A proposed prioritization system for the management of invasive alien plants in South Africa

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EVERY COUNTRY HAS WEED SPECIES WHOSE presence conflicts in some way with human management objectives and needs. Resources for research and control are limited, so priority should be given to species that are the biggest problem. The prioritization system described in this article was designed to assess objectively research and control priorities of invasive alien plants at a national scale in South Africa. The evaluation consists of seventeen criteria, grouped into five modules, that assess invasiveness, spatial characteristics, potential impact, potential for control, and conflicts of interest for each plant species under consideration. Total prioritization scores, calculated from criterion and module scores, were used to assess a species' priority. Prioritization scores were calculated by combining independent assessments provided by several experts, thus increasing the reliability of the rankings. The total confidence score, a separate index, indicates the reliability and availability of data used to make an assessment. Candidate species for evaluation were identified and assessed by several experts using the prioritization system. The final ranking was made by combining two separate indices, the total prioritization score and the total confidence score. This approach integrates the plant's perceived priority with an index of data reliability. Of the 61 species assessed, those with the highest ranks (*Lantana camara, Chromolaena odorata* and *Opuntia ficus-indica*) had high prioritization and high confidence scores, and are thus of most concern. Those species with the lowest ranks, for example, *Harrisia martinii, Opuntia spinulifera* and *Opuntia exaltata,* had low prioritization scores and high confidence scores, and thus are of least concern. Our approach to ranking weeds offers several advantages over existing systems because it is designed for multiple assessors based on the Delphi decision-making technique, the criteria contribute equally to the total score, and the system can accommodate incomplete data on a species. Although the choice of criteria may be criticized and the system has certain limitations, it appears to have delivered credible results.

Introduction

Various publications contain lists of South African plant taxa that are described as 'problem plants', 'declared weeds', 'declared invaders' or 'alien invaders'.[1–3] These taxa have been so described because they possess at least some characteristics that bring them into conflict with human interests or because they are ecologically harmful in certain circumstances. The lists include many species; for example, Wells *et al.*[1] produced a catalogue of problem plants in southern Africa which contains 1653 taxa. This represents a large number of undesirable species, which have varying levels of ecological impact. Given the limited availability of resources for research and control, there is a need to focus attention on the control, study and monitoring of the species presenting the greatest problems.

Policy-makers have two main concerns: 1) to implement legislation to keep potential invasive alien organisms out of their region of jurisdiction, and 2) to manage those alien species already present in their area to curtail their spread and reduce actual and potential impacts.[4] Screening systems for predicting invasive organisms have been devised in many countries to address the first task.[5–9] The second task requires a more spatially explicit approach to identify risk areas, described by Rouget *et al.*,[4] as well as a complementary prioritization system to help direct limited resources for countermeasures.

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The current focus in South Africa is on woody invasives from the commercial forestry sector, where South Africa faces a more severe problem of its kind than any other country.[10] Attempts are being made with managing invasive alien plants, mainly through initiatives such as the Working for Water Programme.[11]

In South Africa, and very likely in other developing countries, there is currently no formal means of identifying those species that are the most problematic and most warranting attention for intervention measures. In view of this, we have designed a system to prioritize research and control efforts against alien invasive plant species that have already become established in this country.

Alien invasive species have numerous deleterious effects on the environment, as summarized by Macdonald *et al.*[12] for impacts in southern Africa. An alien species is defined as one which is remote from its centre of origin, usually from a different continent or subcontinent.

Our system is different from others, that have been designed largely to prevent species invasions at the quarantine stage.[5–9] Our contribution is known as a 'prioritization system', rather than a rating system[6] or ranking[13,14] system. Prioritization generally involves a set of criteria and some sort of scoring system against which the threat posed by a species can be assessed.

Methods

Approach

An effective means of obtaining a reliable assessment for a number of plants is to use a multi-assessor approach, in which the opinions of several individuals are considered to be better than the opinion of a single person (for discussion see Hiebert[14]). This type of approach is less sensitive to biases or to the experience of individuals. Assessors may be able to provide data for some criteria and not for others, depending on their field of expertise. Each assessor's specialization is likely to be different from another's and thus a multi-assessor approach can make optimal use of available data.

Hiebert[14] outlines two decision-making procedures, namely nominal group techniques (NGTs) and the Delphi method. Nominal group techniques involve an interactive group structure whereas the Delphi method uses the individual opinions of experts with no 'face-to-face' interaction.[14] For this reason, the Delphi method has a number of advantages over NGTs, and allows a group of individuals to reach consensus without ever meeting. This helps to reduce certain factors such as dominance of a discussion by one or more participants, and unwillingness to abandon a previous opinion.[14] Apart from the effects of group dynamics and human interaction on responses, it may be difficult to assemble a panel of experts at the same time. The prioritization system was designed so that independent assessments from several different authorities could be made using the Delphi method.

System design

The design of the system refers to the manner in which the scores obtained from the assessment criteria are arranged, combined or weighted to produce a total score for a given species. We followed a modular approach in which 17 assessment criteria were grouped into five modules (Table 1), with each module being dedicated to a particular aspect or issue. A similar approach has been used previously,[6] although the definition of terms differs from those used here.

It is undesirable to have a situation where the potential maximum scores for each criterion can have different values because it may lead to arbitrarily uneven weighting of criteria. To overcome this problem, the score for each criterion is scaled so that the potential maximum score for each criterion is one.[6] Similarly, the score for each module is divided by the number of criteria in that module. The modules can be differentially weighted according to the needs of users, to emphasize aspects of interest.[6,13,15]

Dealing with uncertainty

An issue of concern is how to deal with uncertain or missing data. One option is to omit the criterion (and alter the module scaling factor accordingly), or to add a small penalty score that makes the system err on the conservative side.[6,7] The disadvantage of these approaches is that the total score is artificially inflated by uncertain or missing data. It is thus impossible to determine whether the species has a high score due to data quality issues or because it is genuinely a problem.

To overcome this limitation, we used a separate measure known as a *confidence score*, which indicates uncertainty and availability of data for each criterion. The lower the confidence score the greater the uncertainty and amount of missing data for that criterion. This approach has the advantage that it explicitly indicates a level of confidence in the *total prioritization score* assigned to a species, that is, it can be used as a measure of how much faith should be placed in a given prioritization score, and the further research that is desirable. In addition, the confidence score can be used as a measure of the state of knowledge of a given species.

Using the prioritization system

The prioritization system is applied by scoring each species for each of the criteria (Table 1). These scores are then summed for each module, and the total divided by the number of criteria for which assessments were made in the respective module (criteria for which no score is provided are ignored). The result is a set of module scores that can be weighted according to the needs and emphasis of particular users. For general purposes, modules can be given equal weight. The method is designed so that the user can customize the system by weighting the modules, but the criteria within those modules have fixed weightings that cannot be altered by the user. A final, user-specific prioritization of the candidate species can be made by summing the (un)weighted module scores for each species (this is the equivalent of weighted averaging of modules) and ranking the taxa by this index.

A similar approach is used to calculate the total confidence score for a species. In cases where data are missing, a confidence score of zero is assigned; where data are uncertain, a confidence score of 0.5 is given; where data are certain, a confidence score of 1 is recorded, for a given criterion. A module confidence score is calculated by totalling the confidence scores and dividing by the number of criteria in that module. The sum of the module confidence scores gives the total confidence score (Table 1).

The criteria

The criteria adopted in the prioritization system were selected by the authors at a workshop convened to develop a system for ranking plant species at a national scale. The best assessment criteria may not necessarily be those for which data are available,[13] or for which information can easily be acquired. These constraints as well as ease-of-use considerations influenced the selection of criteria. A detailed account of the selection process and a justification for the inclusion of each criterion can be found elsewhere.[16]

Prioritizing a candidate list of species

The list of candidate species to be assessed was compiled by including those weeds for which herbicides have been registered;[17,18] biocontrol agents have been released;[1,17,19] legislation has been passed[1,17] or for which legislation is proposed.[17] A list of alien invasive species compiled by Richardson *et al.*[3] and a catalogue of taxa targeted by the South African Working for Water Programme[20] was also included.

Independent assessments for the candidate species were then provided by a number of individuals, using the Delphi method. Scores for each criterion were obtained by calculating the median of the individual scores assigned by the assessors. Each criterion score was standardized by dividing it by the potential maximum. These criterion scores were summed to produce the module score, which was standardized by dividing it by the number of criteria used. The total prioritization score was obtained by summing the standardized module scores. The module scores were each given a weighting of one.

Species were ranked according to the product of the total prioritization score and the total confidence score. This provides a single index by which species can be ranked objectively. This approach produces a more realistic ranking of species than those produced by first sorting the list using the prioritization score and then sorting by the confidence score. The ranking should still be interpreted using the total prioritization and total confidence scores in relation to the number of assessors.

Results

Sixty-one species were ranked according to the product of their total prioritization scores and total confidence scores (Table 2). This list is not intended to be a national, prioritized list of South African weeds, but merely demonstrates the use of the procedure and illustrates ways in which the results can be analysed.

Those species that have high prioritization scores and high confidence scores are of most concern, for example, *Lantana camara, Chromolaena odorata* and *Opuntia ficus-indica* (ranked 1, 2 and 3, respectively). Those species that have low prioritization scores and high confidence scores are of least concern, for example, *Harrisia martinii, Opuntia spinulifera* and *Opuntia exaltata* (ranked 59, 60 and 61, respectively).

The highest ranking species (*Lantana camara*) obtained a score of 3.33 and the lowest ranking species (*Opuntia rosea*) scored 1.26 (Table 2). Total confidence scores ranged from 5 to 3.97 and the number of assessors ranged from 3 to 11 (Table 2). Each assessor evaluated a minimum of 12 criteria per species.

Table 1. The elements of the prioritization system. These consist of five modules: Potential Invasiveness, Actual Spatial Extent, Potential Impacts, Potential for Control, and Conflicts of Interest. Each module consists of a number of criteria, with their weightings appearing in square brackets on the right of each criterion. Highest weightings are associated with the most undesirable characteristics.

Modules and criteria		Criterion scores	Confidence scores
MODULE A: POTENTIAL INVASIVENESS			
a) Long-distance dispersal			
There is:			
1) no known long-distance dispersal mechanism	[0]	a/1 = α[1]	
2) a known long-distance dispersal mechanism (dispersal >5 km)	[1]	_/1 = _[2]	a' = _[3]
b) Invasive elsewhere			
The species is invasive elsewhere, outside South Africa?			
1) Yes	[1]	b/1 = β	
2) No	[0]	_/1 = _	b' = _
MODULE B: SPATIAL CHARACTERISTICS			
c) Distribution			
The current percentage of 15′ (quarter degree) grid squares in the entire country (approx. 2000) occupied by the species is:			
1) 1–2% (up to 40 quarter-degree squares), e.g. *Hakea drupacea*	[0]		
2) 3–5% (up to 100 quarter-degree squares), e.g. *Cereus jamacaru* and *Chromolaena odorata*	[1]		
3) 6–10% (up to 200 quarter-degree squares), e.g. *Jacaranda mimosifolia*	[2]		
4) 11–20% (up to 400 quarter-degree squares), e.g. *Prosopis* spp. and *Acacia dealbata*	[3]		
5) 21–40% (up to 800 quarter-degree squares), e.g. *Acacia mearnsii* and *Melia azedarach*	[4]	c/5 = χ	
6) >40% (over 800 quarter-degree squares), e.g. *Opuntia ficus-indica*	[5]	_/5 = _	c′ = _
d) Density			
The species occurs predominantly as:			
1) individual plants	[0]		
2) small clumps	[1]		
3) vast monospecific stands	[2]	d/3 = δ	
4) mixed stands with other invasives	[3]	_/3 = _	d′ = _
MODULE C: POTENTIAL IMPACTS			
e) Biodiversity			
Reduction in biodiversity where the species occurs is:			
1) none	[0]		
2) minor (1–30%)	[1]		
3) moderate (31–80%)	[2]	e/3 = ε	
4) profound (>80%)	[3]	_/3 = _	e′ = _
f) Water resources			
The species' impact on water resources is:			
1) no impact	[0]		
2) reduction of stream flow by 10–30%	[1]		
3) reduction of stream flow by > 30%	[2]	f/3 = ϕ	
4) flow eradicated	[3]	_/3 = _	f′ = _
g) Negative economic impact			
The negative economic impact of the species is:			
1) no negative impact	[0]		
2) <10% reduction in profit	[1]		
3) 11–30% reduction in profit	[2]		
4) >30% reduction in profit	[3]	g/4 = γ	
5) land unusable	[4]	_/4 = _	g′ = _
h) Positive economic impact			
The positive economic impact of the species is:			
1) none	[4]		
2) informal	[3]		
3) small business	[2]		
4) commercial (industrial)	[1]	h/4 = η	
5) any two or more of the above	[0]	_/4 = _	h′ = _
i) Poison status			
The species is poisonous to stock or humans			
1) yes	[1]	i/1 = ι	
2) no	[0]	_/1 = _	i′ = _
MODULE D: POTENTIAL FOR CONTROL			
j) Chemical control			
The options for realistic chemical control of the species are:			
1) not available	[3]		
2) impractical in most situations	[2]		
3) partially successful	[1]	j/3 = φ	
4) effective and practical	[0]	_/3 = _	j′ = _

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Table 1 (*continued*)

Modules and criteria		Criterion scores	Confidence scores
k) Biological control			
The options for biological control of the species are:			
1) complete control	[0]		
2) substantial control	[1]		
3) negligible control	[2]	k/3 = κ	
4) no agents released yet	[3]	_/3 = _	k′ = _
l) Mechanical control			
The options for mechanical control of the species are:			
1) not available	[3]		
2) impractical in most situations	[2]		
3) partially successful	[1]	l/3 = λ	
4) effective and practical	[0]	_/3 = _	l′ = _
m) Legislation			
Legislation to assist in the control of the species (e.g. classification as a declared weed or declared invader) is:			
1) absent	[1]	m/1 = μ	
2) in place	[0]	_/1 = _	m′ = _
n) Accountability			
Can any agency be held accountable for the introduction or proliferation of an invasive species in South Africa?			
1) no	[1]	n/1 = ν	
2) yes	[0]	_/1 = _	n′ = _
MODULE E: CONFLICTS OF INTEREST			
o) Commercial sector			
Possible conflicts of interest at the commercial sector level are:			
1) no conflict	[0]		
2) possible resolution to conflict	[1]	o/2 = ο	
3) biological control precluded	[2]	_/2 = _	o′ = _
p) Informal sector			
Possible conflicts of interest at the informal sector level are:			
1) none	[0]		
2) in cases where rural households harvest plants to meet their daily needs of food or energy	[1]		
3) in cases where rural households sell plants or plant products as a source of income on a supplementary or full-time basis	[2]	p/2 = π _/2 = _	p′ = _
q) Cost/benefit analysis			
The species has:			
1) substantial economic value (including informal sector and commercial markets)	[0]		
2) some economic value (e.g. building material or windbreaks)	[1]		
3) limited value (e.g. ornamental or horticultural value)	[2]	q/3 = θ	
4) no apparent commercial, ornamental or horticultural value	[3]	_/3 = _	q′ = _

Module score	Module confidence
A = ((α + β)/2)Wa = __ [4]	A = (a′ + b′)/2 = __ [5]
B = ((χ + δ)/2)Wb = __	B = (c′ + d′)/2 = __
C = ((ε + ϕ + γ + η + ι)/5)Wc = __	C = (e′ + f′ + g′ + h′ + i′)/5 = __
D = ((φ + κ + λ + μ + ν)/5)Wd = __	D = (j′ + k′ + l′ + m′ + n′)/5 = __
E = ((ο + π + θ)/3)We = __	E = (o′ + p′ + q′)/3 = __
Total prioritisation score = A + B + C + D + E = __ [6]	Total confidence score = A + B + C + D + E = __ [7]

[1]The score for each criterion (indicated by a lower-case Roman letter, e.g. a) is divided by the maximum possible score for that criterion to give the Criterion Score (denoted by a lower-case Greek letter, e.g. α).

[2]The table is designed so that it can be used by an assessor for assigning scores to a given target species. Spaces (marked by underscores) are provided where the criterion and module scores are to be inserted. The system can be used as follows. As an example, in *criterion a* (long-distance dispersal), if the target species has a known long-distance dispersal mechanism, its weighting is 1. This would be written on the first underscore and then divided by the maximum for that criterion (also 1) to give the criterion score of 1, which is written on the next underscore. The same procedure is followed for all criteria in the prioritisation system.

[3]Confidence scores are assigned to each criterion based on the uncertainty and availability of data. For a given criterion, the following confidence scores are used: 0 where data are missing, 0.5 where data are uncertain, and 1 where data are certain.

[4]The sum of the criterion scores divided by the number of criteria in the module gives the module score (denoted by an upper-case Roman letter). Modules can be weighted according to the requirements of the user, by applying a module weighting (Wa, Wb, Wc, Wd, We) to the module score.

[5]A module confidence score is calculated for a module by summing the criterion confidence scores and dividing by the number of criteria in that module.

[6]The total prioritisation score is calculated by totalling the module scores.

[7]The total confidence score is calculated by taking the sum of the module confidence scores.

Table 2. A list of 61 species ranked according to the product of their total prioritization score and the total confidence score.

Rank	Species	Total criteria*	Total confidence	Crit × conf†	No. of assessors‡
Maximum score:		5.00	5.00	–	–
1	*Lantana camara*	3.33	4.52	15.05	11
2	*Chromolaena odorata*	3.06	4.86	14.87	9
3	*Opuntia ficus-indica*	2.96	4.77	14.12	11
4	*Acacia saligna*	2.75	5.00	13.75	3
5	*Cestrum laevigatum*	2.78	4.90	13.62	3
6	*Prosopis* spp.	2.98	4.57	13.62	7
7	*Hakea gibbosa*	2.79	4.88	13.62	3
8	*Tamarix ramossima*	3.02	4.44	13.41	3
9	*Acacia mearnsii*	2.99	4.48	13.40	10
10	*Azolla filiculoides*	2.92	4.57	13.34	10
11	*Solanum mauritianum*	2.95	4.52	13.33	11
12	*Myriophyllum aquaticum*	2.66	4.96	13.19	4
13	*Acacia cyclops*	2.82	4.61	13.00	3
14	*Pinus patula*	2.80	4.63	12.96	3
15	*Salvinia molesta*	2.62	4.90	12.84	3
16	*Pinus elliottii*	2.75	4.63	12.73	3
17	*Pereskia aculeata*	2.58	4.91	12.67	4
18	*Acacia melanoxylon*	2.75	4.58	12.60	4
19	*Cinnamomum camphoratus*	2.65	4.75	12.59	3
20	*Datura stramonium*	2.59	4.83	12.51	3
21	*Arundo donax*	3.08	4.03	12.44	3
22	*Leptospermum laevigatum*	2.85	4.29	12.26	4
23	*Eichhornia crassipes*	2.63	4.65	12.23	5
24	*Ricinus communis*	2.62	4.56	11.95	8
25	*Acacia baileyana*	2.94	3.97	11.67	3
26	*Pinus radiata*	2.83	4.09	11.60	3
27	*Acacia dealbata*	2.70	4.28	11.56	9
28	*Melia azedarach*	2.57	4.49	11.54	8
29	*Caesalpinia decapetala*	2.56	4.48	11.47	10
30	*Acacia decurrens*	2.60	4.37	11.36	3
31	*Pinus halepensis*	2.64	4.29	11.33	3
32	*Pinus canariensis*	2.61	4.29	11.20	3
33	*Nassella trichotoma*	2.44	4.49	10.96	3
34	*Pinus pinea*	2.50	4.38	10.95	3
35	*Cirsium vulgare*	2.37	4.61	10.93	3
36	*Rubus cuneifolius*	2.47	4.37	10.79	3
37	*Solanum elaeagnifolium*	2.38	4.44	10.57	4
38	*Psidium guajava*	2.39	4.41	10.54	9
39	*Pinus pinaster*	2.46	4.28	10.53	9
40	*Paraserianthes lophantha*	2.30	4.48	10.30	4
41	*Litsea glutinosa*	2.50	4.11	10.23	3
42	*Schinus molle*	2.28	4.47	10.19	3
43	*Opuntia aurantiaca*	2.11	4.75	10.02	3
44	*Hakea sericea*	2.23	4.46	9.95	10
45	*Acacia longifolia*	2.24	4.28	9.59	11
46	*Opuntia stricta*	1.97	4.73	9.32	3
47	*Pennisetum clandestinum*	2.04	4.51	9.20	3
48	*Acacia pycnantha*	2.06	4.38	9.02	3
49	*Passiflora edulis*	2.01	4.36	8.76	3
50	*Pistia stratiotes*	1.98	4.35	8.61	3
51	*Opuntia imbricata*	1.86	4.62	8.59	3
52	*Opuntia monocantha*	1.81	4.62	8.36	3
53	*Hypericum perforatum*	2.01	4.07	8.18	3
54	*Solanum sisymbrifolium*	1.76	4.61	8.11	3
55	*Ipomoea purpurea*	1.77	4.47	7.91	3
56	*Opuntia lindheimeri*	1.49	5.00	7.45	3
57	*Jacaranda mimosifolia*	1.47	4.90	7.20	3
58	*Harrisia martinii*	1.42	4.54	6.45	3
59	*Opuntia spinulifera*	1.26	4.83	6.09	3
60	*Opuntia exaltata*	1.28	4.45	5.62	3
61	*Opuntia rosea*	1.26	4.07	5.13	3

*Total criteria refers to the total criterion score and total confidence to the total confidence score.

†Crit × conf refers to the product of the total criterion score and the total confidence score.

‡The number of assessors who provided scores for one or more of the criteria for a given species.

Discussion

Prioritization scores

The maximum possible total prioritization score attainable is 5 and the lowest is zero. Although a number of species that are highly desirable are likely to obtain a total prioritization score that is very close to zero, it is unlikely that any weed will record a total prioritization score of 5 (Table 2).

Some of the results should, however, be treated as preliminary owing to the small numbers of assessors (three in some cases) used to evaluate many of the species. Care should be taken when comparing total prioritization scores calculated from data provided by different numbers of assessors, as was the case here. Total prioritization scores calculated from a greater number of assessors are likely to be more reliable. For example, the score reported for *Acacia mearnsii* (ranked 9th) is much more reliable because it was calculated using data from 10 assessors as opposed to that of *Tamarix ramossima* (ranked 8th), which was calculated using data from only three individuals. Based on our experience, *Tamarix ramossima* appears to have been rated too highly, possibly because only three assessors were involved. Comparing total prioritization scores which were calculated using different numbers of assessments can be likened to contrasting the results of experiments conducted using different sample sizes. The results indicate the need for evaluations to be made using least 10 assessors, although further work is required to establish minimum numbers of opinions to canvass for a dependable result. The system can be used to identify gaps in expertise by noting those species that had small assessor numbers. A potential problem is that a species may not be widespread and thus not known to many people, but may be significant and require action at a local scale, for example, *Tamarix ramossima*.

The reliability of the total prioritization score (and hence of the rank) is clearly dependent on the number of criteria assessed, the quality of the data available to the assessor, and the number of assessors involved. When the results of a species' prioritization are interpreted, each of these factors should be taken into account.

Ideally, all of the criteria would be used to calculate the total prioritization score for a species. However, this is not always possible due either to a genuine lack of, or access to, reliable data. If the total prioritization score is calculated using all the criteria, then one can be sure that all the relevant factors were taken into account. If only some of the criteria are considered, then the species may attain an artificially high or low score due to its unique set of undesirable attributes.

Caution should be exercised when comparing total prioritization scores that were calculated using different numbers of criteria. The total confidence score gives an indication of the perceived quality and availability of data used by an assessor. This measure is extremely important for evaluating the assessments provided by an individual for a given species as well as for evaluating the rank that a species has been assigned.

Confidence scores

Species with confidence scores with values of less than 3.5 were not reported. There is some quality control in the system through 'self-censorship' by the assessors themselves, as they appeared to be unwilling to evaluate a species about which they had inadequate knowledge.

Species which have both high total prioritization scores and high total confidence scores are most likely to pose serious problems (Table 2). *Lantana camara, Chromolaena odorata* and *Opuntia ficus-indica* recorded high prioritization scores (3.33, 3.06 and 2.96, respectively), and high confidence scores (4.52, 4.86 and 4.77, respectively). These species are ranked 1, 2 and 3, respectively (Table 2). These are plants in which the greatest number of resources, human and economic, can confidently be invested.

Species with high total prioritization scores but low total confidence scores indicate an urgent need for further investigation or research to obtain more confidence in their prioritization score and hence their rank. To be conservative, these species should be treated as serious until evidence to the contrary is provided. It is more difficult to justify large investments of resources in these species than in those with high prioritization and high confidence scores. These species should be carefully monitored and researched.

Species with low total prioritization and high total confidence scores are of little cause for concern to weed managers for the foreseeable future. Species with low total prioritization scores and low total confidence scores are of more concern and should be monitored. These species could be a greater problem than their prioritization scores suggest, owing to the uncertainty of the data used to obtain these scores, as indicated by low confidence scores.

Ranks

The highest-ranking species in the list is *Lantana camara* (Table 2), which is described as one of the most serious invader species in South Africa and considered to be one of the world's ten worst weeds.[21] Other species with high total prioritization scores include *Chromolaena odorata, Opuntia ficus-indica, Acacia saligna, Cestrum laevigatum, Acacia mearnsii* and *Prosopis* species (Table 2), which are also considered to be problem weeds in South Africa.[3] Based on our experience, some species appear to have been ranked surprisingly low; these include *Acacia mearnsii, Harrissia martinii, Hakea sericea, Acacia cyclops, Melia azedarach, Acacia dealbata, Pinus pinaster, Psidium gujava, Opuntia stricta* and *Opuntia rosea*. Species that appear to have been ranked unexpectedly highly include *Opuntia ficus indica, Cinnamomum camphoratus, Datura stramonium, Cestrum laevigatum, Schinus molle, Ricinus communis, Myriophyllum aquaticum, Salvinia molesta* and *Tamarix ramossima*.

Unusually high rankings may be attributed in part to the design of the prioritization system and in part to the number of criteria that were assessed to calculate the total score. The prioritization system was designed so that the undesirable attributes of a plant are assigned higher scores than desirable or neutral attributes. The total score mounts only if the plant has an undesirable attribute but it is not reduced if the plant has a desirable one. As a result the desirable attributes are not able to compensate for undesirable ones. For example, *Opuntia ficus-indica* and *Acacia saligna* are widespread and have a number of undesirable attributes but there are effective biocontrol agents available for these species. It would be extremely complex if not impossible to design a system that would be capable of taking these situations into account. Perhaps the best solution is to record the species for which effective biocontrol is available and to reduce their final rankings after the total scores have been calculated.

Unusually high or low rankings for individual species may result from the assessors not evaluating all of the criteria or modules. Obtaining reliable assessments for all criteria and all species is almost impossible but the consequences of missing data need to be considered when evaluating the final ranked list of weeds. This can be done by examining the criterion and module scores for those species that are ranked unusually high or low.

Despite the outliers and some of the potential weaknesses outlined above, the prioritization system appears to have delivered credible results with a meaningful decrease in the status of the species being evaluated as one moves from highest to lowest rank on the list (Table 2). For example, a problem species[21] such as *Lantana camara* is ranked at the top of the list, while *Jacaranda mimosifolia*, which is much less of a problem (at a national scale), is ranked near the bottom of the list (Table 2). The system has heuristic value because it challenges preconceptions about the ranking of species. In addition, the procedure can be used to provide sound reasons for assigning a particular rank to a species. These reasons can be found by performing a detailed examination of the criteria used and the criterion scores that the species were given.

The results of prioritization should be treated with caution because the rank assigned to a species is at least in part affected by the other species included in the list of comparisons. For example, if a number of potentially high-ranking species (that is, highly undesirable plants) are excluded from a list then other, less serious weeds will have higher ranks than they would otherwise have (although the total prioritization scores will be unaffected). This illustrates the need for thoughtful decisions regarding criteria for selection of candidate species for assessment.

A ranking of plant species based on prioritization scores is valid for a limited period because the status of these plants can change due to successful intervention strategies, changes in legislation, introduction of new species, or population increases of certain plants.[22]

The scale at which the prioritization is performed is also likely to influence a species' rank. Rankings produced at a provincial (local) scale are likely to be different from rankings produced at a national (regional) scale. This is because a different list of candidate species will almost certainly be used at the provincial scale because not all of the species included in the national list are likely to occur within the particular province of interest.

Species may have a higher prioritization score than another in a list, indicating a higher rank and therefore a higher priority status. If the prioritization and confidence scores used to assign the ranks are very similar, then this ranking becomes arbitrary. For example, *Melia azedarach* is ranked 28th in our list, based on a prioritization score of 2.57, while *Caesalpinia decapetala* is ranked 29th, based on a prioritization score of 2.56. The confidence scores are 4.48 and 4.49, respectively (Table 2). These scores are not appreciably different, indicating that these ranks should be treated with discretion.

Conclusions

The prioritization system presented here is a useful decision support tool for weed-control and research organizations, not only for South Africa but also in other countries and at various spatial scales. The protocol can be customized according to the needs of these organizations by altering the module weightings or modifying some of the criteria used for assessment. In addition, the system can also be used to assess the state of knowledge of invasive alien plants by determining: (i) shortages in expertise by noting species with low assessor numbers; (ii) gaps in knowledge by identifying species for which few criterion questions were answered; and (iii) lack of insight by examining those species with surprisingly high or low ranks.

The design of the system in terms of standardization of criterion and module scores, the confidence scoring system and the Delphi assessment approach have many advantages. As a result, these design features should be incorporated into future prioritization procedures. These design features are also applicable to prioritization systems used to assess other organisms[6] and to those designed for different management purposes such as risk assessment at the quarantine stage.[5,7]

The prioritization system should be used in conjunction with predictive modelling techniques (see, for example, refs 4, 23, 24) to determine which species are the greatest problem and where management action is required at present and in the future.

We thank Estelle Brink (Selmar Schonland Herbarium, Grahamstown), Clive Bromilow (Bayer Chemicals); Tony Gordon, Martin Hill, Hildegard Klein, Carl Stoltz and Costas Zachariades (ARC – Plant Protection Research Institute); Pat Hulley (Department of Zoology and Entomology, Rhodes University), Dinemari Nel (Western Cape Department of Agriculture), and Geoff Nichols (Geoff Nichols Horticultural Services) for providing additional species assessments. This work was funded by the National Department of Agriculture and the Agricultural Research Council – Range and Forage Institute. Financial assistance from the Foundation for Research Development (now the National Research Foundation), towards the workshop, is gratefully acknowledged. The Agricultural Research Council – Plant Protection Research Institute is thanked for hosting the workshop.

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