of this weed will require regular checking and cleaning of vehicles and machinery moving from infested to uninfested areas. Isolated outbreaks should be treated promptly by applying herbicides and identifying new outbreaks will require awareness and an ability to recognise the species.

In late 2003, South Africa initiated research to investigate the potential for using biological control to combat *P. hysterophorus* (Strathie, McConnachie & Retief 2011), based on the successful management of this species in Australia using nine introduced natural enemies there. In Australia, the extent and density of *P. hysterophorus* has been substantially reduced as a result of concerted biological control efforts between the 1970s and the present (Dhileepan & McFadyen 2012). In South Africa, three species of biological control insects and one rust fungus have been released following assessment of their suitability for introduction. Another rust fungus that was probably introduced simultaneously with *P. hysterophorus* is also present, and other agents are under investigation. Establishment of these agents, although currently limited and variable, is evident. Active attempts to control the species using herbicides also began in 2011, as part of an employment and poverty relief programme.

**Developing a national strategy**

South Africa’s NEM:BA legislation requires that the Minister of Environmental Affairs (who is responsible for the implementation of this Act) ‘must ensure the coordination and implementation of programmes for the prevention, control or eradication of invasive species [section 75(4)]. The regulations in terms of NEM:BA, approved in October 2014, require [section 2(3)] compliance by landowners with such an Invasive Species Management Programme, where such a programme exists. During the course of 2014, workshops involving a range of stakeholders were convened to gather inputs for the development of a National Invasive Species Management Programme for *P. hysterophorus*. This resulted in the drafting of a ‘control and eradication strategy’, as envisaged in the NEM:BA
FIGURE 1: (a) Current distribution of *Parthenium hysterophorus* in South Africa and Swaziland; (b) Historical occurrence showing the number of quarter-degree cells in which the species was present over time. Data are from the Southern African Plant Invaders Atlas (Henderson 2007).
regulations. Inputs by three national and two international experts further improved the document. The strategy described in this paper is based on the draft control and eradication strategy, and provides high-level guidelines for the management of *P. hysterophorus* in South Africa. These guidelines will be given effect in a National Implementation Plan. Grice *et al.*’s (2011) framework for geographic differentiation was adopted to guide the formulation of the South African national strategy and the associated implementation plan for *P. hysterophorus*. While Grice *et al.* (2011) used the term ‘strategic plan’ to describe their framework, we consciously developed two documents, a National Strategy (Terblanche 2014a) and an Implementation Plan (Terblanche 2014b). The National Strategy reviewed the situation in South Africa, provided broad strategic goals, allocated land to management zones following Grice *et al.*’s (2011) framework and proposed high-level performance indicators. The implementation plan provided for the establishment of a national programme overseen by a national co-ordinator and guided by a multi-departmental steering committee, listed appropriate management actions to be taken in each zone and assigned responsibilities and timeframes for the achievement of targets based on available funding.

Outcomes of the process

Key features of the national strategy

The national strategy identified five broad goals, the first of which was to establish a national invasive alien species control programme (as envisaged in NEM:BA) with adequate funding and management capacity to achieve the remaining goals. It was further recognised that a successful national programme would require cross-sectoral co-ordination and collaboration between different spheres of government and stakeholders within South Africa, and within countries bordering South Africa. The remaining four goals align with those proposed by Grice *et al.* (2011), namely to prevent the establishment of *P. hysterophorus* in regions where it is not already present; to detect and locally eradicate new infestations wherever possible; to contain further spread of existing infestations or reduce their extent where possible; and to reduce the impacts on selected assets where containment is no longer possible.

It was explicitly recognised that the achievement of these goals would require interventions that would (a) increase awareness of the problem among stakeholders, enabling them to recognise the species in areas where it has not

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FIGURE 2: The potential distribution of *Parthenium hysterophorus* in South Africa and southern Mozambique, based on three classes of climatic suitability (adapted from McConnachie *et al.* 2011).
occurred as yet, to appreciate the species’ potential impacts and to understand the available management options; (b) ensure that biological control is used to the fullest possible extent to reduce the impacts of *P. hysterophorus* and to supplement other control methods; and (c) encourage the use of sound rangeland management practices that would reduce the risks of further invasion in degraded areas.

Local government in South Africa is overseen by eight metropolitan municipalities and 226 local municipalities, which together cover the whole country. We used municipal boundaries to delineate management zones, as development planning at a local level takes place within municipalities in South Africa. We used the decision tree by Grice et al. (2011) to assign each municipality to one of the five zones: Low-priority prevention areas where the species is not yet present and where habitat is unsuitable for invasion by *P. hysterophorus*; high-priority prevention areas where the species is not yet present but where suitable habitat exists (applicable if > 1% of the municipality has a moderate to high probability for invasion based on climatic suitability, Figure 2); local eradication areas where *P. hysterophorus* exists in localised, low-density populations and where local eradication is deemed feasible; containment areas invaded by *P. hysterophorus* where eradication would not be possible, but where containment is still feasible; and asset protection areas with widespread, dense invasions where containment is not feasible. As detailed distribution data for *P. hysterophorus* were not available, municipalities were assigned to zones during workshops with stakeholders, based on limited data and individual local knowledge (Figure 3).

**Implementation and assessment of the national strategy**

A range of high-level interventions associated with each of the five broad goals of the strategy were identified, along with performance indicators that could be used to assess progress towards the goals (Table 1). It was decided, at this stage, not to assign targets for the indicators in the strategy, but rather to address management targets in the implementation plans, for two reasons. Firstly, targets would need to be assessed in terms of baseline values that reflect...
The establishment of a national invasive alien species control programme for *P. hysterophorus* will require formal approval in terms of NEM:BA, after which a national co-ordinator can be appointed and an inter-departmental steering committee established. The national invasive alien species control programme would be managed from within the national Department of Environmental Affairs (DEA), and the national co-ordinator would be an employee of that department, and would act as chair of the steering committee. The management of invasive alien species is of relevance to, or is influenced by, a number of government departments, notably those responsible for the environment, agriculture, forestry, transport and human health (at national, provincial and local levels), and a steering committee is intended to bring a co-ordinated approach to management that is viewed as an essential ingredient for success. The committee needs to be representative but small enough to be effective. The committee would be responsible for overall co-ordination, identifying sources of funding and monitoring progress in terms of agreed indicators (Table 1).

An important component of the strategy will be to raise awareness of the problem among key stakeholders for two reasons. Firstly, in areas where the species is not yet present, people need to be made aware that it could establish there, and they need to be able to recognise the species. The strategy suggests that this awareness should be created primarily among organisations with existing invasive alien plant clearing operations and agricultural extensions officers, who could report sightings through an online reporting system (www.ispotnature.org/communities/southern-africa).

Secondly, where the species is present, people need to be aware of the dangers that it poses, the ways in which spread and impact can be reduced and the methods available for control. To achieve this, educational material needs to be produced and key stakeholders need to be engaged. The intention is to develop a manual that outlines best management practices regarding the containment and control of *P. hysterophorus*. Most importantly, awareness of the need to limit spread (by limiting the movement of vehicles, livestock and fodder between invaded and uninvaded areas) and to sanitise vehicles and machinery where movement is unavoidable needs to be fostered (see Brunel et al. 2014). This final aspect may be difficult to implement broadly in developing countries like South Africa, except in selected areas (such as the entrance gates to protected areas, where heavy traffic creates a high risk of seed introduction).

Biological control is seen as an indispensable aspect of the strategy. Of the 34 countries where *P. hysterophorus* has invaded, only Australia has managed to achieve a reasonable

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**TABLE 1: Goals of the national strategy for managing Parthenium hysterophorus, with associated high-level management interventions and proposed indicators.**

<table>
<thead>
<tr>
<th>Strategic goal</th>
<th>Associated high-level management interventions</th>
<th>Proposed indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish a national invasive alien species control programme</td>
<td>Obtain official approval for a programme and appoint national co-ordinator</td>
<td>Programme approved and co-ordinator appointed</td>
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<td></td>
<td>Quantity and source the necessary funding</td>
<td>Accurate assessment of funding required</td>
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<td></td>
<td>Establish an inter-departmental steering committee</td>
<td>Proportion of funding secured</td>
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<td></td>
<td>Establish a forum to co-ordinate research</td>
<td>Number of participating stakeholders from national, provincial and municipal departments</td>
</tr>
<tr>
<td>Prevent establishment in unoccupied areas</td>
<td>Identify major pathways of spread and manage to reduce risks of movement</td>
<td>Number of new infestations detected in previously unoccupied areas</td>
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<tr>
<td>Detect and locally eradicate new infestations</td>
<td>Undertake training to raise awareness in targeted groups (e.g. agricultural extension officers)</td>
<td>Number of training sessions in high-risk areas</td>
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<td></td>
<td>Use remote sensing to detect new infestations</td>
<td>Number of high-risk areas surveyed</td>
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<td></td>
<td>Undertake rapid assessments when sightings are reported</td>
<td>Number of reported sightings and time taken to carry out assessments</td>
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<td></td>
<td>Commit to a local eradication campaign</td>
<td>Number of campaigns approved on the basis of assessments and adequate management plans</td>
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<td></td>
<td>Confirm local eradication</td>
<td>Number of successful approved local eradication campaigns</td>
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<tr>
<td>Contain further spread of existing infestations</td>
<td>Map invasions to provide a basis for developing management plans and assessing the effectiveness of management</td>
<td>Area covered by populations of <em>P. hysterophorus</em></td>
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<tr>
<td></td>
<td>Raise awareness among target groups (e.g. land users in infested areas)</td>
<td>Number of awareness pamphlets distributed</td>
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<td></td>
<td>Develop and implement management plans</td>
<td>Number of presentations made</td>
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<tr>
<td></td>
<td>Engage with stakeholders to improve rangeland management practices</td>
<td>Number of press articles published</td>
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<td></td>
<td>Expand the biological control programme</td>
<td>Number of municipalities in containment zones covered by provincial management plans</td>
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<tr>
<td></td>
<td>Proportion of rangelands in healthy condition</td>
<td>Funding available for biological control research</td>
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<td></td>
<td>Increases in the effectiveness of biological control</td>
<td>Number of new biological control agents approved and released</td>
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<td></td>
<td>Number of mass-rearing facilities established</td>
<td>Number of municipalities in asset protection zones covered by provincial management plans</td>
</tr>
<tr>
<td>Reduce the impacts on selected assets</td>
<td>Identify and map selected assets</td>
<td>Number of municipalities in asset protection zones with accurate maps</td>
</tr>
<tr>
<td></td>
<td>Develop and implement management plans</td>
<td>Number of municipalities in asset protection zones covered by provincial management plans</td>
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</tbody>
</table>
degree of control, and this is largely because of the use of biological control. The combination of a suite of natural enemies was required to achieve significant reductions in the abundance and impact of *P. hysterophorus* under different circumstances and seasons in Australia (Dhileepan & McFadyen 2012). In 2003, South Africa became the first African country, and only the third country worldwide, to implement a biological control programme against *P. hysterophorus* (Strathie et al. 2011). This research is funded by the DEA and is carried out by the Plant Protection Research Institute within the Agricultural Research Council. The research will be continued and expanded, and the distribution of approved biological control agents will be strengthened through the use of mass-rearing facilities, sited in asset protection zones with dense infestations.

The potential for using remote sensing to detect and map the occurrence and distribution of *P. hysterophorus* has been improved by recent developments in remote sensing technology. Satellite Pour l’Observation de la Terre (SPOT) 6 can now be used to generate maps of the distribution of *P. hysterophorus* at a spatial resolution of 6 m. The intent is to produce a tool for semi-automated annual monitoring of the 40% area of South Africa identified as suitable for invasion by *P. hysterophorus* (Figure 3), at the appropriate spatial scale and classification accuracy, so that new infestations can be detected early and progress of management interventions can be monitored.

In areas where *P. hysterophorus* has reached such high densities that containment will no longer be possible, the strategy will be to focus on the protection of assets. In this case, given the potential impacts on human health, clearing operations will focus on areas where large numbers of people gather, including clinics, bus stops and schools. Road verges will be regularly cleared to reduce the risks of further spread by means of passing vehicles, and it may also be desirable to attempt to clear infestations from protected areas.

The need for research is recognised in the strategy, and it is proposed to establish a research forum, under the auspices of the programme steering committee, to co-ordinate and review research and to foster information and technology transfer. Priority research topics that have been identified at this stage include the development of biological control solutions and remote sensing applications, the management and reduction of predicted impacts on human health and cultural issues affecting rangeland management.

Finally, engagement with international stakeholders is seen as vital. Gaining control of the existing problem in neighbouring Swaziland and Mozambique will be crucial for the achievement of long-term goals in South Africa, while prevention of spread to other neighbouring countries will require international efforts to prevent spread to new areas. With this in mind, the national steering committee will be tasked with fostering collaborative engagement with neighbouring countries.

**Key features and assessment of the implementation plan**

The implementation plan has been designed to guide actions aimed at achieving the strategic goals outlined above. It sets targets that need to be achieved within a defined timeframe and serves as a framework for the allocation of funds to various projects within the national programme (Table 2). In the case of *P. hysterophorus*, it was decided to recommend the appointment of two regional managers responsible for implementation in the coastal province (KwaZulu-Natal).

### Table 2: Goals, actions and targets associated with the implementation of regional management plans for the control of *Parthenium hysterophorus* in different management zones.

<table>
<thead>
<tr>
<th>Management zone</th>
<th>Degree of invasion by <em>P. hysterophorus</em></th>
<th>Management actions</th>
<th>Targets and timeframes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention (low priority)</td>
<td>Species absent, habitat unsuitable</td>
<td>Reactive responses to reports of presence of weed</td>
<td>None</td>
</tr>
<tr>
<td>Prevention (high priority)</td>
<td>Species absent, habitat suitable</td>
<td>Proactive surveillance</td>
<td>Surveillance reports every six months</td>
</tr>
<tr>
<td>Local eradication</td>
<td>Single, isolated (&gt; 50 km from closest neighbouring population), small (covering &lt; 1 ha) populations</td>
<td>Rapid assessment of reported sightings</td>
<td>Within two weeks</td>
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<td></td>
<td></td>
<td>Develop plan and commit resources if local eradication deemed feasible</td>
<td>Commitment within three months</td>
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<td></td>
<td></td>
<td>Monitor and evaluate progress</td>
<td>Report annually</td>
</tr>
<tr>
<td>Containment</td>
<td>Multiple populations covering &gt; 1 ha, occurring within 50 km from each other, but localised, with &gt; 70% of suitable habitat unininvaded</td>
<td>Map invasions</td>
<td>Within six months of initiation of project, update annually</td>
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<tr>
<td></td>
<td></td>
<td>Develop containment plans with clear goals and timeframes</td>
<td>Within six months of initiation of project, update annually</td>
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<tr>
<td></td>
<td></td>
<td>Raise awareness of the risks of spread within the zone</td>
<td>Annual report on awareness-raising</td>
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<tr>
<td></td>
<td></td>
<td>Implement herbicide assistance programmes</td>
<td>Annual report on herbicide assistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Establish mass-rearing facilities for biological control agents</td>
<td>Annual report on number of biological control agents reared and released</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement containment plans</td>
<td>Assess progress towards goals every six months</td>
</tr>
<tr>
<td>Asset protection</td>
<td>Widespread and continuous populations covering &gt; 30% of suitable habitat</td>
<td>Map invasions</td>
<td>Within six months of initiation of project, update annually</td>
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<tr>
<td></td>
<td></td>
<td>Develop asset protection plans with clear goals and timeframes</td>
<td>Within six months of initiation of project, update annually</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raise awareness of the risks of spread to other zones</td>
<td>Annual report on awareness-raising</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement asset protection plans</td>
<td>Assess progress towards goals every six months</td>
</tr>
</tbody>
</table>

Note: Thresholds for the degree of invasion are first approximations and can be altered if needed.
and inland provinces, respectively. They will report to the national co-ordinator and will be responsible for all activities within their regions. In addition, a database manager and a communications manager will be appointed in each region to oversee GIS mapping and other record-keeping and for awareness-raising, respectively. Within each of these regions, local municipalities will be assigned to one of the five zones and managed accordingly (Table 2). The zones assigned to local municipalities will be reviewed annually, and their status can change depending on the circumstances. For example, if it proves impossible to eradicate a localised population, the municipality will be rezoned from a ‘local eradication’ to a ‘containment’ zone; likewise, in the case where containment goals are not achieved, a municipality can be rezoned from a ‘containment’ to an ‘asset protection’ zone. In an ideal world, ‘local eradication’ zones could be assigned to ‘high-priority prevention’ zones if local eradication is achieved.

Regional management plans (one each for the coastal and inland regions) will in effect be compiled ‘bottom-up’ from targets set and resources assigned to individual municipal areas. Landowners (on private land) and traditional authorities (on communal land) will be encouraged to adhere to best practice guidelines, which will be drawn up and distributed as part of the implementation of the strategy. State subsidies will be made available for the purchase and use of herbicides to control *P. hysterophorus*. On state-owned land (e.g. in protected areas), control will be carried out in terms of the protected area’s management plan, or catered for by other plans (e.g. along road reserves and at government schools and clinics), and supported by labour funded through the ‘Working for Water’ poverty relief programme (see van Wilgen, Le Maitre & Cowling 1998).

Given that funding will almost certainly be a limiting factor, it will be necessary to prioritise interventions. Municipalities with high human population densities, well-managed rangelands and important protected areas, and municipalities that could act as source populations for further spread will be given higher priority over other areas. Sufficient funding should be allocated to priority municipalities, recognising that the alternative (dilution of funding to cover all municipalities) would lead to control efforts falling below a threshold at which the management at all of the municipalities would become ineffective. Assigning priorities and ensuring the effective use of funds will be one of the most challenging aspects of implementation.

Management plans for individual municipalities should meet minimum criteria. These include the formulation of realistic goals that can be met within specified timeframes; the effective integration of mechanical, chemical, biological and other control methods (van Wilgen *et al.* 2011); and the co-ordination of the activities of all stakeholders in the municipal area. Bi-annual progress reports should explicitly address progress towards these goals, and where progress falls short of planned targets, action should be taken to correct the shortfalls. If targets are demonstrably not achievable, the goals of the plans will need to be re-assessed. An adaptive approach to management, which requires that plans should be as flexible as possible to accommodate unforeseen setbacks or unplanned events (e.g. droughts, floods or fires), will need to be adopted.

**Discussion**

**Challenges to implementation**

Growing infestations of *P. hysterophorus* will almost undoubtedly have serious consequences for rural economies and the health of people in the invaded areas of South Africa and neighbouring countries. For example, Wise *et al.* (2007) found that if *P. hysterophorus* were allowed to spread without control, returns to small-scale farmers could decline between 26% and 41%. Ways of avoiding or mitigating these impacts should therefore be sought. Wise *et al.* (2007) further found that the effectiveness of control needed to be greater than 50% for the investment to deliver a positive benefit-cost ratio. This supports the adoption of a strategic approach that seeks to guide the implementation of such efforts and to increase the effectiveness of control.

The strategy described here is yet to be implemented, and those tasked with doing so will face several challenges. A number of diverse factors contribute to the creation of these challenges, and they include ecological features of the target plant as well as the habitats that it invades, social and cultural practices that will influence management, inadequate levels of funding and multiple political considerations (Table 3). It is therefore not clear, at this stage, whether or not the goals of the strategy will be achieved, or even if they are achievable. Despite these uncertainties, large sums of money have been spent (and continue to be spent) on the control of *P. hysterophorus*, and the effectiveness of control needs to be increased above a threshold at which the control becomes economically viable. A strategic approach to control, and a close monitoring of its implementation, will therefore be essential if the likely consequences of failure to control *P. hysterophorus* are to be avoided.

Many weed control programmes fail to set targets or to assess their progress towards targets, for a range of reasons (Denslow & D’Antonio 2005; Reid *et al.* 2009). These include the fact that few managers have the long-term funding, expertise or access to guidance that would underpin assessments, nor are they often in a position to collect the high-quality, quantitative data necessary to conduct assessments. In cases where assessments are made, there is no impetus to publish them, making the few results that do exist difficult to locate. It is nonetheless well recognised that evaluation during and after alien species control programmes is vital for effective management, and that schemes for regular evaluation should be planned well before any control is initiated (Blossey 1999).

The above shortcomings need to be recognised and addressed by those who will be tasked with implementing this strategy. In South Africa, as elsewhere, scant attention has been paid to
monitoring and evaluating the outcomes of management, for a range of reasons (van Wilgen et al. 2012; van Wilgen & Wannenburgh 2016). The risk exists, therefore, that it may not be possible to assess the effect of implementing this strategy unless monitoring and evaluation of indicators is taken seriously from the start. As a result of the challenges summarised in Table 3, the implementation of elements of this strategy may fail to deliver the desired outcomes. It would also be important to recognise this at the outset and to plan for alternative approaches to be adopted if and when it becomes apparent that the desired outcomes are not being achieved (Table 4). For example, although we have included ‘local eradication’ zones proposed by Grice et al. (2011) in our strategy, other research has suggested that not all approaches will be suitable for all weed species, and specifically that the eradication of outliers should not be considered where weeds have short juvenile periods and long-lived seeds (Panetta & Cacho 2014). It is therefore entirely plausible that this aspect of management will fail for this particular weed, given its ability to rapidly disperse and establish in new areas, its annual life cycle and the fact that viable seeds remain in the soil for several years.

Outcomes for other important indicators are also uncertain and could vary from positive to negative (Table 4). These include a failure to develop adequate management plans (necessitating steps to expedite or support planning) or to achieve the desired degree of impact using biological control (impact could vary from complete to negligible control, with far-reaching implications for elements of the strategy). Ultimately, the success of the strategy will be gauged by the degree to which the weed populations are contained or reduced. Assessing this will not be easy, as national-scale control operations are not laid out as experiments with adequate treatments and controls (Kettenring & Adams 2011), but the use of evidence-based approaches for assessing the effectiveness of environmental programmes holds promise for overcoming these challenges (Ferraro & Hanauer 2014).

Implementation of the strategy would have to proceed for several years before it could be reasonably expected that outcomes could be adequately assessed. It would nonetheless be important to institute annual assessments from the start, recognising that outcomes will be uncertain and that there has to be a willingness to adapt depending on the trends detected. In this way, it will be easier both to be able to make appropriate adjustments to the strategy and to derive lessons for the use of similar strategic approaches elsewhere.

Relevance to developing countries

Our proposed strategy is modelled in part on the Australian WONS approach (Thorpe & Lynch 2000), with the use of geographic differentiation to formulate different objectives and approaches for different parts of the species’ range, as proposed by Grice et al. (2011). Reviews of the WONS programme in Australia have revealed several positive consequences and highlighted areas in which the approach could be improved (Beatentrack 2008; Raphael et al. 2010; Reid et al. 2009). There is general agreement that the strategy of targeting WONS had led to marked improvements in awareness, as well as in collaborative governance and the ecological understanding of the target weeds. However, it was found that performance indicators in individual species strategies had been developed at too broad a level, and that they generally lacked quantitative measures and timelines against which progress could be assessed (Beatentrack 2008). Stakeholder surveys have also pointed to a widely perceived need for improved monitoring and evaluation (Raphael et al. 2010). The effectiveness of the proposals for geographical differentiation of management goals (Grice et al. 2011) have not been assessed, although they were useful in the formulation of the strategy described here. Thus, even in developed countries like Australia, it has proved difficult to quantify the effectiveness of management interventions.

There are clearly several factors that would make the implementation of control strategies for priority species more
difficult to implement in developing countries, as such countries lack the resources and expertise that are available in Australia. A simple comparison between Australia and South Africa indicates several such factors. These include levels of affluence and education that will affect the relative difficulty of implementing widespread control programmes. For example, the overall and per capita GDP in 2015 was ~US$1500 billion or ~US$845 000 per person in Australia compared with ~US$366 billion or US$12 000 per person in South Africa (estimates vary according to a range of assumptions and methodologies; e.g. http://statisticstimes.com/economy/countries-by-projected-gdp-capita.php; https://en.wikipedia.org/wiki/List_of_IMF_ranked_countries_by_past_and_projected_GDP_%28PPP%29). Overall education levels (based on the UN education index, see http://hdr.undp.org/en/content/education-index) are higher (0.927) in Australia than in South Africa (0.695), and perhaps more importantly, the disparity between the rich and the poor is noticeably more marked in South Africa than in Australia (Gini coefficients of 0.631 and 0.305, respectively). It is thus more likely that control programmes will succeed in Australia as the general population will be able to better afford control efforts and will be better placed to access and use information. Additional factors that will promote more rapid movement of *P. hysterophorus* across the landscape include the relatively high human population densities in South Africa when compared with Australia (44 vs. 3 people/km²) and the absence of international borders in Australia. Most importantly, the possession of livestock is of enormous cultural importance in communal rangelands in South Africa, leading to overstocking, providing a significant challenge to the management of *P. hysterophorus*.

South Africa, on the contrary, is relatively well off when compared with other developing nations. For example, *P. hysterophorus* is spreading through Swaziland, Mozambique and Zimbabwe, which have even less resources for dealing with the problem (per capita GDPs of ~US$6700, 1100, and 1800 per person for 2015, respectively). While it is in the interest of relatively richer countries to assist their neighbours with the control of alien plants that will pose high risks across international borders, the reality remains that the effective implementation of co-ordinated strategic control programmes will be difficult. In the case of *P. hysterophorus*, effective biological control offers some hope of reducing the problem to manageable proportions, as it has been done in Australia. It is ironic that many developing nations are opposed to the use of biological control, as in many cases it offers a safe and effective way of addressing problems of invasion (Sheppard et al. 2003; van Wilgen, Moran & Hoffmann 2013). We would therefore recommend, in this and many other cases, that biological control be considered as a vital and indispensable component of any alien plant control strategy in developing countries.
Acknowledgements

Financial support for the strategy was provided by the Department of Environmental Affairs-Natural Resource Management Programme. We thank the participants of the workshops, and others, for inputs into the development of this strategy, particularly Philip Blackmore, Michael Braack, Ian Macdonald, Rachel McFadyen, Ian Rushworth, John Wilson and Helmhut Zimmermann. BvW thanks the DST-NRF Centre of Excellence for Invasion Biology and the South African National Biodiversity Institute (SANBI) for funding his involvement. LS, JG and AM thank the Agricultural Research Council of South Africa for facilitating their involvement. HK and IN thank SANBI for the administration behind the strategy.

Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Authors’ contributions

CB led the development of the strategy; L.S. and A.M. made inputs regarding biological control. All of the authors participated in workshops and reviewed various drafts of the strategy. B.v.W. wrote the entire paper for publication.

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