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Invasive alien plants and South African rivers: a proposed approach to the prioritization of control operations

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SUMMARY

1. A number of parallel initiatives in South Africa have been addressing the prioritization and management of invasive alien plant species, the prioritization of rivers for the conservation of biodiversity, and broad-scale planning for water resource management. This paper has combined aspects of these approaches to develop a composite index of prioritization of quaternary catchments for alien plant control purposes.
2. We calculated, for each quaternary catchment, a simple composite index that combined estimates of (i) the number of invasive alien plant species present; (ii) the potential number of invasive alien plant species that would be present if they occupied the full range as determined by climatic envelope models; (iii) the degree of habitat loss in rivers; and (iv) the degree of water stress. Each of the four components contributed between one and four to the combined index, which had a range of values between four and 16.
3. We used a geographic information system to map the distribution of priority catchments for invasive alien plant control. Of the 1911 quaternary catchments in South Africa and Lesotho, just over one-third (650) were in the highest priority category with an index of 13 or more. A relatively small proportion (273, or 14%) of the catchments had the maximum scores of 15 or 16.
4. The approach identified priority areas that have not currently been identified as such, and should provide decision makers with an objective and transparent method with which to prioritize areas for the control of invasive alien plants. We anticipate debate about the way in which components of the index are calculated, and the weight given to the different components, and that this will lead to the transparent evolution of the index. Improvements would also come about through the addition of a more comprehensive list of species, and through the addition of further components.

Keywords: catchment management, conservation planning, Lesotho, water stress, Working for Water programme

Introduction

Rivers are globally threatened by the development of impoundments, flow regulation and pollution (Dudgeon *et al.*, 2006). In addition to these pressures, invasive alien species pose a significant threat to the ecological integrity of river ecosystems, and are often cited as the second most pressing threat (after direct habitat destruction) to global biodiversity (Mooney & Hobbs, 2000). The focus of attention with regard to alien species and rivers has often fallen onto faunal elements, notably alien fish (Rahel, 2000, 2006), and floating aquatic weeds (van Wyk & van Wilgen, 2002), while terrestrial ecologists have focussed largely on

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the impacts of invasive alien plants away from river ecosystems. River ecosystems are nonetheless very important, and several studies have found riparian zones to be more invaded by alien species than other plant communities, and rivers may function as dispersal corridors for the rapid spread of invasive alien plants across landscapes (Thébaud & Debussche, 1991; Pyšek & Prach, 1994; Planty-Tabacchi *et al.*, 1996). It is also widely recognised that river ecosystems cannot be managed in isolation of their catchments (Tinley, 1991; Allan, Erickson & Fay, 1997), but ecological studies that explicitly seek to integrate terrestrial and aquatic aspects of ecosystem management are rare (Dudgeon *et al.*, 2006).

While it is often the case that parallel initiatives aimed at aspects of river or water conservation are attempted in isolation, the fact that they exist offers promising potential for integration. In South Africa, for example, ecologists and water resource planners have focused on a number of aspects relating to the conservation of rivers and water resources in a number of parallel yet largely unrelated initiatives. One of these relates to the impact of terrestrial invasive alien plant species, where the impact of these species on water resources has clearly been demonstrated (Le Maitre *et al.*, 1996, 2002; van Wilgen, Cowling & Burgers, 1996; Dye & Jarmain, 2004), leading to the establishment of one of the largest invasive alien plant clearing programmes globally (van Wilgen, Le Maitre & Cowling, 1998). Provisional estimates indicate that between 1400 and 3300 million m^3 of surface runoff, or between 3% and 7% of the national mean annual runoff, is used by invading alien vegetation. This is in excess of the volume used by native vegetation (Görgens & van Wilgen, 2004). If the spread of such vegetation is not controlled, the impact is likely to increase. Through the government's interventions, large areas are being cleared of alien vegetation. Current policy recognises that the removal and containment of such vegetation should, where applicable, form part of catchment management strategies (Department of Water Affairs and Forestry, 2002).

In a second set of initiatives in South Africa, aquatic ecologists have been developing approaches towards the prioritization of river ecosystems for the conservation of biodiversity. This work (King, Tharme & de Villiers, 2000; Roux, 2001) has been driven by (and even preceded) a number of newly-adopted policies. In particular, South Africa's new water legislation, adopted in 1996, requires that the ecological integrity of river ecosystems be maintained to protect their capacity to deliver goods and services to people on a sustainable basis. South Africa has also ratified the Convention on Biodiversity, and in terms of this is developing a national biodiversity strategy and action plan, which will include an explicit prioritization of river ecosystems for conservation (Driver *et al.*, 2005). Finally, several large-scale initiatives, funded by the Global Environmental Facility, have resulted in the introduction and development of systematic conservation planning to underpin the national biodiversity strategy and plan (Gelderblom *et al.*, 2003; Driver *et al.*, 2005).

A third group of initiatives has arisen under the auspices of studies seeking to secure a reliable supply of water (Department of Water Affairs and Forestry, 2004). South Africa is a dry country, and like many others the demand for water resources often exceeds the capacity of ecosystems to provide them. South Africa's ambitious new water legislation has stretched the managerial capacity to implement the law's new requirements, and has required that catchments be defined in terms of the water stress that they experience to prioritize interventions. Water stress can be quantitatively defined as the difference between water availability and requirements.

The existence of these parallel initiatives offers the opportunity to combine approaches to achieve the maximum positive impacts. The concurrent prioritization of invasive alien species and areas for control operations aimed at conserving water resources, the broad-scale (national) conservation planning, and the prioritization of rivers for conservation, clearly invites a co-ordinated approach. Given advances in processing technology of spatial data, and the growing realisation that holistic solutions to environmental problems are necessary, it is now possible to develop pragmatic and practical approaches that can guide policy and implementation aimed at conserving rivers and water resources.

In this paper, we propose an approach that will enable managers to prioritize river systems and their catchments for the purposes of invasive alien plant control. The approach we propose will combine results from recent work on the spatially explicit predictions of range expansions in important invasive alien plant species (Rouget *et al.*, 2004) with that of conservation planners who have sought to prioritize river ecosystems in terms of the degree of habitat loss, and that of water resource planners who have calculated the water balance of catchments. Our aim was not to conduct an exhaustive analysis of the problem. Rather, we wish to demonstrate the feasibility of an approach that will lead to the prioritization of catchments for alien plant control operations, thus ensuring that such operations can be directed at priority areas in terms of conservation importance, the risk of invasion, and a positive impact on water resources.

Methods

Selection of invasive alien species

We selected 13 invasive alien plant species to illustrate our prioritization exercise. The species were selected from a recently developed list of invasive alien plants in South Africa (Nel *et al*., 2004), and are found in one or more of the major terrestrial biomes of South Africa (including savannas, grasslands, Mediterranean-climate shrublands, and arid-zone shrublands). This list differentiates between species that have invaded riparian zones, and those that have invaded upland areas away from riparian zones. The species selected are those that invade and dominate riparian areas, plus the most important species, in terms of their impact on hydrology, that invade upland areas. We did not consider riparian invaders that are not major ecosystem 'transformers' (i.e. species that form extensive, monospecific stands, dominating or replacing native vegetation), or invaders of uplands whose impacts on evapotranspiration were small. We also did not consider invasive alien species under effective biological control (Zimmermann, Moran & Hoffmann, 2004). The list used here is not intended to be comprehensive, but was chosen to demonstrate the principle.

Establishing the current and future distribution of alien species

The current distribution of the 13 selected invasive alien plant species was determined from the South African Plant Invaders Atlas (SAPIA) database. This atlas comprises nearly 50 000 records for more than 500 species of invasive alien plants, incorporating records from roadside surveys carried out between 1979 and 1993, and the SAPIA project (1994–98), as well records collected on an *ad hoc* basis from 1999 onwards (Henderson, 1998; Nel *et al*., 2004). Records are entries that note the presence, and abundance, of a species in quarter-degree squares (15′ latitude × 15′ longitude, hereafter grid cells). Nel *et al.* (2004) related the range of a species to the number of grid cells in the SAPIA database in which the species was recorded. The categories of range were: very widespread = found in >350 grid cells; widespread = found in 70–350 grid cells; and localised = found in <70 grid cells. The SAPIA database also notes the abundance of species that are recorded in a grid cell in the following categories: rare (one sighting of one or a few plants); occasional (a few sightings of one or a few plants); frequent (many sightings of single plants or small groups); abundant (many sightings of clumps or closed stands); and very abundant (forming extensive stands). Nel *et al.* (2004) used these records to define categories of abundance as follows: abundant = recorded in the SAPIA database as 'very abundant' or 'abundant' in 16% or more of grid cells where it occurred; and common = recorded as 'very abundant' or 'abundant' <16% of grid cells where it occurred.

The potential future distributions of 71 major invasive alien plant species were modelled using a variant of climatic envelope models (Rouget *et al*., 2004). This technique produces spatial estimates of future distribution at a scale of 1′ latitude × 1′ longitude, i.e. a much finer resolution than the estimates of present distribution. We recognise that climate envelope modelling can produce large over estimates of the potential area to be invaded, and that invasive species are limited by many other factors besides climate. Riparian areas would provide an additional 'filter' for habitat suitability for those species that invade such areas. This provides an additional degree of confidence in predictions of future distribution for at least some of the species used in this study.

Establishing the degree of habitat loss in rivers

Important rivers were defined using data on the conservation status and importance of river ecosystems, as identified by the national spatial biodiversity assessment (Driver *et al*., 2005). The data were in the form of river 'signatures', which were derived from geomorphological and hydrological characteristics, including flow variation and baseflow, the key physical drivers of river heterogeneity. Characterising river heterogeneity in this way over time and space is key to predicting pattern and the distribution of river biota (Montgomery, 1999; Rogers & O'Keefe, 2003). River signatures have been used as a basis for characterising river ecosystems that share the same biological response potential and similar biodiversity. Although the results of Driver *et al.*'s (2005) recently-completed study are preliminary and subject to several data limitations, the study has identified broad priorities for the conservation of freshwater biodiversity within mainstem rivers. Mainstem rivers are defined as the longest river segments within quaternary catchments, and did not include any further tributaries. Quarternary catchments are nested subdivisions of primary, secondary and tertiary catchments, where primary catchments refer to the drainage areas of major rivers. Quarternary catchments were delineated as areas of similar total surface runoff for the purposes of water resource planning (Department of Water Affairs and Forestry, 2002). There are 1911 such quarternary catchments in South Africa and Lesotho, and they are larger in arid areas than in wetter areas.

Driver *et al.*'s (2005) assessment identified threatened ecosystems by evaluating habitat loss in each river, using the following definitions:

Critically endangered. River ecosystems that had lost >90% of their original natural habitat, leading to a breakdown of ecosystem functioning (loss of connectivity and/or disruption of flow regimes) and a loss or potential loss of species.

Endangered. River ecosystems that had lost 60–90% of their original natural habitat, and whose functioning was compromised.

Vulnerable. River ecosystems that had lost 40–60% of their original natural habitat, and whose functioning is likely to be compromised if further natural habitat is lost.

Least threatened. River ecosystems that had lost <40% of their original natural habitat, and are therefore relatively intact (although they may be degraded to varying degrees).

Establishing the degree of water stress

A comparison of the available water and the total water requirements for the year 2000 was calculated for 87 sub-water management areas in South Africa (Department of Water Affairs and Forestry, 2004) for the purposes of water resource planning. The data for this comparison were obtained from country-wide situation assessments, and included data on transfers between water management areas and to neighbouring countries. The data enabled a comparison of demand (the sum of all current demands on water, including requirements for meeting ecological targets and international obligations) and supply (available water supplies in the form of river flow, the capacity of impoundments, and interbasin transfers). The statistics enabled a broad perspective of the water situation to be gained at a national scale. We overlaid the estimates for the 87 areas on the 1911 quaternary catchments to derive estimates of water stress or availability (defined here as the difference between water supply and demand) at a quaternary catchment level, assuming that water stress was evenly distributed among all quaternary catchments in a sub-water management area.

Developing priorities for management action

We used quaternary catchments as a basis for prioritization. We calculated, for each quaternary catchment, four indices that provide estimates of (i) the number of invasive alien plant species present; (ii) the potential number of invasive alien plant species that would be present if they occupied the full range as determined by climatic envelope models; (iii) habitat loss in rivers; and (iv) the degree of water stress. We calculated these indices as follows:

Current distribution of invasive species. We overlaid the coverages for grid cells and quaternary catchments using a geographic information system, and recorded the number (out of 13) of species that occurred in overlapping catchments and grid cells. We scored the catchments in terms of the number of species that occurred in the catchments as follows: one = no species present; two = one to three species present; three = four to six species present; and four = seven or more species present. This scaling of the index was aimed at placing a higher priority on those river systems that were invaded by higher numbers of species. This approach assumed that more alien species will have higher impacts than fewer species, as each additional species could both have unique impacts and occupy vacant habitats within the landscape.

Potential distribution of invasive species. We overlaid the modelled coverages for potential plant distributions based on climatic models and recorded the number (out of 13) of species that occurred in overlapping catchments, as above. We scored the catchments in terms of the number of species that would potentially occur there using the same categories as above. This scaling of the index was aimed at placing a higher priority on those river systems that would potentially become invaded by higher numbers of species, for the same reasons as outlined above.

Habitat loss in rivers. We determined in each quaternary catchment the length of rivers that were classified as either endangered or critically endangered, and expressed this length as a percentage of the total length of rivers occurring in the catchment. We scored the catchments as follows: one = 0–25%; two = 26–50%; three = 51–75%; and four = 75–100% of the combined length of rivers in the endangered or critically endangered categories, respectively. This scaling of the index was aimed at placing a higher priority on those river systems that had lost more habitat than others (see Discussion).

Degree of water stress. The difference between water availability and requirements for the year 2000 for each of the 87 areas was used to obtain an index of the degree of water stress experienced within each quaternary catchment. A surplus indicated that all current demands could be met, and that supply exceeded demand, while a zero or negative water balance indicated that current demands balanced or exceeded supply (in these cases, water required for ecosystem maintenance cannot be assured). We scored the catchments as follows: one = lowest water stress (≥11 million m^3 $year^{-1}$ surplus); two = 6–10 million m^3 $year^{-1}$ surplus; three = 1–5 million m^3 $year^{-1}$ surplus; and four = highest water stress (≤0 million m^3 $year^{-1}$). This scaling of the index was aimed at placing a higher priority on those river systems that were experiencing higher degrees of water stress. The highest priority would go to those rivers where demand exceeded supply, and where clearing invasive alien plants would have direct benefits for water supplies and ecosystem protection.

We calculated a simple composite index that combines the four individual indices. We assumed that each of the four estimates above was of equal importance, and we added the individual scores to arrive at the composite index. This gave 13 possible scores for quaternary catchments, ranging from 4 to 16. We then determined the number of catchments in each category, and mapped these in three categories of combined scores: lowest priority (4–8), intermediate priority (9–12), and highest priority (13–16).

Results

Selection of invasive alien species

Of the 13 species of invasive alien plants selected for this study (Table 1), five were major invaders in the riparian zones of perennial rivers, five were major invaders in terrestrial upland environments, one was important in both of these zones, and the remaining two were invaders of ephemeral river beds in arid environments. Table 1 also shows the number of quarter-degree squares in which the species has been recorded, and the range abundance category assigned to it by Nel *et al.* (2004). The five species recorded as 'very widespread' were distributed over the whole country. 'Widespread' species tended to be concentrated in particular regions; four of these (red river gum, cluster pine, Monterey pine and sweet hakea) were in Mediterranean-climate shrubland areas, one (tamarisk) was in arid shrublands, and one (patula pine) in grassland areas. Of the localised species, rock hakea invades Mediterranean-climate shrublands and oleander invades arid shrublands.

Current and future distribution of alien species

The species selected in this study are currently found in 24–557 of a total of 1995 grid cells in South Africa and Lesotho (Table 1). Most of the species were recorded in the south-western extremity of the country, with significant numbers also occurring in the eastern half of the country (Fig. 1). When the potential plant distribution was taken into account, the analysis

Table 1 Selected invasive alien plant species that impact on rivers and their catchment areas in South Africa

Invasive alien plant species	Habitats invaded	Typical impacts on river systems	Range and abundance	Number of quarter-degree squares
Black wattle (*Acacia mearnsii* De Wild.)	Riparian zones of perennial rivers; uplands	Increases total evaporation and decreases streamflow; displaces riparian vegetation and destabilises river banks	Very widespread and abundant	432
Grey poplar (*Populus canescens* [Aiton] Sm.)	Riparian zones of perennial rivers and streams	Increases total evaporation and decreases streamflow; displaces riparian vegetation	Very widespread and abundant	557
Spanish reed (*Arundo donax* L.)	Riparian zones of perennial rivers and streams	Displaces riparian vegetation	Very widespread and common	377
Red river gum (*Eucalyptus camaldulensis* Dehnh.)	Riparian zones of perennial rivers	Increases total evaporation and decreases streamflow; displaces riparian vegetation and destabilises river banks	Widespread and common	123
Weeping willow (*Salix babylonica* L.)	Riparian zones of perennial rivers	Probably increases total evaporation and decreases streamflow; displaces riparian vegetation	Very widespread and common	475
Tamarisk (*Tamarix chinensis* Lour.)	Ephemeral rivers	Potentially depletes groundwater	Widespread and common	92
Mesquite (*Prosopis glandulosa* Torr.)	Ephemeral rivers	Depletes groundwater	Very widespread and abundant	453
Oleander (*Nerium oleander* L.)	Rocky water courses in semi-arid mountain areas	Displaces native streambank vegetation; poisonous	Localised and abundant	24
Cluster pine (*Pinus pinaster* Ait.)	Uplands	Increases total evaporation and decreases streamflow; increases fuel loads and fire intensity, leading to severe erosion after fire.	Widespread and abundant	86
Monterey pine (*Pinus radiata* D. Don.)	Upper catchments	Increases total evaporation and decreases streamflow; increases fuel loads and fire intensity, leading to severe erosion after fire	Widespread and common	71
Patula pine (*Pinus patula* Schltdl. & Cham.)	Uplands	Increases total evaporation and decreases streamflow; increases fuel loads and fire intensity, leading to severe erosion after fire	Widespread and common	90
Sweet hakea (*Hakea sericea* Schrad. & J.C. Wendl.)	Uplands	Probably increases total evaporation and decreases streamflow; increases fuel loads and fire intensity, leading to severe erosion after fire	Widespread and common	78
Rock hakea (*Hakea gibbosa* [Sm.] Cav.)	Uplands	Probably increases total evaporation and decreases streamflow; increases fuel loads and fire intensity, leading to severe erosion after fire	Localised and abundant	18

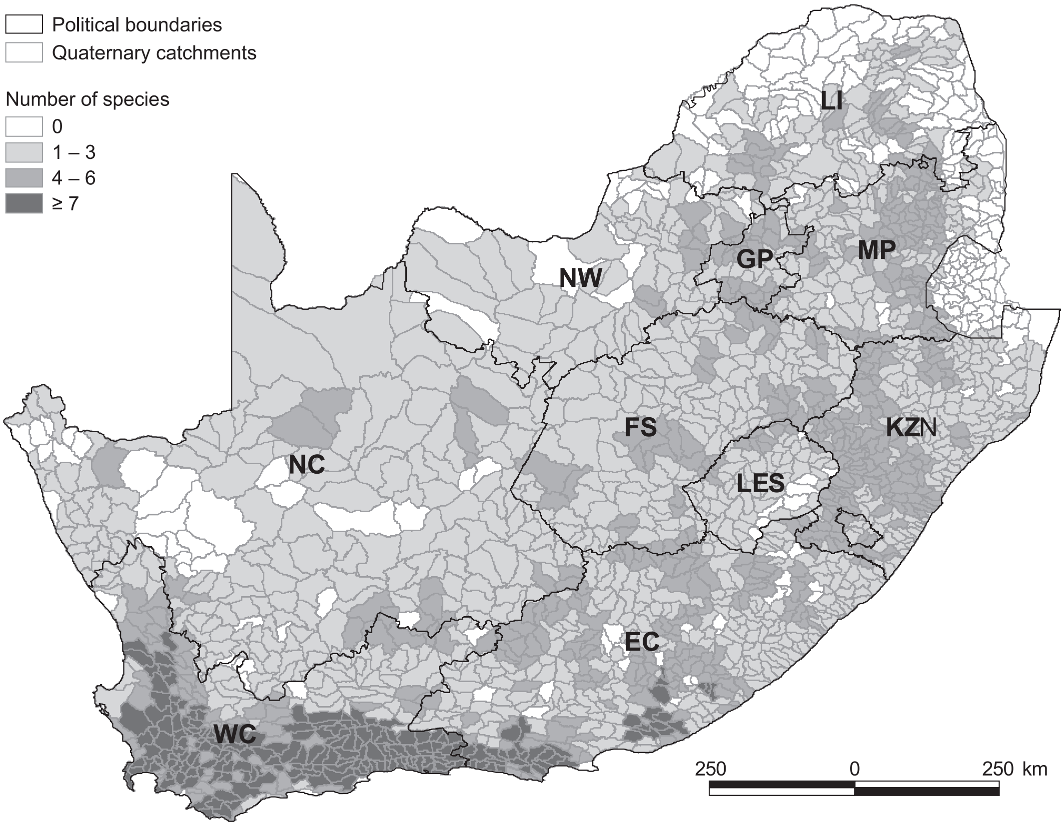

Fig. 1 Distribution (in 2002) of 13 invasive alien plant species by quaternary catchments in South Africa and Lesotho (LES). The nine provinces of South Africa are indicated as follows: WC = Western Cape; EC = Eastern Cape; NC = Northern Cape; NW = North-west; FS = Free State; KZN = KwaZulu/Natal; MP = Mpumalanga; GP = Gauteng; and LI = Limpopo.

indicated that a far greater proportion of the country is at risk from invasion by alien plants in riparian zones and their upland catchments (Fig. 2). In particular, many more species of invasive alien plants are likely to establish in the eastern portions of the country, especially along the southern and eastern escarpment where rainfall is highest.

Ranking habitat loss in rivers

Of South Africa's 120 individual river signatures, 44% were assessed by Driver *et al.* (2005), in terms of habitat loss, as being critically endangered, 27% as endangered, 11% as vulnerable and 18% as least threatened. Rivers in the critically endangered and endangered categories were concentrated in the south, in the central north-west, and in the arid north-west (Fig. 3). Rivers in the remainder of the arid north-west, and along most of the eastern seaboard, were largely assigned to the categories 'vulnerable' or 'least threatened'.

Demand for water resources

Water deficits were identified in more than half of the water management areas in South Africa and Lesotho (Fig. 4), although the results of the National Water Resource Strategy show that a surplus still exists for the country as a whole.

Developing priorities for management action

Of the 1911 quaternary catchments in South Africa and Lesotho, just over one-third (650) had a composite index of 13 or more on our scale from 4 to 16 (Fig. 5). A relatively small proportion of the catchments (273 or 14%) had the highest scores of 15 or 16. The higher priority catchments were concentrated in a number of distinct areas (Fig. 6). These included the southern and south-western parts of the country; a group of catchments in the KwaZulu/Natal province in the east; a group in the centre of the country, around the developed and highly populated areas in the Gauteng

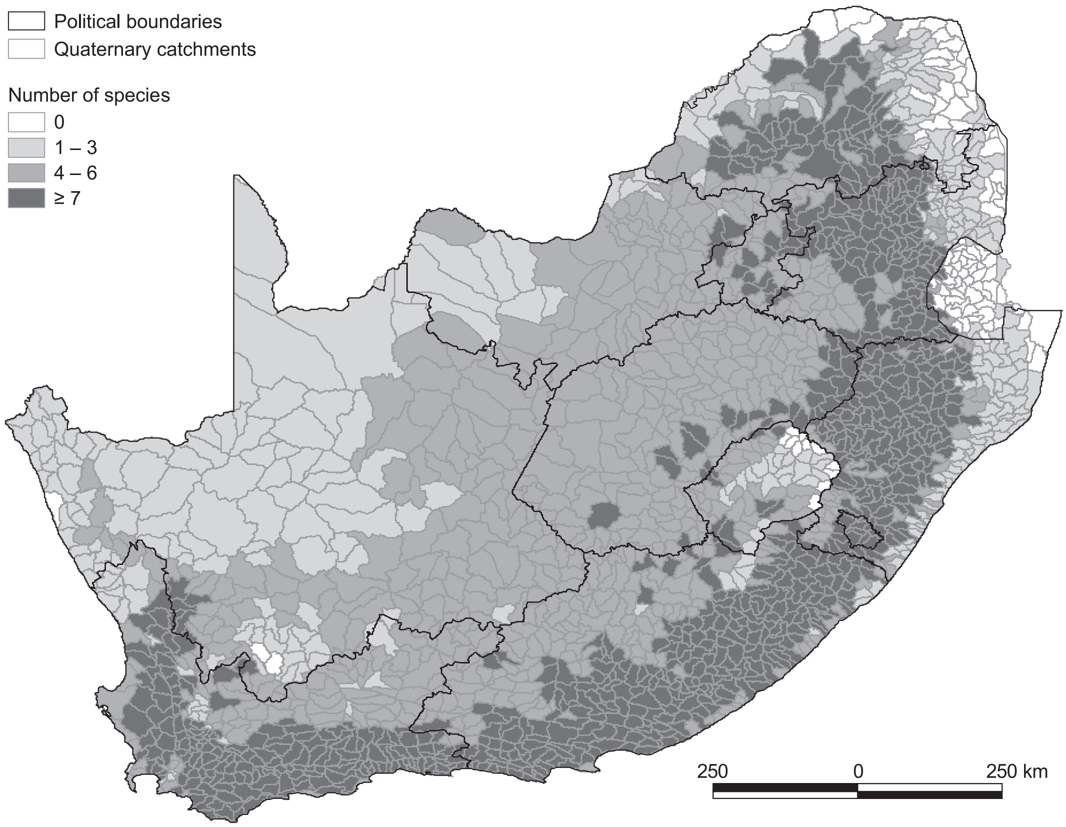

Fig. 2 The potential distribution of 13 invasive alien plant species by quaternary catchments in South Africa and Lesotho.

province; and a group in the mid-northern areas. Catchments with the lowest priorities were those in the extreme west and north-west, and along the eastern seaboard in the Eastern Cape province.

Discussion

Options for prioritization

Alien plant control operations are carried out for a number of reasons. The most important of these in South Africa are to reduce the impacts of invasive alien plants on scarce water resources, and to ensure that biodiversity conservation targets are met. The approach that we propose here seeks to place the highest priorities on river systems that are either currently or potentially invaded by the highest numbers of alien species, that have experienced the highest degree of habitat loss, and that are experiencing the highest degree of water stress. However, the achievement of biodiversity conservation goals on the one hand, and water conservation goals on the other, may require different approaches. For example, it could be argued that rivers who have lost >75% of their original natural habitats should not get the highest priority, and that a focus on rivers that are more intact would be a better option for the conservation of biodiversity. Relatively intact systems would arguably harbour more valuable biodiversity than less intact systems, and should therefore be assigned a higher priority. On the other hand, river systems that have experienced a high degree of habitat loss are probably also the systems where water stress will be high, calling for a higher prioritization. Our rationale for placing a higher priority on rivers that have experienced a high degree of habitat loss is related to the goal of achieving targets with regard to biodiversity conservation. In South Africa, river systems have been grouped into categories based on their 'signatures' (Driver *et al.*, 2005), and targets have been set to conserve a representative sample of each category. If such targets are to be achieved, then it would be necessary to place a higher priority on those systems where a high degree of loss had already been

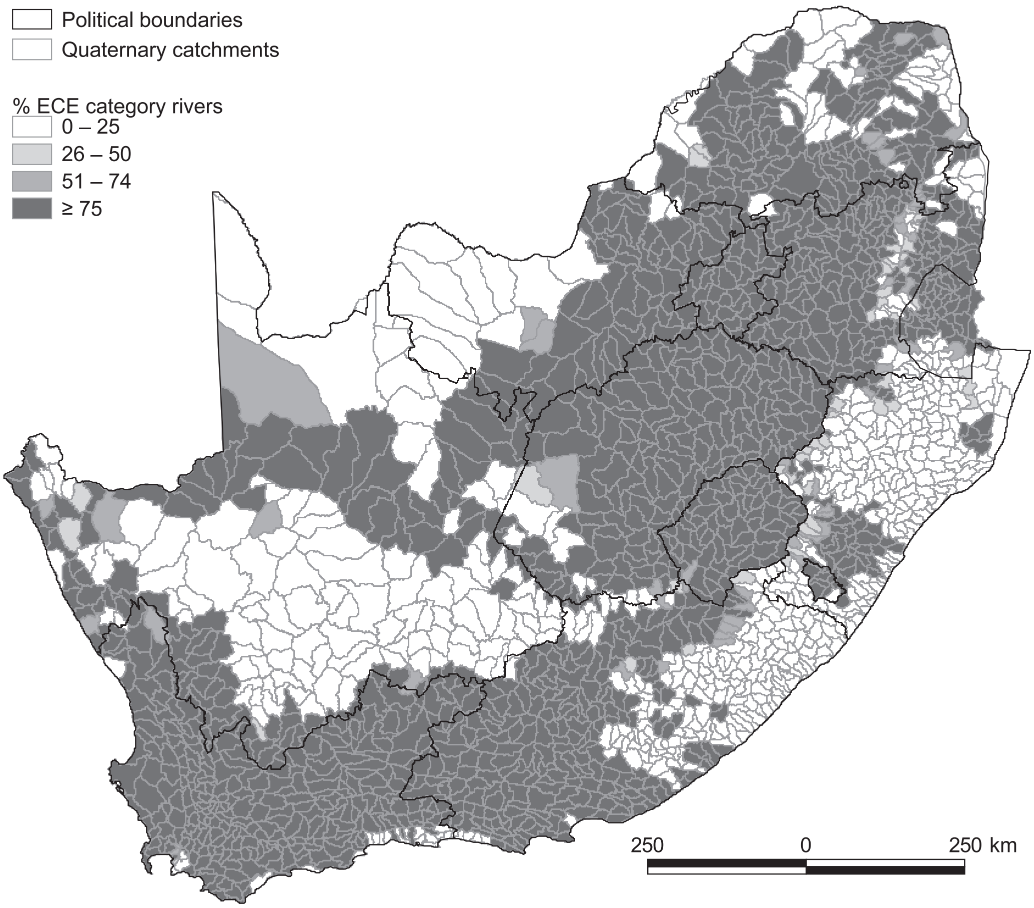

Fig. 3 The distribution of quaternary catchments in South Africa and Lesotho in terms of four categories of habitat loss, based on the proportion of river length in the categories 'endangered' and 'critically endangered' (ECE).

experienced, and where the options for conservation of what remains are limited.

The value of prioritization

This study, although preliminary, has identified emergent priority areas for the clearing of invasive alien plants with a view to conserving rivers and water resources. Results of the analysis show that current priorities in the allocation of funds to clearing projects are not always in line with the priorities defined here. For example, some of South Africa's nine provinces should receive higher priority than others (Fig. 6). If the allocation of funds to provinces was performed on an equal basis, then each province would receive about 11% of the budget. Currently, the Western Cape province receives the largest share (25%) of the budget (Anonymous, 2003), and this is in line with its high priority as assessed in this study. However, our study indicates that the Eastern Cape province was less of a priority, but it receives 15% of the budget. On the other hand, the Gauteng and Free State provinces, which our study has indicated are priority provinces, receive only 3.4 and 1.5% of the budget, respectively. If the approach suggested here is adopted, refined, and applied with diligence, we believe that it will ultimately lead to improved conservation outcomes at national level through an ability to better identify priority areas.

Use and limitations of the approach

The approach described in this paper will provide decision makers with an objective and transparent method with which to prioritize areas for the control of invasive alien plants. It brings together four important considerations in such a way that their individual contributions to an overall list of priorities

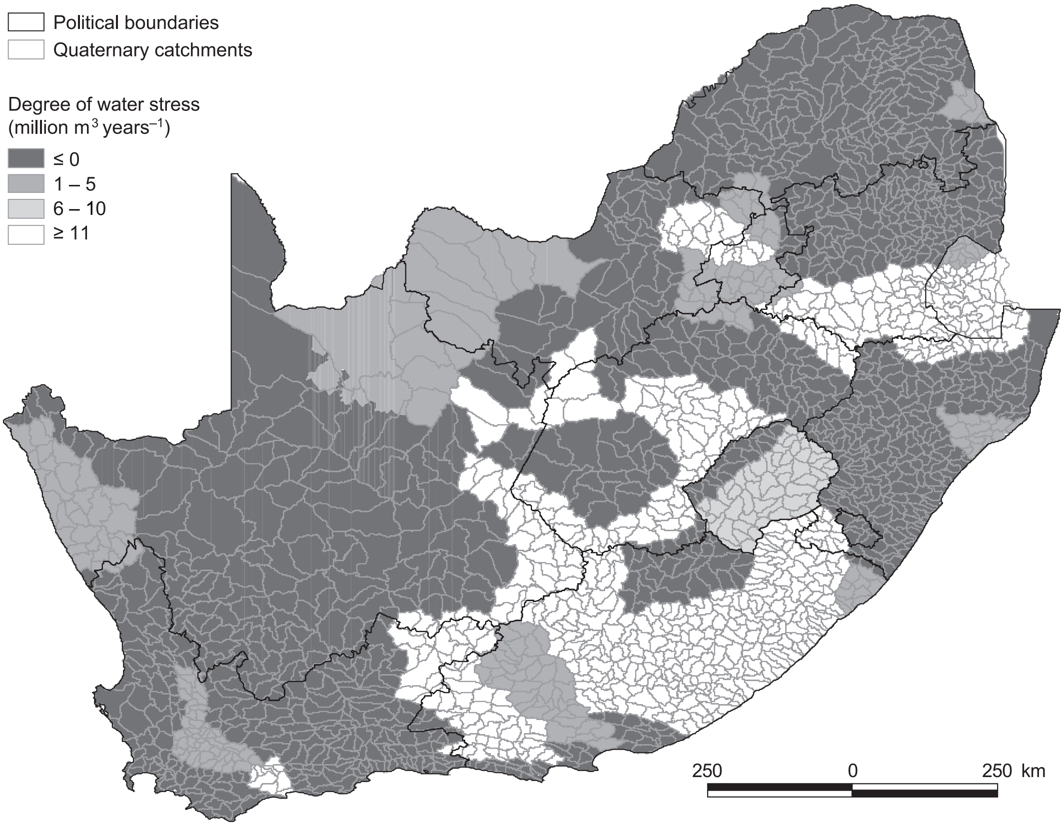

Fig. 4 The distribution of quaternary catchments in South Africa and Lesotho in terms of four categories of water surplus or stress, calculated as the difference between estimated available water and estimated demand in 2000.

becomes evident. If the method is adopted, it will make a contribution to the achievement of diverse goals, including the protection and/or restoration of water resources, and the conservation of river ecosystems and their biodiversity. How components of the index are calculated and how the four different components are weighted was arbitrary and can therefore be debated. As a consequence, the proposed

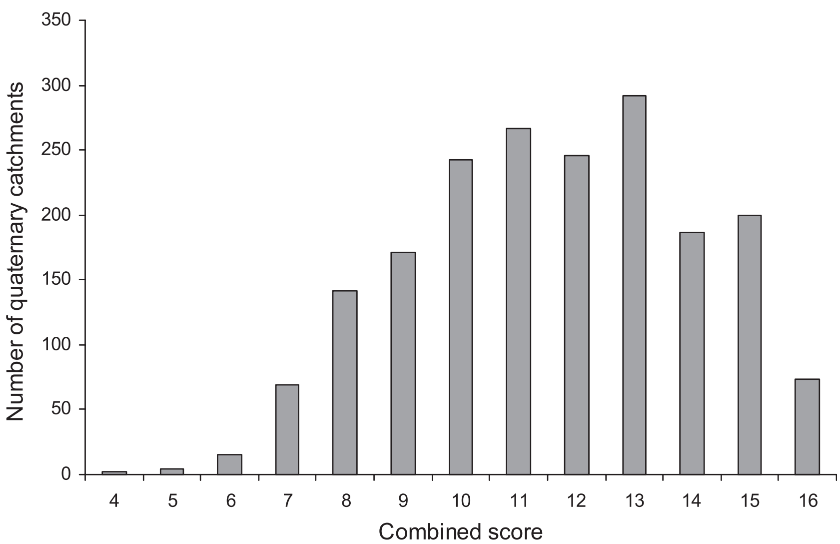

Fig. 5 The number of quaternary catchments in South Africa according to an index of priority for the control of invasive alien plants. The index is a composite of (1) the number of invasive alien plant species present; (2) the potential number of invasive alien plant species; (3) the degree of habitat loss in rivers; and (4) the degree of water stress, and increases with increasing priority relative to these four factors.

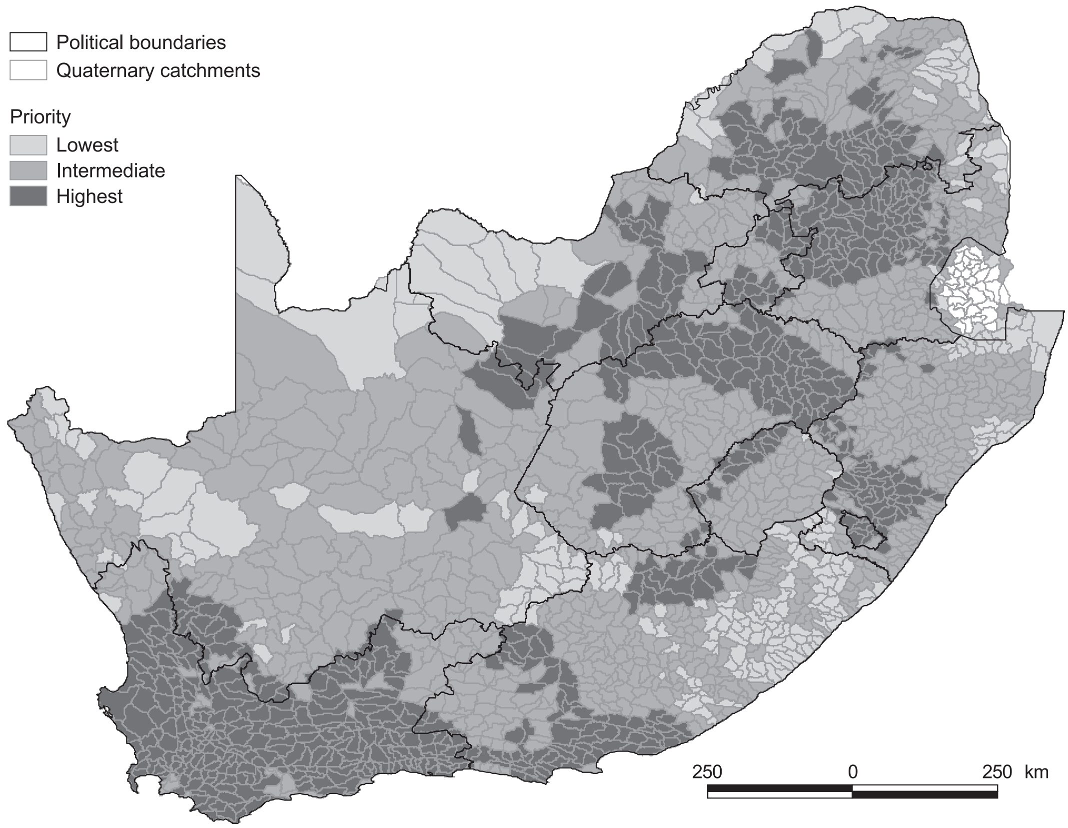

Fig. 6 Distribution of quaternary catchments in South Africa and Lesotho in terms of their priority for the control of invasive alien plants. Priorities are shown in terms of a combined index assigned to individual catchments (see text), grouped as follows: lowest priority (4–8), intermediate priority (9–12), and highest priority (13–16).

composite index may evolve. Improvements would also come about through the addition of a more comprehensive list of species. For example, the inclusion of the potential for future invasions (Nel *et al.*, 2004; Olckers, 2004) would allow for the selection of areas to ensure that they are well managed in terms of preventing invasions, rather than by waiting until they become heavily invaded before action is taken. Further improvements could come about through additional components to the index. For example, invasive alien plant clearing programmes in South Africa have gained political support and funding largely because of their potential to provide employment in poverty stricken and economically depressed areas (van Wilgen *et al.*, 1998; Magadlela & Mdzeke, 2004). In the case of South Africa, therefore, it is almost certain that the potential for poverty alleviation would be added to the list of factors to be included in a prioritization index. Other refinements that could be made would be to include priorities for the conservation of terrestrial biodiversity, and the potential impacts on agriculture; and to improve the determinations of water stress by calculating this at a quaternary catchment level. Finally, the index described in this paper has been applied at a national scale. The concept could also be applied at finer scales, and this may require input data at a correspondingly finer scale. Such data are only likely to be available for limited areas at this stage.

Priority areas and priority species

The method described here will allow managers and policy makers to prioritize areas for action in terms of invasive alien plant clearing programmes. However, the most successful operations in the history of invasive alien plant control have been those that have targeted species rather than geographical areas. Successful alien plant control operations must be based on a sound understanding of the biology and ecology of the target species, and control interventions should be aimed at the most vulnerable aspects of the species' life cycle (van Wilgen, Richardson & Higgins, 2000). While the prioritization of areas for control intervention is important, it is of equal importance that a means for prioritizing species is also developed, to guide policy and research. In this regard, research into the potential for biological control of invasive alien species is important. Biological control has underpinned the successful control of many invasive alien plant species in South Africa (Zimmermann *et al*., 2004), and, when successful solutions can be found, it arguably provides the best means for the long term, sustainable control of invasive alien plant species. The two approaches of prioritization of areas, and research into the ecology, life cycles and biological control of major and emerging weeds (*sensu* Olckers, 2004) should be used jointly to achieve the maximum beneficial impact on invasive alien plant populations.

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