The prioritization of species and primary catchments for the purposes of guiding invasive alien plant control operations in the terrestrial biomes of South Africa

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Executive Summary

Introduction

1. Invasive alien plant control requires the allocation of limited resources to control operations to maximise benefits. The priorities for such allocation are based on a mixture of fact and opinion, interpreted either subjectively or objectively, but often not explicitly so. This project sought to develop an approach that could assist managers and planners in the Working for Water programme to prioritise their activities with a degree of transparency.

2. This report describes the development of methods for the identification of a priority list of (i) invasive alien plants, and (ii) areas (primary catchments) in the terrestrial biomes of South Africa that should be targeted for control by the Working for Water programme. The biomes include the fynbos, grassland, savanna (split into arid and moist), succulent karoo and Nama karoo.

3. We used data on the current and potential distribution of invasive alien plant species to identify a preliminary list of species for each biome. These lists were modified by panels of experts in workshops, to arrive at final lists. We selected only those quaternary catchments within each primary catchment that fell completely or partially within the biome concerned as a basis for the identification of priority areas.

4. We used the Analytic Hierarchy Process (AHP) to facilitate prioritization. AHP is a multiple criteria decision-making tool for setting priorities when both qualitative and quantitative aspects of a decision need to be considered, and for achieving group consensus.

Priorities in the fynbos biome

5. The criteria identified for the prioritization of invasive alien species in the fynbos biome included impacts on (i) ecosystem services (water resources and harvested products); (ii) biodiversity; (iii) fire hazard; and (iv) the impact of removal of alien species that carry some benefit. Each criterion was assigned a weight in terms of its perceived importance, and the largest weights were given to water resources (47%) and biodiversity (32%).

6. A total of 23 taxa (species or groups of species) were identified as priority alien invasive plants in the fynbos biome. Australian acacias (black wattle - *Acacia mearnsii*, long-leaved wattle - *Acacia. longifolia* and golden wattle - *Acacia. pycnantha*), pines (*Pinus pinaster, Pinus radiata and Pinus halepensis*) and poplars (*Populus* species) emerged as the most important taxa in the biome.

7. Three major groups of criteria were identified as a basis for the prioritization of primary catchments in the fynbos biome. These were the value of the land (made up of its value for water production, harvested products, and conservation), the presence of priority invasive alien plants (both current and potential), and the need for socio-economic development.

8. The Berg and Breede catchments emerged as the highest priority. The factors that contributed to the priority of these catchments included their value as water catchments, the high score for conservation value, the high levels of invasion by priority alien species, the potential for workers to find future alternative employment, and the value for harvested products from the catchment.

Priorities in the grassland biome

9. The criteria identified for the prioritization of invasive alien species in the grassland biome included impacts on (i) ecosystem services (water resources and grazing); (ii) biodiversity; (iii) fire hazard and erosion; and (iv) the impact of removal of alien species that carry some benefit. Each criterion was weighed in terms of its perceived benefit, and the largest weights were given to water resources (46.7%) and biodiversity (22%).

10. A total of 17 taxa (species or groups of species) were identified as priority alien invasive plants in the grassland biome. Australian acacias (*Acacia mearnsii* and *A. dealbata*), red river gum (*Eucalyptus camaldulensis*), two species of pines (*Pinus patula* and *P. elliottii*), and bramble (*Rubus cuneifolius*) emerged as the most important taxa in the biome.

11. Six major criteria were identified as a basis for the prioritization of primary catchments in the grassland biome. These were the (i) value of the land for water production; (ii) the value of the land in terms of conservation importance; (iii) the relative value of the land for livestock production; (iv) the extent to which catchments are currently, and potentially, invaded by priority invasive alien plant species; (v) the presence or absence of poverty nodes; and (vi) capacity to hold onto gains realised after initial clearing of alien plants as an important criterion for prioritization. In terms of (iv), catchments were therefore prioritised in terms of the capacity of landowners to hold onto gains. Essentially, this meant that areas with well resourced landowners, and systems of private land ownership would receive preference over areas with poorer landowners or areas with traditional land tenure systems.

12. The Vaal, Olifants and Inkomati catchments emerged as the highest priority. The factors that contributed to the priority of the Vaal were a very high potential for livestock production, and a high value of the land for conservation. Both the Olifants and Inkomati catchments had a high priority because of the large areas infested with priority invasive alien plant species.

Priorities in the moist savanna biome

13. The criteria identified for the prioritization of invasive alien species in the moist savanna biome included impacts on (i) ecosystem services (water resources, and grazing and browsing); (ii) biodiversity; (iii) fire hazard; and (vi) the impact of removal of alien species that carry some benefit. Each criterion was weighed in terms of its perceived benefit, and the largest weights were given to biodiversity (34.6%) and grazing and browsing (32.8%).

14. A total of 15 taxa (species or groups of species) were identified as priority alien invasive plants in the moist savanna

biome. The five most important invasive alien plant species in the biome included lantana (*Lantana camera*), traffic weed (*Chromolaena odorata*), guava (*Psidium guajava*), parthenium (*Parthenium hysterophorus*) and syringa (*Melia azedarach*).

15. Six major criteria were identified as a basis for the prioritization of primary catchments in the moist savanna biome. These were the (i) value of the land for water production; (ii) the value of the land in terms of conservation importance; (iii) the relative value of the land for livestock production; (iv) the extent to which catchments are currently, and potentially, invaded by priority invasive alien plant species; (v) the presence or absence of poverty nodes; and (vi) capacity to hold onto gains realised after initial clearing of alien plants as an important criterion for prioritization.

16. The Umgeni and Olifants catchments emerged as the highest priorities. The factors that contributed to the priority of the Umgeni included a relatively high water runoff, a high degree of invasion by priority alien species, and a high capacity to hold onto gains made by clearing operations. An unusually high area of priority conservation value, combined with a high degree of invasion by priority alien species, contributed to the high ranking of the Olifants catchment.

Priorities in the arid savanna biome

17. The criteria identified for the prioritization of invasive alien species in the arid savanna biome included impacts on (i) ecosystem services (water resources, and grazing and browsing); (ii) biodiversity; and (iii) the impact of removal of alien species that carry some benefit. Each criterion was weighed in terms of its perceived benefit, and the largest weights were given to groundwater resources (50.5%) and biodiversity (22.6%).

18. A total of eight taxa (species or groups of species) were identified as priority alien invasive plants in the arid savanna biome. Mesquite (*Prosopis glandulosa*) was considered to be the most important invasive species by a considerable margin. Other important species included poplars (*Populus* species), pepper trees (*Schinus molle*), queen-of-the-night cactus (*Cereus jamacara*), and syringa (*Melia azedarach*).

19. The same six major criteria that were identified as a basis for the prioritization of primary catchments in the moist savanna biome also applied to the arid savanna biome (point 14 above).

20. Two primary catchments fall partially within the arid savanna biome. Our approach did not identify any significant factors that would separate either of these two catchments as a priority.

Priorities in the Nama karoo biome

21. The criteria identified for the prioritization of invasive alien species in the Nama karoo biome included impacts on (i) ecosystem services (ground and surface water resources, riparian zones, grazing and soil stability); (ii) biodiversity; (iii) agricultural financial viability; and (iv) fire hazard. Each criterion was weighed in terms of its perceived benefit, and the largest weights were given to biodiversity

(24.1%) and groundwater resources (22.4%).

22. A total of 18 taxa (species or groups of species) were identified as priority alien invasive plants in the Nama karoo biome. The most important of these were mesquite (*Prospois glandulosa*); poplars (*Populus* species); red river gum (*Eucalyptus camaldulensis*); Spanish reed (*Arundo donax*); and oleander (*Nerium oleander*).

23. Four major groups of criteria were identified as a basis for the prioritization of primary catchments in the Nama karoo biome. These included (i) the integrity of water resources (permanent and seasonal surface water, groundwater, and biodiversity in riparian ecosystems); (ii) the maintenance of agricultural potential in drylands; (iii) the extent to which catchments are currently, and potentially, invaded by priority invasive alien plant species; and (iv) the opportunities to maximise socio-economic benefits.

24. A total of nine primary catchments fall partially within the Nama karoo biome but only five, with primary catchment D split into two, were assessed. The Ongers-Brak-Seekoei catchment (part of D) emerged as a priority because of its relatively high rainfall and runoff, the high degree of threat from *Prosopis* species and the greatest potential for employment.

Priorities in the succulent karoo biome

25. The same prioritised list of invasive alien species that was used in the Nama karoo was also used in the succulent karoo, as these two biomes are invaded by the same set of species.

26. Three major groups of criteria were identified as a basis for the prioritization of primary catchments in the succulent karoo biome. These included (i) the integrity of water resources (surface water, brak water, groundwater, and biodiversity in riparian ecosystems); (ii) the extent to which catchments are currently, and potentially, invaded by priority invasive alien plant species; and (iii) the opportunities to maximise socio-economic benefits.

27. The Gouritz catchment was given highest priority because it had the greatest annual runoff, and is heavily invaded. The Namaqualand catchments were of lower priority because they are the least invaded, and produce very little runoff.

Conclusions and recommendations

28. Data on the budget allocations for projects in the Working for Water programme were compared to the priorities identified in this study. The results indicate that current expenditure by the Working for Water programme is often in line with the priorities identified here. However, in at least two cases in each biome, the spending in certain primary catchments is either significantly above or below the level that would be appropriate if the priorities identified here are accepted.

29. We recommend the following:

- That the use of AHP be adopted to assist with prioritization, planning, and the allocation of resources;
- That the criteria identified here by the different working groups be consolidated, so that a uniform approach to prioritization can be taken;

- That a spatial database be developed to underpin effective comparisons of areas:
- That a workshop be held involving senior managers in the Working for Water programme to present the results and recommendations for implementation;
- That the approach be applied at different scales appropriate to different levels of planning; and
- That this work be published in the peer-reviewed literature.

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1. Introduction

Invasive alien plant control offers significant challenges to ecosystem managers. They are required to allocate limited funding and other resources to control operations, so as to maximise benefits. These challenges become even greater when control operations strive not only to control invasive alien plants and restore ecosystem health, but also have other aims, for example using the control operations to create employment opportunities, and then leveraging these opportunities to empower disadvantaged communities. The Working for Water programme, aimed both at the control of invasive alien plants and at socio-economic development is an example of an organization that strives to achieve multiple goals. Decision-makers and planners in such organizations are typically required to prioritize their activities in an environment where information is varied in its nature and quality. The final priorities that emerge are of necessity based on a mixture of fact and opinion, interpreted variously either subjectively or objectively, but often not explicitly so. This project sought to develop an approach that could assist managers and planners in the Working for Water programme to prioritise their activities.

The Working for Water programme's strategic plan for the period 2008 – 2012 stresses several points. It recognises that the relative importance of the impacts of invasive alien plants will depend on the specific location and characteristics of a catchment and the water ecosystems within it. It also recognises that impacts depend further on the extent of the exploitation of water, and on patterns of land use. Given these, the potential (positive) impact of an invasive alien plant control programme will differ on a catchment basis. The strategic plan goes on to list three goals in each of the fields of "natural resource management", and "socio-economic development". The natural resource goals are:

(a) Prevent new invasive alien plant problems;
(b) Reduce the impact of existing priority invasive alien plant problems; and
(c) Enhance the capacity and commitment to solve invasive alien plant problems.

The socio-economic development goals are:

(a) Contribute to an enabled environment for sustainable targeted employment opportunities in the natural resource management market;
(b) Facilitate broad-based economic empowerment; and
(c) Build social capital.

This study addressed the development of methods to assist in the achievement of these varied goals. Our approach built on earlier work by the CSIR regarding prioritization (Nel *et al*. 2004; Rouget *et al*. 2004; Mgidi *et al*. 2007; van Wilgen *et al*. 2007). It seeks to develop and test robust methods for the prioritization of both invasive species on the one hand, and invaded areas on the other. The existence and acceptance of such methods has been identified by planners in the Working for Water programme as a priority for progress.

This project was guided by a reference group, consisting of external advisors and experts. The reference group included Mr Derek Malan (Department of Water Affairs and Forestry), Prof. Dave

Richardson (University of Stellenbosch) and Mr Andrew Wannenburgh (Working for Water Programme). At the inaugural meeting of the reference group, it was agreed that the approach would be to prioritise species by biome, and then to prioritize areas. This sequence would allow for the presence of priority species to be considered in the prioritization of areas.

This report presents the outcome of a prioritization exercise for the terrestrial biomes of South Africa. The report describes the methods that were developed, and then presents the results separately for each of 6 terrestrial biomes – fynbos, grassland, arid savanna, moist savanna, succulent karoo and Nama karoo. We sub-divided the savanna biome into arid and moist based on the different suites of alien plants that invade these areas. The arid savannas correspond with the Kalahari Bushveld types and the Kimberley Thornveld Bushveld as defined by Low and Rebelo (1998). All other the other savanna vegetation types are included in the moist savanna.

A short section on conclusions and recommendations follows at the end of the report. The primary aim of this project was to develop methods for prioritization, and the results presented here should be interpreted in that light. The priorities arrived at in this exercise will not necessarily be accepted as the final priorities. The approach, if adopted, will nevertheless provide a sound basis for the transparent debate and ultimate acceptance of priorities. The need for a better approach to prioritization in the Working for Water programme is obvious. The programme has spent billions of rands during since its inception in 1996, and continues to spend significant amounts without a sound basis for prioritization. These funds need to be invested in areas of highest priority in the interests of all concerned.

2. Methods

2.1 Selection of biomes

The decision to use biomes (as opposed to, for example, provinces) as a basis for prioritization was a logical one. Biomes tend to be associated with a particular set of ecosystem services, and they tend to be invaded by a particular set of invasive alien plants. As such, the identification of priority areas within biomes can be based on a logical set of criteria, and alien species can be prioritized in terms of their potential impacts on these criteria. For the purposes of this exercise, we selected the major terrestrial biomes – fynbos, savanna, grassland, Nama karoo and succulent karoo biomes – as described by Low and Rebelo (1998). Because of significant differences in terms of invasive alien plant species, we also split the savanna biome into arid and moist savannas.

2.2 Selection of invasive alien plant species within biomes

We used the South African Plant Invaders Atlas (SAPIA) database (Henderson 1998) to derive a list of species that occurred in > 10% of the quarter degree squares in each biome. These are the "present" problem species. We used Rouget *et al.* 2004's estimates of future potential to list those species that had the potential to invade > 20% of the fynbos biome. These are the "future" problem species. We used 20% as a threshold for selecting species for inclusion in the future list, and not 10% as in the case of the present list, given the greater degree of uncertainty involved. This list was used as a starting point for discussion with a group of experts, and modified accordingly during workshops.

2.3 Selection of priority areas within biomes

We used primary catchments as a basis for prioritization. This high level was selected (rather than, for example, secondary, tertiary of quaternary catchments) for two reasons: first, it is necessary to prioritize areas at a national level, with a view to high-level allocation of budgets; and secondly, it provides a manageable number of units for comparison with regard to criteria. The selection of catchments as a basis for prioritization (rather than, for example, district municipalities) was also influenced by the fact that data on water use and the degree of water stress, which would be a key criterion for prioritization, are available on a catchment basis.

2.4 Process used to prioritize species and areas

We used the Analytic Hierarchy Process (AHP) to facilitate a process of prioritization (Saaty 1990). AHP is a multiple criteria decision-making tool for setting priorities when both qualitative and quantitative aspects of a decision need to be considered, and for achieving group consensus. The technique was developed in the 1970's by Dr Thomas Saaty, a mathematician, and enables users to deal with the intuitive, the rational and the irrational, and with risk and uncertainty in complex settings.

The prioritization of alien invasive alien plants involves the assessment of quantifiable and subjective criteria which are not normally directly comparable. A way of dealing with this complexity is to rank the various criteria in terms of their importance relative to each other (for example, is rate of spread more important than the cost of control?). Once criteria have been ranked, the candidate species are scored on a scale from low to high in terms of each criterion (for example, is their rate of spread high or low?). The product of this exercise is a list of species that are prioritised in terms of their contribution to the criteria.

We used Expert Choice decision support software (Anon. 2002) to facilitate the selection process. This involved setting a goal, breaking the goal down into its constituent parts and assigning relative weights to each of these in order to arrive at ranked criteria. Scoring was on a relative basis comparing each species or area to each other species or area relative to each criterion. Relative scores for each choice are computed within each level of the hierarchy. Scores are then synthesised through a model contained in the Expert Choice software. The process yields a composite score for each choice at every level as well as an overall score.

3. Results for the fynbos biome

3.1 Species selected in the fynbos biome

Our approach initially identified 30 invasive alien plant species (17 trees, 8 shrubs, 3 grasses, 1 succulent and 1 annual) as important in the fynbos biome. Of these species, 25 were seen as problems currently, and 5 more were not currently a problem, but could potentially become a problem in future. Nine of the 25 species that currently occupy >10% of the biome were not classified as future problems, as they did not have the potential to occupy >20% of the biome.

At an expert workshop, a number of changes were made to this list. A total of 7 species were removed from the list. These included species that were not regarded as a threat to natural ecosystems in the biome (*Acacia baileyana*, *Agave americana*, two species of *Atriplex*, *Datura stramonium*, *Melia azedarach and Nicotiana glauca*). Two species were added to the list; these were *Acacia pycnantha* (golden wattle) and *Pennisetum setaceum* (fountain grass). It was also decided to combine the three pine species, and to treat them as a single "species" for the purposes of this exercise. The final list therefore contained 23 alien plant taxa (species or groups of species) (Table 1).

Table 1. *The 23 invasive alien plant taxa selected for prioritization in the fynbos biome.*

Species	Life form	Current or future threat?
Acacia cyclops (red eye)	Medium evergreen tree	Both
Acacia longifolia (long leaved wattle)	Medium evergreen tree	Both
Acacia mearnsii (black wattle)	Medium evergreen tree	Both
Acacia melanoxylon (blackwood)	Tall evergreen tree	Both
Acacia saligna (Port Jackson willow)	Medium evergreen tree	Both
Acacia pycnantha (golden wattle)	Medium evergreen tree	Both
Arundo donax (giant reed)	Tall reed	Both
Cortaderia selloana (Pampas grass)	Tall evergreen grass	Present
Eucalyptus camaldulensis (red river gum)	Tall evergreen tree	Both
Eucalyptus cladocalyx (sugar gum)	Tall evergreen tree	Both
Eucalyptus lehmannii (spider gum)	Medium evergreen tree	Future
Hakea drupacea (sweet hakea)	Tall evergreen shrub	Both
Hakea gibbosa (rock hakea)	Tall evergreen shrub	Present
Hakea sericea (silky hakea)	Tall evergreen shrub	Both
Lantana camara (lantana)	Shrub	Present
Leptospermum laevigatum (Australian myrtle)	Medium evergreen tree	Both
Paraserianthes lophantha (stink bean)	Medium evergreen tree	Both
Pennisetum clandestinum (Kikuyu grass)	Perennial grass	Present
Pines (*Pinus halepensis*, Aleppo pine; *Pinus pinaster*, cluster pine; and *Pinus radiata*, Monterey pine).	Tall evergreen coniferous trees	Both
Pennisetum setaceum (fountain grass)	Tufted perennial grass	Future
Populus canescens (grey poplar)	Tall deciduous tree	Present
Rubus fruticosus (European blackberry)	Thorny shrub	Both
Solanum mauritianum (bugweed)	Small tree	Present

3.2 Agreed criteria for the assessment of species

Four major groups of impact or benefits associated with invasive alien plants in the fynbos biome were identified. The impacts were those on ecosystem services, biodiversity and fire hazard. The fourth criterion addressed the impact of removal of invasive alien plants in terms of a *lack* of benefits in cases where the invasive plant has some use (Table 2).

The impact of invasive alien plants on ecosystem services was considered by the group of experts to be the most important of the impacts, and was assigned a weighting of 55%. Given the importance of the Cape mountain areas as water catchments, and the importance of water resources for sustaining agriculture, industry and towns, the impacts on water were assigned the greatest weight (47% of the total). The impact of invasions on reducing harvested products, mainly cut flowers, was rated as of lesser importance (8% of the total).

The impact of invasions on biodiversity was rated as the next-most important category. The biodiversity value of the fynbos is well known, and it constitutes the smallest of six floral kingdoms in the world, with over 6000 endemic plant species. Besides water production and wildflower harvesting, this biodiversity has been evaluated in terms of its value for hiker visitation, ecotourist visitation, endemic species and genetic storage (Higgins *et al.*, 1997), all of which were found to add significant value to the resource.

The impact of invasions on changing fire regimes was also considered significant, and was assigned a weight of 7.5%. Invasions of fire-prone ecosystems by plant species that alter the fuel properties of the vegetation can lead to increases in fire intensity and soil erosion. Invasion of grasslands and shrublands by tall trees and shrubs increases the amount of plant material (fuel load) that can burn. Typical fuel loads in grass and shrublands are around 0.3 - 4 tonnes per hectare (van Wilgen and Scholes 1997), while invaded sites have up to 10 times more fuel (10 - 25 tonnes per hectare (van Wilgen and Richardson 1985). While ecosystems in South Africa are normally quite resilient to regular burning, these increased fuel loads lead to higher intensity fires and a range of detrimental effects. Physical damage to the soil can occur, resulting in increased erosion after fire. For example, 6 tonnes of soil per hectare was lost following fires in pine stands compared to 0.1 tonnes per hectare following fire in adjacent fynbos in the Western Cape (Scott, Versfeld and Lesch 1998).

Alien plant invasions can also have some benefits. Flowers (especially those of certain eucalyptus species) can provide pollen resources that sustain bee colonies (Johannsmeier and Mostert 1995), and these in turn are important for the deciduous fruit industry located in the biome. Alien invasive trees, notably species of *Eucalyptus* and *Acacia*, often provide valuable firewood. Finally, there are other "value-added" products (for example ornamental carvings and furniture) that have some value. Overall the expert group rated the importance of these attributes as 5.5% of the total weight.

Table 2. *Nested criteria identified as significant for the purposes of prioritizing invasive alien plant species in the fynbos biome with regard to their impact on the integrity of fynbos ecosystems. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	Weighting assigned (%)	Sub-criterion	Weighting assigned (%)
Impacts on ecosystem services	55	Impact on water resources	47
		Impact on harvested products	8
Impact on biodiversity	32	Impact on biodiversity	32
Impact on fire hazard	7.5	Impact on fire hazard	7.5
Lack of benefits	5.5	Pollination services	3.6
		Firewood	1.4
		Value-added products	0.5
Totals	**100**		**100**

3.3 Prioritization of species in the fynbos biome

In order to rank the invasive alien plant species in terms of their overall impact, the AHP process requires that each invasive alien plant species be compared to each other species with regard to each of the criteria. The basis for comparisons is shown in Table 3. Expert evaluators were asked to consider these criteria, taking into account the species' current distribution across the biome, as well as its potential distribution in future.

Table 3. *Criteria and associated basis of comparison between species used in the comparison of invasive alien plants in the fynbos biome.*

Criterion	Basis for comparison
Impact on water resources	Species were classified into those that invade riparian zones, those that invade landscapes away from riparian zones, and those that invade both areas. Species that invade both were rated higher than those that invaded riparian zones only. Species that invade riparian zones were rated considerably higher than those that invaded only landscapes away from riparian zones. Within this framework, species were compared with respect to leaf area and biomass. The degree of water use was assumed to be in proportion to biomass and leaf area, and species with higher biomass and leaf area were assigned higher priority.
Impact on harvested products	The degree to which the alien species is able to displace the indigenous species from which products were harvested.
Impact on biodiversity	The degree to which the alien species is able to displace indigenous species.
Impact on fire hazard	The fuel properties of the invasive alien species, and the degree to which it is able to dominate natural vegetation and contribute to the formation of continuous fuel beds. Species with higher biomass, finer fuel, and ability to produce copious amounts of dry litter were scored higher than species with lower biomass, coarser fuel, and lower litter production rates.
Removal of pollination services	The relative importance of the species as a source of pollen.
Removal of a source of firewood	The ability of the species to produce good-quality firewood. Non-woody species were rated as very low, and woody species were compared in terms of the quality and amount of wood that they produced.
Removal of a source of value-added products	The importance of the species for the production of any product other than pollen or firewood. Species with no obvious potential in this regard were rated as very low.

Black wattle (*Acacia mearnsii*) emerged as the invasive alien plant species of highest priority in the fynbos biome (Figure 1), as a result of its significant impacts on water, biodiversity and fire hazard, its widespread occurrence, and its ability to invade both riparian areas and landscapes. Pine trees (*Pinus* species) were rated second for similar reasons. While pines were adjudged to have slightly less impact on water resources than black wattles, their impact on fire hazard was higher, as they have a high biomass, fine needles, and produce copious amounts of needle litter. The placing of poplars as the next most important species was surprising. Although poplars are relatively restricted in distribution, they were adjudged to have very high impacts on water resources, and are widespread in riparian areas.

Species that emerged as least important included all of the grass species. These species are not large, and will not have significant impacts on water resources. Given that impacts on water resources were given large relative weightings, this result is therefore not surprising.

The relatively low priority assigned to both *Hakea sericea* and *Acacia cyclops* warrants comment. Both species are widespread and abundant in the fynbos biome, and should have significant impacts. In the case of *Acacia cyclops*, the relatively low priority assigned to the species is a result of the fact that it occurs mainly in coastal areas (away from the main water catchments); it has recently come under increasingly effective biological control; and it is an important species for firewood supply. In the case of *Hakea sericea*, the species is widespread across an area of approximately 800 x 200 km, and occurs mainly in rugged, inaccessible and fire-prone mountainous areas. The species is serotinous, and produces copious amounts of seed that are spread after fires. It has a long history of control effort, which included a combination of felling and burning, augmented by biological control. Esler *et al*. (submitted) estimated that the overall distribution of the species was reduced by 64 %, from 531 229 to 191 094 ha between 1979 and 2001, as a result of mechanical clearing. They also suggest that biological control may have been largely responsible for the failure of the species to re-colonize cleared sites, or to spread to new areas following unplanned wildfires. Esler *et al*. (submitted) proposed that resources used for clearing *Hakea* in the past can be reallocated to mechanical control efforts against other invasive species (such as pines) for which effective biological control options are not available.

Figure 1/…

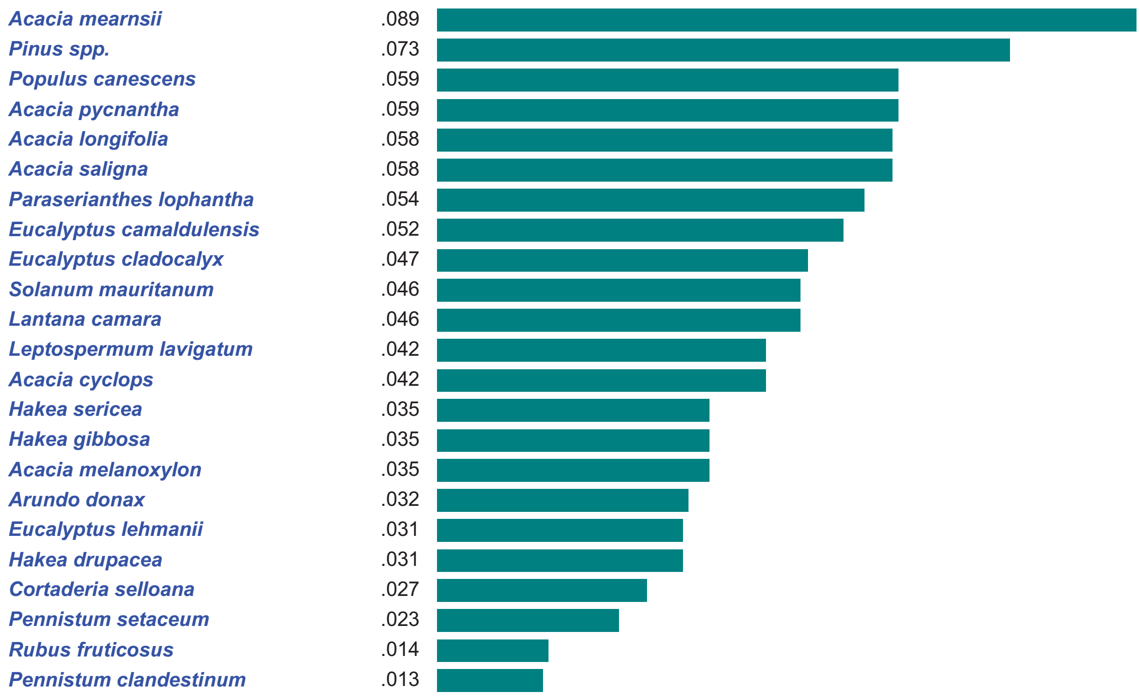

Figure 1. *The relative importance and final ranking of invasive alien plant species in the fynbos biome.*

3.4 Primary catchments selected in the fynbos biome

A total of 13 primary catchments fall partially within the fynbos biome if the splitting of primary catchment G is taken into account (Table 4). We split primary catchment G into two parts: G1 comprises rivers flowing to the north and west (essentially the Berg River catchment) and G2 the rivers flowing to the south and east (see Figure 2). For the purposes of comparison, we selected only those quaternary catchments within each primary catchment that fell completely or partially within the fynbos biome.

Table 4. *The 13 primary catchments used as a basis for the prioritization of areas for the control of invasive alien plant species in the fynbos biome.*

Primary catchment designation	**Primary catchment name**
D	Orange (Sak River)
N	Sundays
M	Swartkops and Port Elizabeth
P	Kariega/Cowie
Q	Great Fish
G2 – South	Kogelberg to Agulhas
E	Olifants/Doring
F	Namaqualand

G1 – North	Berg (coastal plain)
H	Breede
J	Gouritz
K	Outeniqua coast
L	Gamtoos and Kouga

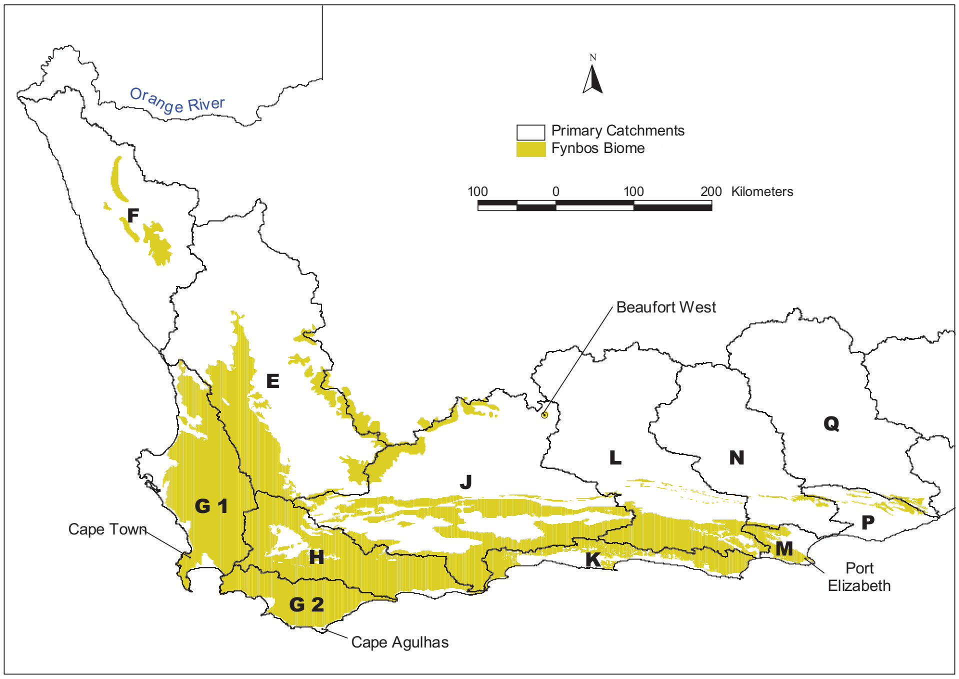

Figure 2. *The correspondence of the fynbos biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names. Note that primary catchment G is spilt into two parts: G1= rivers flowing to the north and west and G2 =rivers flowing to the south and east.*

3.5 Agreed criteria for assessment of primary catchments in the fynbos biome

Three major groups of criteria were identified as a basis for the prioritization of primary catchments in the fynbos biome. These were the value of the land, the presence of priority invasive alien plants, and the need for socio-economic development (Table 5).

The value of the land for water production was ranked by a group of the experts. The group used data from studies on the degree of water stress (Department of Water Affairs and Forestry, 2004) to inform the comparison between catchments. Water stress was defined as the difference between water availability and requirements for the year 2000 (van Wilgen *et al*. 2007). Catchments with a higher degree of water stress were given a higher priority. In addition, the group considered the presence of dams and water supply schemes, with higher preference being given to catchments with more, or larger water supply schemes (mainly dams).

The value of the land for harvested products was gauged from expert knowledge. Most of this value arose from the cut-flower trade (where flowers are harvested from the natural vegetation, see Turpie *et al*. 2003). Additional products, including reeds harvested for thatch, boegoe, and heuningbos tea, were also considered. Catchments that had a higher level of harvesting activity were assigned a higher priority.

The value of the land in terms of conservation importance was estimated using spatial data on protected areas and conservation priorities (Driver *et al*. 2005). We ranked primary catchments in terms of the total area within each primary catchment that fell within a protected area, plus the total area that had been identified as either endangered and critically endangered (Driver *et al*. 2005) outside of protected areas. The rationale for this was (i) Working for Water should strive to maintain state-owned protected areas free of invasive alien plants, and (ii) Working for Water should further seek to target priority areas outside of conservation areas.

Primary catchments were also compared with respect to the extent to which they are currently, and potentially, invaded by priority invasive alien plant species. The current extent of invasion by priority invasive alien species was estimated from data in the SAPIA database (Henderson 1998). We calculated a score for each quarter degree square in the catchment based on the presence and abundance of these priority species in the SAPIA database. In the case of the fynbos biome, we used the five taxa of highest priority (Australian acacias, including *Acacia mearnsii*, *A. longifolia* and *A. pycnantha*, pines and poplars). The SAPIA database records the species in abundance categories as either absent, rare, occasional, frequent, abundant or very abundant. For each quarter degree square in the primary catchment concerned, we noted the species with the highest abundance. A score was then calculated for each primary catchment as:

$$S = \Sigma (n_i \times w_i)$$

Where S = the priority score of the primary catchment, n_i = the number of squares containing at least one priority species with abundance = i (i = highest abundance category of any priority species in the square concerned), and w_i = the weight assigned to abundance category i. We used the weighting system proposed by Henderson (2007) as follows: very abundant = 1000, abundant = 200, frequent = 50, occasional = 10 and rare = 1. Where quarter degree squares did not contain any of the priority species, we assume w_i to be zero. Primary catchments were prioritized according to the relative values of these priority scores.

The potential extent to which these species could invade the primary catchment was estimated from a modelling exercise using climatic envelopes (Rouget *et al*. 2004). We calculated the area of the fynbos proportion of each catchment that could potentially be occupied by priority species, and assigned priorities in relation to these areas of potential occupation.

In order to prioritise primary catchments with regard to the need for socio-economic development, we intended to make use of areas identified specifically as rural priority poverty nodes by the South African government. However, the fynbos biome does not contain any such nodes. Because the number of unemployed people will always exceed the capacity of Working for Water to employ them, and because no areas were priority poverty nodes, we ranked all primary catchments in the fynbos biome as equal with regard to this criterion. This will not, however, be the case in other biomes.

In line with all other poverty relief projects, Working for Water is required to employ workers for no more than two years in each 5-year cycle. Workers are provided with limited training that theoretically improves their chances either securing gainful employment after leaving the programme, or successfully setting up their own businesses (Magadlela and Mdzeke 2004). These chances will be enhanced in catchments that have higher levels of economic activity. Primary catchments were therefore compared in terms economic activity; primary catchments with higher levels of economic activity received higher priority. In practice, this meant assigning highest priorities to primary catchments containing or in the proximity of cities and larger towns.

Table 5. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the fynbos biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Value of the land	71.4	Value for water	45.7
		Value for harvested products	4.8
		Conservation importance	20.9
Presence of priority invasive alien plants	14.3	Current impact of invasive alien plants	3.7
		Potential impacts of invasive alien plants	7.2
The need for socio-economic development	14.3	The need for short-term job creation	7.2
		The opportunities for staff exiting the programme to find alternative employment	7.1
Totals	**100**		**100**

3.6 *Prioritization of primary catchments in the fynbos biome*

In order to rank the primary catchments in terms of their overall priority, AHP requires that each area be compared to each other area with regard to each of the criteria. The basis for comparisons is shown in Table 6.

Table 6. *Criteria and associated basis of comparison between primary catchments used in the comparison of areas in the fynbos biome.*

Criterion	**Basis for comparison**
Value of the land for water	Primary catchments were compared by the expert group on the basis of water stress (higher water stress indicated a higher priority) and the presence of water schemes, mainly dams (the presence of larger water schemes indicated a higher priority).
Value of the land for harvested products	Primary catchments were compared by the expert group on the basis of individual's knowledge of the area. Catchments where harvesting activities were greater were given a higher rank.
Value of the land in terms of conservation importance	Primary catchments were compared in terms of the sum of the area (in hectares) that fell into protected areas, plus habitats had been placed in the endangered or critically endangered categories (see section 3.5). Catchments with a larger area in these categories were given a higher priority than catchments with a lower area, in direct proportion to the areas concerned.
Current impact of invasive alien	Primary catchments were compared in terms of the presence of priority alien

Criterion	Basis for comparison
plants	invasive species (Australian acacias, including *Acacia mearnsii*, *A. longifolia* and *A. pycnantha*, pines and poplars). We calculated a score for each quarter degree square in the catchment based on presence and abundance in the SAPIA database (see section 3.5). Catchments with higher scores were given a proportionally higher priority.
Potential impacts of invasive alien plants	Primary catchments were compared in terms of the potential presence of priority alien invasive species (Australian acacias, including *Acacia mearnsii*, *A. longifolia* and *A. pycnantha*, pines and poplars). We used the potential area that could be invaded, based on climatic modelling (see section 3.5). Catchments with higher estimates of potentially invaded areas were given a proportionally higher priority.
The need for short-term job creation	Considered as equal for all primary catchments (see section 3.5)
The opportunities for staff exiting the programme to find alternative employment.	Primary catchments were compared in terms of the opportunities for workers who exit the programme to use the skills that they developed during their employment. In this regard, catchments that contained cities or large towns were given a higher priority.

The Berg and Breede catchments emerged as the highest priority following the assessment process (Figure 3). The factors that contributed strongly to the priority of the Berg River catchment included its value as a water catchment area for the agriculture of the region and as a water supply area to Cape Town, the high score for conservation value, and the potential for workers to find future alternative employment. The factors that contributed strongly to the priority of the Breede River catchment included the fact that current levels of invasion by priority species were high, its value as a water catchment area for the agriculture of the region and as a water supply area to Cape Town, and the value for harvested products from the catchment. The potential of future spread by priority invasive alien plants did not assist greatly in separating priorities, as all of the primary catchments could potentially become almost fully invaded.

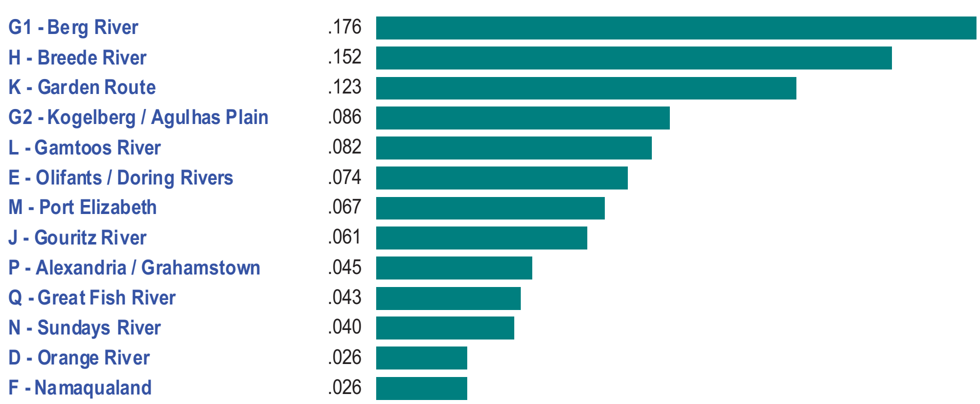

Figure 3. *The relative importance and final ranking of primary catchments in the fynbos biome.*

4. Results for the grassland biome

4.1 Species selected in the grassland biome

Our approach initially identified 32 invasive alien plant species (18 trees, 5 shrubs, 5 herbs, 1 grass, 2 succulents and 1 annual) as important in the grassland biome. Of these species, 19 were seen as problems currently, and 13 more were not currently a problem, but could potentially become a problem in future. Seven of the 19 species that currently occupy >10% of the biome were not classified as future problems, as they did not have the potential to occupy >20% of the biome.

At an expert workshop, a number of changes were made to this list. A total of 16 species were removed from the list. These were species that were considered by the expert group as species that did not invade pristine grasslands, and they included the following: *Acacia baileyana* (Bailey's wattle); *Acacia melanoxylon* (blackwood); *Achyranthes aspera* (burweed); Agave americana (American agave); *Cuscuta campestris* (common dodder); *Echinopsis spachiana* (torch cactus); *Eucalyptus grandis* (rose gum); *Jackaranda mimosifolia* (jackaranda); *Lantana camara* (lantana); *Melia azedarach* (Persian lilac); *Nicotiana glauca* (wild tobacco); *Pinus halepensis* (Aleppo pine); *Psidium guajava* (guava); *Rubus fruticosus* (European blackberry); *Solanum sisymbriifolium* (wild tomato); and *Xanthium strumarium* (large cocklebur). The expert group also added four taxa to the list: (i) *Cotoneaster franchetii* and *C. pannosus* (Orange and silver-leaf cotoneasters); (ii) *Eucalyptus cinerea* (florist gum); and (iii) *Salix fragilis* (crack willow). It was also decided to combine the three *Acacia*, two cotoneaster and two poplar species, and to treat them as a single "species" for the purposes of this exercise. The final list therefore contained 17 alien plant taxa (species or groups of species) (Table 7).

Table 7. *The 17 invasive alien plant taxa selected for prioritization in the grassland biome.*

Species	**Life form**	**Current or future threat?**
Acacia mearnsii, dealbata and *decurrens* (Black, silver and green wattle)	Medium evergreen trees	Both
Arundo donax (Giant reed)	Tall reed	Both
Campuloclinium macrocephalum (Pom-pom weed)	Perennial herb	Both
Chromolaena odorata (Triffid weed)	Sprawling shrub	Present
Cotoneaster franchetii and pannosus (Orange and silver-leaf cotoneasters)	Shrubs	Species were added by expert group as "both"
Eucalyptus camaldulensis (Red river gum)	Tall evergreen tree	Future
Eucalyptus cinerea (Florist gum)	Tall evergreen tree	Future
Ipomoea indica (Morning glory)	Perennial twiner	Future
Pinus elliottii (Slash pine)	Tall evergreen coniferous tree	Future
Pinus patula (Patula pine)	Tall evergreen coniferous tree	Both
Populus x canescens and *alba* (Grey and white poplars)	Tall deciduous trees	Present
Pyracantha angustifolia (Yellow firethorn)	Evergreen shrub	Future
Robinia pseudoacacia (Black locust)	Medium deciduous tree	Future
Rubus cuneifolius (American bramble)	Sprawling shrub	Present
Salix babylonica (Weeping willow)	Medium deciduous tree	Both
Salix fragilis (Crack willow)	Medium deciduous tree	Both
Solanum mauritianum (Bugweed)	Shrub or small tree	Both

4.2 Agreed criteria for the assessment of species

Four major groups of impact or benefits associated with invasive alien plants were identified. The impacts were those on ecosystem services, biodiversity and fire hazard. The fourth criterion addressed the impact of removal of invasive alien plants in terms of a *lack* of benefits in cases where the invasive plant has some use (Table 8).

The impact of invasive alien plants on ecosystem services was considered by the group of experts to be the most important of the impacts, and was assigned a weighting of 58.4%. Given the importance of the grassland areas as catchments for the major river systems of South Africa, and the importance of water resources for sustaining agriculture, industry and towns, the impacts on water were assigned the greatest weight (46.7% of the total). The impact of invasions on reducing grazing, and harvested products (mainly thatching grass) was rated as of lesser importance (11.7% of the total).

The impact of invasions on biodiversity was rated as the next-most important category. Grasslands are important biodiversity areas (Reyers *et al*. 2005). South Africa's grasslands host a very high diversity of plant species, second only to the Cape Floral Kingdom (greater at a 1000m^2 scale; O' Connor and Bredenkamp 1997). A high degree of endemism also occurs with nearly half of South Africa's 34 endemic mammals found in the grassland biome. Several small and threatened mammals are also restricted to the biome. It is home to 52 of the 122 Important Bird Areas in South Africa and contains the highest global priority Endemic Bird Area and contains 10 of the 14 globally threatened bird species found in South Africa. The biome houses 22% of South Africa's endemic reptiles, a third of the threatened butterflies and five of the 17 Ramsar wetlands in South Africa. In terms of ecosystem services, the biome is an important source of many provisioning services of food, fibre, medicines and water, has high carbon storage potential, is an important source of forage and livestock and forms an important component of the country's tourism industry. Based on total habitat loss, degree of fragmentation and estimation of future threat the grassland biome has been identified as critically endangered (Reyers *et al*. 2001; Olsen and Dinerstein 2002).

The impacts of invasions on changing fire regimes were also considered significant, and were assigned a weight of 9.8%. The motivation for the inclusion of this criterion is the same as for fynbos ecosystems (see above). Physical damage to the soil can occur following fires in invaded sites, resulting in increased erosion after fire. For example, 37 tonnes of soil per hectare was lost following fires in pine stands compared to 1.8 tonnes per hectare in adjacent grassland in the KwaZulu-Natal Drakensberg (Scott and van Wyk 1990; Scott and Schulze 1992; van Wyk 1985).

Alien plant invasions can also have some benefits. The expert group identified building material (from alien trees and *Arundo donax*), fodder (from wattles), fire wood and charcoal (from alien trees), and fruit (from brambles) as being of benefit.

Overall the expert group rated the importance of these attributes as 9.8% of the total weight.

Table 8. *Nested criteria identified as significant for the purposes of prioritizing invasive alien plant species in the grassland biome with regard to their impact on the integrity of grassland ecosystems. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	Weighting assigned (%)	Sub-criterion	Weighting assigned (%)
Impacts on ecosystem services	58.4	Impact on water resources	46.7
		Impact on grazing and harvested products	11.7
Impact on biodiversity	22	Impact on biodiversity	22
Impact on fire hazard	9.8	Impact on fire hazard	9.8
Lack of benefits	9.8	Lack of benefits	9.8
Totals	**100**		**100**

4.3 Prioritization of species in the grassland biome

In order to rank the invasive alien plant species in terms of their overall impact, the AHP process requires that each invasive alien plant species be compared to each other species with regard to each of the criteria. The basis for comparisons is shown in Table 9. The expert evaluators were asked to consider these criteria, taking into account the species' current distribution across the biome, as well as its potential distribution in future.

Table 9. *Criteria and associated basis of comparison between species used in the comparison of invasive alien plants in the grassland biome.*

Criterion	Basis for comparison
Impact on water resources	Comparisons were done in a similar manner to the fynbos biome, see Table 3.
Impact on grazing resources and harvested products	The degree to which the alien species is able to displace the indigenous species which are important for grazing, or from which products were harvested.
Impact on biodiversity	The degree to which the alien species is able to displace indigenous species.
Impact on fire hazard	Comparisons were done in a similar manner to the fynbos biome, see Table 3.
Lack of benefits	The relative importance of species in terms of the overall benefit that it may offer. Species with no obvious potential were rated as very low.

The experts were of the opinion that invasive alien plants do not invade pristine grasslands in general. In their opinion, many invasive species become invasive in grasslands that have been degraded, for example by overgrazing, leading to further deterioration. We rated species as more important if the group believed that they could invade undisturbed grassland (for example pom-pom weed in the highveld and bramble in frost-prone areas of the KwaZulu/Natal mist belt).

In the grassland biome, tree species, including wattles (*Acacia mearnsii*, *A. dealbata and A. decurrens*), red river gum (*Eucalyptus camaldulensis*) and pines (*Pinus patula* and *P. elliottii*) were regarded as the most important invaders (Figure 4). This is due mainly to their proportionally large impacts on water resources, especially when compared to smaller shrubs that would not have such a large impact on water resources. These trees would also impact negatively on biodiversity and on grazing and harvesting of other products in natural grasslands. Pom-pom weed (*Campuloclinium macrocephalum*) and bramble (*Rubus cuneifolius*) received fairly high ratings because of their ability to invade pristine grasslands, impacting severely on grazing, harvested products, and biodiversity.

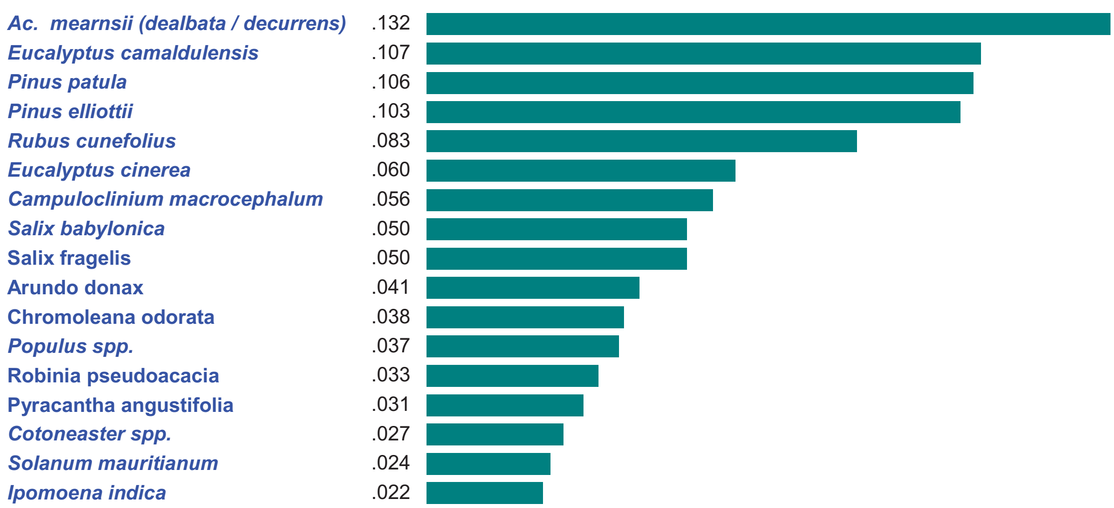

Figure 4. *The relative importance and final ranking of invasive alien plants in the grassland biome. Acacia mearnsii, A. dealbata and decurrens were treated as one taxon for the purposes of this study.*

4.4 Primary catchments selected in the grassland biome

A total of 13 primary catchments fall partially within the grassland biome (Figure 5). Primary catchments A, N, Q and R were excluded because grasslands only occupy a small proportion of these primary catchments, leaving nine primary catchments in our analysis (Table 10). For the purposes of comparison, we selected only those quaternary catchments within each of these nine primary catchments that fell completely or partially within the grassland biome (Figure 5).

Table 10. *The nine primary catchments used as a basis for the prioritization of areas for the control of invasive alien plant species in the grassland biome.*

Primary catchment designation	Primary catchment name
B	Olifants
C	Vaal
D	Orange
S	Great Kei
T	Umzimvubu
U	Umgeni
V	Tugela
W	Pongolo
X	Inkomati

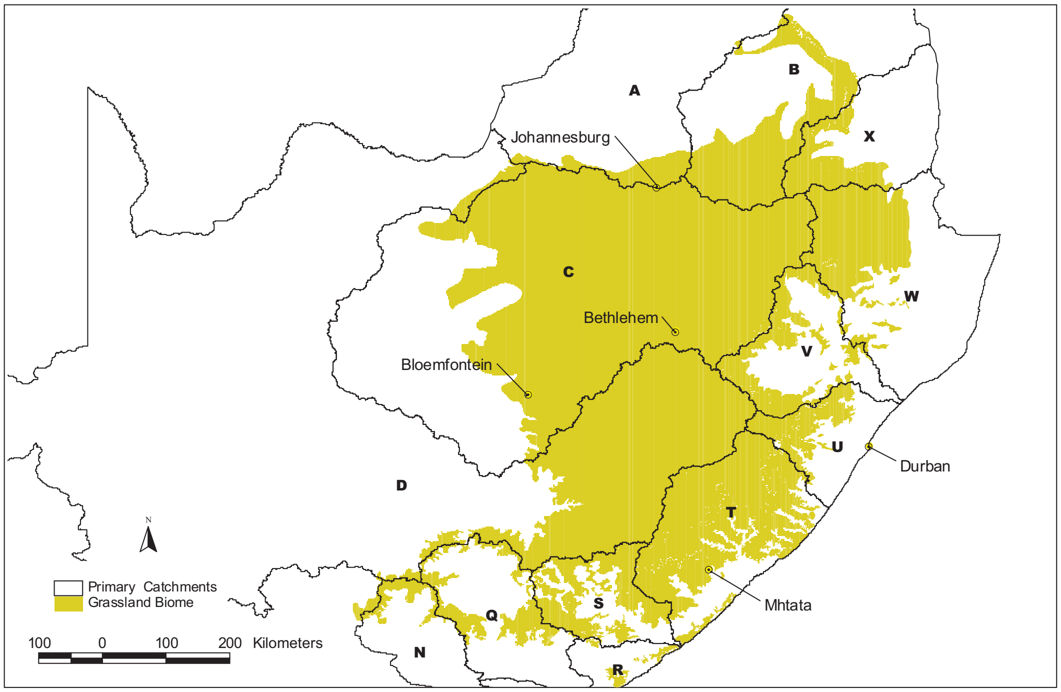

Figure 5. *The correspondence of the grassland biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names (see Table 10).*

4.5 Agreed criteria for assessment of primary catchments in the grassland biome

Six major criteria were identified as a basis for the prioritization of primary catchments in the grassland biome (Table 11). Of these, only the criterion relating to the value of the land as a water catchment was subdivided.

The value of the land for water production was ranked by a group of the experts, based on the relative proportion of water generated by the primary catchment. Water stress was defined as the difference between water availability and requirements for the year 2000 (van Wilgen *et al*. 2007). Primary catchments with a higher degree of water stress were given a higher priority.

The value of the land in terms of conservation importance was estimated using the same source of data on protected areas and conservation priorities, and the same methods, as the fynbos biome.

The relative value of the land for livestock production was estimated by comparing primary catchments with respect to their potential to support livestock. This potential was derived from estimates of the mean livestock production (in large livestock units per km^2) (Scholes 1998). Scholes mapped potential livestock in 10 classes: 0 – 1, 1 – 2, 2 – 3, 3 – 4, 4 – 6, 6 – 8, 8 – 10, 10 – 14, 14 – 18 and 18 – 22 livestock units per km^2. We took the midpoint of each class, and multiplied it by the area with the corresponding carrying capacity to estimate the number of livestock units that could be supported. We assumed that only untransformed (natural) vegetation would support livestock, and deducted the area of transformed vegetation (Thompson 1996) from the vegetation cover layer in each catchment before the above calculation was made. A score was then calculated for each catchment as:

$$S = \Sigma (n_i \times w_i)$$

Where S = the priority score of the catchment, n_i = the area in km^2 of the *i*th livestock potential class, and w_i = the midpoint value for the *i*th livestock potential class. Catchments were prioritized according to the relative values of these priority scores.

Primary catchments were also compared with respect to the extent to which they are currently invaded by priority invasive alien plant species by calculating a priority score in the same way as for the fynbos biome. In the case of grasslands, the five taxa of highest priority that were used to calculate the score were wattles (*Acacia mearnsii*, *A. dealbata and A. decurrens*), red river gum (*Eucalyptus camaldulensis*), patula pine (*Pinus patula*), slash pine (*Pinus elliottii*) and bramble (*Rubus cuneifolius*).

Primary catchments were compared with regard to the presence or absence of poverty nodes as defined by DPLG (2007). When two catchments were compared, catchments containing more poverty nodes (mapped at a district council level) were given a higher score in proportion to catchments with fewer poverty nodes.

The expert group identified the issue of capacity to hold onto gains realised after initial clearing of alien plants as an important criterion for prioritization. They argued that, in their experience, many areas cleared by Working for Water simply regressed to an invaded status following clearing as landowners clearly did not have the capacity to hold onto gains made. Primary catchments were therefore prioritised in terms of the capacity of landowners to hold onto gains. Essentially, this meant that areas with relatively well resourced landowners, and systems of private land ownership would receive preference over areas with poorer landowners or areas with traditional land tenure systems. State-owned land was also given priority, both because the state does have access to funds, and because the state has to lead by example.

Table 11. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the grassland biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	Weighting assigned (%)	Sub-criterion	Weighting assigned (%)
Value of the land as a water catchment	23.4	Relative importance as a water production area	15.6
		Relative degree of water stress	7.8
Value of the land for conservation	13.9	None	13.9
Value of the land for livestock production	7.0	None	7.0
Presence of priority invasive alien plants	18.9	None	18.9
Presence of priority poverty nodes	3.2	None	3.2
Capacity to hold onto gains realised after initial clearing of alien plants	33.6	None	33.6
Totals	**100**		**100**

4.6 Prioritization of primary catchments in the grassland biome

The Vaal catchment emerged as the highest priority following the assessment process (Figure 6). The factors that contributed strongly to the priority of the Vaal were a very high potential for livestock production, and a high value of the land for conservation (the catchment has a great deal of endangered habitats outside of formal conservation areas). The Olifants and Inkomati catchments were assigned high priorities because of the large areas infested with priority invasive alien plant species. The expert group that selected the weighting for criteria in the grasslands gave a great deal of weight to the capacity to hold onto gains after initial clearing of invasive alien plants, and this factor also contributed significantly to the high priority for the top three catchments. It must be stressed, however, that the allocation of weightings for this factor were not supported by robust data. The weightings for the different criteria are shown in Table 12.

Figure 6. *The relative importance and final ranking of primary catchments in the grassland biome.*

***Table 12**. Values used for different criteria in the comparison of primary catchments in the grassland biome.*

Criterion	Primary catchment								
	B	**C**	**D**	**S**	**T**	**U**	**V**	**W**	**X**
Value of the land for water production – runoff volumes (millions of m^3/yr)	2904	4567	7147	1042	7383	3121	3990	4741	2871
Value of the land for water production – ranking of relative water stress	3	2	0	1	0	2	2	2	1
Area of priority conservation importance (km^2)	8680	34560	7610	700	4800	1880	1550	2200	2260
Value of land for livestock production (estimated livestock units x 1000)	163	1284	892	179	465	68	177	135	83
Score for presence of priority invasive alien plant species	14194	7624	3843	5301	9305	5609	7157	9991	8667
Number of rural poverty nodes	2	1	3	1	6	1	1	2	0
Capacity to hold onto gains	?	?	?	?	?	?	?	?	?

5. Results for the moist savanna biome

5.1 Species selected in the moist savanna biome

Our approach initially identified 26 invasive alien plant species (11 trees, 7 shrubs, 1 herb, 1 grass, 2 succulents and 4 climbers) as important in the entire savanna biome. Of these species, 13 were seen as problems currently, and 13 more were not currently a problem, but could potentially become a problem in future. Four of the 13 species that currently occupy >10% of the biome were not classified as future problems, as they did not have the potential to occupy >20% of the biome.

It was recommended at an expert workshop that the savanna biome be divided into arid and moist components based on the different suites of alien plants invading these areas. The arid savanna corresponds with the Kalahari Bushveld types plus the Kimberley Thornveld Bushveld defined by Low and Rebelo (1996). All other savanna types are included in the moist savanna. Arid savanna also corresponds well with the Eastern Kalahari Bushveld and Kalahari Duneveld Bioregions of Mucinia and Rutherford (2006). Moist savanna includes all the remaining savanna bioregions.

A total of 13 plants were removed from the initial list as these were considered by the expert group as species that were not of importance as invaders of moist savanna. They included the following: *Acacia baileyana* (Bailey's wattle); Agave americana (American agave); *Cuscuta campestris* (common dodder); *Echinopsis spachiana* (torch cactus); *Ipomoea indica* (morning glory); *Macfadyena unguis-cati* (cat's claw creeper); *Nicotiana glauca* (wild tobacco); *Prunus persica* (peach); *Solanum mauritianum* (bugweed); *Solanum seaforthianum* (Potato creeper); and *Xanthium strumarium* (large cocklebur). In addition, two other invaders (*Prosopis glandulosa*, mesquite and *Robinia pseudoacacia*, black locust) were removed, but included as important invaders in the arid savanna. The expert group also added four taxa to the list: *Cereus jamacaru* (Queen of the night); *Parthenium hysterophorus* (Parthenium); *Pereskia aculeata* (Barbados gooseberry); and *Schinus terebinthifolius* (Brazilian pepper tree). It was also decided to combine the two pines, and two *Senna* species, and to treat them as a single taxon. The final list therefore contained 15 alien plant taxa (species or groups of species) (Table 13).

Table 13. *The 15 invasive alien plant taxa selected for prioritization in the moist savanna biome.*

Species	**Life Form**	**Current or future threat?**
Acacia mearnsii (Black wattle)	Medium evergreen tree	Both
Arundo donax (Giant reed)	Tall reed	Present
Caesalpinia decapetala (Mauritius thorn)	Thorny evergreen shrub	Present
Cereus jamacaru (Queen of the night)	Spiny succulent tree	Added
Cestrum laevigatum (Inkberry)	Evergreen shrub or small tree	Future
Chromolaena odorata (Triffid weed)	Scrambling shrub	Present
Jacaranda mimosifolia (Jacaranda)	Deciduous tree	Both
Lantana camara (Lantana)	Compact shrub	Both
Melia azedarach (Persian lilac)	Deciduous tall tree	Both
Parthenium hysterophorus (Parthenium)	Annual herb	Added
Pereskia aculeata (Barbados gooseberry)	Spiny shrubby vine	Added
Pinus spp. *(elliottii and patula)*	Tall evergreen coniferous trees	Both

Psidium guajava (Guava)	Small evergreen tree	Both
Senna spp. (Peanut butter cassia and others)	Softly wooded shrubs	Both
Schinus terebinthifolius (Brazilian pepper tree)	Medium evergreen tree	Added

5.2 Agreed criteria for the assessment of species

Four major groups of impact or benefits associated with invasive alien plants were identified. The impacts were those on ecosystem services, biodiversity and fire hazard. The fourth criterion addressed the impact of removal of invasive alien plants in terms of a *lack* of benefits in cases where the invasive plant has some use (Table 14).

The impact of invasive alien plants on ecosystem services was considered by the group of experts to be the most important of the impacts, and was assigned a weighting of 49.2%. Given that the savanna biome is not as important as other biomes (such as fynbos and grassland) as a water catchment area, the relative importance assigned to water resources was lower than in other biomes (16.4%). Grazing, browsing, and harvested products, on the other hand, were assigned 32.8%, recognising the significant role that savannas play in support of two major industries – cattle farming and game ranching.

The impact of invasions on biodiversity was rated as the single most important category, with 34.6% of the weight. While savannas are not generally regarded being as important as the fynbos, grassland or succulent karoo biomes with regard to biodiversity, they do nonetheless deliver significant biodiversity-related benefits.

The impact of invasions on changing fire regimes was also considered significant, and was assigned a weight of 8.1%. The motivation for the inclusion of this criterion is the same as for fynbos and grassland ecosystems (see above).

Alien plant invasions can also have some benefits. The expert group identified the same group of benefits associated with the invasive species in the grassland biome.
Overall the expert group rated the importance of these attributes as 8.1% of the total weight.

***Table 14**. Nested criteria identified as significant for the purposes of prioritizing invasive alien plant species in the moist savanna biome with regard to their impact on the integrity of moist savanna ecosystems. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Impacts on ecosystem services	49.2	Impact on quality and quantity of water resources	16.4
		Loss of grazing, browsing and harvested products	32.8
Impact on biodiversity	34.6	None	34.6
Lack of benefits	8.1	None	8.1
Increased fire hazard	8.1	None	8.1
Totals	**100**		**100**

5.3 Prioritization of species in the moist savanna biome

In order to rank the invasive alien plant species in terms of their overall impact, the AHP process requires that each invasive alien plant species be compared to each other species with regard to each of the criteria. The basis for comparisons is shown in Table 15. The expert evaluators were asked to consider these criteria, taking into account the species' current distribution across the biome, as well as its potential distribution in future.

Table 15. *Criteria and associated basis of comparison between species used in the comparison of invasive alien plants in the moist savanna biome.*

Criterion	Basis for comparison
Impact on quality and quantity of water resources	Comparisons were done in a similar manner to the fynbos biome, see Table 3.
Loss of grazing, browsing and harvested products	The degree to which the alien species is able to displace the indigenous species which are important for grazing or browsing, or from which products were harvested.
Impact on biodiversity	The degree to which the alien species is able to displace indigenous species.
Impact on fire hazard	Comparisons were done in a similar manner to the fynbos biome, see Table 3.
Lack of benefits	The relative importance of species in terms of the overall benefit that it may offer. Species with no obvious potential were rated as very low.

In the moist savanna biome, *Chromolaena odorata* and *Lantana camara* emerged as the most important invasive species. These species are both widespread, difficult to control, and will impact significantly on grazing and biodiversity (Figure 7). Two tree species (guavas, *Psidium guajava* and syringas, *Melia azedarach*) were considered as very important. Parthenium weed (*Parthenium hysterophorus*) was also regarded as a significant threat by the expert group.

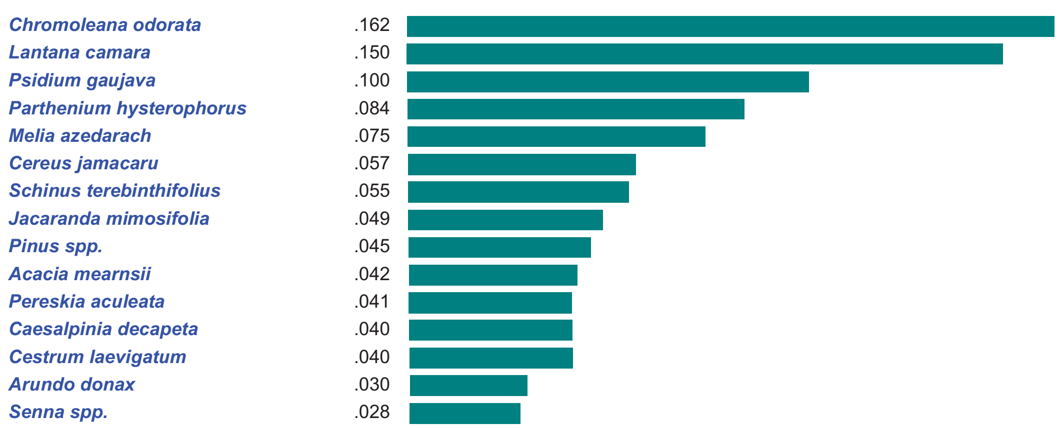

Figure 7. *The relative importance and final ranking of invasive alien plant species in the moist savanna biome.*

5.4 Primary catchments selected in the moist savanna biome

A total of 11 primary catchments fall partially within the moist savanna biome (Figure 8). Primary catchments P, Q, R, S and T were excluded because moist savannas only occupy a small proportion of these primary catchments. Primary catchment X was inadvertently omitted, leaving 8 primary catchments in our analysis (Table 16). For the purposes of comparison, we selected only those quaternary catchments within each of the final set of primary catchments that fell completely or partially within the moist savanna biome (Table 16).

Table 16. *The eight primary catchments used as a basis for the prioritization of areas for the control of invasive alien plant species in the moist savanna biome.*

Primary catchment designation	Primary catchment name
A	Limpopo
B	Olifants
P	Kariega / Cowie
R	Keiskamma / Buffalo
S	Great Kei
U	Umgeni
V	Tugela
W	Pongolo

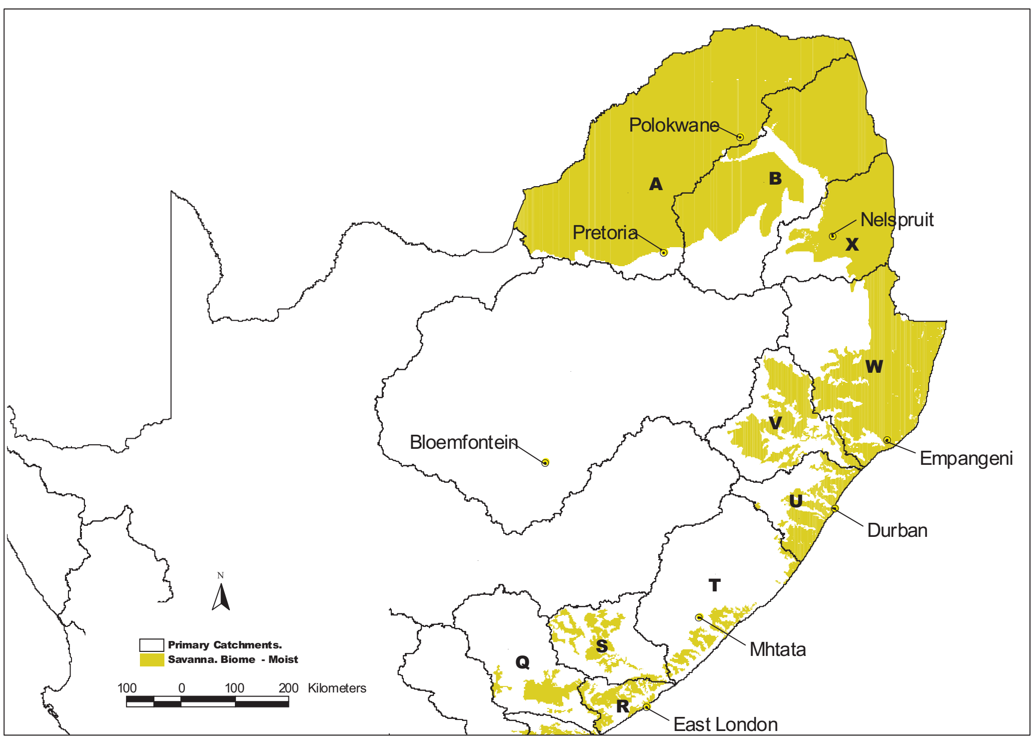

Figure 8. *The correspondence of the moist savanna biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names (see Table 16).*

5.5 Agreed criteria for assessment of primary catchments in the moist savanna biome

Six major criteria were identified as a basis for the prioritization of primary catchments in the moist savanna biome (Table 17). Of these, the criterion relating to the value of the land as a water catchment was subdivided.

The value of the land for water production was ranked by a group of the experts, based on the relative mean annual rainfall in the primary catchment. Water stress was defined as the difference between water availability and requirements for the year 2000 (van Wilgen *et al*. 2007). Primary catchments with a higher degree of water stress were given a higher priority.

The value of the land in terms of conservation importance was estimated using the same source of data on protected areas and conservation priorities, and the same methods, as the fynbos biome.

The relative value of the land for livestock production was estimated in the same way as for the grassland biome.

Primary catchments were also compared with respect to the extent to which they are currently invaded by priority invasive alien plant species by calculating a priority score in the same way as for the fynbos biome. In the case of moist savannas, the five taxa of highest priority that were used to calculate the score were lantana (*Lantana camara*) and triffid weed (*Chromolaena odorata*), guava (*Psidium guajava*), parthenium (*Parthenium hysterophorus*) and syringa (*Melia azedarach*).

Primary catchments were compared with regard to the presence or absence of poverty nodes in the same way as was done for grassland catchments.

The capacity to hold onto gains realised after initial clearing of alien plants was assessed in the same way as for grasslands.

Table 17. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the moist savanna biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Value of the land as a water catchment	12.4	Relative importance as a water production area	4.1
		Relative degree of water stress	8.3
Value of the land for conservation	16.6	None	16.6
Value of the land for livestock production	9.8	None	9.8
Presence of priority invasive alien plants	19.1	None	19.1.
Presence of priority poverty nodes	3.6	None	3.6
Capacity to hold onto gains realised after initial clearing	38.5	None	38.5
Totals	**100**		**100**

5.6 Prioritization of primary catchments in the moist savanna biome

The Umgeni and Olifants catchments emerged as the highest priorities following the assessment process (Figure 9). The factors that contributed strongly to the priority of the Umgeni included a relatively high water runoff, a high degree of invasion by priority alien species, and a high capacity to hold onto gains made by clearing operations (Table 18). In the case of the Olifants catchment, an unusually high area of priority conservation value, combined with a high degree of invasion by priority alien species, contributed to the high ranking of this catchment area.

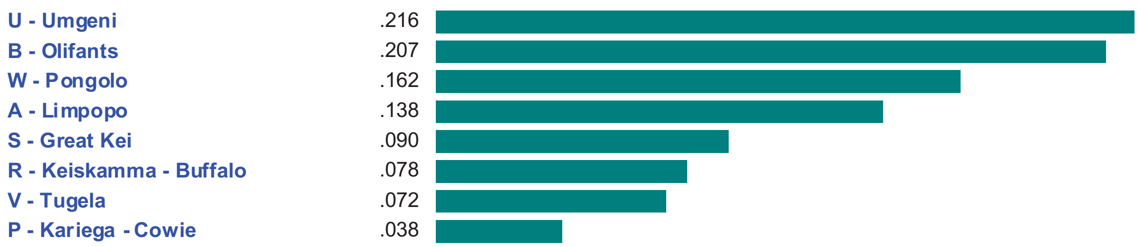

Figure 9. *The relative importance and final ranking of primary catchments in the moist savanna biome.*

Table 18. *Values used for different criteria in the comparison of primary catchments in the moist savanna biome.*

Criterion	**Primary catchment**							
	A	**B**	**P**	**R**	**S**	**U**	**V**	**W**
Value of the land for water production – runoff volumes (millions of m^3/yr)	2381	2904	172	578	1042	3121	3990	4741
Value of the land for water production – stress.	?	?	?	?	?	?	?	?
Area of priority conservation importance (km^2)	1058	1967	23	9	0.4	196	43	528
Value of land for livestock production (estimated livestock units x 1000)	384	205	6	46	64	23	147	241
Score for presence of priority invasive alien plant species	6109	8604	134	329	1327	7313	1746	1312
Number of rural poverty nodes	0	3	0	0	1	2	0	3
Estimated capacity to hold onto gains	0	1	1	2	2	3	1	2

6. Results for the arid savanna biome

6.1 Species selected in the arid savanna biome

A description of the rational for dividing the savanna biome into arid and moist savannas is given in section 5.1. The eight species selected by the expert group as important alien invasive plants in the arid savanna biome (Table 19) were a subset of species identified as important in the entire savanna biome. They included five tree species, two succulent species and one grass species.

Table 19. *The eight invasive alien plant taxa selected for prioritization in the arid savanna biome.*

Species	**Life form**
Arundo donax (Giant reed)	Tall grass
Cereus jamacaru (Queen of the night)	Succulent
Melia azedarach (Persian lilac)	Tree
Opuntia spp	Succulent
Populus x canescens (Grey poplars)	Tree
Prosopis x glandulosa (Mesquite)	Tree
Robinia pseudoacacia (Black locust)	Tree
Schinus molle (Pepper tree)	Tree

6.2 Agreed criteria for the assessment of species

Three major groups of impact or benefits associated with invasive alien plants were identified. The impacts were those on ecosystem services, and on biodiversity, as well as the impact of removal of invasive alien plants in terms of a *lack* of benefits in cases where the invasive plant has some use (Table 20).

The impact of invasive alien plants on ecosystem services was considered by the group of experts to be the most important of the impacts, and was assigned a weighting of 67.4%. The largest proportion of this weighting (50.55%) went to the impact on water resources. This is because of the potential impacts of invasive alien trees, and noticeably *Prosopis* species, on groundwater resources. Grazing, browsing, and harvested products were assigned 16.85%, arising mainly from the invasion of dry riparian areas which have the best grazing in these regions.

The impact of invasions on biodiversity was assigned 22.6% of the weight. While arid savanna is not generally regarded being as important as the fynbos, grassland or succulent karoo biomes with regard to biodiversity, they do nonetheless deliver significant biodiversity-related benefits.

Alien plant invasions can also have some benefits. The expert group identified the benefits arising from *Prosopis* (pods as a source of fodder, and firewood) and *Arundo* (as building material) as the most important of these benefits. Overall the expert group rated the importance of these attributes as 10.1% of the total weight.

***Table 20**. Nested criteria identified as significant for the purposes of prioritizing invasive alien plant species in the arid savanna biome with regard to their impact on the integrity of arid savanna ecosystems. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	Weighting assigned (%)	Sub-criterion	Weighting assigned (%)
Impacts on ecosystem services	67.4	Impact on water resources	50.55
		Impact on grazing and harvested products	16.85
Impact on biodiversity	22.6	Impact on biodiversity	22.6
Lack of benefits	10.1	Lack of benefits	10.1
Totals	**100**		**100**

6.3 Prioritization of species in the arid savanna biome

In arid savanna areas, the expert group identified mesquite (*Prosopis glandulosa*) as the most important invasive species by a considerable margin (Figure 10). This was because of the widespread distribution of the species along dry river courses, where it has a significant impact on water resources, biodiversity and grazing resources. The remaining species were assigned a roughly equal, but lesser degree of importance.

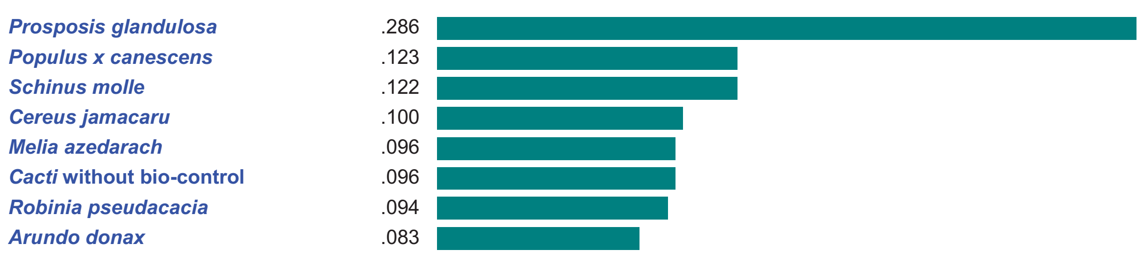

***Figure 10.** The relative importance and final ranking of invasive alien plants in the arid savanna biome.*

6.4 Primary catchments selected in the arid savanna biome

There are only two primary catchments that fall within the arid savanna biome in South Africa (Table 21). For the purposes of comparison, we selected only those quaternary catchments within each primary catchment that fell completely or partially within the arid savanna biome (Figure 11).

Table 21. *The two primary cachments used as a basis for the prioritization of areas for the control of invasive alien plant species in the arid savanna biome.*

Primary catchment designation	**Primary catchment name**
C	Vaal
D	Orange

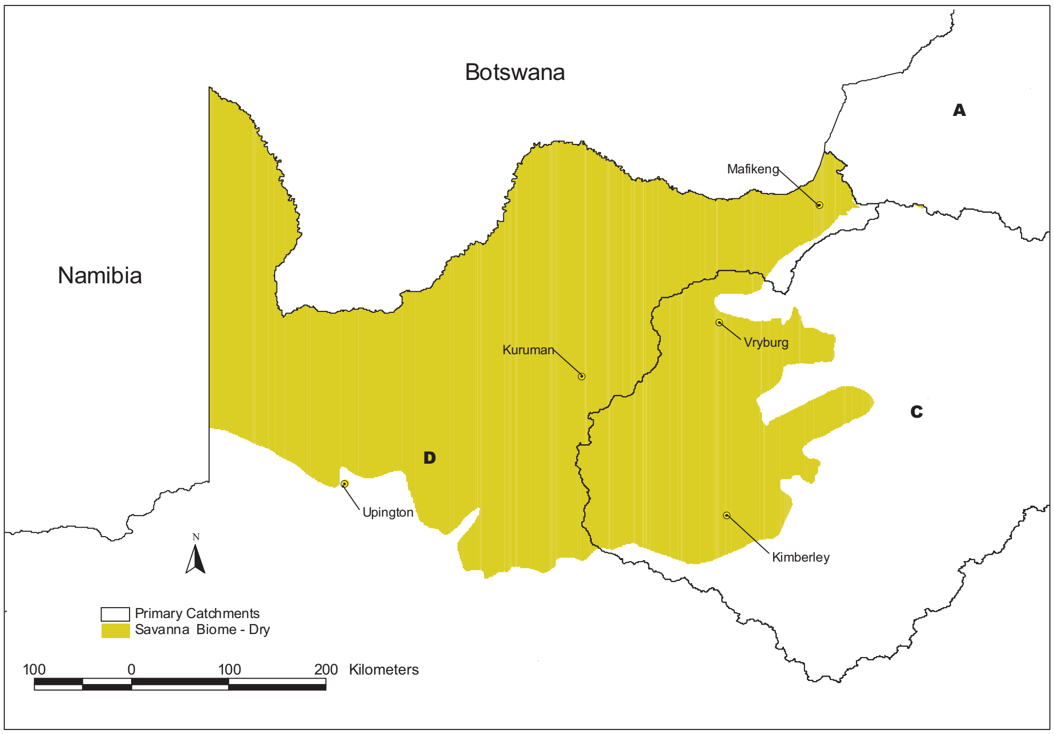

Figure 11. *The correspondence of the arid savanna biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names (see Table 19).*

6.5 Agreed criteria for assessment of primary catchments in the arid savanna biome

Six major criteria were identified as a basis for the prioritization of primary catchments in the arid savanna biome (Table 22). Of these, the criterion relating to the value of the land as a water catchment was subdivided.

The value of the land for water production was ranked by a group of the experts, based on the relative mean annual rainfall in the primary catchment. Water stress was defined as the difference between water availability and requirements for the year 2000 (van Wilgen *et al.* 2007). Primary catchments with a higher degree of water stress were given a higher priority.

The value of the land in terms of conservation importance was estimated using the same source of data on protected areas and conservation priorities, and the same methods, as the fynbos biome.

The relative value of the land for livestock production was estimated in the same way as for the grassland biome.

Primary catchments were compared with respect to the extent to which they are currently invaded by priority invasive alien plants by calculating a priority score in the same way as for the fynbos biome. In the case of moist savannas, the five taxa of highest priority that were used to calculate the score were mesquite (*Prosopis glandulosa*), poplar (*Populus canescens*), Peruvian pepper (*Schinus molle*), queen-of-the-night cactus (*Cereus jamacara*) and syringa (*Melia azedarach*).

Primary catchments were compared with regard to the presence or absence of poverty nodes in the same way as was done for grassland catchments.

The capacity to hold onto gains realised after initial clearing of alien plants was assessed in the same way as for grasslands.

Table 22. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the arid savanna biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Value of the land for water production	24.2	Water production area	3.0
		Water stressed area	21.2
Value of the land in terms of conservation importance	6.3	None	6.3
Value of the land for livestock production	8.2	None	8.2
Presence of priority invasive alien plants	20.6	None	20.6
Presence of priority poverty nodes	3.3	None	3.3
Capacity to hold onto gains realised after initial clearing.	37.4	None	37.4
Totals	**100**		**100**

6.6 Prioritization of primary catchments in the arid savanna biome

Only two primary catchments occurred in the arid savanna biome, and our approach did not identify any significant factors that would separate these catchments (Table 23). As a result, both primary catchments are approximately equal in priority (Figure 12).

Figure 12. *The relative importance and final ranking of primary catchments in the arid savanna biome.*

***Table 23.** Values used for different criteria in the comparison of primary catchments in the arid savanna biome.*

Criterion	**Primary catchment**	
	C	**D**
Value of the land for water production – runoff volumes (millions of m^3/yr)	4567	7147
Value of water – relative degree of stress	75	25
Area of priority conservation importance (km^2)	213	1016
Value of land for livestock production (estimated livestock units x 1000)	145	90
Presence of priority species (lumped present and future – make note in report)	4561	5934
Number of rural poverty nodes	0	1
Relative capacity to hold onto gains	1	1

7. Succulent and Nama karoo biomes

7.1 General approach

The initial plan was to consider the succulent and Nama karoo biomes as a single biome and the initial selection of species was based on this classification. At the workshop the experts disagreed and the final solution was: (a) to regard the species as common to both biomes, as they are all important invaders in both biomes and (b) to weight the primary catchments within each biome separately because impacts on biodiversity are a major issue in the Little Karoo where grazing is relatively unimportant, and grazing is very important and biodiversity less so in the Nama karoo. The transitional shrublands between succulent karoo and fynbos (i.e. thicket and renosterveld) were considered to be part of the succulent karoo for this analysis because they share some of the major invasive alien plants and they are closely intermingled. Pine species were identified as invaders of the succulent karoo but their invasions are almost entirely confined to the transitional shrublands.

7.2 Species selected in the karoo biomes

We initially identified 12 species as posing a present or future threat to the succulent and Nama karoo biomes, including six tree species, three shrubs, a cactus and a grass species. This list was discussed with the experts and the final set that was selected is given in Table 24. The species that were removed from the original list included *Acacia cyclops*, *A. longifolia* and *A. saligna* which were removed because they are only invasive in a limited area of either biome and are under biocontrol. *Agave americana* is not considered an aggressive invader nor is *Atriplex lindleyi* which is primarily an indicator of degraded areas and not an aggressive invader of karoo veld in good condition. Seven other species also were excluded because they are considered relatively minor problems in these biomes. The cacti added to the list were grouped and divided into those with and without effective biocontrol because both groups are widespread and still cause problems to farmers, even though some are under biocontrol and thus are less of a threat. The species in the two groups of cacti in Table 24 are:

- Under biocontrol: *Opuntia imbricata, O. ficus-indica, O. humifusa, O. stricta, O. engelmannii and O. lindheimerii* (but not their hybrid); *Harrisia martini, Cereus jamacaru* (both forms)

- Ineffective biocontrol: *O. humifusa* with the incorrect agent biotype. This combination was included in the group with no control.

- No biocontrol: *Opuntia macrodasys, Echinopsis spachiana, O. leptocaulis, O. robusta x lindheimerii* hybrid, *Opuntia* sp. (possibly *humifusa x engelmannii*), *Tephrocactus articularis, Hylocereus* sp., *Cylindropuntia* sp.

Other species that were added included *Caesalpinia gilliesii*, annual grasses (e.g. *Bromus, Hordeum* and *Stipa* species), *Pennisetum setaceum, Xanthum spinosum* and the aquatic species *Myriophyllum spicatum.* The *Caesalpinia* and *Myriophyllum* species have recently been identified as emerging invaders, the latter probably being widespread but largely unnoticed until recently (Debbie Sharp, personal communication).

Table 24. *The 18 invasive alien plant taxa selected for prioritization in the Nama and succulent karoo biomes. Some taxa include several species.*

Species	**Life Form**	**Nama or succulent karoo (Fynbos transition)**	**Current or future threat?**
Arundo donax (giant reed)	Tall reed	Both (Yes)	Both
Annual grasses	Annual grass	Succulent (Yes)	Both
Atriplex nummularia (old man saltbush)	Erect multi-stemmed shrub	Succulent	Both
Cacti with effective bio-control agents	Spiny and un-armed succulent shrubs	Both	Both
Cacti without effective bio-control agents	Spiny and un-armed succulent shrubs	Both	Both
Caesalpinia gilliesii (bird-of- paradise bush)	Large shrub	Nama	Future
Casuarina equisetifolia (beefwood)	Tall evergreen tree	Both (Yes)	Both
Eucalyptus camaldulensis (red river gum)	Tall evergreen tree	Both (Yes)	Both
Myriophyllum spicatum (spiked water-milfoil)	Rooted submerged water plant	Both	Both
Nerium oleander (oleander)	Multi-stemmed evergreen shrub	Succulent (Yes)	Both
Pennisetum setaceum (fountain grass)	Tufted perennial grass	Both (Yes)	Future
Pinus halepensis (Aleppo pine)	Tall evergreen coniferous tree	Nama (Yes)	Future
Populus x canescens (grey poplar)	Tall deciduous tree	Both (Yes)	Both
Prosopis x glandulosa (mesquite)	Multi-stemmed small tree	Both	Both
Schinus molle (pepper tree)	Evergreen tree	Both	Both
Solanum elaeagnifolium (Satan's bush)	Herbaceous shrublet with annual stems and perennial roots	Nama	Both
Tamarix ramosissima (pink tamarisk)	Small evergreen tree	Both (Yes)	Both
Xanthium spinosum (boetebos)	Much branched annual	Both	Both

7.3 Agreed criteria for the assessment of species

Four major groups of impacts associated with invasive alien plants were identified: ecosystem services, species richness (surrogate for biodiversity), agricultural financial viability and fire hazard. Impacts on ecosystem services were grouped into four categories: groundwater and surface water resources, riparian zones, natural pasture (browsing and grazing) and soil stability. The fourth criterion addressed the impact of removal of invasive alien plants in terms of a *lack* of benefits in cases where the invasive plant has some use (Table 25). We did this because the simplest way to deal with known benefits (e.g. nectar from *Eucalyptus*) was to treat these beneficial attributes as offsets against the impacts. For example, if two species had the same scores for all the other impacts, but one species had value for fodder, then the species which produced fodder would be given a lower score because its net impact is less than the species with no fodder value.

***Table 25**. Criteria and nested sub-criteria used in assessing the significance of the impacts of invasive alien plant species in the Nama and succulent karoo biomes on the integrity of karoo ecosystems. The relative weightings are given for each criterion and sub-criterion based on pairwise comparisons.*

Criterion	Weighting assigned (%)	Sub-criterion	Weighting assigned (%)
Impacts on ecosystem services	57.0	Impact on ground water	22.4
		Impact on surface water	12.5
		Impact on riparian zones	9.9
		Displacement of natural pasture	7.1
		Impact on soil stability	5.1
Impact on species richness	24.1		24.1
Impact on agricultural financial viability	12.4	Lack of fodder, firewood and other products	3.1
		Negative impact on livestock and game	9.3
Increased fire hazard	6.5		6.5
Totals	100		100

The impact on ecosystem services was considered to be the most important and was given a weight of 55% in the pairwise comparisons. Within the ecosystem services, by far the greatest weight was given to impacts on groundwater (22.4%) which reflects the importance of groundwater for humans, livestock and crops in these dry biomes, especially the Nama karoo. Impacts on groundwater were assessed using the plant size, root spread and root depth, and the impact of reduced soil moisture on groundwater recharge. The next highest weight was given to impacts on surface water resources which are confined to springs and perennial river systems. The ranking of species impacts on water resources was based on plant size and growth form in line with the biomass model (Le Maitre *et al*. 1996). Water resources were considered critical because they are essential for all economic activity in the karoo, both for sustaining livestock and for irrigation of crops because it is generally too dry for dryland crops. Climate change is expected to result in a decrease in rainfall which will exacerbate the effects of invasive plants with high water use.

The displacement of native pasture species by invading plants, especially those that form dense stands or are thorny and hinder access by livestock was considered the next most important at 7% followed by the impact of soil stability, both in dryland areas and by species that invade floodplains and river banks (e.g. poplars and *Arundo*), with 5%. Extensive grazing of livestock is the major agricultural activity, particularly in the Nama karoo, and species which displace natural pasture (e.g. *Prosopis, Opuntia*) are considered significant threats (Harding and Bate 1991; Henderson 1991; Poynton 1988). The cacti are considered particularly aggressive because they are able to invade pastures in good condition. Soil stability was identified as an issue because several species tend to destabilize soil both before and after clearing by displacing ground layer vegetation and creating water repellent soils (see Scott *et al*. 1998 for detailed descriptions of water repellency).

The impact of invasions on species richness was rated as the next-most important category with a weight of 24%. The most important factor here was how aggressive the species is and how effectively it replaces native species, transforms the habitat, hinders recovery (e.g. salt bush salinizes soils and slows recovery) and whether or not the species tends to grow in more species rich habitats or vegetation types within the biomes. It is likely that *Arundo* has significant impacts on aquatic systems, including reducing water quality and displacing amphibians and invertebrates. Indigenous birds that use *Phragmites* tend not to use *Arundo*. *Nerium* reduces riverine biodiversity both on the river banks and in the aquatic environment. Recovery after clearing is also very poor once *Nerium* has formed dense stands. *Myriophyllum* invades all water bodies, including oligotrophic water and vleis, and is dispersed by water birds. It shades out all other aquatic life and excludes fish species by forming a physical barrier.

Impacts on the financial viability of agriculture were considered the next most important and were divided into two groups: impacts on fodder and impacts on livestock and game. The most important was the loss of fodder from natural pasture. This is a function of both the extent of invasions and the density of the stands in invaded areas and, thus, the hindrance to access by livestock. A number of species have additional negative impacts on livestock and game animals because they are poisonous, produce seeds which form tangles in wool or have thorns which impede animal movement and damage their hides. Species which from dense stands or hinder access also reduce the value of the area for commercial meat and trophy hunting. The benefits of species as which provide fodder (e.g. *Prosopis*) or other products were offset against the negative effects in the pairwise comparisons.

The final factor was the impact of invasions on fire regimes. The occurrence of fires is likely to increase following invasions of grasses, both annuals and perennial species such as *Pennisetum.* These species are particularly problematic in the succulent karoo because they are highly flammable and the resulting fires can have a devastating impact on the succulent flora (Forrester 1988; Richardson *et al*. 2000; Milton 2004). Similar invasions of arid environments by *Bromus* species have transformed millions of hectares of desert shrublands in North America (D'Antonio and Vitousek 1992). *Arundo donax* is also highly flammable and its high biomass can lead to intense fires which kill native species growing in or near to *Arundo* stands and can facilitate soil and river bank erosion.

7.4 Prioritization of species for the two karoo biomes

The final species ranking shows that *Prosopis glandulosa* was given the highest weight (11%), followed by *Eucalyptus camaldulensis*, *Populus canescens* and *Arundo donax* (Figure 13). *Prosopis* was ranked highly because of its impact on both water resources and natural pastures while the other three species all have a significant impact on water resources. Although *Myriophyllum* only invades water bodies, it was given a substantial weight because it affects water quality and has a significant impact on aquatic biodiversity. The importance of biocontrol for reducing the threat posed by invasive cacti is reflected in the much greater weight given to species without biocontrol. The lowest ranked species were shrubs whose main impact is on natural grazing and, potentially, on livestock. *Pennisetum* was given a relatively low weight because it has little impact on water resources and is largely confined to road verges at present. If, however, it begins to invade water courses more widely, it could have impacts on the riparian ecosystems which are key habitats for fauna (Dean and Milton 1999).

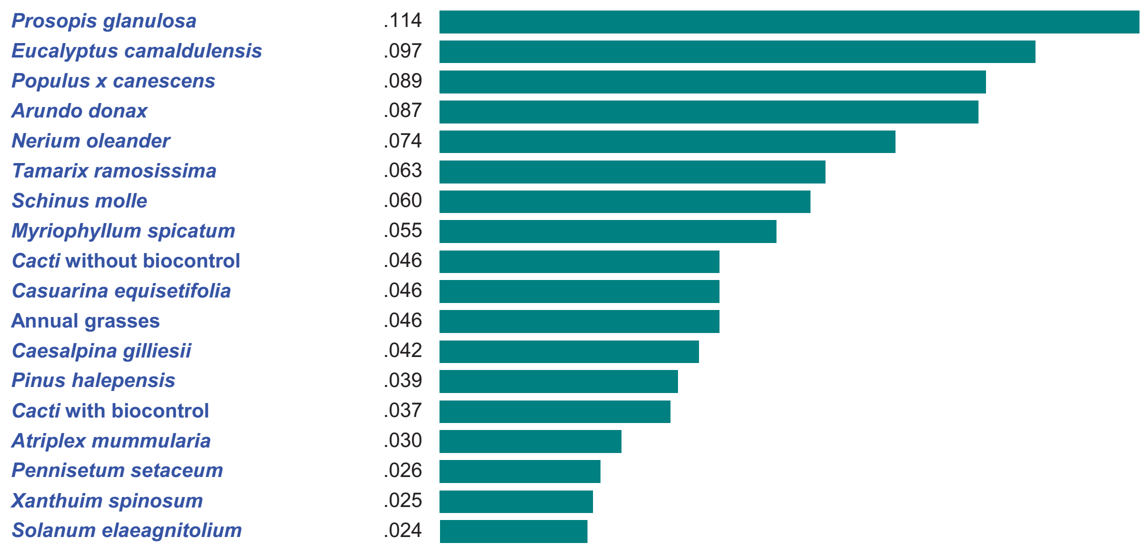

Figure 13*. The relative importance and final ranking of invasive alien plant species in the Nama and succulent karoo biomes*

7.5 Primary catchments selected in the succulent karoo biome

The succulent karoo biome as mapped by Low and Rebelo (1996) includes parts of primary catchments D (Orange), E (Namaqualand), H (Breede), J (Gouritz) (Figure 14). The Breede River catchment was excluded because it is primarily a fynbos catchment and is dealt with in the section on fynbos. Likewise, primary catchment D is almost entirely in the Nama karoo and is dealt with later in this report. A more recent and detailed vegetation map (Mucina and Rutherford 2006) shows that the succulent karoo biome extends eastwards into primary catchment L (Gamtoos). After discussion the Gamtoos catchment was left out because the experts did not know the succulent karoo portion of the catchment well enough to be able to asses the impacts of invaders. The final set was, therefore, restricted to those in Table 26.

Table 26. *The three primary catchments used as a basis for the prioritization of areas for the control of invasive alien plant species in the succulent karoo biome.*

Primary catchment designation	**Primary catchment name**
E	Namaqualand
F	Olifants and Doring
J	Gouritz

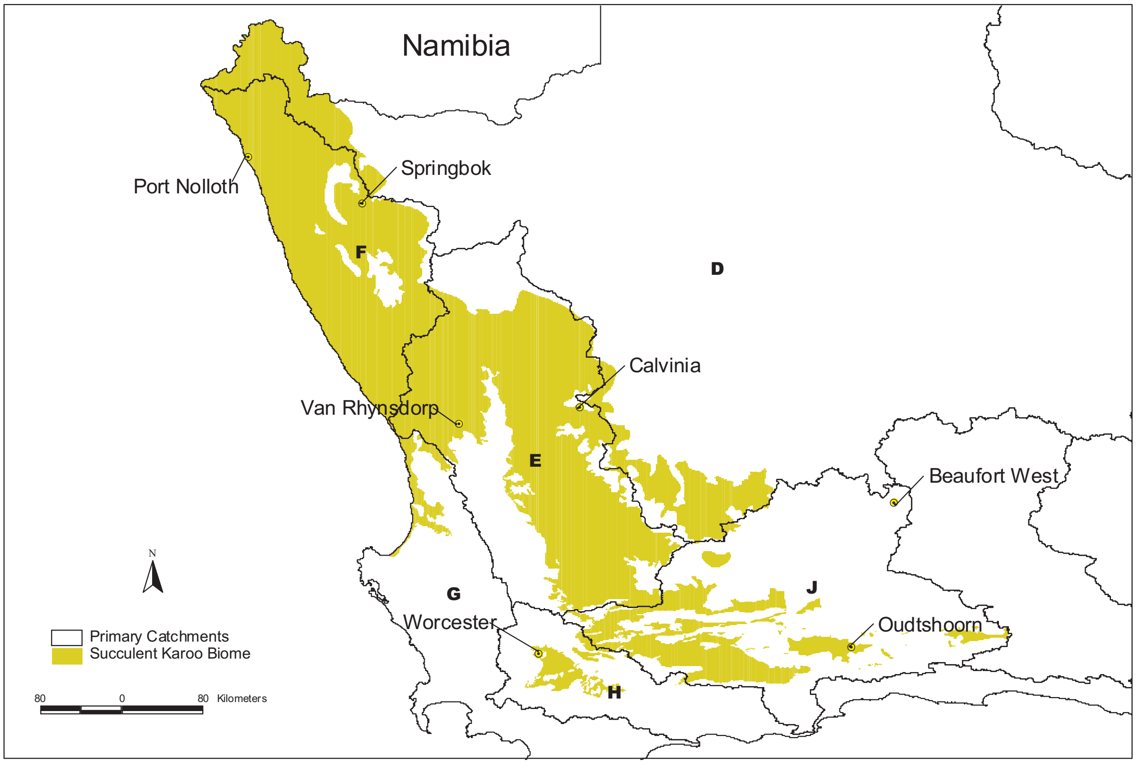

Figure 14. . *The correspondence of the succulent karoo biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names (see Table 26).*

7.6 Agreed criteria for the assessment of primary catchments in the succulent karoo biome

The most important criterion in the weighting of the primary catchments was the estimated impact of the invading species on water resources (55%, Table 27). In the succulent karoo the surface waters and their associated ecosystems are considered more important (26.5%) than the groundwater systems (13.9%) because they are more species rich and more severely threatened by invasive alien species. The freshwater systems are also the main source of water for all the towns and rural settlements. Irrigation farming depends primarily on freshwater from dams but there is a large groundwater scheme which supplies water to irrigation farmers in the Oudtshoorn-Calitzdorp area. Brak water systems are also considered to be threatened by reductions in the freshwater inflows because the freshwater probably kept the salinity levels in these reaches lower in the past.

The riparian ecosystems are also considered to be the most threatened ecosystems in the biome, partly because they are also threatened by the abstraction of freshwater for irrigation and for human and industrial use. Current and future impacts were considered to be of equal importance (Table 27) but future opportunities for employment were considered far more important than current jobs, because clearing had the potential to free up water for future economic development.

Table 27. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the succulent karoo biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Retain integrity of the water resource	55.0	Retain fresh surface water systems	26.5
		Retain brak water systems	6.2
		Retain ground water systems	13.9
		Protect biodiversity	8.4
Presence of priority invasive alien plants	21.0	Current impact	10.5
		Potential impact	10.5
Maximise socio-economic benefits	24.0	Short term job creation	6.0
		Opportunities for future jobs	18.0
Totals	**100**		**100**

7.7 Prioritization of primary catchments in the succulent karoo biome

The Gouritz catchment has the greatest annual runoff of the three primary catchments and is also considered the most heavily invaded and so was given the greatest weight in the analysis (Figure 15). The Namaqualand catchments were considered the least threatened both because they are the least invaded and partly because they produce very little runoff. Groundwater resources are very limited and important in northern Namaqualand and should be considered in finer scales prioritisation studies. *Prosopis* species are rapidly invading Tanqua karoo and other parts of the Doring River system and should be given a high priority at the scale of that catchment.

Figure 15. *The relative importance and final ranking of primary catchments in the succulent karoo biome.*

7.8 Primary catchments selected in the Nama karoo biome

Primary catchment D which includes the middle and lower Orange River catchment was considered too biogeographically heterogeneous to be assessed as a single catchment and was divided into an eastern (D2, wetter) and a western portion (D1, drier). The Nama karoo occupies a relatively small proportion of primary catchment C (Figure 16; Vaal River) which falls largely in the grassland and savanna biomes so it was excluded from the analysis. Primary catchment Q (Sundays River) falls largely in the thicket biome which is included in the savanna biome in this study. The final set was, therefore, the two parts of primary catchment D and primary catchments J, L and N (Table 28, Figure 16).

Table 28. *The five primary catchments used as a basis for the prioritization of areas for the control of invasive alien plant species in the Nama karoo biome.*

Primary catchment designation	**Primary catchment name**
D1	Orange (Ongers, Brak and Seekoei rivers)
D2	Orange (Sak and Hartebees rivers)
J	Gouritz
L	Gamtoos
N	Sundays

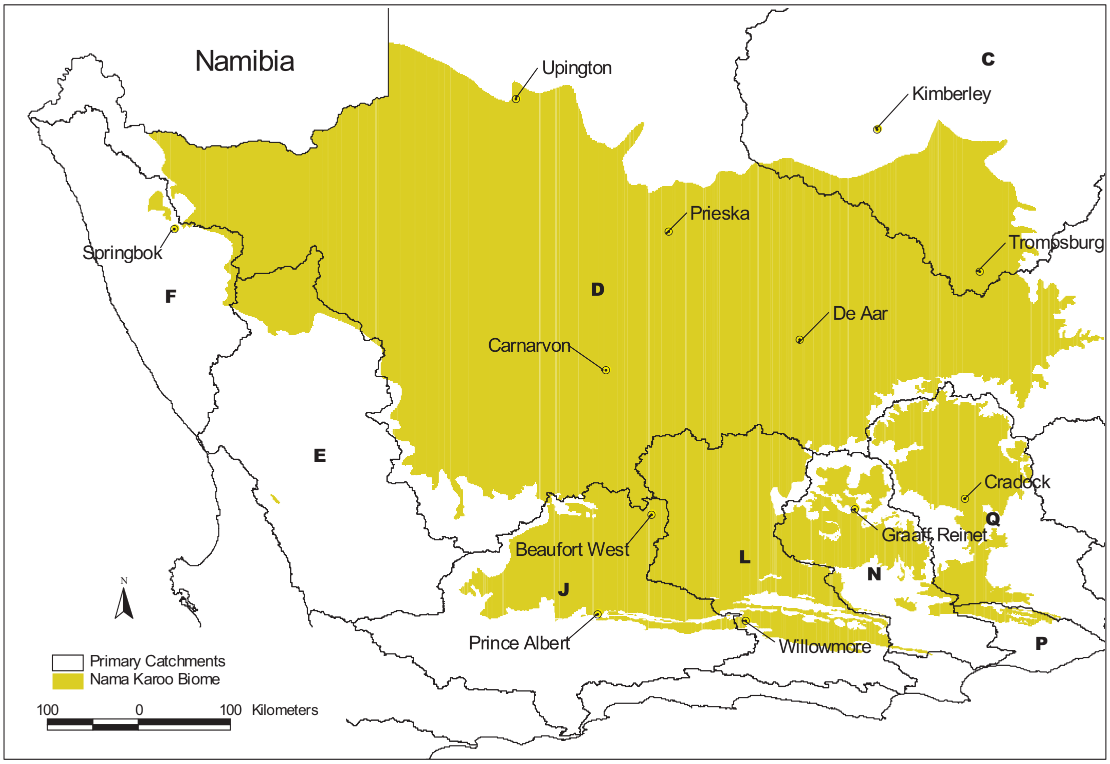

Figure 16. *The correspondence of the Nama karoo biome (shaded) with primary catchment boundaries. Letters indicate primary catchment names (see Table 28).*

7.9 Agreed criteria for the assessment of primary catchments in the Nama karoo biome

The reaches of the Orange River itself were grouped with the tributaries: D2 from Kakamas to about Bethulie in the southern Free State and D1 from Kakamas to the river mouth. The eastern section (D1) includes the Upington area with its extensive areas of irrigated agriculture. The area also has the highest potential for jobs which influenced the weighting given to this sub-catchment for socio-economic benefits (Table 29). The greatest weight was given to the protection of water resources (45.9%), with groundwater getting more than half the weight of the sub-criteria (24.8%). This is because groundwater is critical for the grazing industry which is the main agricultural practice in terms of the area that is farmed. Groundwater is also very important for most towns and the only water source for many of them. The high impact invasive alien plants mainly invade the productive river systems, adding to the weight given to water resources. The Nama karoo has a relatively low number (and proportion) of threatened species compared with other biomes, so biodiversity was given a relatively low weight (7.5% Table 29). Its value for natural grazing is much higher than the succulent karoo so maintenance of agricultural potential was weighted separately and given a high weight. The Nama karoo has been heavily invaded by *Prosopis* species but there are many areas which are at risk of invasion and where densities are still low and could increase significantly. The potential for greater future impacts was, therefore, given a high weight and control operations should be prioritized to deal with these areas. Future job opportunities were weighted more than current ones provided that Working for Water is able to adequately train their contractors and establish them in viable businesses. This is not really the case at present.

Table 29. *Nested criteria identified as significant for the purposes of prioritizing primary catchments in the Nama karoo biome with regard to focusing scarce resources so as to obtain maximum benefit. Higher-level criteria are divided into sub-criteria, and the relative weightings are given for each.*

Criterion	**Weighting assigned (%)**	**Sub-criterion**	**Weighting assigned (%)**
Retain integrity of the water resource and biodiversity	45.9	Retain permanent and seasonal surface water	13.7
		Retain ground water systems	24.8
		Protect biodiversity	7.5
Maintain agricultural potential in drylands	17.1	None	17.1
Presence of priority invasive alien plants	22.6	Current impact	5.6
		Potential impact	16.9
Maximise socio-economic benefits	14.4	Short term job creation	4.8
		Opportunities for future jobs	9.6
Totals	**100**		**100**

7.10 Prioritization of primary catchments in the Nama karoo biome

Catchment D2 has more rainfall and runoff than catchment D1 and is considered more threatened by invaders such as *Prosopis* species because the moister environment increases the likelihood of seedling recruitment (Figure 17). Invading plants therefore have the potential to spread and increase in density more rapidly, increasing the threats to water resources, agricultural potential and socio-economic benefits. Catchment D2 also has the greatest potential for employment so it was given the greatest weight. Both sub-catchments of primary catchment D were considered more threatened by invaders than the Nama karoo portions of the other catchments and, thus, were given the highest weights. The other three primary catchments were more or less equal in terms of the threats posed by invading species. The Nama karoo portion of primary catchment J has the lowest runoff and grazing potential and so received the lowest weight with the other two primary catchments falling in between.

Figure 17. *The relative importance and final ranking of primary catchments in the Nama karoo biome.*

In summary, the highest ranked invasive alien plants across both biomes are tree species (*Prosopis, Eucalyptus, Populus*) except for *Arundo* which probably also uses about as much water as the trees (Figure 13). The next three species are also larger shrubs or trees. This is due largely to their impacts on both surface and groundwater resources and their tendency to invade riparian zones which are productive parts of the landscape and support highly threatened aquatic ecosystems (Nel *et al*. 2007). The threats posed by *Prosopis* were weighted as being much greater than the benefits it currently provides. Within the succulent karoo the greatest weight was given to the Gouritz River catchment (J) followed by the Olifants-Doring (E). Within the Nama karoo the greatest weight was given to the middle Orange River system (upstream of Kakamas) largely because of the relatively high runoff and the degree of threat posed by highly aggressive invading species, notably *Prosopis*. The two biomes differed with more weight being given to biodiversity in the Little Karoo and more to agricultural potential in the Nama karoo. More weight was given to surface water and freshwater systems in the Little Karoo and more to groundwater in the Nama karoo because agriculture and rural settlements depend more heavily on groundwater in the Nama karoo.

8. Conclusions and recommendations

8.1 Current budget allocations according to identified priorities

We obtained data on the budget allocations for projects in the Working for Water programme for the financial year 2007/08 from Mr Andrew Wannenberg. The data included an annual budget and the geographic co-ordinates of each project. We overlayed these data on the biome and primary catchment data layers to derive information on the budgets allocated to biomes within primary catchments.

Current expenditure of the Working for Water programme in the fynbos biome is essentially in line with the priorities identified here (Figure 18). If anything, spending could be increased in primary catchment H (Breede River, priority 15.2%, and budget R9.3 million), and decreased in primary catchment K (Garden Route, priority 12.5%, budget 21.5 million).

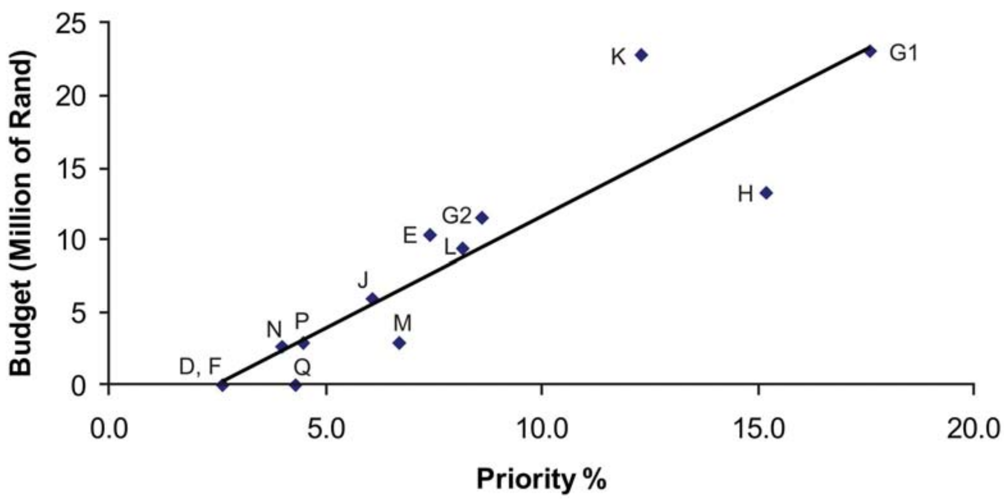

***Figure 18.** Annual budgets of Working for Water in 13 primary catchments in the fynbos biome in relation to priorities identified in this study. Note that primary catchment G is spilt into two parts: G1= rivers flowing to the north and west and G2 =rivers flowing to the south and east (see Figure 2).*

Current expenditure of the Working for Water programme in the grassland biome indicate that the amounts budgeted for each primary catchment are in line with the priorities identified here (Figure 19), with two exceptions. The Umzimvubu catchment (primary catchment T) receives a budget of R9.6 million, and has a priority of 10.4%, indicating that too much funding is going into this particular catchment. On the other hand, the Inkomati catchment (primary catchment X) receives only R1.3 million, despite a priority of 14.1%, indicating that more funding would be appropriate in this area.

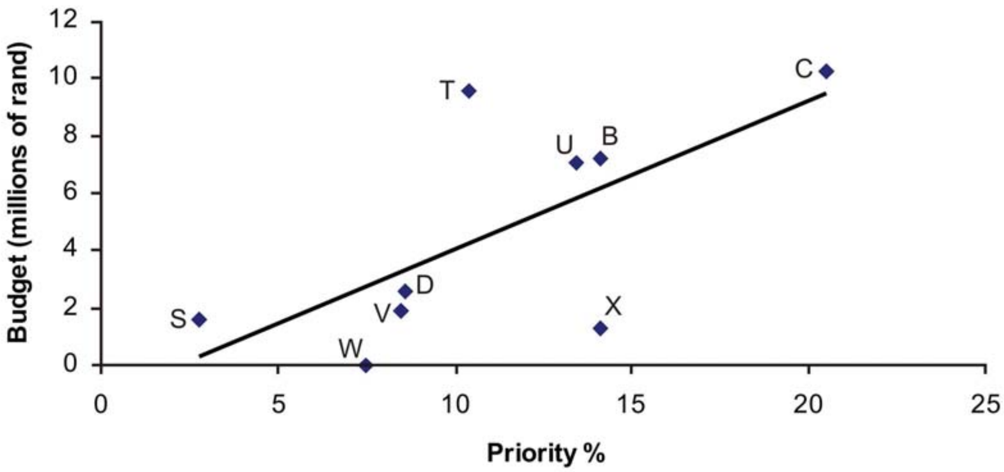

Figure 19. *Annual budgets of Working for Water in nine primary catchments in the grassland biome in relation to priorities identified in this study.*

Current expenditure of the Working for Water programme in the moist savanna biome indicate that the amounts budgeted for each primary catchment are not always in line with the priorities identified here (Figure 20). The Limpopo catchment (primary catchment A) receives a budget of R21.5 million, and has a priority of 13.8%, indicating a significant over-allocation of funds to this catchment. On the other hand, the Umgeni catchment (primary catchment U) receives only R2.8 million, despite a priority of 21.6%, indicating that significantly more funding would be appropriate in this catchment.

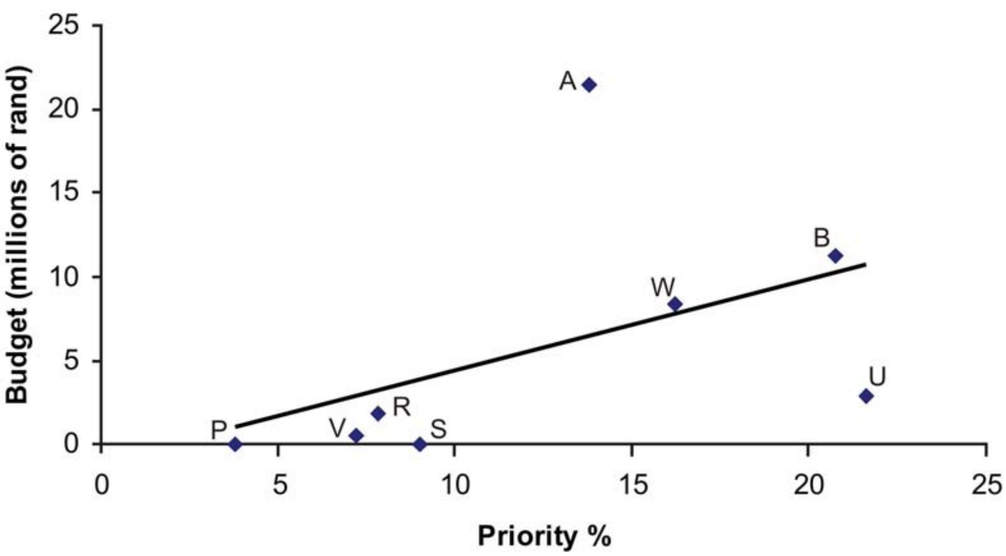

Figure 20. *Annual budgets of the Working for Water in eight primary catchments in the moist savanna biome in relation to priorities identified in this study.*

The only two primary catchments in the arid savanna biome were allocated the same level of priority. These two catchments also receive similar annual budgets (Figure 21), indicating that budget allocations are appropriate.

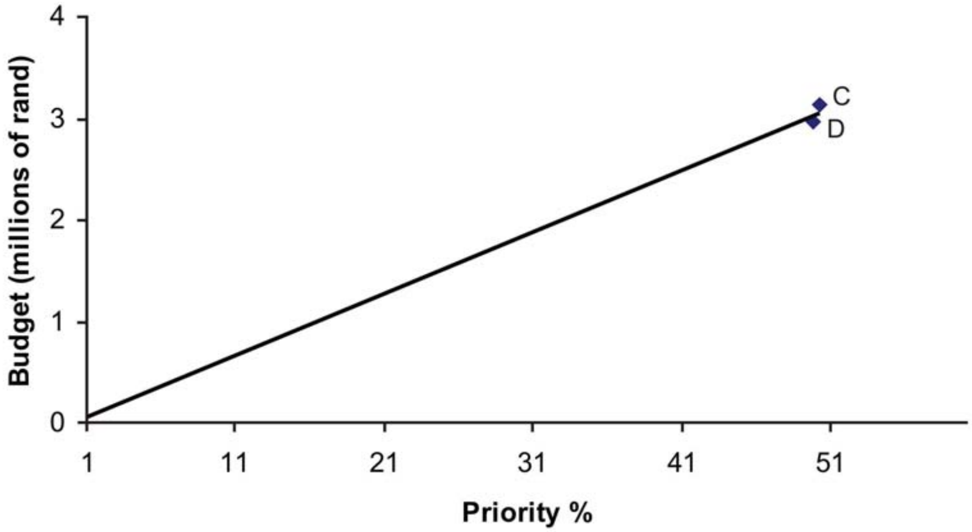

***Figure 21**. Annual budgets of the Working for Water in two primary catchments in the arid savanna biome in relation to priorities identified in this study.*

Currently, the Working for Water programme only allocates funding to one of the three primary catchments in the succulent karoo biome (Figure 22). The fact that the programme appears to be totally inactive in the highest-priority catchment (primary catchment J, Gouritz) suggests that and appropriate portion of the available funds should be re-allocated to that catchment.

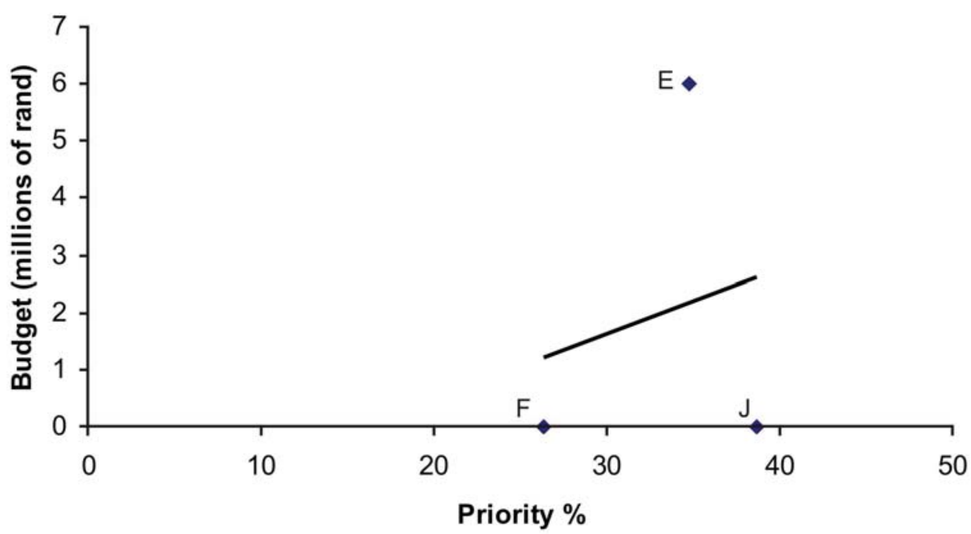

***Figure 22.** Annual budgets of the Working for Water in three primary catchments in the succulent karoo biome in relation to priorities identified in this study.*

Current expenditure of the Working for Water programme in the Nama karoo is essentially in line with the priorities identified here (Figure 23). However, it does appear that funds may have been over-allocated to primary catchment J (the Gouritz), which has an annual budget of 1.9 million, but has the lowest priority (9.9%).

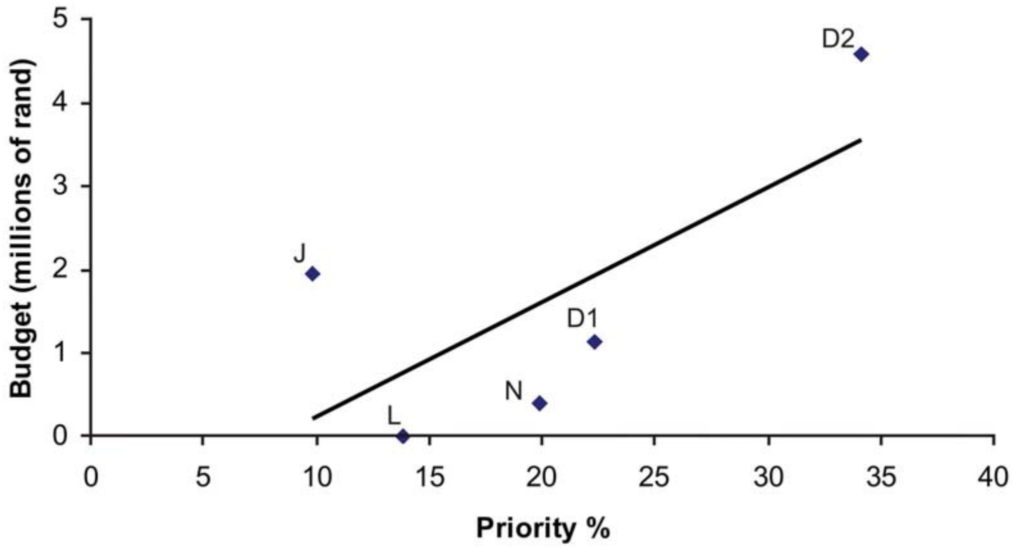

Figure 23. *Annual budgets of the Working for Water in five primary catchments in the Nama karoo biome in relation to priorities identified in this study. Note that primary catchment D is spilt into two parts: D1= Ongers, Brak and Seekoei rivers and D2 = Sak and Hartebees rivers (see Section 7.8).*

8.2 Approaches adopted

This study has used different groups of experts in the different biomes to identify criteria for prioritization. As a result, the approach used in different biomes is not uniform. In some cases, the groups used expert opinion or local understanding to inform comparisons, and in other biomes we used data where they were available. The time available for this project did not allow us to finalise a uniform approach for all biomes. The use of data-informed comparisons (such as those done for the savanna and grassland biomes, see Tables 12 and 18) would probably produce more robust prioritizations if they were applied uniformly across biomes. On the other hand, our approach of consulting different expert groups independently has produced a richer range of criteria than may otherwise have been the case. We stress that the most important outcome of this exercise has been the development and testing of a methodology, rather than the results themselves. We conclude that the use of the Analytic Hierarchy Process (AHP) holds a great deal of promise for use in the prioritization of Working for Water's activities, and consequently for the more effective and efficient investment of its funds and the achievement of its overall goals.

8.3 Recommendations

This study has been successful in developing a preliminary approach to the prioritization of both species and areas for control operations. However, a number of follow-up actions will be needed if this approach is to deliver its full potential in terms of helping the Working for Water programme to improve its operations and its impact. With this in mind, we recommend the following:

That the use of AHP be adopted by Working for Water's planning office to assist with prioritization, planning, and the allocation of resources to projects;

That the criteria identified here by the different working groups be consolidated, so that a uniform approach to prioritization can be taken across the organization as a whole;

That a spatial database be developed to underpin effective comparisons of areas. This database could contain data relating to many of the criteria identified here, including mean annual runoff, the locality of important groundwater aquifers, the degree of water stress, conserved areas, areas of threatened or critically threatened conservation importance, livestock production potential, the distribution of invasive alien species, land ownership, and the location of poverty nodes.

That a workshop (or presentation) be held involving senior managers in the Working for Water programme, with a view to (i) raising awareness of the study and its implications amongst decision-makers and planners within the programme; (ii) obtaining input regarding its adoption and/or modification, and (iii) agreeing on the process for its possible adoption and implementation.

That the approach be applied at different scales appropriate to different levels of planning. This study has focussed at the level of biomes, with a view to prioritizing scarce resources within each biome. It is clear that further prioritization will be required at different scales. At a national scale, for example, the programme needs to consider the allocation of funds among the biomes themselves, which will require a comparison between biomes rather than within a single biome. Secondly, finer-scale prioritization will be required within the individual catchment areas, for example between quaternary catchments within primary catchments. The programme should consider commissioning work in this regard if the full benefits of this exercise are to be realised.

That this work be published in the peer-reviewed literature. This will have a number of advantages, including (i) ensuring that the work is subjected to rigorous review; (ii) ensuring a permanent and widely-retrievable record of the work; and (iii) enabling the wider dissemination of the approach and results, particularly to other organizations involved in control operations.

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