A SYSTEMATIC SPATIAL PRIORITISATION FOR INVASIVE ALIEN PLANT CONTROL IN SOUTH AFRICA

Andrew Wannenburgh

Dissertation submitted in fulfilment of the requirements for the degree of Master of Science in the Department of Environmental and Geographical Science, University of Cape Town, South Africa.

November 2006

ABSTRACT:

Current funding of the one of the world's largest programmes dealing with invasive alien plant control, South Africa's *Working for Water* (WfW) programme, is insufficient to tackle the problem with equal urgency in all parts of the country. It is therefore faced with the problem of setting priorities for action, and maximising the efficiency of its efforts. In order to determine whether the choices made on where resources are invested to control invasive alien plants in South Africa are valid/defensible, a systematic prioritisation was conducted and compared to the prioritisation in place in WfW. Using weighted linear combination within a spatial multi-criteria decision analysis approach, several criteria of the complementary species and area objectives were combined to identify areas where opportunities to meet individual goals for invasive alien plant control are synergistic. The evaluation criteria chosen for this study were: range, abundance and effect of terrestrial, transformer species; disturbance; terrestrial biodiversity value; river biodiversity value; water resource value and natural agricultural resource value. Annual operational project expenditure was used to represent the WfW prioritisation. At a national scale, a weak positive correlation of 0.274 was obtained between the systematic and WfW prioritisations. The highest correlation between the systematic and WfW prioritisations was for the range criterion (0.796) and the lowest for the disturbance criterion (-0.349). At a regional scale, the correlation between the systematic and WfW prioritisations was highest for the WfW North-West region (0.670) and lowest for the WfW Free State region (-0.016). The conclusion of this study is that a systematic data-driven prioritisation is weakly correlated with the prioritisation in use by WfW. Also, while there has been good targeting of infestations of invasive alien species with clear ecosystem impacts, there is room for improvement in targeting these species in areas where the opportunities to meet individual goals are synergistic, particularly with regard to areas of low disturbance and high conservation or production value. Furthermore, while the WfW North-West region is good at assessing priority, considerable improvement is required in the WfW Free State, Gauteng and KwaZulu-Natal regions.

DECLARATION:

I declare that this dissertation is my own work and has not been submitted in any form to another university. I have used the Harvard convention for citation and referencing. Each contribution to, and quotation in, this thesis from the work(s) of other people has been attributed, and has been cited and referenced.

Signed: .....

KEYWORDS:

Invasive alien plants, prioritisation, GIS, *Working for Water* Programme, spatial multi-criteria decision analysis

ACKNOWLEDGEMENTS:

The Department of Water Affairs & Forestry funded this study through its *Working for Water* Programme. My supervisor, Shirley Butcher, is thanked for useful comments on the drafts.

LIST OF ACRONYMS/ABBREVIATIONS:

DEAT	Department of Environmental Affairs & Tourism
DoA	Department of Agriculture
DPW	Department of Public Works
DWAF	Department of Water Affairs & Forestry
EPWP	Expanded Public Works Programme
GIS	Geographic Information System
MAR	Mean Annual Runoff
MSAccess	Microsoft Access database software
MSExcel	Microsoft Excel spreadsheet software
NWRS	National Water Resource Strategy
R	Rand (South African monetary currency)
RSA	Republic of South Africa
SAPIA	Southern African Plant Invaders Atlas
WfW	The *Working for Water* Programme
WIMS	*Working for Water* Information Management System

TABLE OF CONTENTS:

1. INTRODUCTION

1.1 Background, context & significance

The spread of invasive alien species is now recognised as one of the greatest threats to the ecological and economic well being of the planet. These species are causing enormous damage to biodiversity and the valuable natural agricultural systems upon which we depend (McNeely *et al.*, 2001). Sound management strategies require an objective means for setting priorities, always a highly challenging task. Generally speaking, highest priority should go to infestations that are the fastest growing, most disruptive, and affect the most highly valued areas (Wittenberg & Cock, 2001). In South Africa, one of the strategic interventions identified to ensure good invasive alien species management practices is to ensure that informed prioritisation of all established invasive alien species occurs at national level, and then is adapted accordingly at provincial levels (Macdonald *et al.*, 2004).

South Africa's *Working for Water* (WfW) programme was initiated in 1995 to conduct and co-ordinate alien plant management throughout South Africa. The programme leads alien-plant management initiatives in all natural and semi-natural ecosystems. It has grown into one of the most successful integrated land management programmes in the world and the largest environmental programme on the African continent. The enterprise's success has been attributed to its multi-faceted and cross-disciplinary nature that has enabled it to leverage local and international funding and continuing political support (Van Wilgen *et al.*, 1996; van Wilgen & van Wyk, 1998; Richardson & van Wilgen, 2004; Van Wilgen, 2004; Hobbs, 2004). WfW is the only major response to the problem of invasive alien plants, since the high costs of clearing discourage private efforts and are usually unaffordable in other conservation management budgets of state departments. Nevertheless current funding of the WfW programme is insufficient to tackle the problem with equal urgency in all parts of the country. It is faced with a problem of setting priorities for action, and maximising the efficiency of its efforts (Turpie, 2004).

WfW is a multi-departmental initiative of three core national government departments: Department of Water Affairs & Forestry (DWAF), Department of Environmental Affairs & Tourism (DEAT) and Department of Agriculture (DoA). The

lead agency and administrative home of WfW is DWAF. WfW's vision is: "A country, and region, in which invasive alien species are controlled or eradicated, and introductions of potentially invasive alien species are prevented, in order to contribute to economic empowerment, social equity and ecological integrity". WfW's mission is: "To contribute to the sustainable prevention and control of invasive alien plants, and thereby the optimising of the conservation and use of natural resources. In doing so, it will address poverty relief and promote economic empowerment and transformation within a public works' framework" (WfW, 2004a).

The WfW programme seeks to contribute to the following long-term goals:

- **Ecological:** To improve the ecological integrity of our natural systems through the prevention and control of invasive alien plants.
- **Hydrological:** To enhance water security through the prevention and control of invasive alien plants.
- **Agricultural:** To help to restore the productive potential of land and water through the prevention and control of invasive alien plants.
- **Socio-economic Empowerment:** To develop and enhance the socio-economic benefits for participants, from preventing and controlling invasive alien plants.
- **Economic Development:** To develop and enhance the economic development benefits from preventing and controlling invasive alien plants.
- **Institutional Development:** To build an effective and efficient organization that optimizes co-operative government, partnerships, transformation, staff development and learning. (WfW, 2004a).

Currently, the programme receives 88% of its R400 million/annum revenue from the Expanded Public Works Programme and the balance (i.e. 12%) from DWAF. The EPWP allocation criteria are that programmes: operate in poorest areas or provinces and particularly in rural areas; enhance capacity building for human development; provide jobs and in doing so, benefit the community; provide for infrastructure in poor areas; have impact on households where single women are main source of income; and be implemented in areas where projects could become sustainable (Eberhard *et al.*, 2003)

The WfW national office then makes an allocation annually to each WfW region, whose boundaries follow DWAF Water Management Areas (see Figure 1.1). A Water Management Area is an area established as a management unit in the National Water Resource Strategy (DWAF, 2004) within which a future catchment management agency will conduct the protection, use, development, conservation, management and control of water resources (RSA ,1998). The boundaries of the 19 water management areas (that is, those boundaries that are not defined by international boundaries or South Africa's coastline) lie mostly along the divides between surface water catchments. The number of water management areas and the location of their boundaries were determined by considering factors such as: the institutional efficiency of creating a large number of catchment management agencies (each managing a relatively small area, compared with a small number of agencies, each managing a larger area); the potential for a catchment management agency to become financially self-sufficient from water use charges; the location of centres of economic activity; social development patterns; the location of centres of water-related expertise from which the agency may source assistance; and the distribution of water resources infrastructure.

The WfW planning guidelines (WfW, 2001b) state that each WfW region is required to compile a regional strategic plan that covers the whole region and provides the framework within which all operations should take place. It is to be drawn up in a consultative process with all relevant stakeholders in the region (government, NGO, community groups, environmental groups, etc.) and reviewed from time to time. **Quaternary catchment** boundaries are to be used as the basis for project boundaries. This basic unit of area resolution was used in the WR90 series of reports published by the Water Resource Commission (Midgley *et al.*, 1994). The primary drainage regions are divided into secondary, tertiary and quaternary catchments. The quaternary catchments have been created to have similar mean annual runoffs: the greater the runoff volume the smaller the catchment area and vice versa (DWAF, 2002). The WfW Regional Strategic Planning Process guidelines (WfW, 2002) listed the following criteria that would need to be considered when defining the spatial side of the regional strategic plan: poverty nodes, water stressed catchments, areas of great biological importance (e.g. conservation areas), targeted invasive species, extent of invasion, type of invasion, rate of invasion of particular species (e.g. *Chromoleana odorata*), where the programme will make the greatest

impact at the least cost (cost-benefit) and where WfW can work on its existing partnerships.

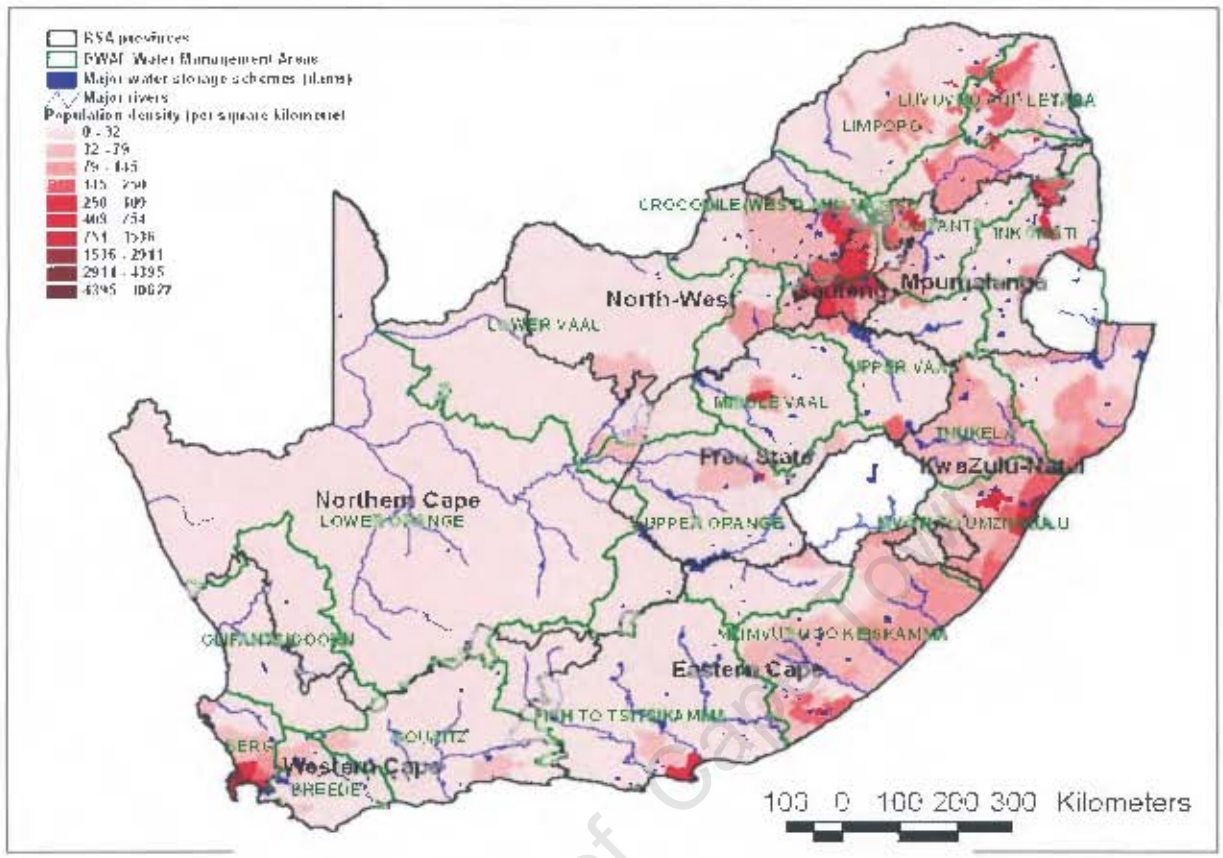

Figure 1.1 RSA provinces, DWAF Water Management Areas, major water storage schemes (dams), major rivers & population density (per 2001 census district) of South Africa

1.2 Motivation & justification

Although major advances have been made in the science of invasion ecology, much less progress is being made in improving our ability to manage invasions. WfW should be informed by advances in invasion ecology in order to maximise efficiency in terms of prediction and priority. What is needed is a concerted effort from practitioners in all specialities, to "connect the dots" in their research endeavours, and to link the disciplinary boxes in science and management, if the global threat of invasive plants is to be effectively countered (Hulme, 2003; Richardson *et al.*, 2004; Richardson, 2004).

In 1997, an external evaluation of the WfW programme commissioned by the European Union found that the separation of leadership and management was a source of concern because of the manner in which it influenced prioritisation of

projects and because it drove expansion of the programme at the expense of strategic planning and baseline data gathering. The programme was unique in the manner in which it set out to simultaneously deliver water benefits, social welfare and environmental restoration, but this complicated programme planning and design. The sources of funds, particularly the start up funding, also moulded planning and design of the programme. Funds drawn from the Reconstruction and Development Programme (RDP) were released against a business plan in the format required by the Department of State Expenditure, which was responsible for allocation of RDP funding. This format did not require that the usual planning process of DWAF be followed. Consequently, pre-feasibility and feasibility studies were not conducted. Once launched the imperatives of "spending the money efficiently, on time and within budget" gave the WfW programme an urgency and impetus in which strategic planning was perceived as a process that would result in delays that would fatally flaw the programme. The process adopted by programme management resulted in minimal start-up time and in a remarkably good stream of social benefits to the rural poor. However, there was widespread concern amongst project managers and implementing agencies with the inadequate level of strategic planning, feasibility assessment and with project prioritisation and initiation (Breen *et al.*, 1997).

Referring to projects, in the same way as with programme planning, the European Union external evaluation found that the imperative of getting projects going took precedence over planning. Thus projects were initiated at locations where management capacity was available and where there was sufficient awareness of invasive alien plant and social welfare needs. Consequences were that projects initiated did not have appropriate data that could be used to assess feasibility or to set measurable attainable goals in respect of water, social welfare and environmental rehabilitation. For instance, in most cases the area to be treated in a particular catchment was not known as it had not been mapped; hydrological studies to determine incremental water benefits had not been carried out; neither costs nor benefits had been quantified annually over a period of 25 years and the technical feasibility and economic viability of any project was not known. The evaluation concluded that it was urgently required to ensure that WfW was cost-effective and defensible (Breen *et al.*, 1997).

In 1998, the *Working for Water* Programme acknowledged the criticisms for not having a coherent strategic plan, and for failing to undertake the research that must underpin such a plan. In defence it contended that it would take years of intense research to understand the extent and consequences of invading alien plants and that the calculation of a return on the investment from working in one area rather than another involved so many variables, that it would not have been possible to put the poverty relief money to work. An admission was made that some projects were initiated for "peace" and others "opportunistically". It was conceded that the programme was aware of these limitations and that mechanisms had been put in place to deal with them (WfW, 1998).

In 2003, an aquatic ecology and hydrology specialist report found that the WfW planning guidelines (WfW, 2001b) made no mention of either information on the presence of aliens or other ecological/hydrological criteria that would be important in order to select one area rather than another (strategic decision-making) rather focussing on criteria used to define their boundaries (Ractliffe *et al.*, 2003). The report argued that the objectives of the WfW programme would not be achieved by simply cutting down trees in randomly selected places, but given the magnitude of the problem, required the appropriate targeting of species and areas. The criteria that were used in clearing selection should reflect the central mandate of the WfW programme. The report further claimed that WfW was failing to use existing data on the extent of the invasive alien plant problem and on strategic areas for clearing and that no spatial information on the strategic priorities of the programme had been synthesized at a national level, for use nationally or to inform regional planning (Ractliffe *et al.*, 2003).

Ractliffe *et al.*, (2003) also reported that there had been frank admittance from WfW national office and regional personnel that projects have too often been selected for a variety of reasons, including political expediency and logistical convenience. Such criteria did not contribute to the mission of the WfW programme (i.e. the control & prevention of invasive alien plants). This was identified as a critical shortcoming of the programme, as it is thereby unable to demonstrate that it has used its funds to the most strategic effect. Because there was no national basis for assessing the validity of selecting one project location over another, this raised questions about the validity/defensibility of the choices made on where resources are invested, both

between regions and within regions in relation to the actual area targeted for clearing. The report concluded that WfW had not been operated by systematically establishing which would be the most strategic areas nationally to target for clearing operations, in relation to the type and characteristics of alien infestation in different parts of the country. The report stressed the importance of national planning both in ensuring that the priorities of WfW are being addressed in the operational activities of the programme, and that they are being addressed efficiently – for example, strategic prioritisation of catchments where multiple goals can be met simultaneously. At a national level this would require information of the sort that will allow for identification of areas where opportunities to meet individual goals are synergistic. Spatial information on aliens, intersected with a range of other indicators, representing the programme goals, would enhance the information available to decision-makers. In relation to any programme evaluation process, national spatial information is crucial for a quantitative assessment of the extent to which the programme is meeting its goals, and an extremely powerful tool for manipulating spatially complex data (Ractliffe *et al.*, 2003).

Also in 2003, a terrestrial ecology specialist report found that no objective prioritisation had taken place at a national level and that in trying to balance the objectives of WfW (i.e. enhanced water security, ecological integrity and social development), the overall goal of WfW (i.e. invasive alien plant control) may have inadvertently received lower priority during strategic planning. The report believed that the role of the WfW national office should be to define overall policy and standards and to provide technical support in the various fields. The report also recommended that the WfW national office set the national priorities for the programme and synthesize information from the regions to check whether these are on target and that regional budgets be adjusted to achieve these national priorities (Holmes *et al.*, 2003).

Also in 2003, an external evaluation of the WfW programme conducted by Common Ground Consulting concluded that for most projects there had been no attempt to provide or collate existing material that defined the broader context in the catchment and resulting priorities for integrated catchment management. A key concern was the adequacy of strategic (operational and geographical) planning for the achievement of the stated purpose, goals and objective (Laros *et al.*, 2003).

In 2004, Turpie maintained that there had not been any prioritisation strategy in place in WfW to ensure that the benefits of the programme's current activities were maximised (Turpie, 2004).

Also in 2004, Görgens & Van Wilgen felt that existing knowledge needed to be more effectively used to prioritise clearing operations by selecting areas for clearing in terms of water-related benefits (Görgens & Van Wilgen, 2004).

In 2005, a review of the Common Ground external evaluation found that there still appeared to be a lack of consensus regarding the spatial targeting for clearing (Laros, 2005). Laros (2005) felt that this was a key priority to be addressed if the programme wished to deliver effectively on its core purpose. At the regional level, the most important for spatial targeting for clearing, there appeared to be inconsistency with the prioritisation approach applied. Despite the regional strategic planning process, spatial targeting for clearing required a coherent approach applied across the country appropriate to the relevant provincial conditions. Laros (2005) further reasoned that should the WfW regions fail to implement this approach this would significantly affect the overall impact and effectiveness of WfW as an invasive alien plant control and management programme, i.e. delivery on its core purpose/mission.

1.3 Scope, aim, objectives, design, question & hypothesis

The **scope** of this dissertation is the transparent, strategic, systematic, objective, spatial prioritisation of areas for control of established, terrestrial invasive alien plants in South Africa where opportunities to meet individual goals are synergistic. Prioritisation of emerging species was not dealt with, as this requires a species-based approach (Nel *et al.*, 2004a). Other invasive species (e.g. invertebrates, birds and mammals) and aquatic invasive plants were excluded due to their high mobility. Also, despite their proximity to South Africa, the neighbouring countries of Lesotho and Swaziland were excluded as WfW has no jurisdiction in these sovereign countries.

Criteria on **poverty** were excluded from this study as the link between invasive alien plant control and poverty relief funding is fragile (van Wilgen *et al.*, 2001).

Furthermore, Laros *et al.* (2003) believe that the spatial prioritisation of invasive alien clearing interventions should not be driven by poverty relief-based targeting (that is by targeting areas where there is the greatest level of poverty). While it is recognized that social development and poverty relief are critical priorities for South Africa as a whole, it is believed that WfW should focus first and foremost on its key purpose. WfW should, however, consider how clearing in strategically targeted areas may be undertaken in order to maximize social benefits. The "poverty nodes" referred to in the WfW Regional Strategic Planning Process guidelines (WfW, 2002) are actually Integrated Sustainable Rural Development Programme (ISRDP) nodes. This 10-year programme initiated in 2001, targets rural communities especially women, youth and the disabled and is implemented in 13 district municipalities. It aims to alleviate poverty by: ensuring access to education, health, social welfare/grants and functional district clinics serving the communities; expanding labour markets through stimulation of Local Economic Development (LED) programmes; improving service delivery (access to water and sanitation, electricity and energy, telephone services); building of access roads to improve transportation to reach social amenities and economic markets, post-office and post office agents and improving social asset capital (household assets, incomes and expenditure) (DPLG, 2001).

The **aim** of this dissertation is to determine whether the choices made on where resources are invested to control invasive alien plants in South Africa are valid/defensible.

The specific **objectives** of this dissertation are:

- To conduct a systematic prioritisation of areas for invasive alien plant control in South Africa.
- To compare these results with the WfW prioritisation of areas for invasive alien plant control.

The **research design type** is the empirical analysis of existing numerical data (secondary data analysis) (Parsons & Knight, 1995) using spatial multi-criteria decision analysis. Decision analysis is a set of systematic procedures for analyzing complex decision problems. The basic strategy is to divide the decision problem into small, understandable parts; analyze each part; and integrate the parts in a logical

manner to produce a meaningful solution. Decision making itself is broadly defined to include any choice or selection of alternative course of action, and is therefore of importance in many fields in both the social and natural sciences, including geographical information sciences. The types of decision problems that interest geographers and spatial planners typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria. Accordingly, many real-world spatial planning and management problems give rise to geographic information system (GIS) – based multicriteria decision making (MCDM). GIS-based (or spatial) multicriteria decision analysis can be defined as a collection of techniques for analyzing geographic events where the results of the analysis (decisions) depend on the spatial arrangement of the events. Spatial multicriteria analysis is a part of broadly defined spatial analysis (Malczewski, 1999).

The **research question** is: How well does a systematic prioritisation (A) correlate with the WfW prioritisation (B)

Correlation will be measured with the **correlation coefficient**, r, where r lies between –1 and +1. $r > 0$ indicates a positive linear relationship. $r < 0$ a negative linear relationship and $r = 0$ indicates no linear relationship between A and B (Ott, 1988). The significance of a correlation coefficient is as follows (Fowler *et al.*, 1998):

- Value: 0.00-0.19 (very weak)
- Value: 0.20-0.39 (weak)
- Vaue: 0.40-0.69 (modest)
- Value: 0.70-0.89 (strong)
- Value: 0.90-1.00 (very strong)

A GIS-based analysis requires both spatial and attribute data. The spatial resolution is perhaps the primary concern. Data were available at differing spatial resolutions and would have to be brought to a common analytical scale in both spatial and attribute terms. The unit chosen as a basis for comparison/prioritization is the **quaternary catchment**, in line with the WfW planning guidelines (WfW, 2001b). All data were re-scaled to this unit. The 1,825 quaternary catchments that have their centres in the boundaries of South Africa (Figure 1.2) total 1,218,259 km^2 have a mean area of 668 km^2, range from 47 km^2 to 18,107 km^2.

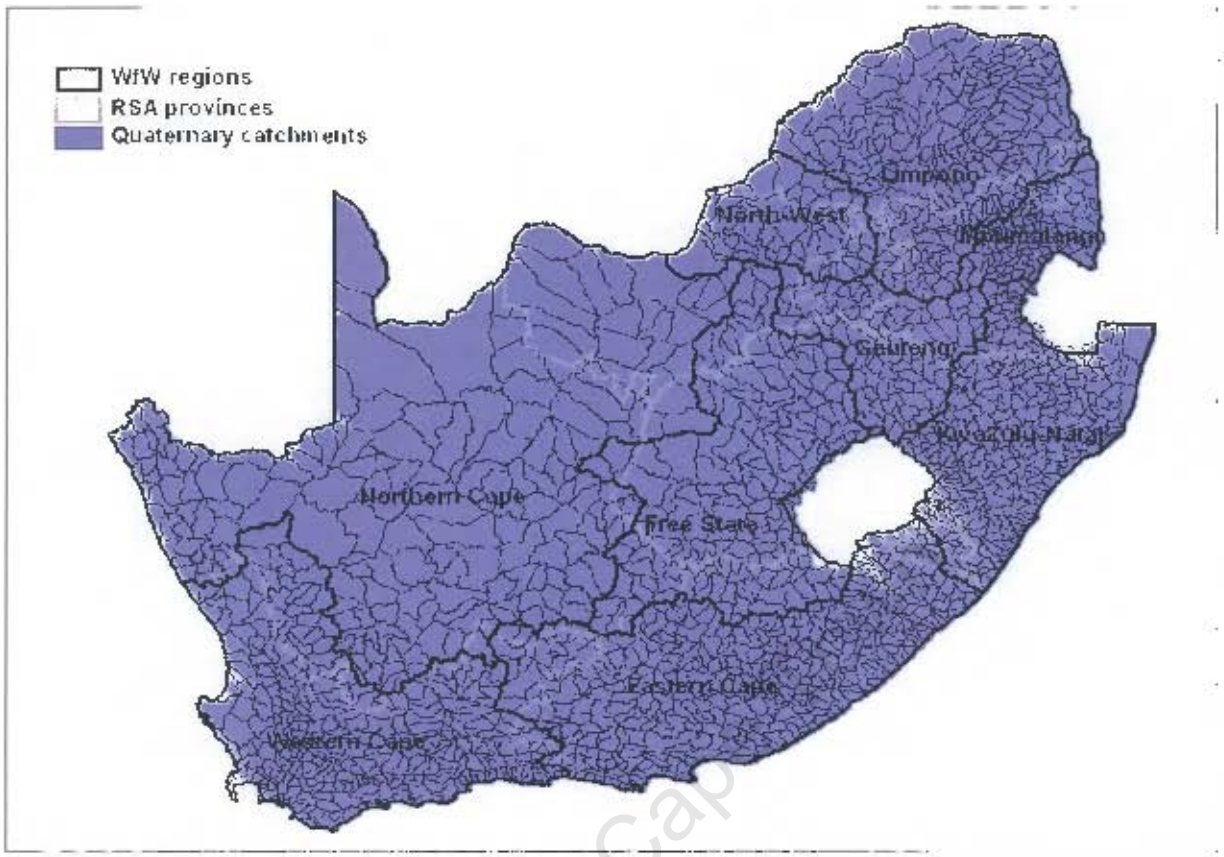

Figure 1.2 The 1,825 quaternary catchments that have their centres in the boundaries of South Africa (after Midgley *et al.*, 1994)

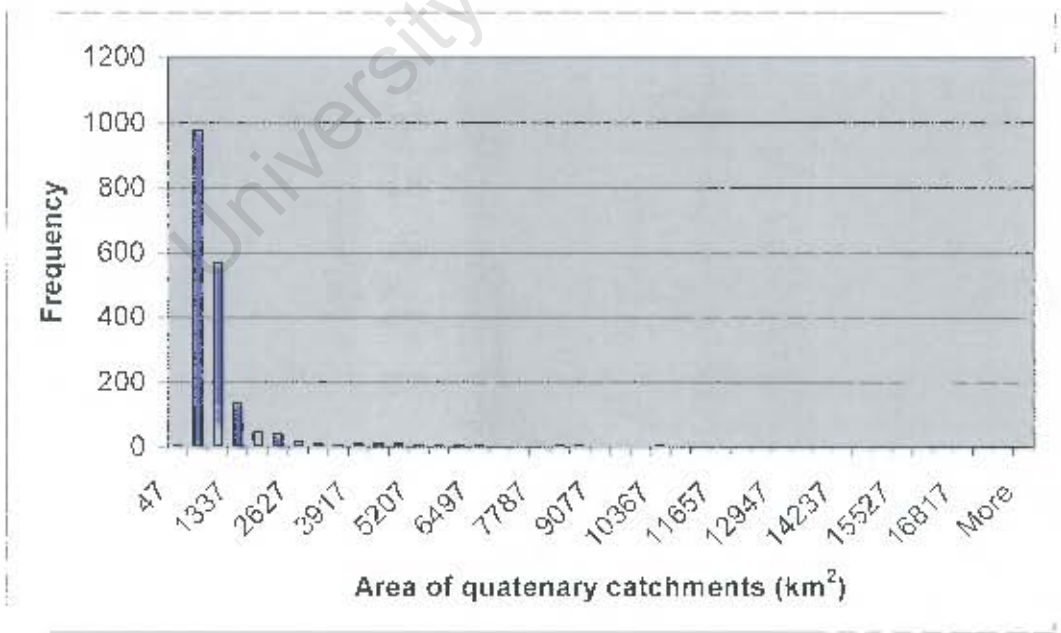

Figure 1.3 Frequency histogram for area (km^2) of the 1,825 quaternary catchments that have their centres in the boundaries of South Africa.

For the purposes of this methodology it was required that all data be expressed numerically. The research data were measurable on at least an interval scale (Parsons & Knight, 1995).

2. LITERATURE REVIEW

2.1 Previous work

Previous studies that investigated the topic of prioritisation for invasive alien plant control and the criteria they used are summarised in Table 2.1. Those that expressed their prioritisation spatially are discussed in further detail below.

Table 2.1 Summary of prioritisation criteria used in previous South African studies

Broad criteria	Specific criteria	Study	Scale
Species	Current distribution/range	Macdonald & Jarman, 1984	Fynbos Biome
		Macdonald & Jarman, 1985	KwaZulu-Natal
		Van Wilgen *et al.*, in press.	National
	Potential distribution/range	Macdonald & Jarman, 1984	Fynbos Biome
		Macdonald & Jarman, 1985	KwaZulu-Natal
		Rouget *et al.*, 2004a; Mgidi *et al.*, in prep.; Van Wilgen *et al.*, in press.	National
	Current distribution & density	Versfeld *et al.*, 1998; Robertson *et al.*, 2003; Nel *et al.*, 2004a	National
	Feasibility of control	Macdonald & Jarman, 1984	Fynbos Biome
		Macdonald & Jarman, 1985	KwaZulu-Natal
		Robertson *et al.*, 2003	National
	Rate of spread	Macdonald & Jarman, 1984	Fynbos Biome
		Macdonald & Jarman, 1985	KwaZulu-Natal
		Mgidi *et al.*, 2005	National
	Effects	Macdonald & Jarman, 1984	Fynbos Biome
		Macdonald & Jarman, 1985	KwaZulu-Natal
		Robertson *et al.*, 2003	National
	Current hydrological impact	Versfeld *et al.*, 1998; Le Maitre *et al.*, 2000	National
	Potential hydrological impact	Le Maitre *et al.*, in prep.	National
	Potential rangeland impact	Le Maitre *et al.*, in prep.	National
	Potential biodiversity impact	Le Maitre *et al.*, in prep.	National
	Potential invasiveness	Robertson *et al.*, 2003	National
	Conflicts of interest	Robertson *et al.*, 2003	National
Hydrological value of area	Compulsory water-use licensing areas.	Gibson & Low, 2003; Ractliffe *et al.*, 2003	National
	Ecological Importance & Sensitivity (DWAF, 1999)	Ractliffe *et al.*, 2003	National
	Habitat loss in rivers (Nel *et al.*, 2004b)	Van Wilgen *et al.*, in press.	National
	Degree of water stress (DWAF, 2004)	Van Wilgen *et al.*, in press.	National
Ecological value of area	Threatened terrestrial vegetation types (Low & Rebelo, 1996)	Ractliffe *et al.*, 2003	National
	Biodiversity irreplaceability (expert knowledge)	Gibson & Low, 2003	National
Agricultural value of area	Grazing potential (Schoeman *et al.*, 2002)	Gibson & Low, 2003	National
	Arable potential (Schoeman *et al.*, 2002)	Gibson & Low, 2003	National

Versfeld *et al.* (1998) (Figure 2.1) made the first attempt to set clear national priorities for the *Working for Water* Programme to ensure funding was appropriately targeted, using mostly expert knowledge of the extent of invasions in South Africa undertaken in 1996–97 (Le Maitre *et al.*, 2000). However, the emphasis of this assessment was on mapping species believed to use more water than native vegetation, so succulent (e.g. Cactaceae), herbaceous (e.g. grasses, annuals) and aquatic invaders were generally excluded. The areas of commercial plantations of the invading species, and invasions in the major urban and metropolitan areas were also excluded. The data from this survey need to be interpreted with caution. This mapping exercise was aimed at providing a "broad brush" estimate of the extent of invasions, and various data sets from other sources were also included in the final database. The estimates derived from this survey have elicited considerable discussion, and opinions on the accuracy of the data are strongly divided. According to this national survey, about 10 million hectares of South Africa has been invaded by the approximately 180 species that were mapped. Of South Africa's nine provinces, the Western Cape has the most extensive invasions followed by the Northern and Mpumalanga Provinces. However, KwaZulu-Natal and the Eastern Cape were not adequately mapped, and the true extent in these provinces is likely to be closer to the percentage for Mpumalanga which has similar climate, vegetation, history of colonisation and land-use patterns (van Wilgen *et al.*, 2001).

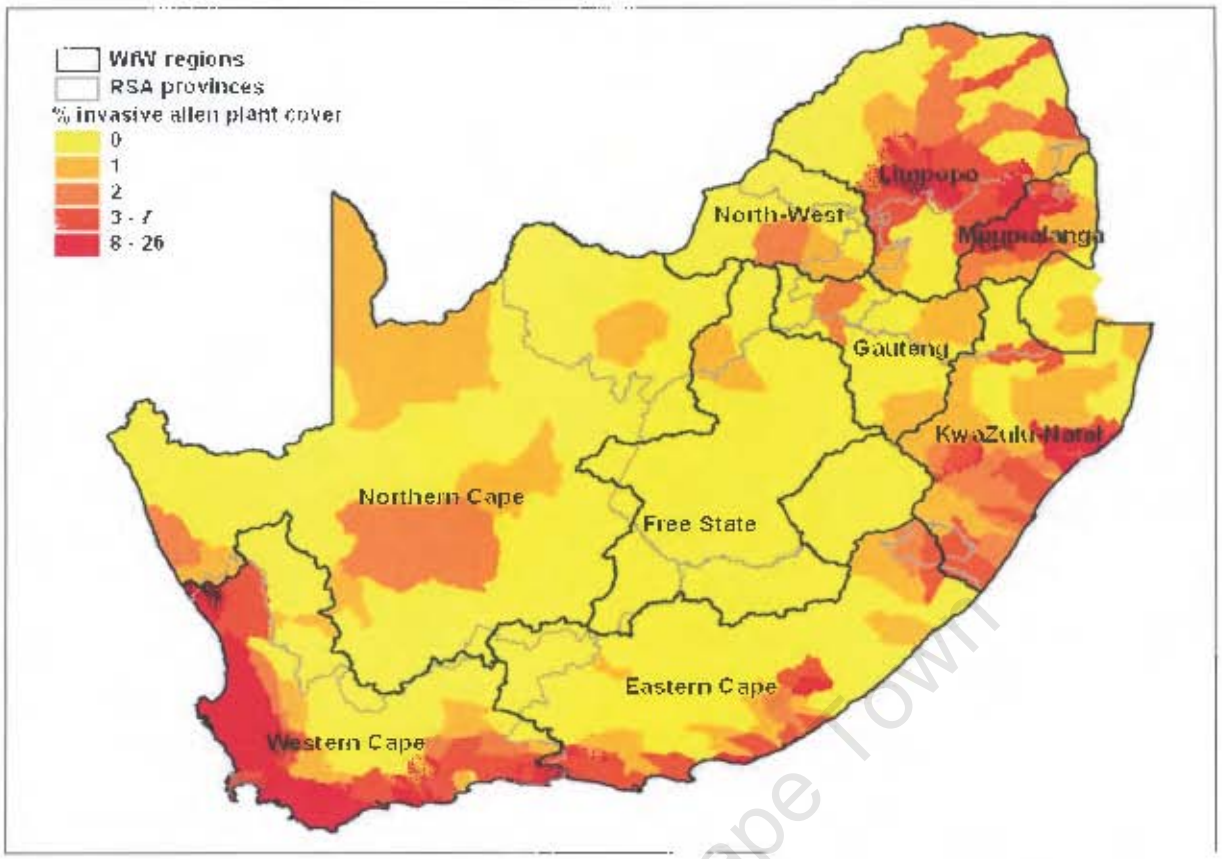

Figure 2.1 Percentage of invasive alien plant cover (condensed hectares) per tertiary catchment (graduated colour classified by 5 equal areas) of South Africa (Versfeld *et al.*, 1998)

Gibson & Low (2003) and Ractliffe *et al.* (2003) used compulsory water-use licensing areas as an indicator of hydrological importance (Figure 2.2). These are areas which are, or are soon likely to be, under "water stress" (for example where the demands for water are approaching or exceed the available supply, where water quality problems are imminent or already exist, or where the water resource quality is under threat) or where it is necessary to review prevailing water use to achieve equity of access to water (RSA, 1998). However, this hydrological indicator is seen as insufficient as certain factors, for example groundwater abstraction has not been taken into account in certain areas. Also, since Ractliffe *et al.* (2003) did their study using threatened vegetation types (Low & Rebelo, 1996) as a surrogate for conservation importance, a new dataset (Rouget *et al.*, 2004b) has become available. Gibson & Low (2003) used a gap prioritization approach. In gap prioritization models, areas of the country are prioritized in an iterative fashion – at each iteration, a single criterion is chosen to act as a "filter" restricting further analyses of the remaining criteria only to the priority areas identified for that single criterion. However, this hierarchical iterative approach is extremely dependant on the

type of criterion (or filter) applied at each iteration, and will be conceptually flawed if filters are applied at incorrect levels of iteration. These types of analyses also prevent investigation of possible cumulative effects in parts of the country where different criteria interact.

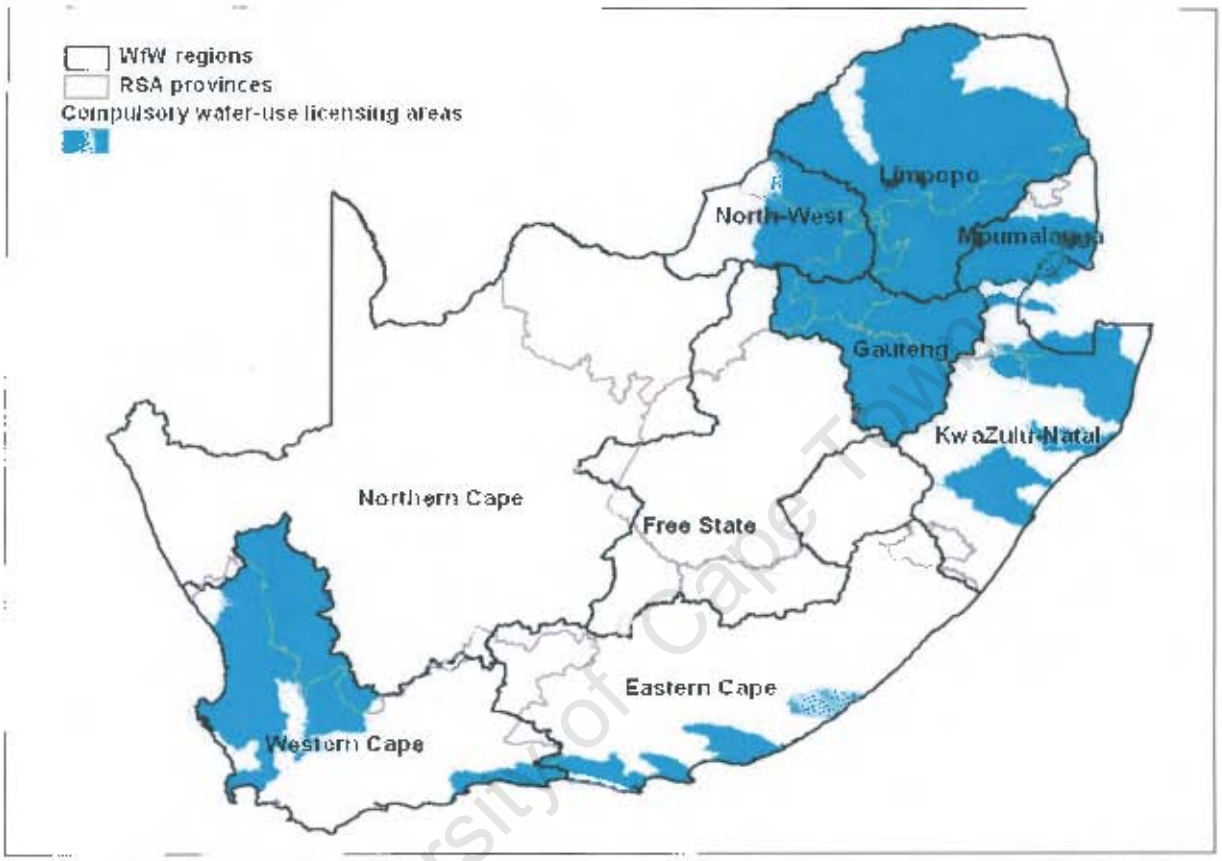

Figure 2.2 Compulsory water-use licensing areas (Ractliffe *et al.*, 2003)

Nel *et al.*, 2004a (Figure 2.3) used species distribution and abundance data from Southern African Plant Invaders Atlas (SAPIA) to identify 117 major plant invaders that were recorded as either widespread, or localised but abundant. But impact of invasive alien species is defined as the product of a species' range, abundance and per capita effect (Parker *et al.*, 1999).

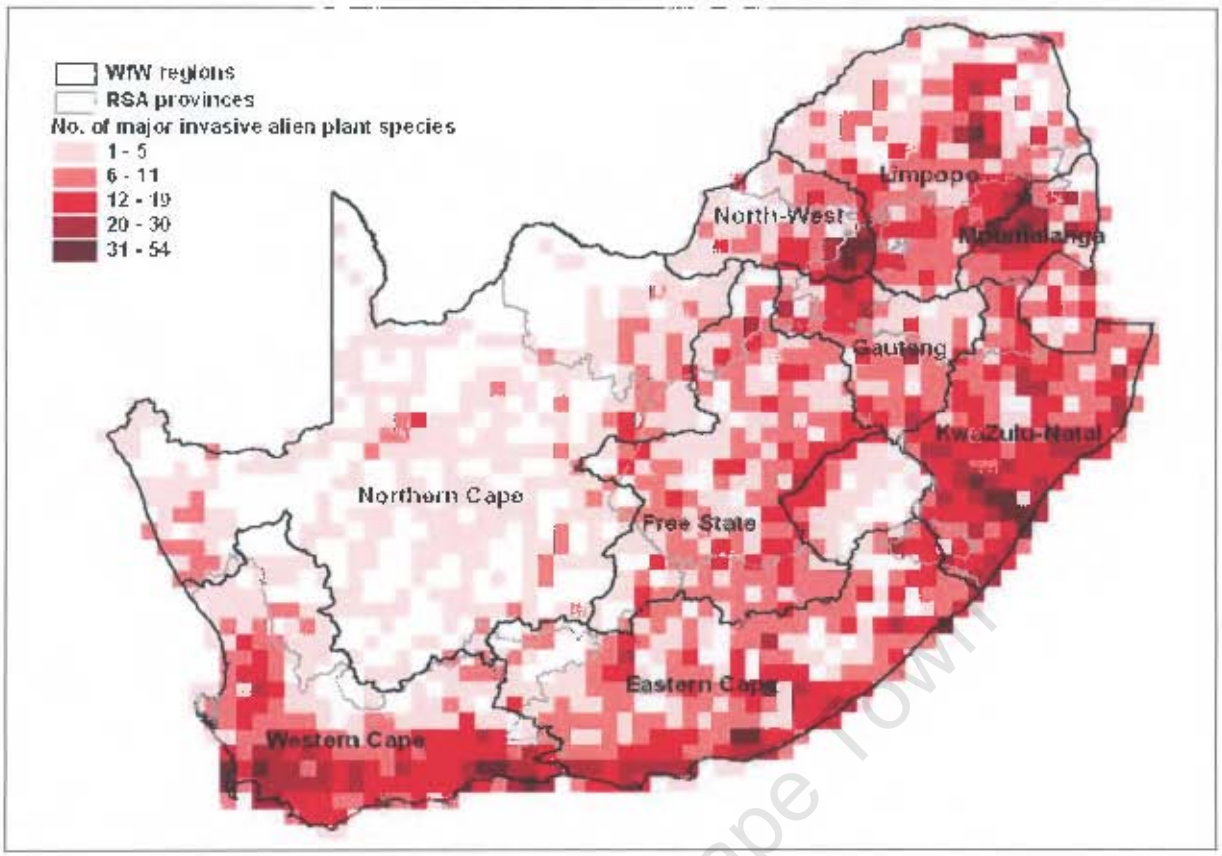

Figure 2.3 Distribution of major invasive alien species per quarter degree square (graduated colour classified by 5 natural breaks) (Nel *et al.*, 2004a)

Rouget *et al.*, 2004a (Figure 2.4) quantified alien plant invasion potential based on an assessment of the climatic correlates of distribution of 71 major invasive alien plants. This product was also used by Driver *et al.* (2005) to rank priority areas according to combined level of future pressures on biodiversity. However, not all alien plant invaders can be considered as having the same impact, so the impact of plant invasions might not be directly related to the number of potential plant invaders.

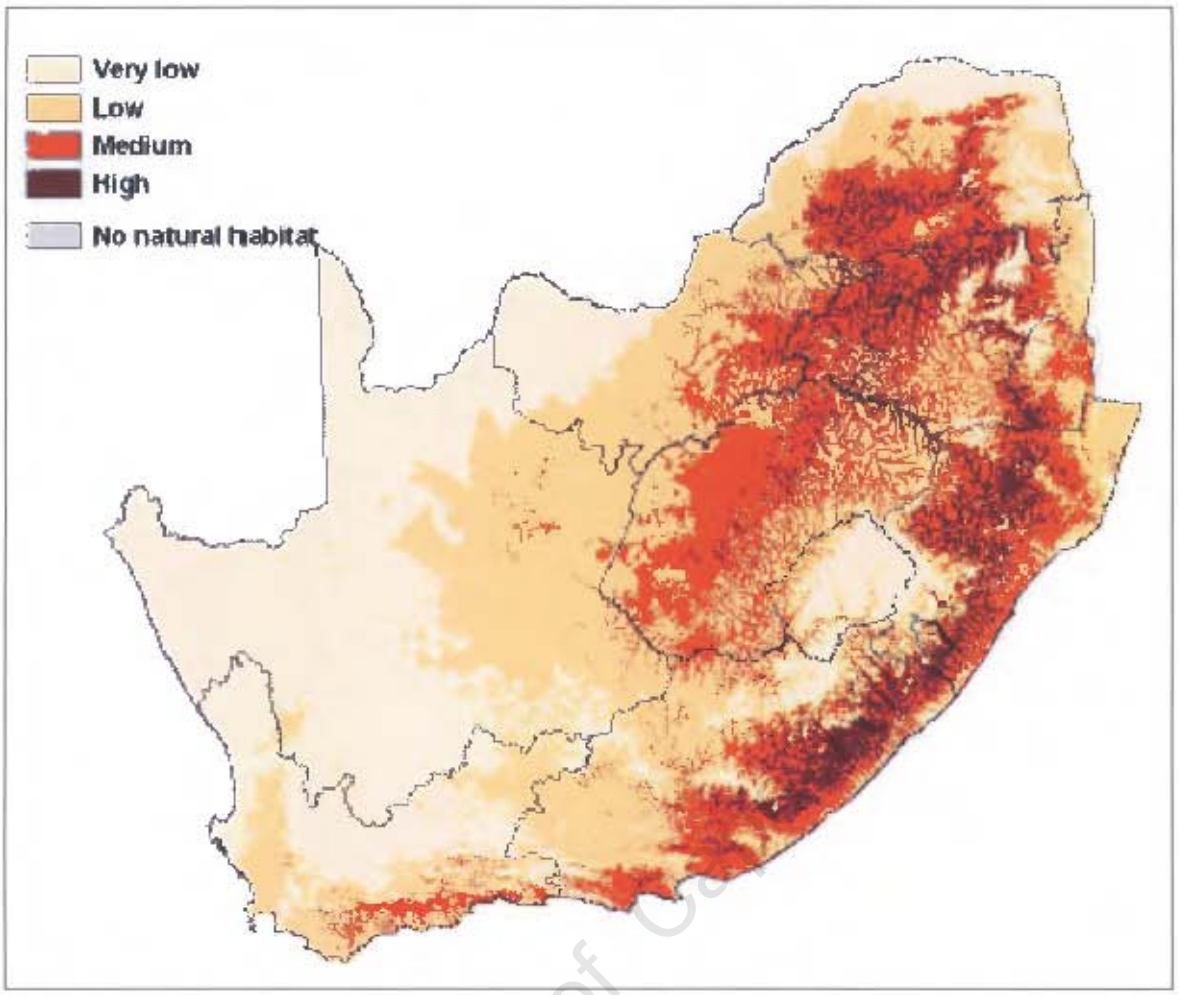

Figure 2.4 Alien plant invasion potential based on climatic suitability of 71 major invasive alien plants (Rouget *et al.*, 2004a)

Le Maitre *et al.* (in prep) (see Figure 2.5) assessed the potential impacts of a suite of 71 major and 28 emerging plant invaders on biodiversity, water resources and the productivity of natural rangelands in South Africa, Lesotho and Swaziland. The scores for these impacts were based on a survey of the literature and included the following factors: per capita impact estimated for attributes such as size and growth form as an index of potential transpiration, ability to transform natural communities and toxicity to livestock, multiplied by their natural ability to form dense stands to give a per population impact. The population scores were multiplied with estimates of the extent of their climatically suitable range to give a total impact score. The geographic distribution of the impacts in the region was also assessed using data sets from previous studies which predicted the distribution of the climatically suitable areas for each species. However the findings of this study are subject to substantial uncertainties. The per capita impact scoring system that was developed is pragmatic but is based on logical deduction rather than rigorous analysis. Many of the scores are based on personal observation and experience (by the authors and other

experts) rather than documented studies, as data on these impacts, whether per capita or per population, are lacking. The predictions of the climatically suitable areas for the different species are also subject to substantial uncertainties.

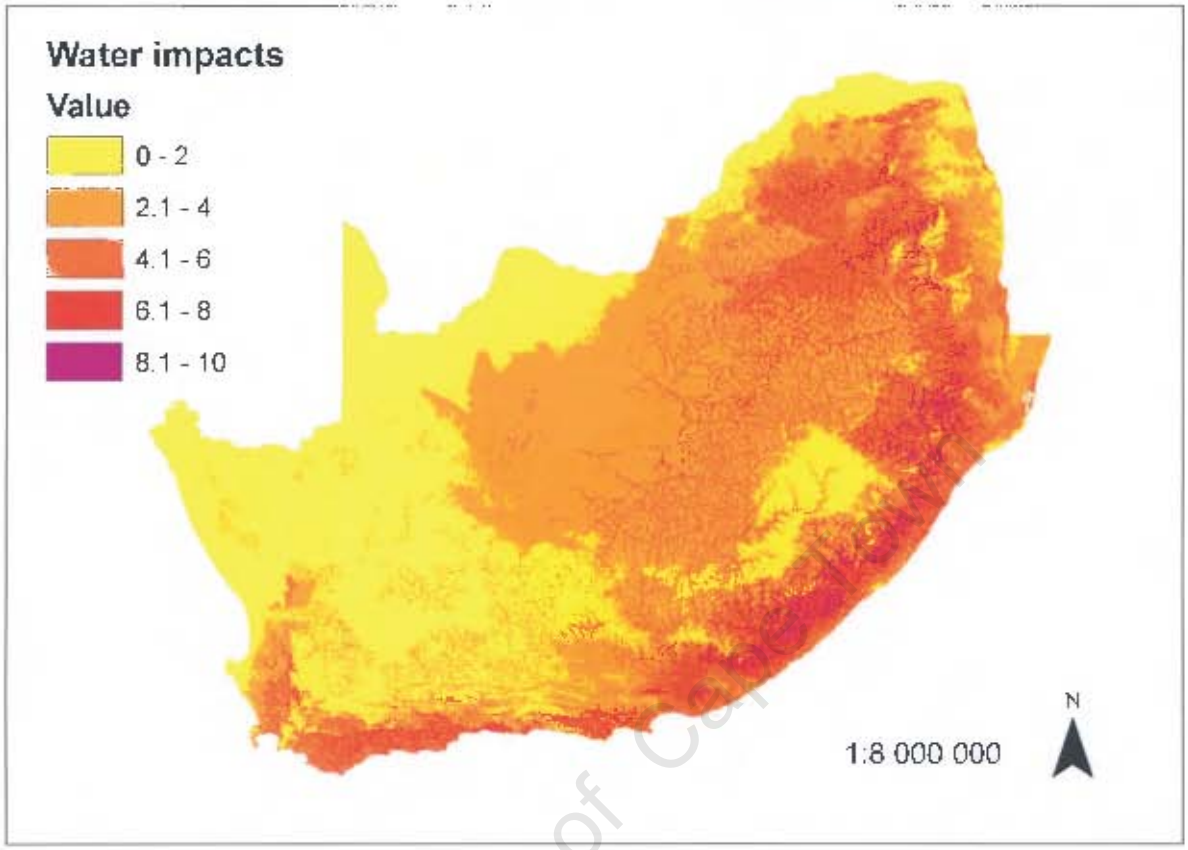

Figure 2.5 Geographic distribution of the relative impacts of 71 major invader plant species on water resources (Le Maitre, in prep.)

Van Wilgen *et al.* (in press) calculated, for each quaternary catchment, a simple composite index that combined estimates of (1) the number of invasive alien plant species (out of a selection of 13) present; (2) the potential number or alien plant species that would be present if they occupied the full range as determined by climatic envelope models; (3) the degree of habitat loss in rivers; and (4) the degree of water stress. The approach was, however, aimed at placing a higher priority on river systems. The combined priority map was not available for comparison at time of writing.

In summary, all of the above studies had limitations and ignored the possible effects of disturbance, terrestrial biodiversity value and primary productivity value. My contribution to this topic will be to investigate the effects of these and compare my results with the actual prioritisation in place in WfW.

2.2 Suggested approaches

In 1997, an external evaluation of the WfW programme conducted by the European Union (Breen *et al.*, 1997) suggested that a national strategy, reflecting the most rational way of achieving water savings through control of alien invasive plants, should be developed and that feasibility studies should be carried out for any project prior to investment. The evaluation recommended that protocols for prioritising selection of projects should be developed and that the logical framework approach be considered, as it would help to organise and structure the projects. The following criteria were identified in a workshop:

- Increased water supply for domestic, agricultural and industrial use
    - Where there is a demand for water
    - Where clearing benefits existing and future Water Schemes
    - Where rural communities will benefit from streamflow
    - Where increased water supply will enhance agricultural development
    - Where clearing will increase water levels in aquifers
    - Where clearing has the greatest benefit in terms of water (by species)
- To improve catchment stability
    - Where it will benefit species diversity
    - Where it will contribute to instream requirements of aquatic systems
    - Where the value of the natural resource is greater
    - Where clearing will reduce fire intensity and frequency
    - Relation to areas surrounding (e.g. invasion)
    - Position in landscape (Breen *et al.*, 1997).

In 1998, a preliminary assessment of alien invading plants and water resources in South Africa identified factors that were considered important for effective prioritisation through a series of workshops and discussion groups and conceded that, in practice, the application of these factors is determined by the availability of suitable data (Versfeld *et al.*, 1998). The following were considered factors, together with suggested rules, for which information was available:

- Species factors:
    - Prioritise "explosive species"
    - Prioritise recognised high water users

    - Prioritise most severely invaded catchments
    - Prioritise less invaded catchments
    - Prioritise catchments where invasions are at low densities or of limited extent
    - Potential extent and rate of spread
- Ecological area factors:
    - Prioritise high species diversity areas and biodiversity "hotspots"
    - Prioritise protected areas
- Hydrological area factors:
    - Prioritise catchments with high runoff per unit area
    - Prioritise riparian invasions
    - Prioritise catchments that deliver water where the level of demand is high and cannot be met in other ways
    - Prioritise catchments supplying a water scheme
    - Prioritise areas where the invasion of river banks may obstruct flow or destabilise the banks making them subject to scouring, and where flooding may damage infrastructure
- Agricultural area factors:
    - Prioritise high use and high resource productivity of the land
    - Prioritize high value, high production, high potential land

In contrast, the preliminary assessment considered the following factors as having no information available:

- The threat to community water supply
- The negative effect of the invasion on catchment stability (riparian zone stability, soil erosion)
- Cost & time to control catchment (control methods & costs; accessibility; availability of implementing agents, infrastructure and workforce)
- Realizable potential of the land for use or production
- Dependence of communities on invaders (particularly as a fuelwood resource)
- Benefits of clearing in terms of local job creation, community upliftment and other socio-economic aspects
- Sustainability or achievability (Versfeld *et al.*, 1998)

In 1999, the WfW Operational Manual stressed that in development programmes of the nature of WfW it was the selection of individual projects that was crucial to

success and that planning was the key to proper project selection. The manual suggested a meeting of government departments to identify priority project areas that were based on or verified against poverty statistics, potential for partnerships and water resource needs (Corbett, 1999).

In 2000, at the WfW Best Management Practices workshop, it was contended that although there were several specified goals and objectives of *Working for Water*, this was a fairly complex issue as not all objectives were necessarily compatible for each project or situation. The workshop suggested that the process of selecting project locations for vegetation clearing should be based on a decision-making process, which takes all the objectives into account. For example, a candidate location should be rated according to its potential to facilitate the achievement of the maximum range of prioritized goals (e.g. environmental, social and economic) as possible (Roberts *et al.*, 2000).

In 2001, the WfW Strategic Plan recognised that the selection of areas in which to focus the resources for clearing alien plants is a critical one. Firstly, WfW needed to be able to have access to the best data on which to base decisions about where to clear alien plants. Secondly, it needed to develop a set of defensible rules by which project areas are selected. These rules needed to take into account the strategic objectives and guiding principles of the programme (economic empowerment, ecological stability and social justice). This included the need to focus on water resources through a focus on upper catchments (particularly stressed catchments) and river courses, a need to focus on poverty eradication in poor areas, and a need to protect bio-diversity hotspots and wetlands. WfW also need to take a holistic ecological approach, where the consequences of selecting certain areas, while leaving others, on the overall effectiveness of the control programme are fully understood. The strategic plan set a deadline of June 2001 for a set of criteria for the selection and prioritisation of alien plant clearing projects, including wetland rehabilitation, to be in place (WfW, 2001a).

In 2002, the WfW Ecology Research Strategy recommended that information was required for effective national strategic planning of alien control programmes for the selection of priority areas at national and regional levels. It suggested that a set of priorities for dealing with the alien plant problem in South Africa, based on current

and potential future impacts of alien invasive plants on water resource (i.e. priority catchment areas), biodiversity, fire management, soil erosion, riverbank stability and grazing should be developed. The Strategy also suggested that the analysis should look at employment, poverty and other issues. An analysis of this kind would inform WfW management where they should be working and concentrating their clearing efforts (Fourie *et al.*, 2002).

In 2003, a national invasive alien plant survey inception report recommended that a comprehensive and rigorous spatial modelling approach be adopted, which is based on well documented multi-criterion evaluation techniques. The report used an example of a model that is conducted through raster modelling in GIS software, based on the weighted linear combination technique. In this technique, weights are applied to each factor through pairwise comparison, and factors are then aggregated linearly to produce a single priority layer. The report asserted that there are many variations to the approach that need to be considered and suggested the following processes and activities in order to achieve this: workshops with a core working group to design an appropriate and to formulate an action plan for the modelling process; acquisition and analysis of South African Plant Invaders Atlas (SAPIA) database and data set of rangeland potential; updating and review of all criteria on a provincial basis through the collection of data, and holding of workshops with recognised local experts in order to produce standardised data sets for incorporation into the model (Gibson & Low, 2003).

Also in 2003, an aquatic ecology and hydrology specialist report maintained that within tertiary catchments there was too much variability in both ecological and social conditions, which mitigated against the usefulness of selection at this scale and suggested that spatial or descriptive information could be sought at the quaternary catchment scale, in order to provide a basis for comparing the merits of each quaternary catchment. While some information would only be available at coarser scales this did not render such information useless (Ractliffe *et al.*, 2003).

Also in 2003, a terrestrial ecology specialist report asserted that there needs to be a hierarchical approach to prioritizing projects (i.e. quaternary catchments) at a national scale in order to bring invasive alien plants under effective control. Control of the most aggressive invasive alien plants (i.e. transformers that generally have a

medium to long-distance dispersal mode, e.g. by wind, vertebrate or water, and capitalize on natural disturbance regimes, e.g. post-fire situations) should be the top priority. Less aggressive invasive alien plants occurring in other quaternary catchments should be a lower priority until additional funding is available, but should be controlled within those quaternary catchments selected at the first iteration. At a national scale, the second iteration (after aggressive species) should prioritize those quaternary catchments in which the greatest ecological and hydrological benefits accrue. In the case of terrestrial areas, catchments with low to medium alien infestation levels in which clearance would stimulate good vegetation recovery, is an example of a high priority area. Another example of a high priority area is one of national conservation importance (i.e. threatened and under-conserved vegetation type or biodiversity hotspot). The third iteration should target areas in which land productivity may be improved (e.g. for agriculture, forestry or grazing) and poverty nodes. Although the social development initiatives of the programme are important, the main purpose of WfW is alien plant control, and unless an effective strategy to control aliens is implemented, the objectives of improved ecological integrity and water security will not be achieved. As poverty nodes cut across most districts and regions, it is hoped that the objective of social development may be nested within this suggested prioritization framework. The fourth iteration should target state-owned land (Holmes *et al.*, 2003).

Also in 2003, an external evaluation of the WfW programme conducted by Common Ground Consulting made a case that strategic planning, whether at regional or national level, required information pertaining to the priorities of programme and that such priorities should include transformer or invader species, conservation areas, water stressed or key water supply catchments, high importance catchments and the presence of key biodiversity hotspots. Following on, either within these ecological priorities or at the within-project level, socio-economic information and priorities would allow better integration of social development objectives into ecological objectives, and better achievement of social development objectives. The most appropriate basis for planning therefore should be the provision of spatial information defining these priority areas (ecological and socio-economic). The evaluation recommended that a GIS planning tool be used in prioritizing projects, so that available biome-scale and provincial spatial information, e.g. on conservation priorities or land-use types, may be used to inform decisions (Laros *et al.* 2003).

In 2004, the National Water Resource Strategy (NWRS) stated that from a water resource management perspective, alien vegetation control in specific catchments may be prioritized by considering the balance between water availability and water requirements, and the probable increase in runoff that will result from clearance (DWAF, 2004).

Also in 2004, the National Strategy for Dealing with Invasive Alien Species in South Africa contended that one of the key and complex steps in a national strategy to manage already established invasive alien species was the establishment of priorities for action. The Strategy suggested that this step should ideally involve full inventory and distribution surveys, assessments of ecological, economic and socio-cultural impacts (often requiring active research), and widespread consultations with all the affected sectors of society (Macdonald *et al.*, 2004).

In 2005, the National Spatial Biodiversity Assessment (NSBA) suggested that there was a need to focus alien clearing efforts on areas where socio-economic needs (e.g. water production and poverty alleviation) coincide with areas of high biodiversity priority (Driver *et al.*, 2005).

Also in 2005, the National Biodiversity Strategy and Action Plan (NBSAP) recommended that key opportunities within the *Working for Water* programme were in the identification and prioritization of sites to be cleared so that these overlap more with biodiversity priority areas (DEAT, 2005).

2.3 Spatial multi-criteria decision analysis

Project appraisal is usually carried out by means of cost-benefit analysis or multi-criteria decision analysis, the former being the most common method, a relatively straightforward comparison of economic costs and benefits (Marais *et al.*, 2001). A start has been made within WfW to develop a system to prioritise catchments for the implementation of clearing programmes based on a cost-benefit model in which the returns to investment in the competing areas will be compared, taking the social benefits of the programme into account. However, the actual decision process stands to be delayed because of the immense task of populating the models, especially in terms of the biodiversity values involved (Turpie, 2004). Even assuming

that the valuation tools used within cost-benefit analyses could perform the tasks they purport to, it can be argued that placing a monetary value on certain environmental features, risks or externalities may be a questionable exercise. Multi-criteria decision analysis eliminates the necessity for monetary valuation, thus avoiding the ethical debates surrounding this issue (Joubert *et al.*, 1997).

Decisions about management of invasive species exhibit all of the characteristics that decision analysis is supposed to be good for: uncertain outcomes; many, potentially conflicting, objectives; and multiple interest groups who may be affected differently by decisions taken (Maguire, 2004). A decision analysis process not only adds validity to a decision, but this process often demonstates that inaction due to lack of complete information can have serious consequences (Maguire, 1991). A lesson that applies to this process is that a simple plan, even one quickly done on imperfect data, is better than no plan. This is not an easy lesson for many scientists, who are often reluctant to give definitive answers or put forward clear guidelines when the questions are complex and the answers uncertain (Driver *et al.*, 2003).

Figure 2.6 presents a three-stage hierarchy of intelligence, design, and choice to represent the decision making process. In the intelligence phase, data are acquired, processed, and exploratory data analysis is performed. The design phase usually involves formal modelling/GIS interaction in order to develop a solution set of spatial decision alternatives. The integration of decision analysis techniques and GIS functions is critical for supporting the design phase. The choice phase involves selecting a particular alternative from those available. In this phase, specific decision rules are used to evaluate and rank alternatives. The three stages of decision making do not necessarily follow a linear path from intelligence, to design, and to choice (Malczewski, 1999).

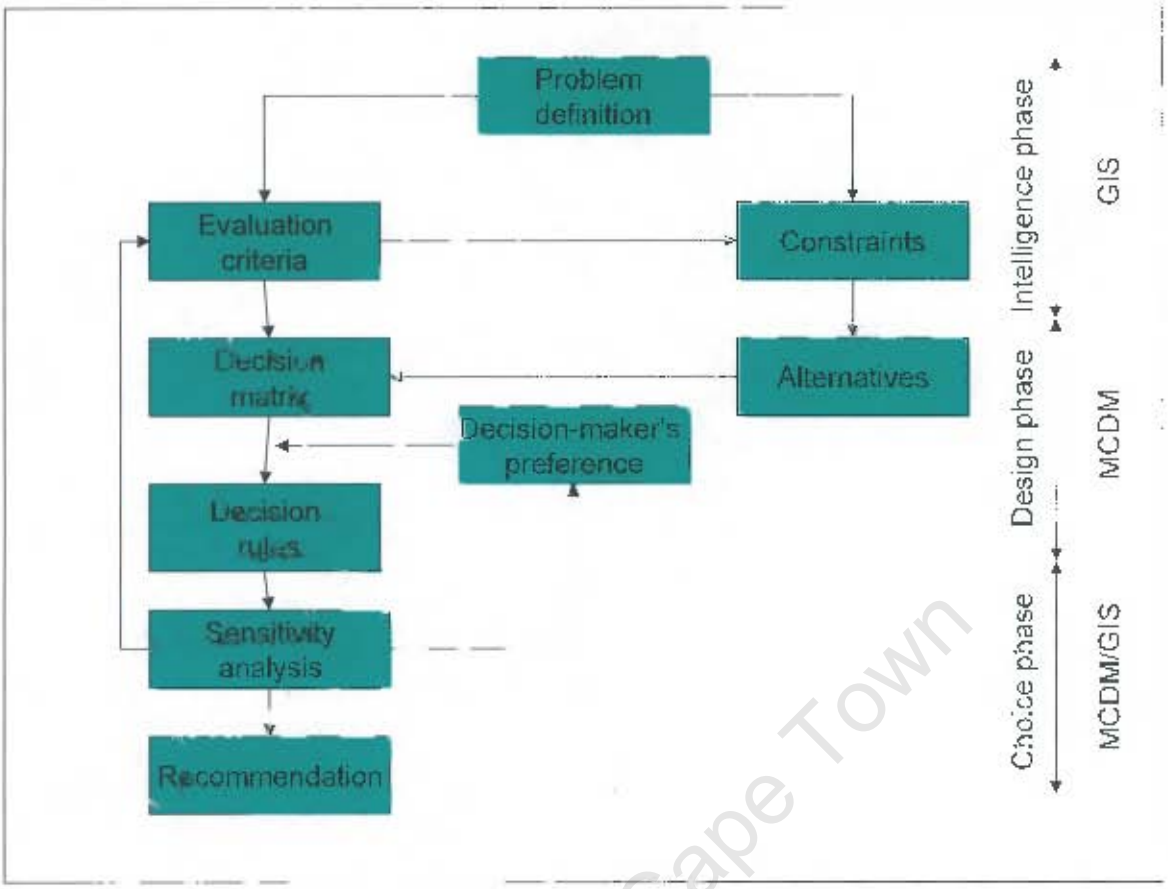

Figure 2.6 Decision flowchart for spatial multi-criteria analysis (after Malczewski, 1999).

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses, different land allocations and so on. Rational human behaviour involves the evaluation of choice alternatives based on some criteria (Eastman *et al.*, 1993). Any decision-making process begins with the recognition and definition of the decision problem. Broadly defined, the decision problem is a perceived difference between the desired and existing states of a system. It is a "gap" between the desired and existing states as viewed by a decision maker (Malczewski, 1999).

Once the decision problem is identified, the spatial multicriteria analysis focuses on the set of evaluation criteria (objectives and attributes). To be more specific, this step involves specifying (1) a comprehensive set of objectives that reflects all concerns relevant to the decision problem, and (2) measures for achieving those objectives. Such measures are called attributes. A measurable scale must be established for each attribute (Malczewski, 1999).

An objective is a perspective that serves to guide the structuring of decision rules (Eastman *et al.*, 1993). The degree to which objectives are met, as measured by the attributes, is the basis for comparing alternatives. The evaluation criteria are associated with geographical entities and relationships between entities and therefore can be represented in the form of maps. An evaluation criterion map is a unique geographical attribute of the alternative decisions that can be used to evaluate the performance of the alternatives. Evaluation criteria maps are also referred to as attribute maps (or thematic maps or data layers in GIS terminology). A constraint map displays the limitations on the value that attributes and decision variables may assume. The process of generating alternatives should be based on the value structure and be related to the set of evaluation criteria (Malczewski, 1999).

At this stage, the decision maker's preferences with respect to the evaluation criteria are incorporated into the decision model. The preferences are typically expressed in terms of the weights of relative importance assigned to the evaluation criteria under consideration. Broadly speaking, the purpose of criterion (objective or attribute) weights is to express the importance of each criterion relative to other criteria. The derivation of weights is a central step in eliciting the decision maker's preferences. Given the set of alternatives, attributes, and associated weights, the input data can be organized in the form of a decision matrix or table (Malczewski, 1999).

The procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. Decision rules typically contain procedures for combining criteria into a single composite index and a statement of how alternatives are compared using this index. Choice functions provide a mathematical means of comparing alternatives. Since they involve some form of optimization (such as maximising or minimizing some measurable characteristic), they theoretically require that each alternative be evaluated in turn. The actual process of applying the decision rule is called evaluation (Eastman *et al.*, 1993). Eventually, the unidimensional measurements (geographic data layers) and judgements (preferences and uncertainty) must be integrated to provide an overall assessment of the alternatives. This is accomplished by an appropriate decision rule or aggregation function. It is the

decision rules that dictate how best to rank alternatives or to decide which alternative is preferred to another (Malczewski, 1999).

2.4 Species and area criteria

Limited resources dictate that choices must be made about **where** to focus control efforts, and **which species** to select for control (Nel *et al.*, 2004a). But there is debate about the options of treating all weeds within a specific site or concentrating on treating priority weeds on all land/water on which they are found (Blood, 2002). The New Zealand Department of Conservation makes a distinction between "weed-led' and "site-led" programmes. "Weed-led" programmes aim to minimize the potential future impacts of invasive weeds by managing priority species before they become a major problem. The term "weed-led" is used because such programmes involve first selecting the species to be controlled and then determining where control is required to meet the programmes objectives. "Site-led" programmes aim to protect the natural values of priority areas from the existing or potential impacts of invasive weed species growing within the area. The term "site-led" is used because planning these programmes involve: first selecting high priority management units based on their biodiversity values; then carrying out the weed control or other activities necessary to protect the significant natural values of the management unit (Owen, 1998).

Wilson *et al.* (1985), contend that where established weeds are to be considered, the question of species-directed versus area-directed control is often irrelevant because: (1) the weeds are very seldom mixed, occurring in more or less distinct stands; (2) each invaded area presents different circumstances, requiring different approaches to control, and (3) it is obviously desirable to clear invaded areas, rather than merely remove one species at a time. The general aim in alien control should be to clear **area-by-area**, but certain factors (e.g. species present, terrain, availability of resources) may be limiting, so that in practice control may require to be species-directed. Therefore, control should be area-directed, but because of practical and financial constraints it may be limited, within areas, to being species-directed. Control should also be integrated, to insure clearing of the whole areas and effective control of each species. The only situation in which control should be entirely species-directed is in the case of possible invaders that still occupy only small areas. These may be controlled and possibly even eradicated by aiming control

programmes at these particular species. Another species-directed situation is that of biocontrol (Wilson *et al.*, 1985).

Kluge & Erasmus (1991) concurred by arguing that implicit in the species-based approach is the idea that, starting at the top of a list of priorities, the status of each alien invader species should, in turn, be permanently changed by a concerted control programme. Experience, they contend, has shown that apart from a few highly successful biological control programmes, this is not a realistic goal and that there is also no precedent for the eradication of an alien invader plant species. They reason that a more realistic goal therefore, is to aim to reduce all the alien invasive plants within a well-defined unit of vegetation to a level where they do not present a problem. This unit may be a paddock, a patch of natural forest or, ultimately, a whole farm (Kluge & Erasmus, 1991). Cronk & Fuller (1995) also believe that in some situations a geographically planned approach will be more suitable than a species based one, especially where a variety of invaders are threatening localised reserves.

However, van Wilgen *et al.* (in press) argue that the most successful operations in the history of invasive alien plant control have been those that have targeted **species** rather than geographic areas. Successful alien plant control operations must be based on a sound understanding of the biology and ecology of the target species, and control interventions should be aimed at the most vulnerable aspects of the species' life cycle. While the prioritization of areas for control intervention is important, it is of equal importance that a means for prioritising species is also developed, to guide policy and research (van Wilgen *et al.*, in press). Blood (2002) agrees that both approaches have merit from the perspectives of conservation and cost-effectiveness.

2.5 Species criteria

2.5.1 Current & potential extent (including rate of spread)

The Global Invasive Species Programme (GISP) toolkit of best prevention and management practices for invasive alien species, contends that under the category current and potential extent of the alien species, priorities are assigned to alien species in order to first, prevent the establishment of new pest species, second, eliminate small, rapidly-growing infestations, third, prevent large infestations from

expanding, and fourth, reduce or eliminate large infestations. To do this, the toolkit reasons that priorities should be assigned in the following sequence:

1. Alien species not yet on the site but which are present nearby. Pay special attention to alien species known to be pest elsewhere in the region.
2. Alien species present on the site as new populations or outliers of larger infestations, especially if they are expanding rapidly.
3. Alien species present on the site in large infestations that will continue to expand.
4. Alien species present on the site in large infestations, which are not expanding. You may have to learn to "live with" (i.e. mitigation) certain alien species or infestations that you cannot control with available technology and resources. However, keep looking for innovations that might allow you to control them in the future (Wittenberg & Cock, 2001).

2.5.2 Current & potential impact

Under the category current and potential impact of the alien species, the Global Invasive Species Programme (GISP) toolkit of best prevention and management practices for invasive alien species, contend that the order of priorities should be based on the management goals for the site. The following sequence is suggested:

1. Alien species that alter ecosystem processes such as fire frequency, sedimentation, nutrient cycling, or other ecosystem processes. These are alien species that "change the rules of the game", often altering conditions so radically that few native plants and animals can persist.
2. Alien species that kill, parasitise, hybridise or outcompete natives and dominate otherwise undisturbed native communities.
3. Alien species that do not outcompete dominant natives but:
    - Prevent or depress recruitment or regeneration of native species; or
    - Reduce or eliminate resources (e.g. food, cover, nesting sites) used by native animals; or
    - Promote populations of invasive non-native animals by providing them with resources otherwise unavailable in the area; or
    - Significantly increase seed distribution of non-native plants or enhance non-native plants in some other way
4. Alien species that overtake and exclude natives following natural disturbances such as fires, floods or hurricanes, thereby altering natural succession, or that hinder restoration of natural communities. Note that alien species of this type

should be assigned higher priority in areas subject to repeated disturbances (Wittenberg & Cock, 2001).

2.5.3 Difficulty of control and establishing replacement species

Cronk & Fuller (1985) assert that control should be seen as the "art of the possible" and no control measures should be taken against alien species whose control is inherently impossible. They use the example of the Kruger National Park to show that careful consideration of the invaders on a case-by-case basis is often revealing. This protected area had 113 invasive plants species, of which 7 had serious ecological impacts. A long-term strategy of control had succeeded in eliminating 10 species from the park and control was feasible for another 14. The other 82 plants were either "out of control' (and thus control is too expensive to contemplate), not serious enough in their ecological impacts to merit control or regularly renewed from outside the park (so control would be pointless) (Cronk & Fuller, 1995). This view was supported by Wells *et al.* (1986a) who declare that the importance of any weed depends on three basic factors: its biological characteristics, the damage that it has or could cause, and our ability to control it (Wells *et al.*, 1986a).

The Global Invasive Species Programme (GISP) toolkit of best prevention and management practices for invasive alien species, contends that under the category difficulty of control and establishing replacement species, priorities should be assigned in the following order:

1. Alien species likely to be controlled or eradicated with available technology and resources and which desirable native species will replace with little further input.
2. Alien species likely to be controlled but will not be replaced by desirable natives without an active restoration programme requiring substantial resources.
3. Alien species difficult to control with available technology and resources and/or whose control will likely result in substantial damage to other, desirable species and/or enhance other non-indigenous species.
4. Alien species unlikely to be controlled with available technology and resources. Finally, pest species whose populations are decreasing or those that colonize only disturbed areas and do not move into (relatively) undisturbed habitats or affect recovery from the disturbance can be assigned the lowest priorities (Wittenberg & Cock, 2001).

2.6 Area criteria

2.6.1 Disturbance

"Environmental weeds", are defined as invasive alien plants that impact on natural or semi-natural (terrestrial and freshwater) ecosystems (Richardson, 2001). A natural ecosystem is an ecosystem not perceptibly altered by humans, while a semi-natural ecosystem is defined as an ecosystem which has been altered by human actions, but which retains significant native elements (Shine *et al.*, 2000).

"Agrestal or ruderal weeds" are defined as alien plants that dominate disturbed areas, for example, where resource levels, altered through tillage, fertilization and irrigation, provide environments suitable for invading species (Richardson *et al.*, 1997). An agricultural habitat (including a forest plantation) is generally a highly managed system that is extremely artificial, differing from most natural habitats in terms of competition, nutrient levels, diversity, disturbance and composition (Cronk & Fuller, 1995).

Many landowners and resource managers do not understand that weed problems are often the result of human practices that have led to resource degradation. Such practices include overgrazing, cultivation and disturbance of natural vegetation. Natural occurrences, including fire and drought, may also contribute to the process of degradation and may have a significant effect in already disturbed and fragmented landscapes. In these situations, weeds are a symptom of the degraded state of land, rather than the cause of that degradation. This lack of understanding often leads to unsuccessful attempts at weed control, rather than rehabilitation of the resource; the treatment of the symptom rather than the cause. Any direct weed control undertaken in such circumstances will require repeated application and achieve only short-term success (Commonwealth of Australia, 1999).

Because of the scarcity of resources available for conservation management and restoration, some means of setting priorities for action need to be established. A framework for this (Figure 2.7) was suggested by Hobbs & Humphries (1995), based on the relative degree of disturbance of sites and their relative value in terms of production or conservation. Four distinct regions can be recognized in which the type of action required is fairly evident.

In the bottom right of the diagram are sites of high value (as defined by the situation) that are relatively undisturbed (given that few area are completely free from human disturbance). Such sites are liable to be relatively free of invasion at present, and thus the management objective should be to keep them that way. These sites should be treated as "fortresses", and management resources should be directed at minimizing human-induced disturbance and the dispersal and establishment of invaders (Hobbs & Humphries, 1995).

At the top right are sites of high value that are subjected to greater levels of disturbance and that hence are more susceptible to invasion. The management objective here should be to change these sites to high value and low disturbance by reducing or removing the disturbing influence, controlling current invasions, and preventing further invasion. Most control-related management activity should be directed at such sites (Hobbs & Humphries, 1995).

In the bottom left of the diagram are sites of low value that are subject to little or no management input. At the top left are sites of low value that are subject to high levels of disturbance. Although these sites may be subject to rapid change and extensive invasion, they should be regarded as a low priority for management action because attempts to control invasions are unlikely to succeed. These four regions in the diagram may have relatively clear management priorities, but the large area in the middle represents areas where priority assessment is more difficult. The prevailing trend is one of transition from the bottom right to top left as environmental degradation becomes more widespread. Attempts to reverse this trend are liable to be costly and time consuming, and the allocation of resources to these efforts must be based on a rational, cost-benefit approach that takes into account factors such as reversibility, ease of treatment, and likelihood of success. This ecosystem approach to management of invasive plants needs to be placed in a regional context. For instance, watercourses and riparian areas represent ecosystem types highly vulnerable to invasion. Spread of aquatic and riparian weeds often occurs by transport of seeds downstream. Any control program should therefore concentrate on the upper parts of a catchment first so that control areas are not reinvaded from upstream. Similarly, although a particular area may have relatively low value *per se*, it may be important in a regional context, and treatment of invasion problems may be

necessary to minimize spread into adjacent areas of higher value (Hobbs & Humphries, 1995).

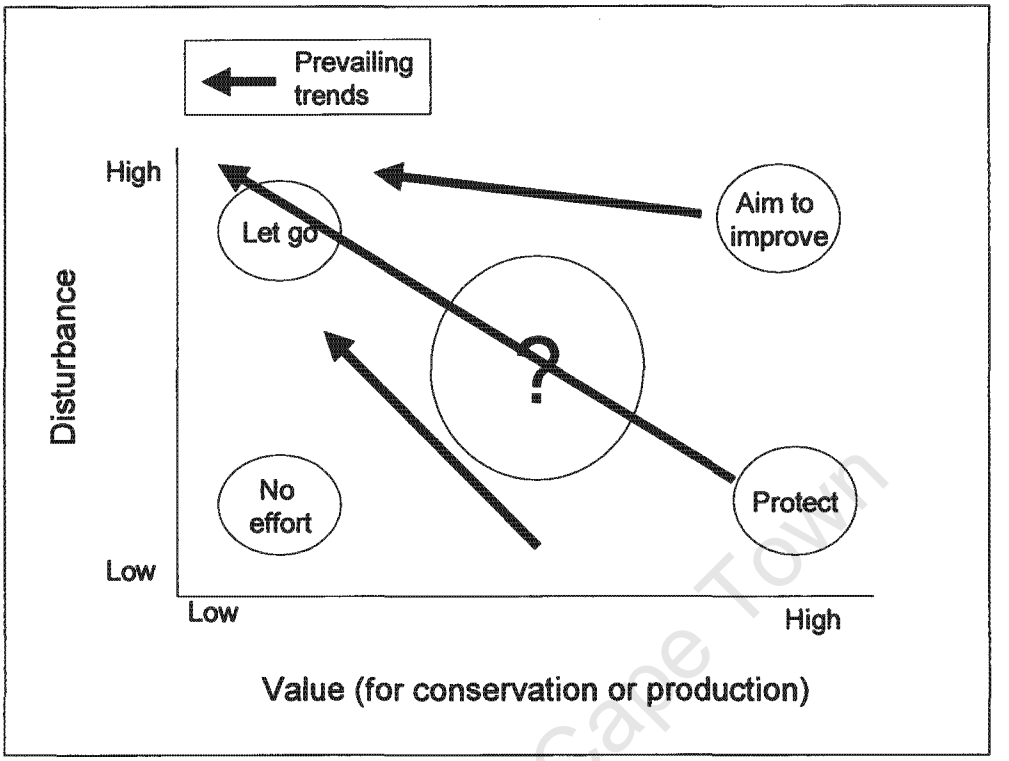

Figure 2.7 Framework for setting priorities for action (after Hobbs & Humphries, 1995).

2.6.2 Value of habitats/areas

For value of the habitats/areas the species actually or potentially infests, priorities should be assigned in the following order:

1. Infestations that occur in the most highly valued habitats or areas – especially areas that contain rare or highly valued species or communities and areas that provide vital resources.
2. Infestations that occur in less highly valued areas. Areas already badly infested with other pests may be given low priority unless the species in question will make the situation significantly worse (Wittenberg & Cock, 2001).

Much of the discussion of ecological effects of invasive alien plants has been purely anecdotal in nature as demonstrated by the following list of 7 major effects repeatedly used by Versfeld & van Wilgen (1986); Cronk & Fuller (1995); Richardson *et al.* (1997) and Van Wilgen & van Wyk (1998):

- replacement of diverse systems with single- (-or mixed) species stands of aliens

- plant extinction
- alteration of soil chemistry
- alteration of geomorphological processes
- alteration of the fire regimes
- alteration of hydrology
- destruction of riparian habitat.

Only recently have attempts been made to describe these effects in terms of **biodiversity and ecosystem services** (Richardson & van Wilgen, 2004). The term biodiversity refers to genes, species (plants and animals), ecosystems, and landscapes, and the evolutionary processes that allow these elements of biodiversity to persist over time. South Africa's biodiversity provides an important basis for economic growth and development. Keeping our biodiversity intact is also vital for ensuring ongoing provision of ecosystem services. Loss of biodiversity puts aspects of our economy and quality of life at risk, and reduces socio-economic options for future generations. People are ultimately fully dependent on living, functioning ecosystems and the services they provide. Loss of biodiversity leads to ecosystem degradation and subsequent loss of important species, which tends to harm the rural poor more directly – poor people have limited assets and are more dependent on common property resources for their livelihoods, while the wealthy are buffeted against loss of ecosystem services by being able to purchase basic necessities and scarce commodities. Our path towards sustainable development, poverty reduction and enhanced human well-being for all, is therefore dependent on how effectively we conserve biodiversity within the 9 broad priority areas for conservation action (Figure 2.8) (Driver *et al.*, 2005). The Millennium Ecosystem Assessment (2005) report makes it clear that human well-being depends on four types of ecosystem services flowing from natural capital (i.e. the Earth's non-renewable and renewable resources). Two of these pertain to invasive alien plants

- Supporting services (needed by all the others); that include soil formation, nutrient and water cycling, and primary production
- Provisioning services; that yield food, water, firewood, timber, fibre, and genetic material.

The South African government's policy regarding invasive alien plants and **biodiversity**, is to develop control and eradication programmes, based on a priority-

rating system and in relation to costs and resources that will consider threats posed to biodiversity, as well as social, economic, and environmental costs and benefits derived from using and removing identified organisms (RSA, 1997a).

Although the preservation of the nation's biodiversity is well recognized by the WfW Programme as being one of the major justifications for clearing of invasive alien plants, it has generally been assumed that if clearing meets the programme's hydrological objectives it will also meet the biodiversity conservation objectives. However, it has been shown that the interaction between invasive alien plants and biodiversity is extremely complex and that this assumption might well not be valid in all cases (Macdonald, 2004).

Biodiversity planners consider invasive alien plant invasion a form of habitat degradation. The 1996 National Land Cover database (Fairbanks *et al.*, 2000) classified 6% of the country as "degraded" but the mapping of this is not considered consistent across the country (Rouget *et al.*, 2004b).

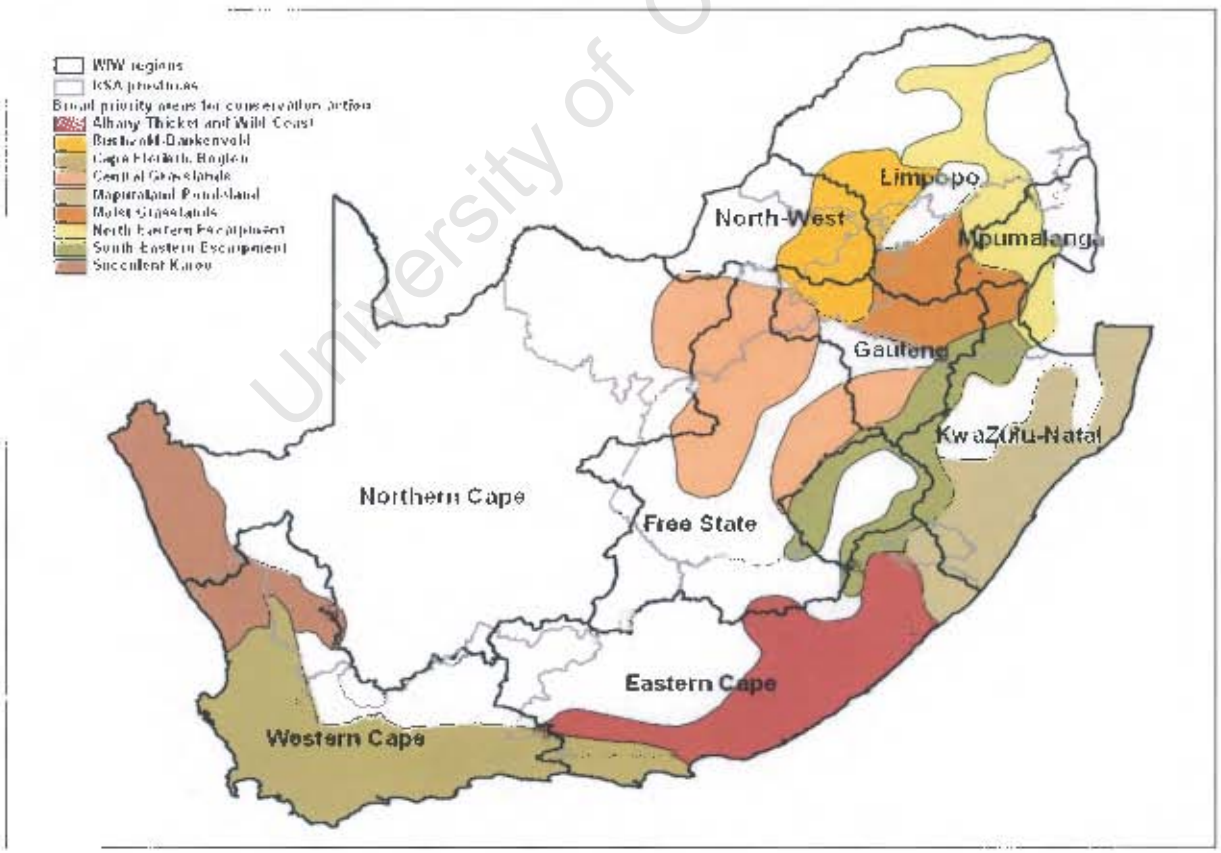

Figure 2.8 The 9 broad priority areas for conservation action (Driver *et al.*, 2005).

The South African government's policy regarding invasive alien plants and **water utilization and conservation**, is to make water available to new users without harming the interests of existing users by removing water-hungry invasive plants and trees (RSA, 1997b).

Southern Africa is, generally, a semi-arid region. Overall, average runoff only constitutes 9% of the total rainfall, with 91% of all precipitation evaporating again. This compares poorly with the world average runoff ratio to rainfall of 35% (Schulze *et al.*, 1997). The country has no natural lakes and few aquifers, so most of the water used comes from rivers. In the drier parts of the country where rivers are seasonal or ephemeral, ground water is used. Surface water resources include rivers, estuaries and wetlands. In South Africa, about 40% of rivers are seasonal. Although the rivers in the eastern part of the country are relatively short, together they contribute more than half of South Africa's runoff. South Africa's mountain catchments represent only 8% of the land – but generate 49% of the runoff. With surface water being so unevenly distributed, both in time and space, it is not surprising to discover that water is not always naturally available where people need it most. Most of the rivers in South Africa have been impounded, with dams or weirs built to store water. Inter-basin transfer schemes, like the Tugela-Vaal Scheme and the Lesotho Highlands Water Project, pipe water between catchments to supply large urban populations, agriculture and industry.

Integrated catchment management has brought an ecological perspective to bear on the management of fresh water resources. The National Water Act (RSA, 1998), views fresh water as part of an ecosystem, not simply a resource independent of its environment to be exploited by the most efficient means possible. The law requires provision of what is known as the ecological reserve – sufficient stream flow to support aquatic plants and animals and ensure continuity of ecological processes. In the more arid parts of South Africa where most rivers are ephemeral and flow only after rain, many people rely on underground water from aquifers to supply their domestic and agricultural needs. Groundwater accounts for 15% of water used in South Africa, and supplies about 280 towns and villages. Almost 80% of the ground water supply is used for irrigation (Hoffman & Ashwell, 2001). Water is a key limiting resource in South Africa, in terms of economic growth and meeting basic human

needs. The conservation of water catchments in a good ecological state (i.e. with natural vegetation) is crucial to water quality and quantity (Rouget *et al.*, 2004b).

Total natural water runoff in a catchment (see Figure 2.9), or the amount of water entering stream flow, is determined primarily by the amount of precipitation (see Figure 2.10) and the degree to which this precipitation is intercepted by plant biomass and thereby lost to evapo-transpiration. Runoff thus varies in response to seasonal and inter-annual variation in rainfall, the latter taking place within approximately 9-year cycles of wet and dry years. Seasonal variation is pronounced throughout most of the country, with the rainy season coinciding with the summer growing season for most of the country, with the exception of the winter-rainfall area which encompasses most of the fynbos biome. Total annual runoff can be divided into two main components: low flows and high flows. Both components are vital to the ecological functioning of rivers, the maintenance low flows securing the habitat of aquatic organisms, and the high flows (floods) providing a scouring function which maintains the physical characteristics of the river system. Runoff may be captured in dams ranging from large-scale reservoirs to small farm dams, or may be abstracted directly from rivers (using pumps and weirs) or from groundwater (with boreholes and windmills). All of these methods of water supply are used for agriculture. Industrial needs are met almost entirely from large-scale reservoirs, and domestic supplies are mostly from large schemes and boreholes (Marais *et al.*, 2001).

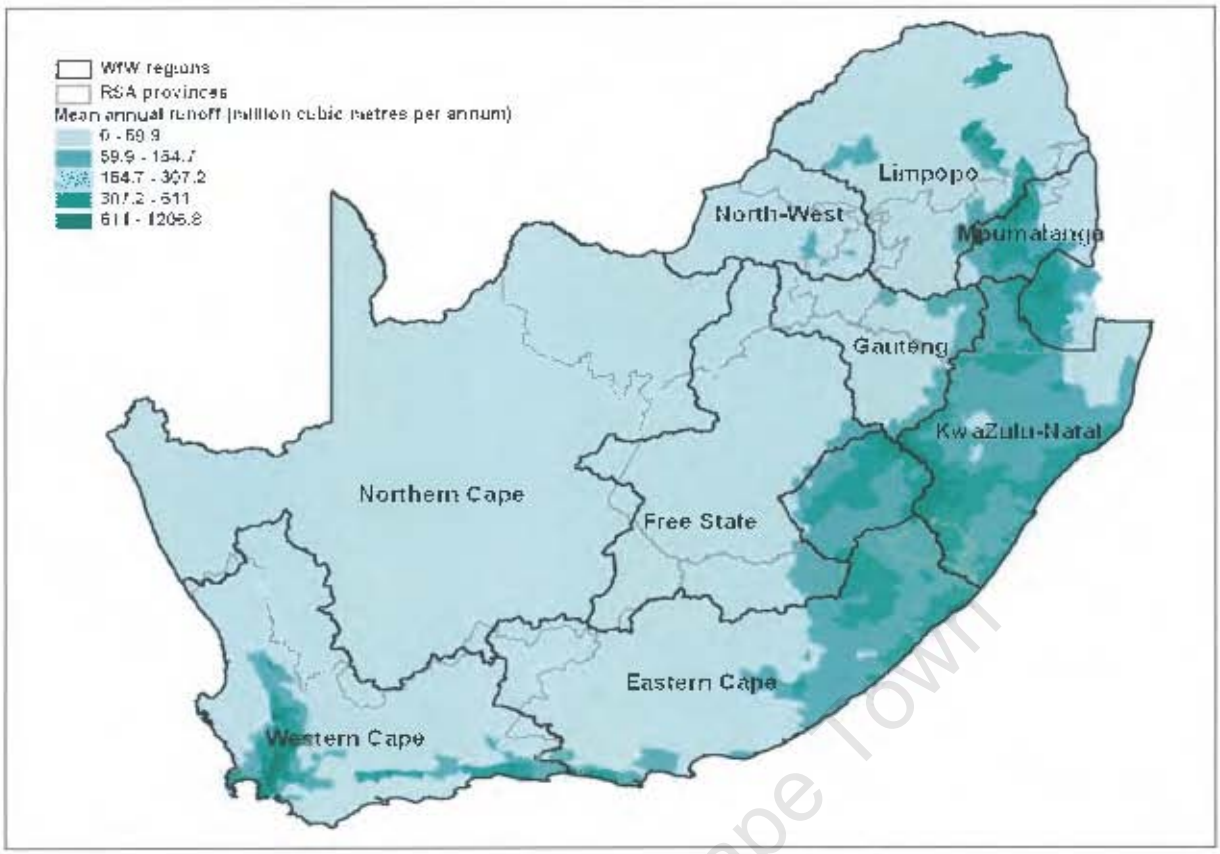

Figure 2.9 Mean annual runoff per quaternary catchment (graduated colour classified by 5 natural breaks) (Midgley *et al.*, 1994)

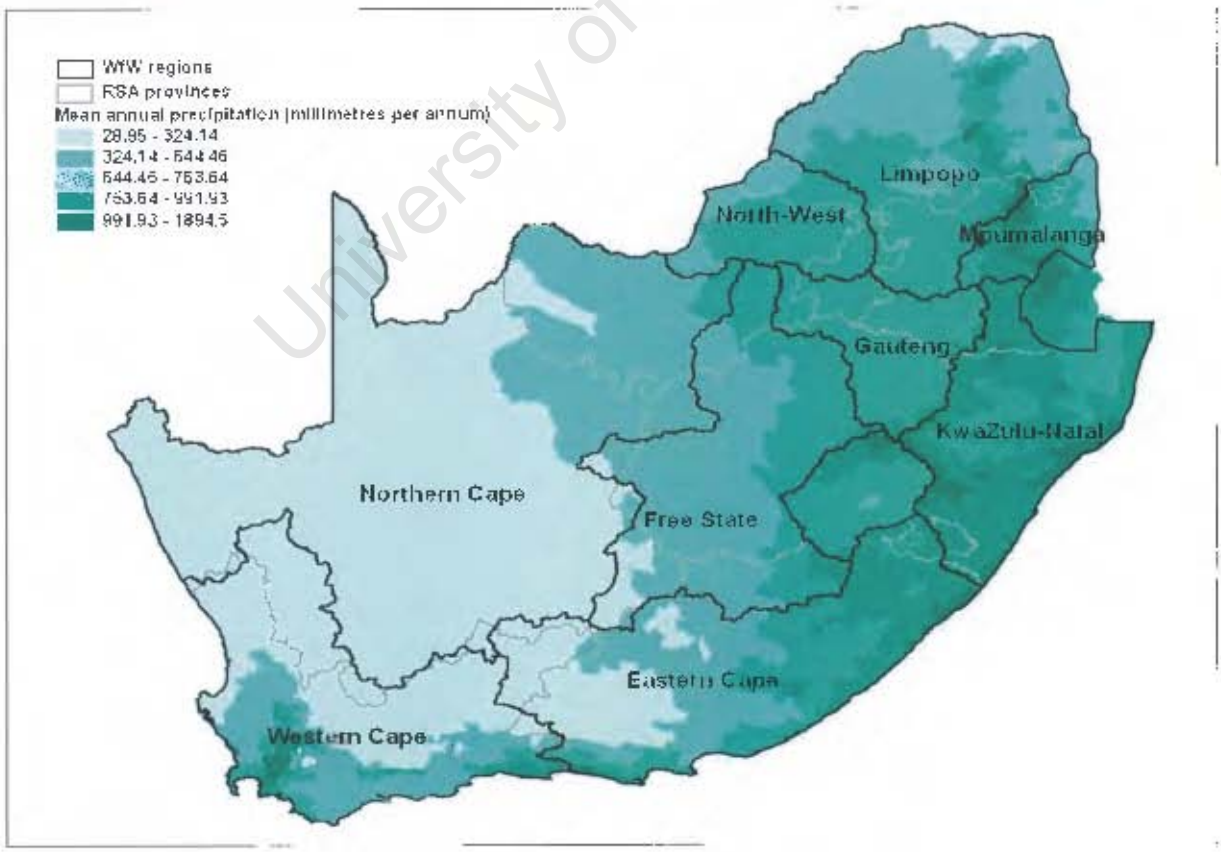

Figure 2.10 Mean annual precipitation per quaternary catchment (graduated colour classified by 5 natural breaks) (Midgley *et al.*, 1994)

Seasonal and inter-annual variability of rainfall has an important effect on the water supply of a catchment. In large schemes, reservoir levels are filled mostly by high flows during the rainy season, and replenishment during high rainfall years may provide water for several years into a dry cycle. Large water supply schemes are constructed taking this variability into account, such that a dam is expected to meet water demands for 7 out of 10 years, on average. A decrease in average runoff would thus lead to increased number of years in which water shortages occur, a situation which can only be prevented by increasing the capacity or number of dams in the catchment (and only up to a point). Note that the decreased capacity of large dams to supply water needs may also arise from sedimentation due to excessive erosion in the catchment, or from increased water demands, as well as from decreased stream flow. Small dams, often constructed on non-perennial streams, are also usually filled by high flows during the wet season. Because of their small capacity, these dams do not benefit from further high flows, which run over the top. Thus small dams rely on sufficient flows to replenish them each year. Direct abstraction from rivers may only occur when rivers are flowing. Farmers using this means of supply are thus most vulnerable to changes in low flows, as they rely on water abstraction mainly during the dry season. Borehole water supplies are only affected by extended droughts over periods of years (Marais *et al.*, 2001).

Le Maitre *et al.* (2000) calculated the incremental water use (i.e. the additional water use compared with the natural vegetation) using the following equation: Water use (mm) = 0.0238 x biomass (g/m^2) which was derived from catchment studies. The total incremental water use of invading alien plants is estimated at 3.300 million m^3 of water per year. About a third of the estimated total water use, by volume, is accounted for by alien invaders in the Western Cape, followed by KwaZulu-Natal (17%), the Eastern Cape (17%) and Mpumalanga (14%). The greatest reduction, as a percentage of mean annual runoff, was found in the arid Northern Cape (17%), followed by the Western Cape (15%) and Gauteng (10%) (Le Maitre *et al.*, 2000). However, the National Water Resources Strategy gives the estimate at 1,400 m^3 (Görgens & Van Wilgen, 2004).

The South African government's policy on invasive alien plants and agriculture is to provide assistance and law enforcement for the appropriate management of the **natural agricultural resources** (RSA, 1995).

Hoffman & Ashwell (2001) conducted an assessment of the contribution to veld degradation by invasive alien plants using mapping by workshop participants at magisterial district scale (Figure 2.11). Rural poverty, historical land distribution policies and inappropriate land use practices have resulted in veld degradation being the most severe in communal areas. The most widespread veld degradation problem in South Africa is change in the composition of plant species. In many communal areas loss of plant cover is a problem. Bush encroachment and alien plants are generally more of a problem in commercial farming areas. Although the communal areas are in greatest need of government support to combat land degradation, it is the commercial farming areas that currently contribute most to South Africa's food security. But the expert knowledge nature of this data was considered too subjective for this study.

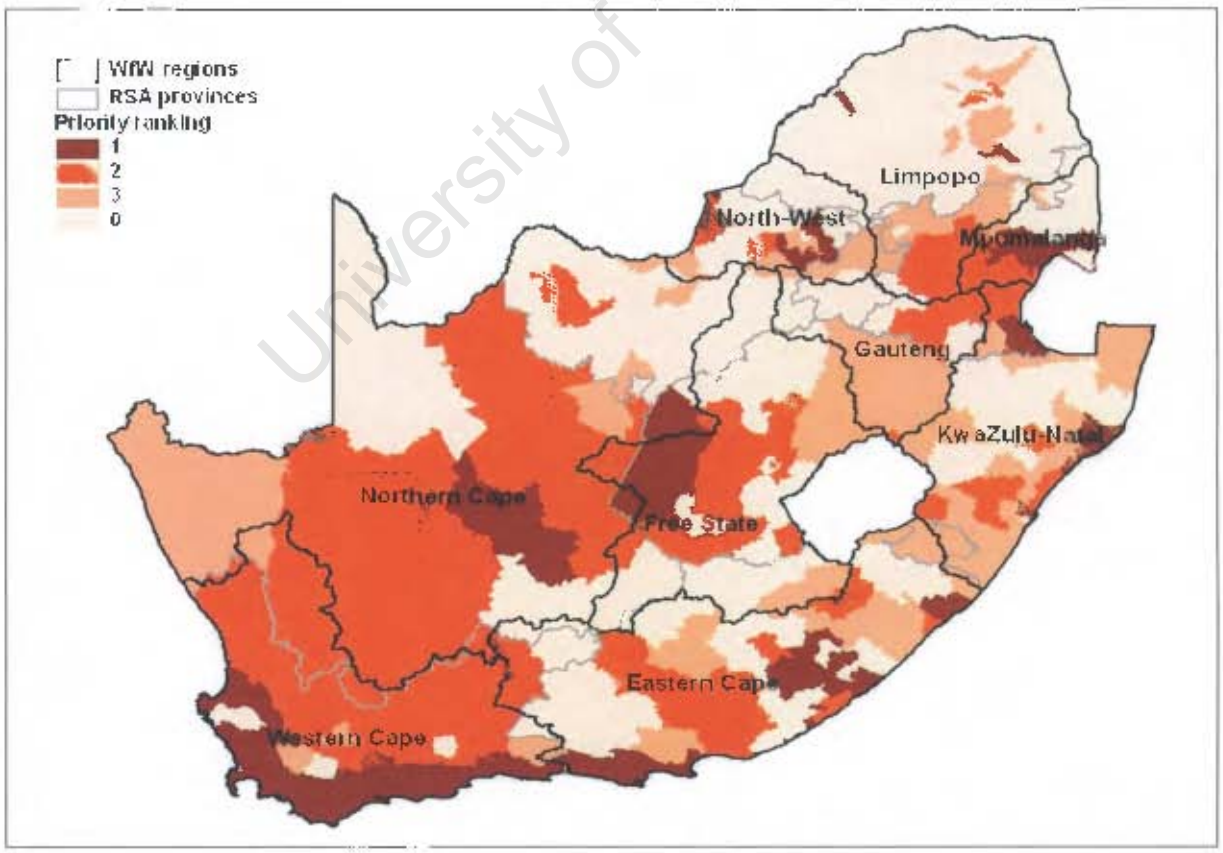

Figure 2.11 The 213 of the total of 367 magisterial districts in South Africa where the contribution to veld degradation by invasive alien plants is considered a priority (Hoffman & Ashwell, 2001).

In summary, the literature recommends that prioritisation for invasive alien plant control should consist of species and area criteria using spatial multi-criteria decision analysis. The criteria for species should be based on available suitable data on species extent and impact. The criteria for area should be based on available suitable data on biodiversity and ecosystem services. The two major ecosystem services that pertain to invasive alien plants are the provisioning service of water yield and the supporting service of primary production.

3. METHODS

The **methods** used were ESRI's (2002) ArcView Version 3.3 GIS software including the "Geoprocessing", "JPEG (JFIF) Image Support" and "Projection Utility Wizard" extensions. All shapefiles were analysed in the Geographic co-ordinate system with Decimal Degree map units and WGS84 spheroid. Where areas had to be calculated, shapefiles were projected into the Transverse Mercator planar co-ordinate system and analysed with the "calcapl.ave" script. Use was also made of Microsoft's Access & Excel Version 2000 database and spreadsheet software and the "Analysis ToolPak" statistical data analysis "Add In" tool.

A list of the **materials** used is summarised in Table 3.1.

Table 3.1 Summary table of spatial data used in this study

Data	Source	Spatial Scale
Quaternary catchments	Midgley *et al.*, 1994	1:50,000
Southern African Plant Invaders Atlas (SAPIA)	Henderson *et al.*, 1998	Quarter degree square (15' latitude x 15' longitude)
Transformed landcover	Fairbanks *et al.*, 2000	1:250,000
Threatened terrestrial ecosystems	Rouget *et al.*, 2004b	1:50,000
Threatened river ecosystems	Nel *et al.*, 2004b	1:50,000
Water yield balance	DWAF, 2004	1:250,000
Primary productivity	Schulze *et al.*, 1997	1:250,000

3.1 Systematic prioritisation (A)

Dataset A was analysed using a **spatial-multi-criteria analysis** approach (Malczewski, 1999). The type of decision in this study is one of selection (i.e. a decision about alternative features to include in a set). Decisions needed to be made that satisfied several objectives that were complementary. Multi-objective decisions can often be solved through a hierarchical extension of the multi-criteria evaluation process (Eastman *et al.*, 1993). The procedure used in this study for the multi-criteria evaluation is **weighted linear combination** (i.e. each factor is multiplied by a weight and then summed to arrive at a final composite index).

The decision problem **goal** of this study is the identification of areas where opportunities to meet individual goals for invasive alien plant control are synergistic. The (multiple) **objectives** in this study are to prioritise by species and area criteria.

The (multiple) **attributes** chosen for this study are:

- Range of terrestrial, transformer species.
- Abundance of terrestrial, transformer species.
- Effect of terrestrial, transformer species.
- Disturbance.
- Terrestrial biodiversity value.
- River biodiversity value.
- Water resource value.
- Natural agricultural resource value.

Each of these attributes is explained and discussed in the sections that follow.

3.1.1 Choice of species

The species were selected from a recently developed list of 117 major invasive alien plant species which are defined by Nel *et al.* (2004a) as species that have already had a substantial impact on natural and semi-natural ecosystems in South Africa, that are likely to constitute the prime concern for managers, and projects aimed at their control should receive the largest proportion of funding over the next few decades.

A subset of major invasive alien plant species are the transformers, taxa that have clear ecosystem impacts. These species have a high impact, as they "change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem". It is these species, comprising perhaps only about 10% of invasive species, that have profound effects on biodiversity and that clearly demand a major allocation of resources for control (Richardson, 2001; Holmes *et al.*, 2003). They are of principal concern to managers (Richardson & van Wilgen, 2004). Transformers are plants that can as monospecies dominate or replace any canopy or sub-canopy layer of a natural or semi-natural, thereby altering it structure, integrity and functioning (Swarbrick, 1991). The most serious environmental weeds are in this group, which includes (terrestrial) trees, aggressive climbers, thicket –forming shrubs

and dense herbs (Henderson, 2001). Van Wilgen *et al.* (2001) use two categories of invaders: "discrete-trait invaders" (DTIs) and "continuous trait invaders" (CTIs). DTIs add a new function, such as nitrogen fixation, to the invaded ecosystem, whereas CTIs differ from natives only in traits, such as litter quality or growth rates, that are distributed continuously among species. Results from several parts of the world show that DTIs generally have greater ecosystem-level impacts than CTI's, although the latter can also bring about such changes, especially if they make up a large proportion of an ecosystem's biomass. The most dramatic effects of alien plants in South African systems have clearly been from DTIs.

Of the 69 transformer species listed in Henderson (2001) the following were excluded from this study:

- 5 because of their aquatic habitat: *Azolla filiculoides*, *Eichhornia crassipes*, *Myriophyllum aquaticum*, *Pistia stratiotes*, *Salvinia molesta.*
- 8 owing to their status as emerging weeds, which as opposed to major weeds currently have a lower impact on natural and semi-natural ecosystems in South Africa (i.e. a lower product of range, abundance and effect) and are currently afforded lower priority in management (Nel at al., 2004a): *Cinnamomum camphora, Eucalyptus grandis, Nasella tenuissima, Nephrolepis exaltata, Pereskia aculeata, Pennisetum purpureum, Pinus taeda, Rosa rubiginosa.*

The final list of 56 species (Appendix 1) was compared with 6 other lists of high impact species. These were:

- Wells *et al.* (1986b) lists 43 (terrestrial) transformer invasive alien species
- Richardson *et al.* (1997) lists 80 (terrestrial) important environmental weeds
- Versfeld *et al.* (1998) lists 40 species considered to be significant water users
- Robertson *et al.* (2003) lists 56 prioritised (terrestrial) species
- Holmes *et al.* (2003) lists 29 fast-spreading/ transformer species
- Nel *et al.* (2004a) lists 111 (terrestrial) major invaders

Because impact of invasive alien species is defined as the product of a species' **range**, **abundance** and per capita **effect** (Parker *et al.*, 1999; Richardson & van Wilgen, 2004) a coverage for each of these components was created. But because Parker *et al.* (1999) concede that the linear way the equation has been formulated is

probably a gross oversimplification, I defined impact as the sum of a species' range, abundance and per capita effect.

3.1.2 Range of terrestrial, transformer species

The most comprehensive set of range records for the whole country is the SAPIA database (Henderson, 1998; Richardson & van Wilgen, 2004). This atlas comprises nearly 50,000 invasive alien plant records for more than 500 species, incorporating records from roadside surveys carried out between 1979 and 1993, and the SAPIA project (1994–1998), as well as records collected on an *ad hoc* basis from 1999 onwards (Henderson 1998; Nel *et al.* 2004a). Records are entries that note the presence, and abundance, of a species in quarter-degree square grid cells (15' latitude x 15' longitude).

Each species was queried in the SAPIA MSAccess database, those recorded as present exported into an MSExcel spreadsheet and added as a field in the attribute table of coverage of quarter-degree square grid cells. A new field was created and the count of all species recorded per quarter-degree square grid cell calculated. The coverages for quarter-degree square grid cells containing the number of species present data and quaternary catchments were overlaid to create a new theme containing the features and attributes of both. Then a summary table was created using the quaternary catchment field and the maximum number of species that were recorded as present in overlapping quarter-degree square grid cells.

A limitation of the data is the re-scaling of the data in that the number of species per quarter degree square was assumed to occur throughout the quarter degree square and was allocated to each quaternary catchment polygon intersecting that quarter degree square. There are 1,810 quarter degree squares and 1,825 quaternary catchments, respectively, that have their centres in the boundaries of South Africa.

3.1.3 Abundance of terrestrial, transformer species

The only systematic source of data on species abundance also comes from the SAPIA database (Henderson, 1998), which records the abundance of species as "rare" (one sighting of one or a few plants), "occasional" (a few sightings of one or a few plants), "frequent" (many sightings of single plants or small groups), "abundant"

(many sightings of clumps or closed stands) and "very abundant" (forming extensive stands) (Richardson & van Wilgen, 2004; Nel *et al.*, 2004a).

Each species was queried in the SAPIA MSAccess database, those recorded as "very abundant" or "abundant" exported into an MSExcel spreadsheet and added as a field in the attribute table of a coverage of quarter-degree square grid cells. A new field was created and the sum of all species recorded per quarter-degree square grid cell calculated. The coverages for quarter-degree square grid cells containing abundance species present and the quaternary catchments were overlaid to create a new theme containing the features and attributes of both. Then a summary table was created using the quaternary catchment field and the maximum number of species that were recorded as present in overlapping quarter-degree square grid cells.

A limitation of the data, apart from the re-scaling assumption, is that records where the species was recorded as "rare", "occasional" and "frequent" were omitted in an effort to place the emphasis on the most abundant species.

3.1.4 Effects of terrestrial, transformer species

The development of an understanding of environmental effects of invasive alien plants would be extremely useful. Unfortunately, no standard system exists for the objective quantification of the many and varied environmental effects of invasive alien plants worldwide. As in other parts of the world, effects of plant invasions in South Africa have been measured in numerous ways, making comparisons between biomes within a region, or with other regions or countries, difficult. Many descriptions of impacts are anecdotal or correlative (comparing invaded sites with uninvaded sites, or comparing one site at different times), or are based on the performance of the invader in other parts of the world. Very few detailed studies, and no manipulative experiments, have been done to determine the magnitude, mechanisms of effects, and implications of effects of invasive alien plants in South Africa. Nevertheless, some conclusions can be drawn as to the types and magnitudes of effects caused by the most important plant invaders (Parker *et al.*, 1999; Van Wilgen *et al.*, 2001 Richardson & van Wilgen, 2004).

Data on the effects of species were collected from literature and assigned to one or all of three categories: "ecological effect", "hydrological effect" and/or "agricultural

effect" (APPENDIX 1). Species assigned to the "ecological effect" category were those catalogued by Wells *et al.* (1986a) as being a conservation "kind of weed". Species assigned to the "hydrological effect" category were those listed by Versfeld *et al.* (1998) as "significant water users" or included by Van Wilgen *et al.* (2001) as having an effect that "decreases streamflow". Species assigned to the "agricultural effect" category were those listed by Hoffman & Ashwell (2001) as having an "effect on agricultural production" or catalogued by Wells *et al.* (1986a) as being a "pastoral (natural)" "kind of weed". Although most alien invasive plants occur in natural pastures, they were not considered by Wells *et al.* (1986a) to be "pastoral (natural)" weeds unless they were considered to interfere with the pasture industry by having one or more of the following undesirable characteristics: replacing preferred vegetation (grass), (more palatable element), poisonous, tainting (milk), (meat), unpalatable, irritant (skin), sticky (fruit), thorny (fruit), contaminant (fodder), (wool), causing physical injury, obstructive (access), (digestion) etc.

Each species recorded in APPENDIX 1 as having three effects was added in the attribute table of a coverage of quarter-degree square grid cells where that species was also recorded as being present. A new field was created and the count of all species recorded in a quarter-degree square grid cell calculated. The coverages for quarter-degree square grid cells containing the number of species with 3 effects were overlaid with quaternary catchments to create a new theme containing the features and attributes of both. Then a summary table was created using the quaternary catchment field and the maximum number of species.

A limitation of the data, apart from the re-scaling assumption, is that the following 8 terrestrial, transformer species had no documented effects in the above literature: *Campuloclinium macrocephalum, Cardiospermum grandiflorum, Hedychium coccineum/gardnerianum, Hedychium coronarium/flavescens, Ipomoea alba/indica, Litsea glutinosa, Macfadyena unguis-cati* and *Salix fragilis*. Also species having only one or two effects were omitted in an effort to place the emphasis on species with the most effects. However, a larger number of effects does not necessarily mean a greater overall effect of the species concerned. Although the Parker *et al.* (1999) model assumes that the individual contributions of the range, abundance and effect are all multiplicative, Le Maitre *et al.*, (in prep.) argue that the data needed to

substantiate this are lacking and adopted a conservative approach that assumed that the characteristics contributing to the effect scores are additive.

3.1.5 Disturbance

A total of 16% (13.5% cultivated, 1.5% forest plantation, 1.1% urban and 0.1% mines & quarries) of South Africa has been transformed and 6% degraded (Fairbanks *et al.*, 2000).

Areas where natural habitat has been irreversibly lost as a result of various types of land use were identified using the 1996 National Land Cover database (Fairbanks *et al.*, 2000) as the 2000 National Land Cover database was not available at the time of writing. The 1996 National Land Cover database was derived from the interpretation of 1996 LANDSAT 5 TM satellite imagery and was released in 2000. The 1996 National Land Cover database has 31 landcover classes. The following 12 landcover classes were selected and converted to a separate shapefile of "untransformed" areas: Forest & Woodland, Forest, Thicket & bushland, Shrubland and low Fynbos, Herbland, Unimproved grassland, Dongas & sheet erosion scars, Degraded: forest and woodland, Degraded: thicket & bushland, Degraded: unimproved grassland, Degraded: shrubland and low Fynbos, Degraded: herbland.

Both the "untransformed" areas and quaternary catchments coverages were overlaid to create a new theme containing the features and attributes of both. Then, this new theme was projected into planar co-ordinates, the areas updated and re-projected into geographic co-ordinates. Lastly, a summary table was created using the quaternary catchment field and the sum of untransformed areas. Then a new field was created and the percentage of untransformed area per quaternary catchment calculated.

A limitation of the data is that the "degraded" classes were included as "untransformed". This was done because the mapping of "degraded" classes was not considered consistent across the country by Rouget *et al.* (2004b). Also, we know that further loss of natural habitat has taken place since 1996, particularly in some areas of KwaZulu-Natal and the Western Cape. Thus this layer represents an underestimate of irreversible loss of natural habitat (Rouget *et al.*, 2004b).

3.1.6 Terrestrial biodiversity value

The identification of conservation priorities, at a vegetation type level, should at least take into consideration the following factors: plant species diversity and turnover, habitat transformation and current protection levels. Ecosystem status takes into account the first two, species diversity and turnover (through biodiversity targets), and habitat transformation. Ecosystem status aims at identifying threatened ecosystems (here vegetation types). It is based on the classification scheme developed by IUCN to categorise species into, among other categories, "critically endangered", "endangered", and "vulnerable" species (Rouget *et al.*, 2004b).

Focusing conservation efforts on threatened species is crucial for maintaining biodiversity. However, conserving the natural habitats and functioning ecosystems in which species occur will ensure species persistence. The identification of threatened ecosystems aims to address this. The recognition of threatened ecosystems by international organisations such as IUCN and national governments could prove to be a powerful conservation tool. It is envisaged that specific land-use restrictions will be applied in threatened ecosystems.

Although the Biodiversity Act in South Africa (RSA, 2004) allows for the listing of threatened ecosystems, no standard approach for identifying them has been suggested. The approach used by Rouget *et al.* (2004b) focuses on the retention of ecosystem functioning (such as pollination, nutrient cycling) and plant species diversity at the landscape scale. Rouget *et al.* (2004b) made use of the Mucina & Rutherford (2004) vegetation map consisting of 441 vegetation types and 17,809 polygons in South Africa, Lesotho and Swaziland. The area of the vegetation types ranges from 21 ha to 4,982,132 ha. This map is the best attempt to map vegetation patterns at a relatively fine scale for South Africa, Lesotho and Swaziland. It is a considerable improvement on the previous vegetation map available (Low & Rebelo, 1996), which identified only 69 vegetation types at a much coarser scale. These vegetation types were classified based on the extent of remaining area (currently not transformed) of each vegetation type in relation to its biodiversity target. Rouget *et al.* (2004b) recognise that this approach is simplistic and that many other factors should be taken into account (such as habitat degradation), but that this represents the first attempt towards deriving an objective and defensible method for the identification of threatened ecosystems.

- "Critically endangered" vegetation types have been transformed to such an extent that the remaining habitat is less than that required to represent 75% of species diversity (i.e. the biodiversity target); in other words, one would expect species loss to take place in such vegetation type.
- "Endangered" vegetation types have lost more than 40% of their original extent and are exposed to partial loss of ecosystem function.
- "Vulnerable" vegetation types have lost more than 20% of their original extent, which could result in some ecosystem functions being altered.
- No significant disruption of ecosystem functioning is assumed in "least threatened" vegetation types, which still have more than 80% of their original extent untransformed.

Of the 438 vegetation types classified (lagoons and lake systems were ignored) 21 (5%) were "critically endangered", 58 (13%) were "endangered", 70 (16%) were "vulnerable", and 289 (66%) were not threatened. Of the "critically endangered" vegetation types, 14 are in the fynbos biome, five are in the forest biome, one is in the grassland biome, and one is a wetland vegetation type.

All "critically endangered" and "endangered" vegetation types were selected from the Rouget *et al.* (2004b) coverage and converted to a new shapefile. Then, this new shapefile and the "transformed" areas coverages were overlaid to create a new theme containing the features and attributes of both. Next, all "untransformed", "critically endangered" and "endangered" vegetation types were selected and converted to a new shapefile. Then, this new shapefile was projected into planar co-ordinates, the areas updated and re-projected into geographic co-ordinates. Lastly a summary table was created using the quaternary catchment field and the sum of untransformed, critically endangered and endangered vegetation types. Then a new field was created and the percentage of untransformed, critically endangered and endangered vegetation types per quaternary catchment calculated.

A limitation of the data is that vegetation types classified as "vulnerable" or "least threatened" were omitted in an effort to place the emphasis on the most endangered vegetation types. A limitation of the threatened ecosystems approach is that it could be argued that ecosystems that have lost greater than 75% of their original natural

habitats should not get the highest priority, and that a focus on ecosystems that are more intact would be a better option for the conservation of biodiversity. Relatively intact systems would arguably harbour more valuable biodiversity than less intact systems, and should therefore be assigned a higher priority. The rationale for placing a higher priority on ecosystems that have experienced a high degree of habitat loss is related to the goal of achieving targets with regard to biodiversity conservation. In South Africa targets have been set to conserve a representative sample of each ecosystem (Driver *et al.*, 2005). If such targets are to be achieved, then it would be necessary to place a higher priority on those systems where a high degree of loss had already been experienced, and where the options for conservation of what remains are limited.

3.1.7 River biodiversity value

For identifying threatened river ecosystems, the approach used by Nel *et al.* (2004b) focuses on the retention of ecosystem functioning (such as trophic interactions and nutrient cycling) and aquatic species diversity at the landscape scale. River conservation status was derived based on the extent of remaining intact (natural or near-natural) river length of each river heterogeneity signature in relation to its biodiversity target. These signatures were derived from geomorphological and hydrological characteristics (including flow variation and baseflow). Although the approach adopted by Nel *et al.* (2004b) is very simplistic and many other factors need to be taken into account (such as connectivity), it represents the first attempt towards deriving an objective method for the identification of threatened riverine ecosystems.

Focusing conservation efforts on threatened species is crucial for maintaining biodiversity. However, to ensure species persistence, it is crucial to conserve the natural habitats in which these species occur. The identification of threatened ecosystems is aimed at addressing this need. The recognition of threatened ecosystems by national government could prove to be a very powerful conservation tool, since it is envisaged that specific land use restrictions will be enforced in threatened ecosystems. From a river policy and management perspective, it would be even more powerful if future approaches were able to match the threatened ecosystem classes (critically endangered, endangered, vulnerable and least threatened) with the water classification classes (e.g. natural, moderately impacted,

heavily impacted and unacceptably degraded). This will facilitate the integrated management of South Africa's threatened terrestrial and aquatic natural resources.

The approach to identifying the conservation status of ecosystems is based on the loss of integrity and the subsequent loss of habitat in each ecosystem, relative to two thresholds: one for maintaining healthy ecosystem functioning, and one for conserving the majority of species associated with the ecosystem. As river integrity is eroded and habitat is lost in an ecosystem, its functioning is increasingly compromised, leading eventually to the collapse of the ecosystem and to loss of species associated with that ecosystem.

River heterogeneity signatures were combined spatially with river integrity data to calculate the intact length of each river heterogeneity signature. Intact length was compared to the total length of each river heterogeneity signature to derive conservation status categories of each signature, where:

- "Least threatened" river heterogeneity signatures have an intact length ≥ 60% of their total length;
- "Vulnerable" river heterogeneity signatures have an intact length ≥ 40% of their total length;
- "Endangered" river heterogeneity signatures have an intact length ≥ their conservation target (in this case, 10% of their total length);
- "Critically endangered" river heterogeneity signatures have an intact length below their conservation target (in this case 10% of their total length);

"Critically endangered" ecosystems have lost so much of their original natural habitat that ecosystem functioning has broken down and species associated with the ecosystem have been lost or are likely to be lost. "Endangered" ecosystems have lost significant amounts of their original natural habitat, so their functioning is compromised. "Vulnerable" ecosystems have lost some of their original natural habitat, and their functioning will be compromised if they continue to lose natural habitat. "Least threatened" ecosystems have lost only a small proportion of their original natural habitat, and are largely intact (although they may be degraded to varying degrees).

Of South Africa's 120 individual river signatures, 44% were assessed, in terms of habitat loss, as being "critically endangered", 27% as "endangered", 11% as "vulnerable", and 18% as "least threatened" (Nel *et al.*, 2004).

All "critically endangered" and "endangered" rivers were selected from the Nel *et al.* (2004b) coverage and converted to a new shapefile. Lastly, a summary table was created using the quaternary catchment field and the sum of critically endangered and endangered rivers. Then a new field was created and the percentage of critically endangered and endangered rivers per total length of mainstem rivers occurring in the quaternary catchment calculated. All rivers were at the same spatial scale and deemed to have undergone similar generalization.

A limitation of the data, apart from the threatened ecosystems approach, is that rivers classified as "vulnerable" or "least threatened" were omitted in an effort to place the emphasis on the most endangered river ecosystems.

3.1.8 Water resource value

In Appendix D of the National Water Resource Strategy (DWAF, 2004) water management areas were divided into 87 sub-areas to enable improved representation of the water resources situation in the country and to facilitate the applicability and better use of information for strategic management purposes. Delineation of the sub-areas was based on practical considerations such as the size and location of sub-catchments, the homogeneity of natural characteristics, the location of pertinent water infrastructure such as dams, and economic development.

Fresh water results from precipitation in the form of rain, fog, hail and snow. Water that can potentially be abstracted for use runs off the land surface to appear in streams and lakes, as well as infiltrating to become groundwater. In natural equilibrium, that is, before interference by humankind, the water that is seen on the land surface is the integrated result of surface and groundwater. The total quantity of surface flow which is the average annual runoff originating from a certain geographic area is referred to as the mean annual runoff (MAR).

Water that can reliably be withdrawn from a water source at a relatively constant rate is referred to as the yield. Owing to the erratic and unreliable nature of river flow in

South Africa, only a small portion of the MAR is available as yield in its natural unregulated state. By storing water during periods of high flow for abstraction when natural stream flows are lower, the yield is increased.

As indicated above, surface water and groundwater form part of the same hydrologic continuum – the hydrological cycle - and merely represent different manifestations of water in its natural state. Abstraction of groundwater therefore generally does not represent an additional source to surface water. However, groundwater does offer an alternative means of accessing the water resource and has the advantage of wide geographic availability and, typically, a smaller temporal variation than surface water. The combined use of surface and groundwater increases the proportion of water available as practical usable yield.

For the purposes of the NWRS, available water is defined as the total quantity of water that can be available for practical application to desired uses. It includes the yield from surface water and groundwater, as well as return flows from the non-consumptive use of water and water transferred from one catchment to another. The quantity of available water further depends on the location of use and the assurance of supply at which it is required, while the quality of water in relation to the quality requirements for particular uses has a direct bearing on the usability of the water. In the NWRS all yields and requirements have been standardised at a 98 per cent assurance of supply, that is, a risk of some level of failure during two out of 100 years on average. Actual water allocations must, however, take into account the required assurance of supply for specific uses.

In contrast to domestic and economic uses of water, where relatively constant availability is required, unregulated flows are preferred for ecological purposes, as these display the natural variability to which ecosystems have adapted. Water to meet ecological requirements is required to remain within the water body and is therefore not regarded as water that is available for other uses. In highly regulated systems the unregulated portion of streamflow that remains after other uses have been satisfied may not be sufficient to meet the requirements for the ecological component of the Reserve. These flows will then have to be augmented from the yield, which will result in a corresponding reduction of the water available for other purposes.

Water deficits exist in more than half of the water management areas in South Africa although the results of the National Water Resource Strategy show that a surplus still exists for the country as a whole.

A coverage of the water yield balance per quaternary catchment was created by dividing the quaternary catchment coverage into the 87 sub-areas (shown in the hardcopy maps of Appendix D of the National Water Resource Strategy (DWAF, 2004). These corresponded largely to the secondary water catchments. Then the figures provided in the water yield balance columns of Appendix D of the National Water Resource Strategy (DWAF, 2004) were captured per sub-area.

A limitation of the data is the assumption that water yield balance was distributed evenly among all quaternary catchments that were contained in each of the 87 sub-areas polygons.

3.1.9 Natural agricultural resource value

Primary productivity can be expressed as the harvestable yield in tons per hectare at a specific location for a complete growing season. The original concept is based on the combination of rainfall, evaporation, vegetation and soil characteristics. Primary productivity gives an indication of the ability of the land to produce crops or the ability of the natural biomes to produce vegetation essential to sustain game, cattle, sheep or goats. It is therefore a very important factor in the quest for sustainable use of the environment and economic activity (Schulze *et al.*, 1997).

The Schulze *et al.* (1997) coverage of primary production was sourced from the Environmental Potential Atlas for South Africa (ENPAT) (van Riet *et al.*,1997).

The coverages for primary production and quaternary catchment were overlaid to create a new theme containing the features and attributes of both. Then, a summary table was created using the quaternary catchment field and primary production units.

A limitation of the data is the assumption that primary productivity was distributed evenly among all quaternary catchments that were contained in each of the 94 primary production polygons.

3.1.10 *Systematic prioritisation composite*

The **decision rule** for this study using the analytic hierarchy process method is shown in figure 3.1. The weighting of the complementary (multiple) objectives of species and areas was made to place two-thirds of the emphasis on the area criteria based as the majority of the literature supports an area-lead approach. A separate field was created in the quaternary shapefile for each of the eight attributes (Figure 3.2). Then each record of an attribute was "standardised" by expressing it on a scale of 0-1 by dividing its value by the highest value in that field, to allow for comparison of values that have different units, value and ranges. Finally, guided by the WfW policy that equal weighting had to be given to ecological, hydrological and agricultural impacts of invasive alien plants in the prioritization of work (owing to the uncertainty of relative magnitude of each attribute), each attribute was weighted equally by multiplying it by the factor 0.125 (1/8) and combined into a composite index (WfW, 2004b).

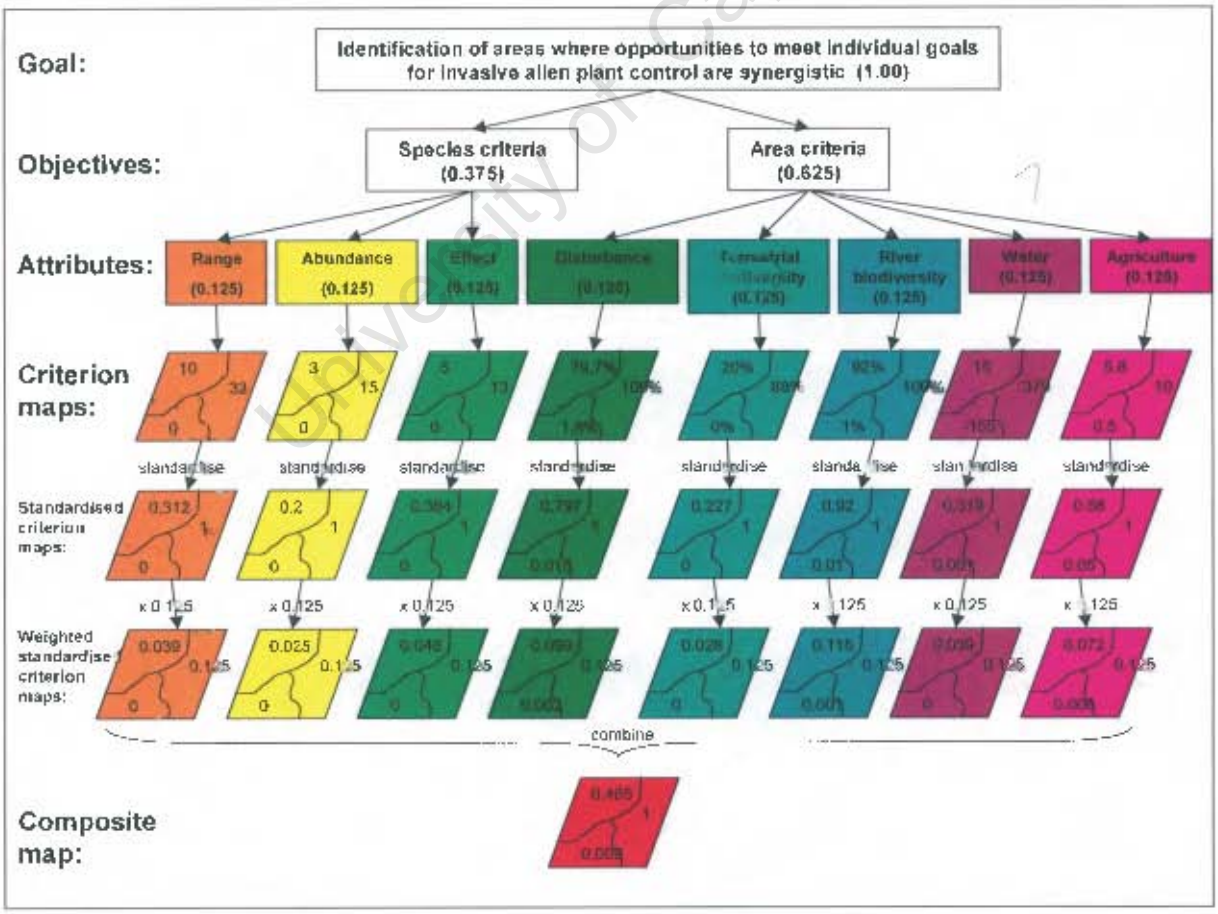

Figure 3.1 The decision rule for this study using the analytic hierarchy process method

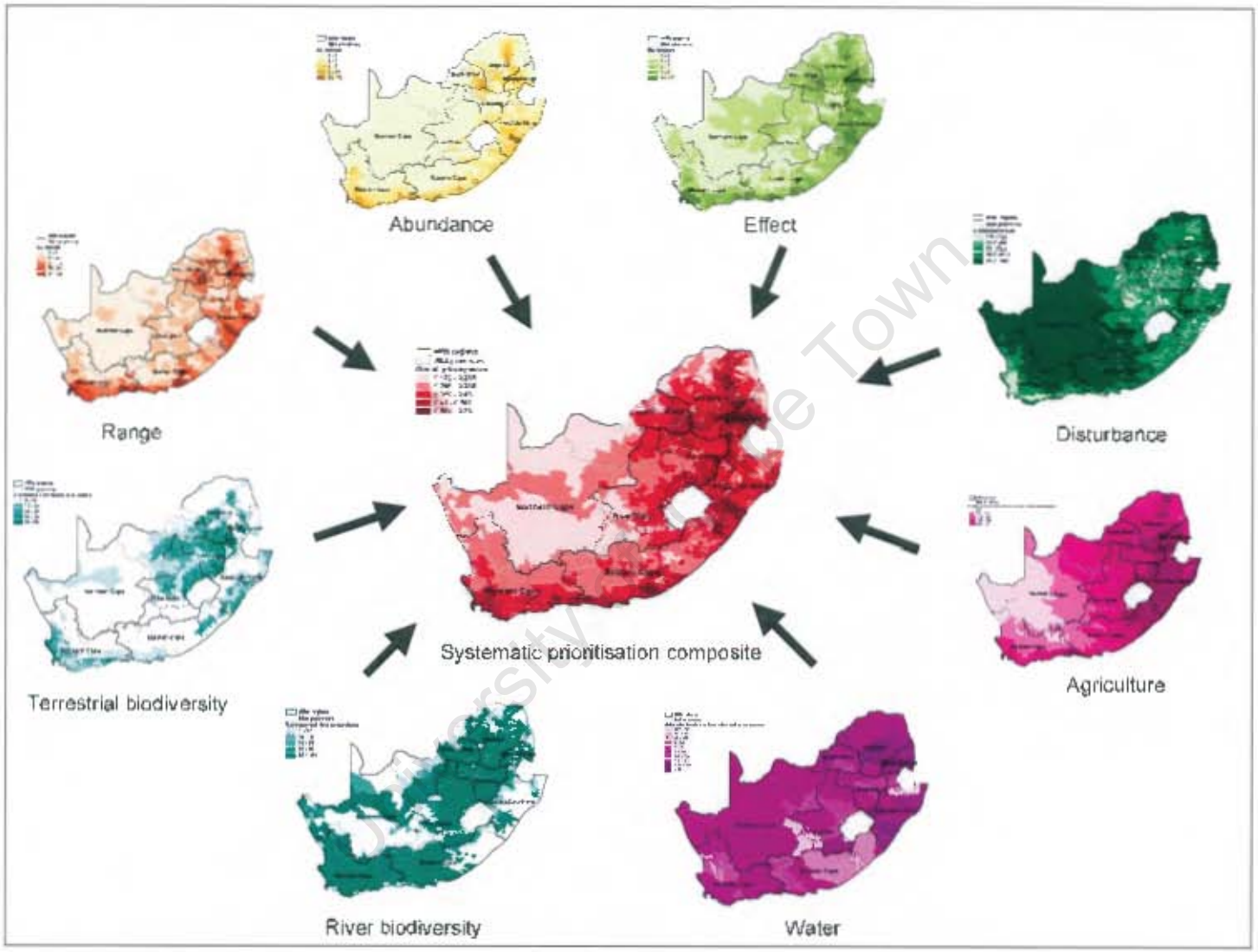

Figure 3.2 The 8 criteria that were weighted and combined to make up the systematic prioritisation composite (individual composites shown in chapter 4)

3.2 WfW prioritisation (B)

WfW operational project expenditure is defined as the annual expenditure on wages, herbicide, transport, personal protective equipment and equipment & consumables costs that are directly attributed to a WfW project as opposed to the annual management expenditure which includes management salaries & transport, training & social development, biological control and mapping costs and cannot be directly attributed to a WfW project. WfW operational project expenditure accounts for about 70% of WfW total expenditure (Marais *et al.*, 2004). An annual operational project expenditure amount in 2006 Rands was extracted from the 4th quarter 2005/6 Expanded Public Works Programme (EPWP) Monitoring an Evaluation spreadsheet (DPW, 2006) per WfW project.

The boundaries of each WfW project were extracted from the *Working for Water* Information Management System (WIMS) and merged to create a national coverage of all WfW projects. The attribute table of the coverage of all WfW projects was then populated with the annual operational project expenditure amount in 2006 Rands. Where a WfW project did not follow quaternary catchment boundaries, the quaternary catchments that "intersect" these WfW projects were selected and added to the coverage of all WfW projects.

A limitation of this data is that where a WfW project included more than one quaternary catchment it was assumed that the expenditure was evenly distributed among all quaternary catchments included. Also, using operational project expenditure as an indicator of "invested resources" is that it does not account for differences in species and workload. More persondays per unit area (and therefore greater expenditure) are required for higher densities and larger size classes. Another limitation is the assumption that the 2006 operation project expenditure equates with priority when expenditure for some projects initiated at the inception of the programme in 1995 has decreased owing to the less expensive nature of follow-up clearing versus initial clearing and regional re-prioritisation.

3.3 Systematic vs. WfW prioritisations (A vs. B)

The systematic prioritisation was compared to the WfW prioritisation using a correlation matrix (Parsons & Knight, 1995) generated by the Microsoft's Excel "Analysis ToolPak" statistical data analysis "Add In" tool.

The data was then considered at a WfW regional scale to allow for a comparison relative to the data for each WfW region. This was done by extracting the data per WfW region and recalculating the overall priority scores. This meant that each record of an attribute had to be "standardised" by re-expressing it on a scale of 0-1 by dividing its value by the new highest value in that field. A comparison of each region was then conducted using a correlation matrix per WfW region.

4. RESULTS & DISCUSSION

4.1 Systematic prioritisation (A)

4.1.1 Choice of species

The proportion of the 56 species selected for this study that occur on other national invasive alien plant lists is shown in figure 4.1. The data for this figure is presented in APPENDIX 2. The relatively close correspondence between the species selected for this study and lists compiled using other data sources and criteria, demonstrates that there is general agreement on which are the most important species.

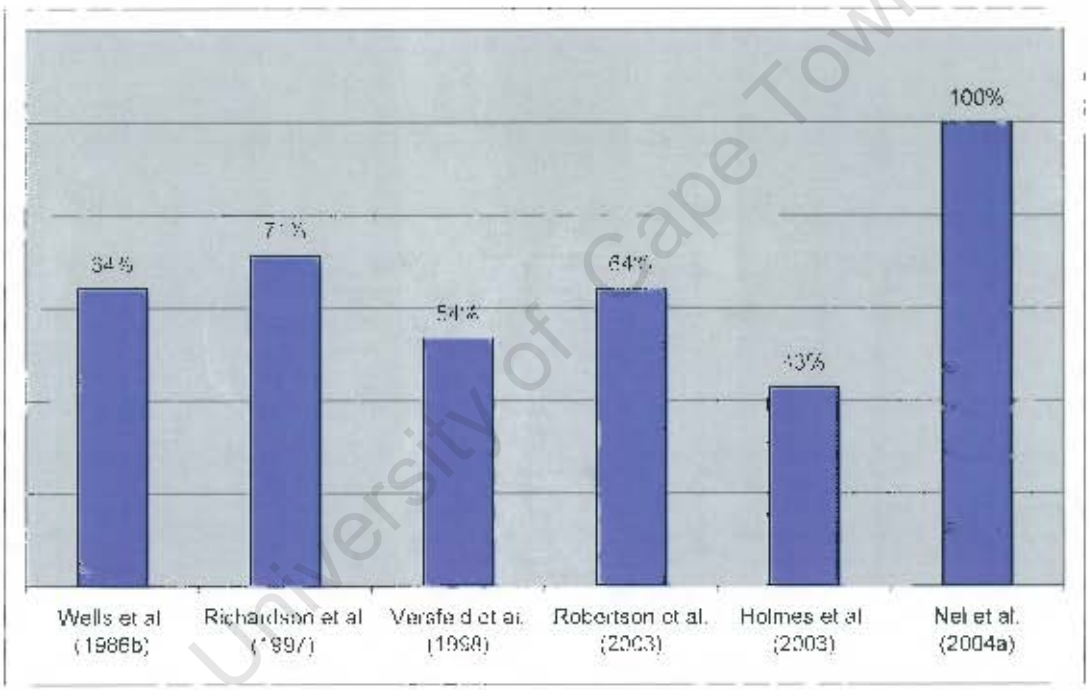

Figure 4.1 Proportion of 56 species selected that occur on other national invasive alien plant lists (arranged in chronological order).

4.1.2 Range of terrestrial, transformer species

The number of terrestrial, transformer species per quaternary catchment is shown in figure 4.2. There was a mean of 10 species oer quaternary catchment.

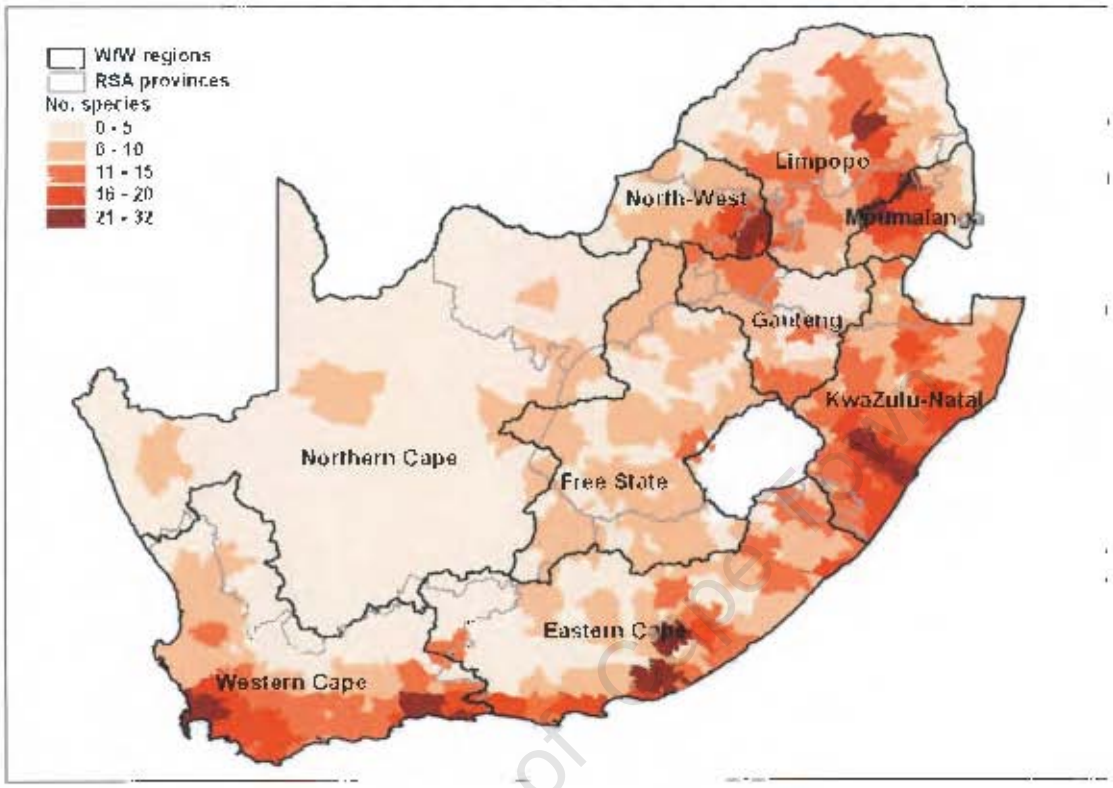

Figure 4.2 Range of terrestrial, transformer species per quaternary catchment (graduated colour classified by 5 natural breaks).

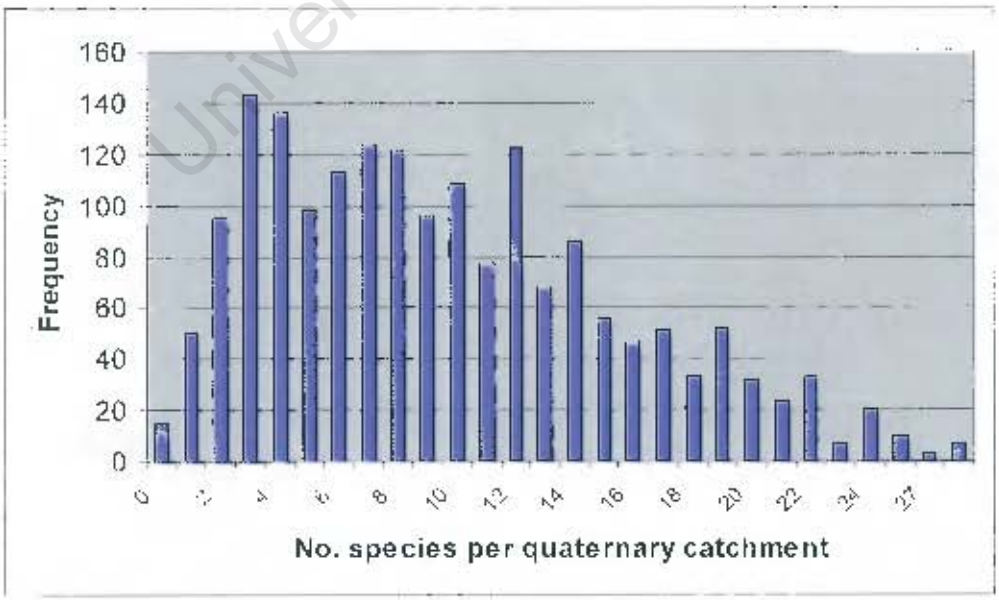

Figure 4.3 Frequency histogram for the number of terrestrial, transformer species per quaternary catchment.

4.1.3 Abundance of terrestrial, transformer species

The number of terrestrial, transformer species per quaternary catchment is shown in figure 4.4. There was a mean of 3 species per quaternary catchment .

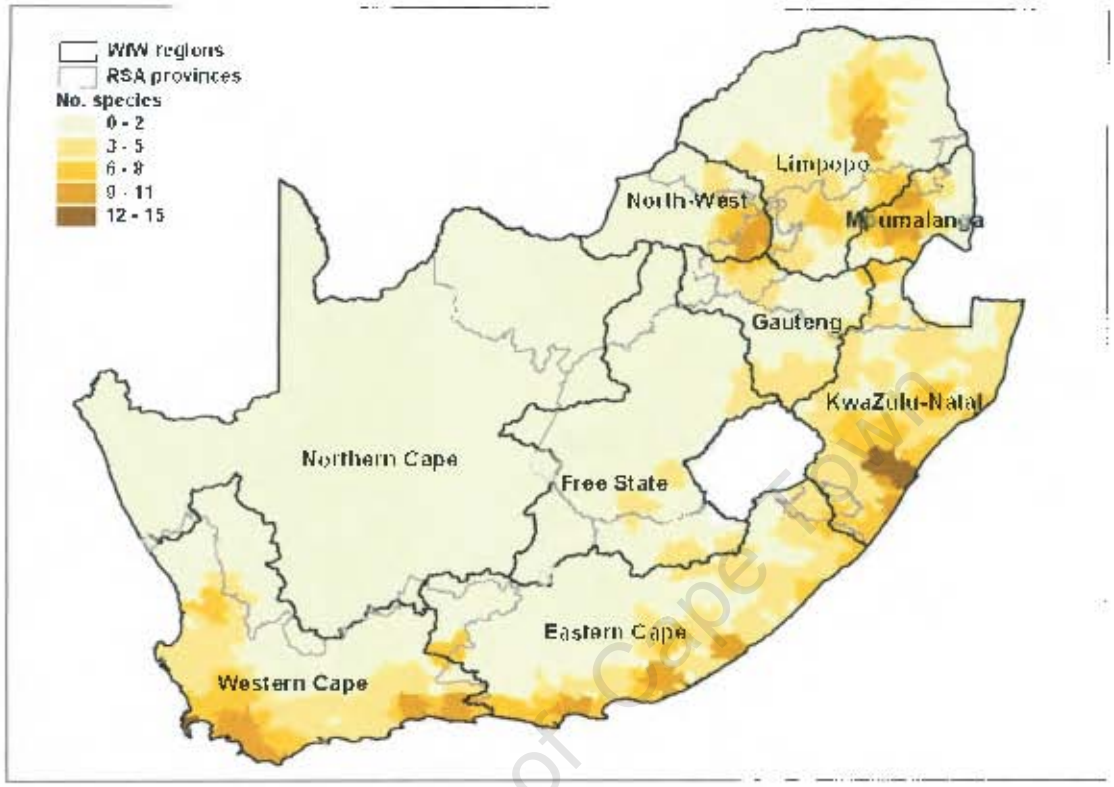

Figure 4.4 Abundance of terrestrial, transformer species per quaternary catchment (graduated colour classified by 5 natural breaks).

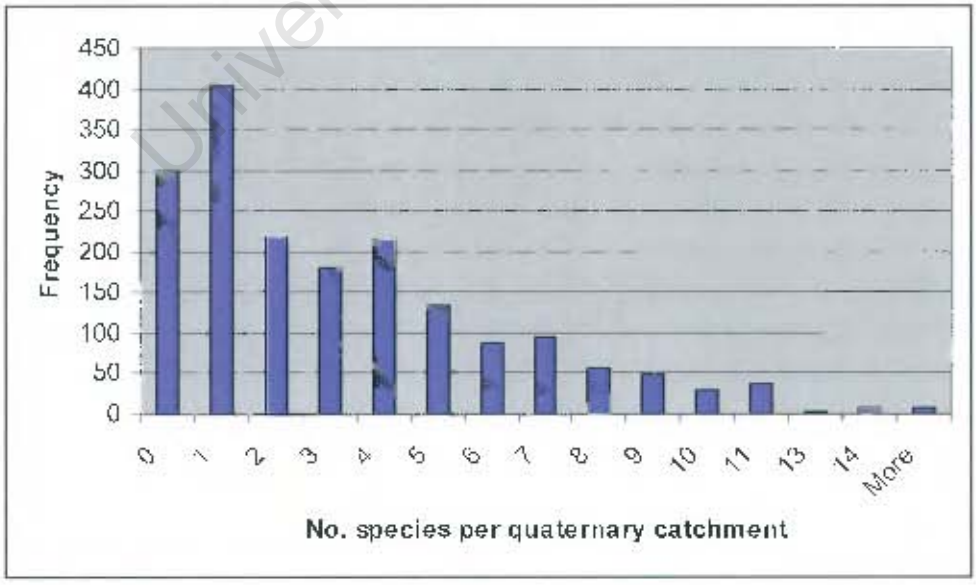

Figure 4.5 Frequency histogram for number of abundant terrestrial, transformer species per quaternary catchment

4.1.4 Effects of terrestrial, transformer species

The number of terrestrial, transformer species with 3 effects per quaternary catchment is shown in figure 4.6. There was a mean of 5 species per quaternary catchment.

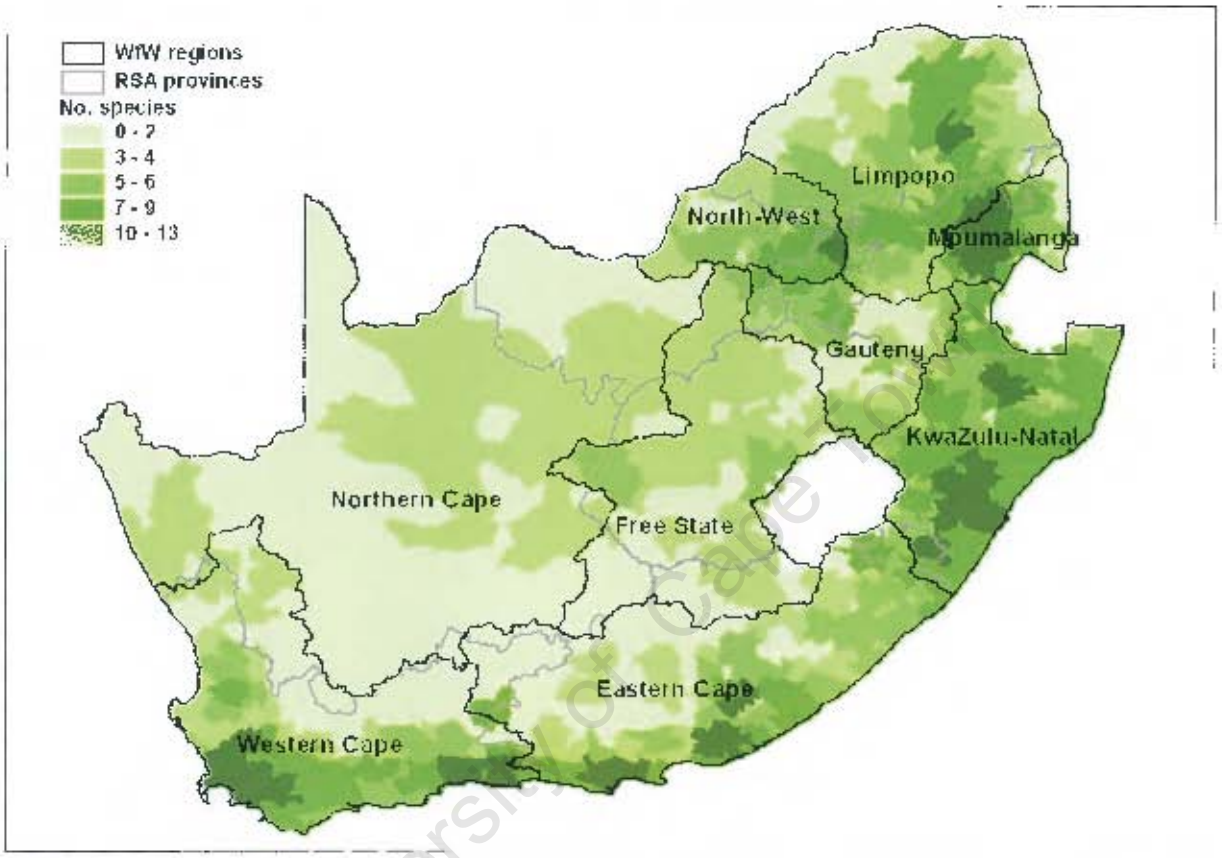

Figure 4.6 Effects of terrestrial, transformer species per quaternary catchment (graduated colour classified by 5 natural breaks).

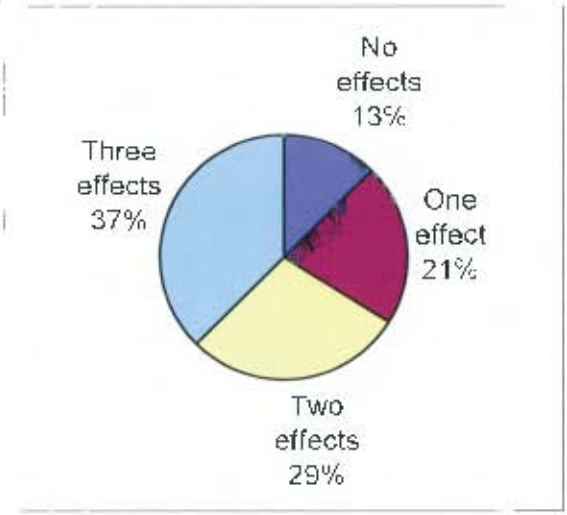

Figure 4.7 Percentage of terrestrial, transformer species per number of effects

4.1.5 Disturbance

The percentage of untransformed land cover per quaternary catchment is shown in figure 4.8. There was a mean of 79.7% untransformed land cover per quaternary catchment.

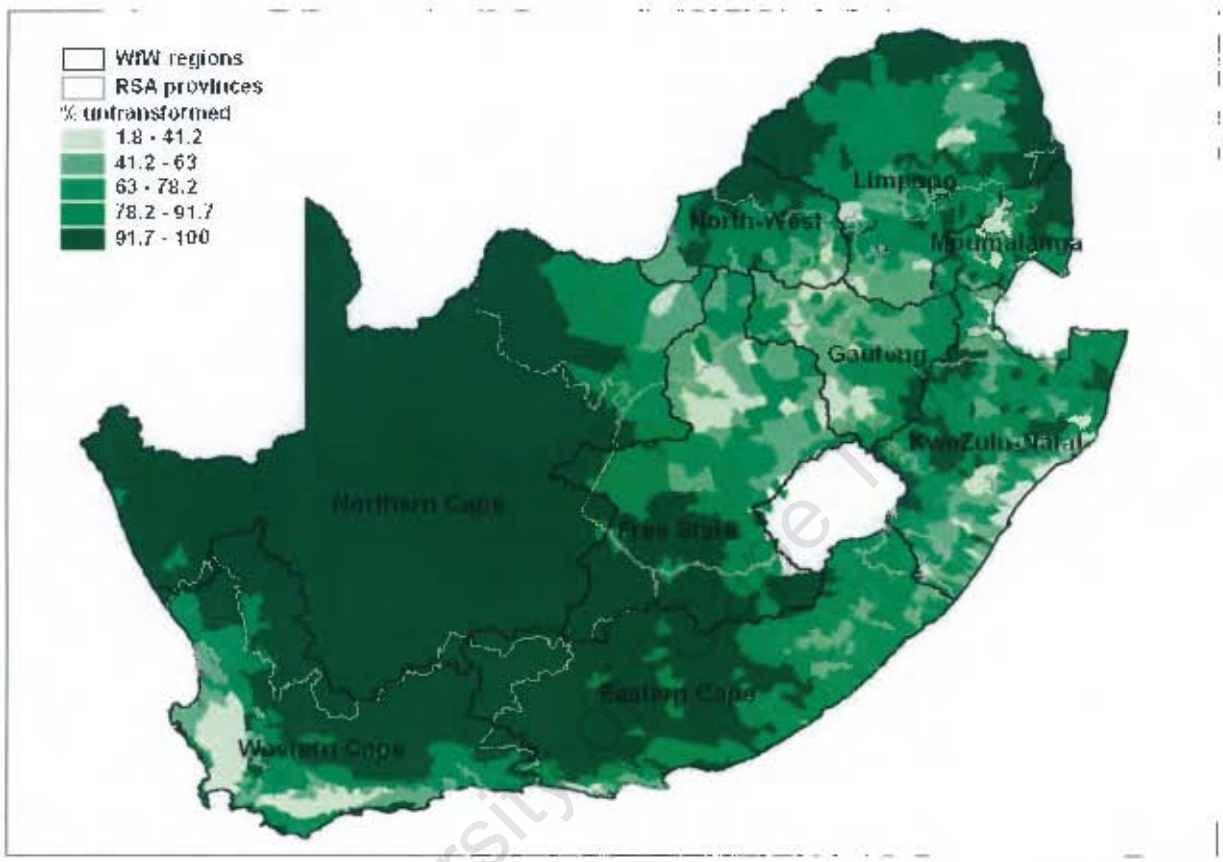

Figure 4.8 Percentage of untransformed land cover per quaternary catchment (graduated colour classified by 5 natural breaks).

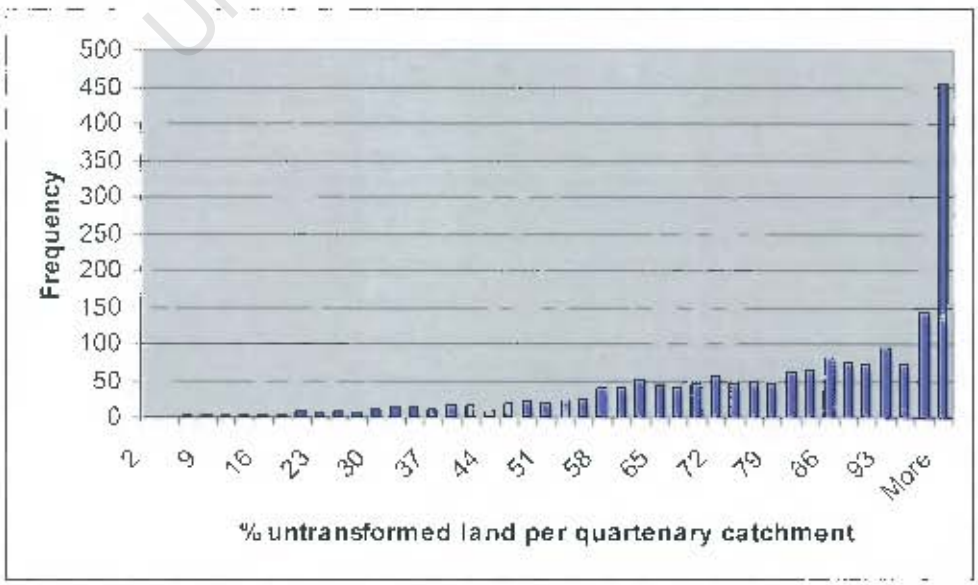

Figure 4.9 Frequency histogram for the percentage of untransformed land cover per quaternary catchment.

4.1.6 Terrestrial biodiversity value

The percentage of critically endangered and endangered terrestrial ecosystems per quaternary catchment is shown in figure 4.10. There was a mean of 20% critically endangered and endangered terrestrial ecosystems for the 830 quaternary catchments included.

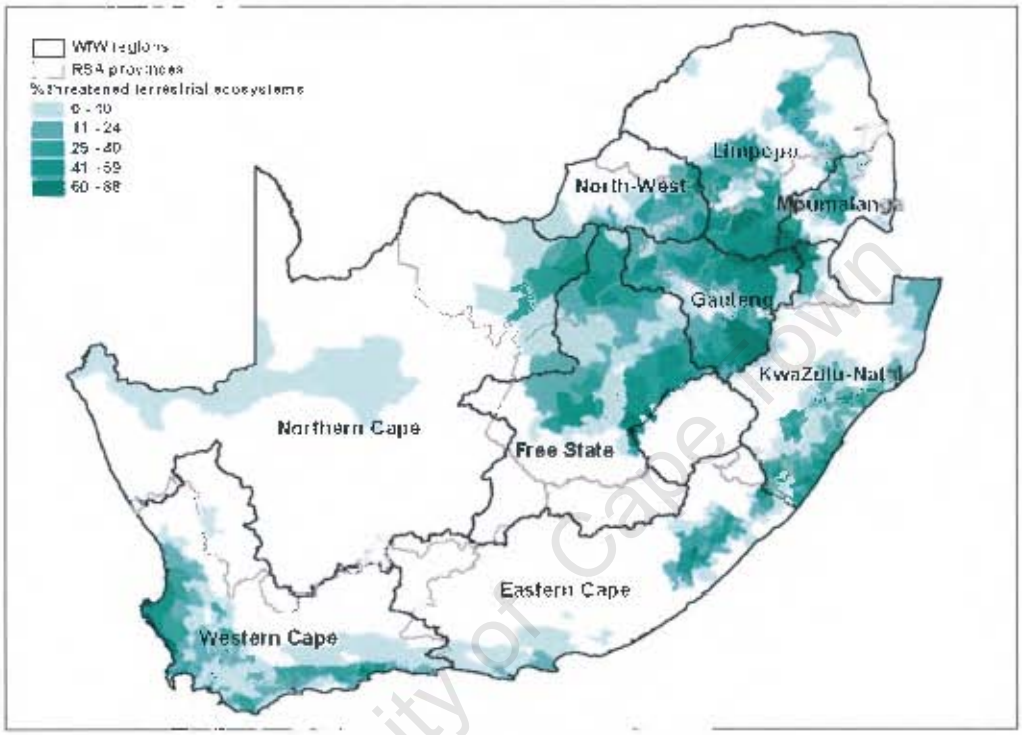

Figure 4.10 Percentage critically endangered and endangered terrestrial ecosystems per quaternary catchment (graduated colour classified by 5 natural breaks).

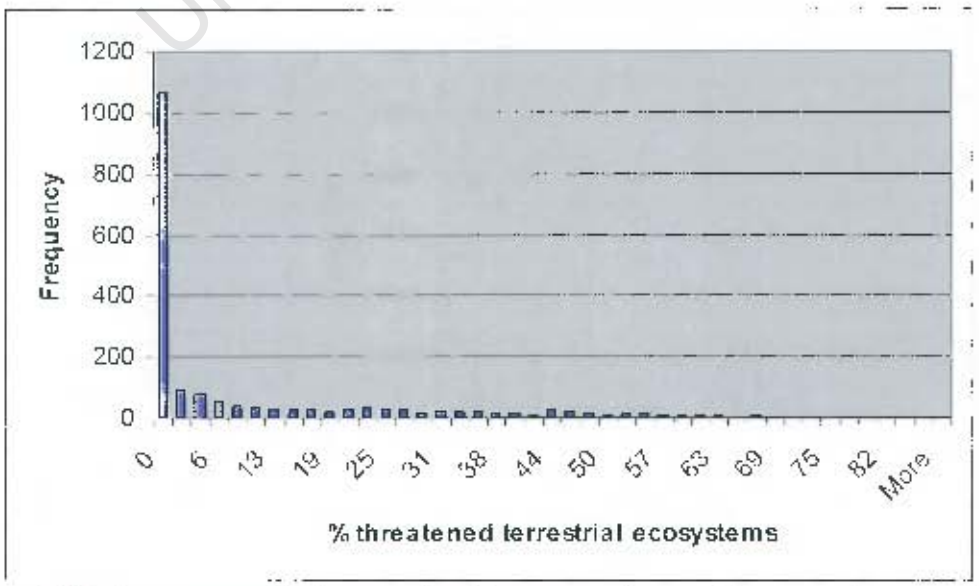

Figure 4.11 Frequency histogram for the percentage critically endangered and endangered terrestrial ecosystems per quaternary catchment.

4.1.7 River biodiversity value

The percentage of critically endangered and endangered river ecosystems per quaternary catchment is shown in figure 4.12. There was a mean of 92% critically endangered and endangered river ecosystems for the 1,401 quaternary catchments included.

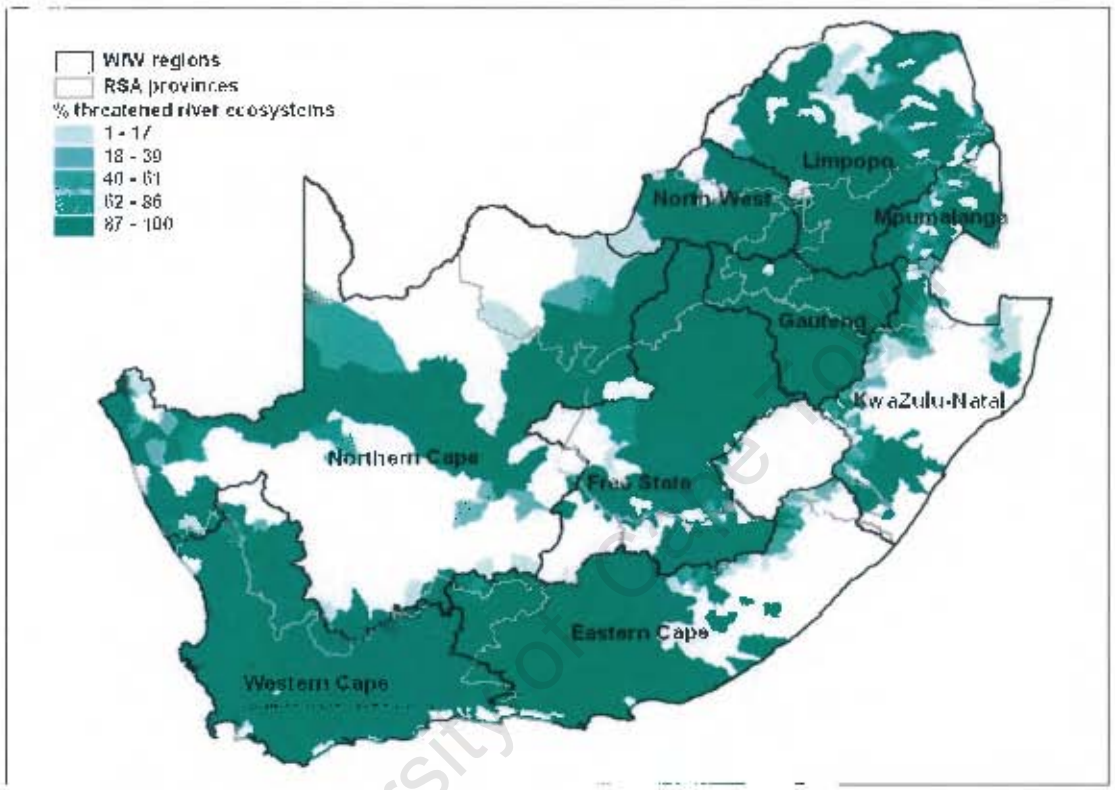

Figure 4.12 Percentage critically endangered and endangered river ecosystems per quaternary catchment (graduated colour classified by 5 natural breaks).

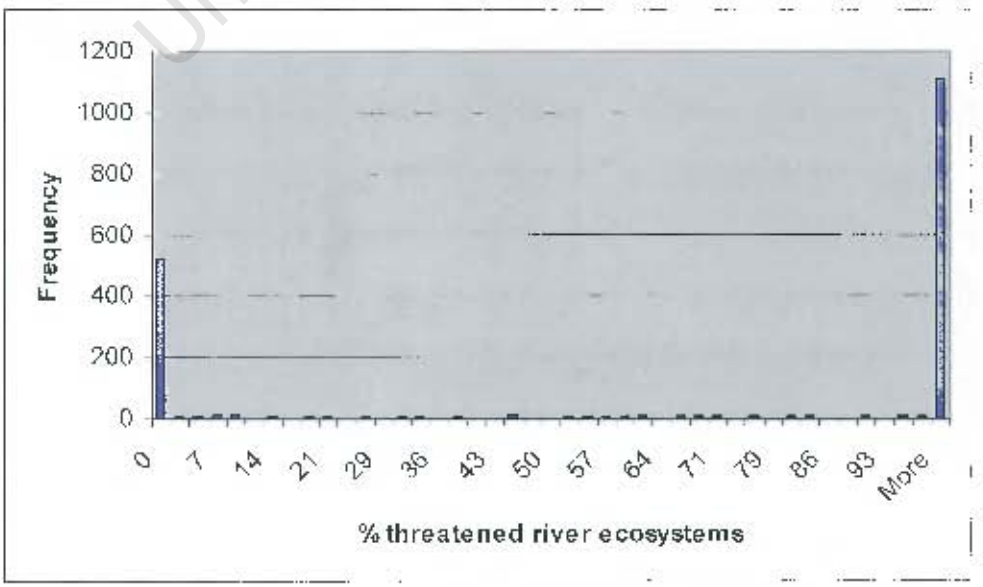

Figure 4.13 Frequency histogram for the percentage critically endangered and endangered river ecosystems per quaternary catchment.

4.1.8 Water resource value

The water yield balance per quaternary catchment is shown in Figure 4.14. There was a mean of 15 million cubic metres/annum per quaternary catchment.

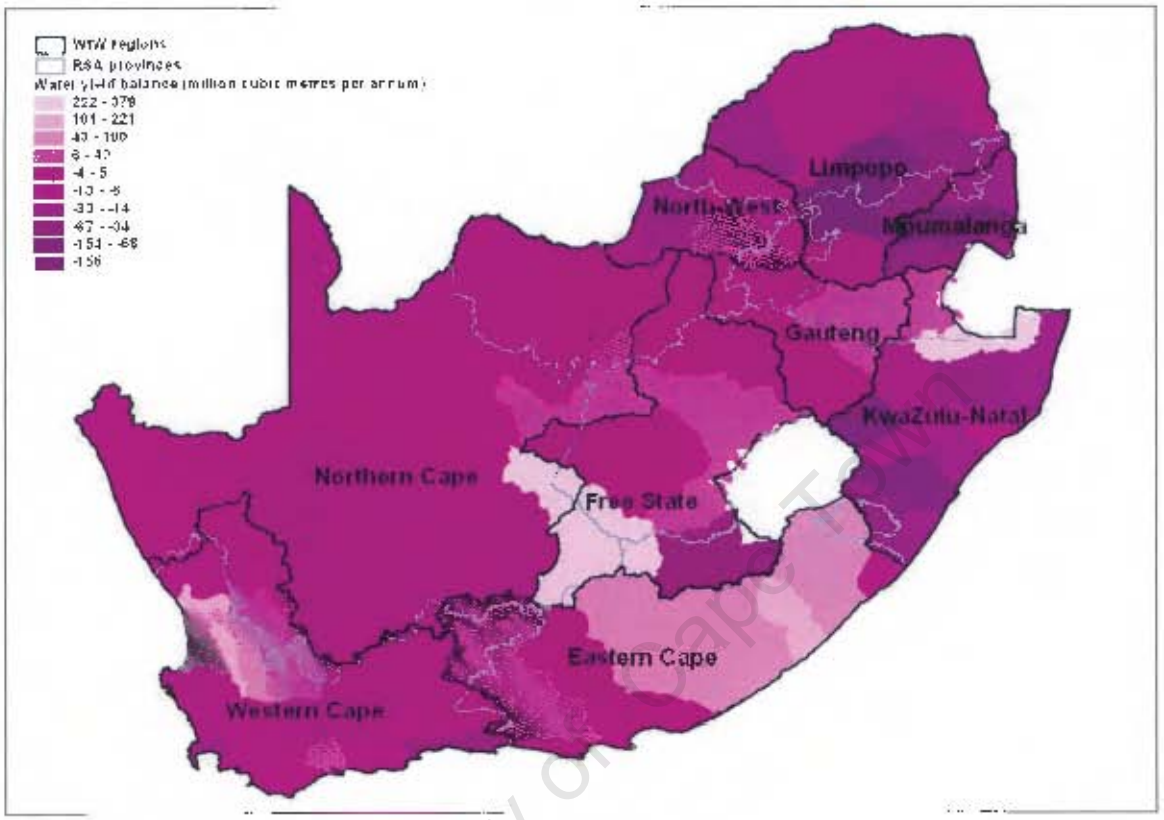

Figure 4.14 Water yield balance per quaternary catchment (graduated colour classified by 10 natural breaks owing to small differences in breaks).

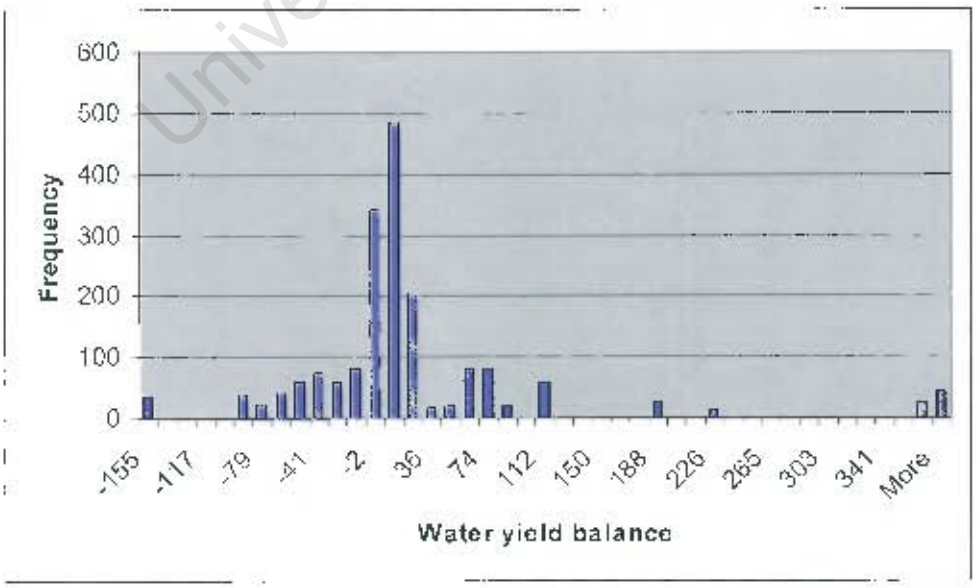

Figure 4.15 Frequency histogram for the water yield balance per quaternary catchment

4.1.9 Natural agricultural resource value

The primary production per quaternary catchment is shown in figure 4.16. There was a mean of 5.8 tons/hectare/growing season per quaternary catchment.

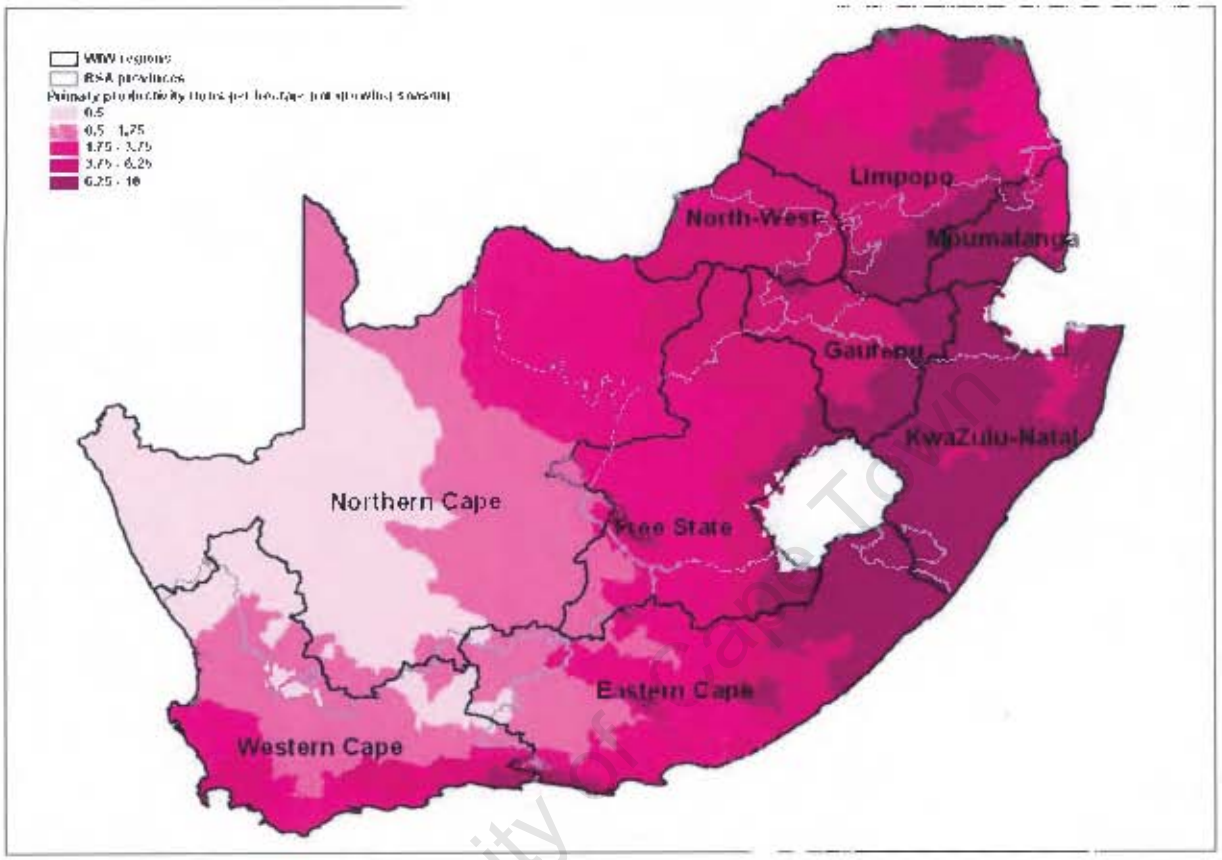

Figure 4.16 Primary production per quaternary catchment (graduated colour classified by 5 natural breaks).

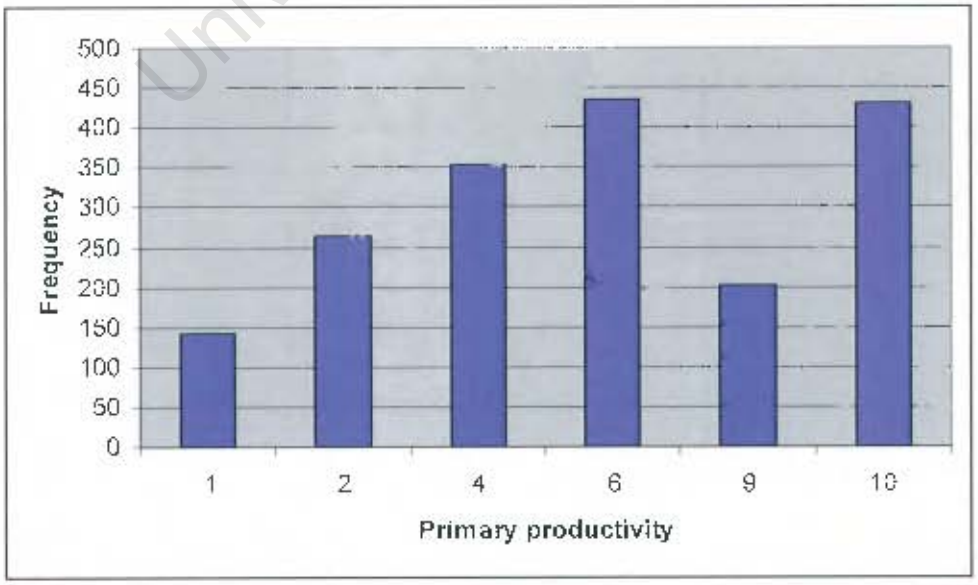

Figure 4.17 Frequency histogram for primary production per quaternary catchment.

4.1.10 *Systematic prioritisation composite*

The systematic prioritisation composite overall priority scores per quaternary catchment is shown in figure 4.18. There was a mean overall priority score of 0.3851 per quaternary catchment. The relatively close correspondence between the areas identified as priorities in the systematic prioritisation and the Nel *et al.* (2004a), Rouget *et al.* (2004a) and Le Maitre *et al.* (in prep.) studies (Figures 2.3, 2.4 and 2.5), demonstrates that there is general agreement on which are the most important areas (i.e. along the southern and eastern coasts of South Africa, along the eastern escarpment of KwaZulu-Natal and Mpumalanga, and around the eastern Free State and Gauteng provinces).

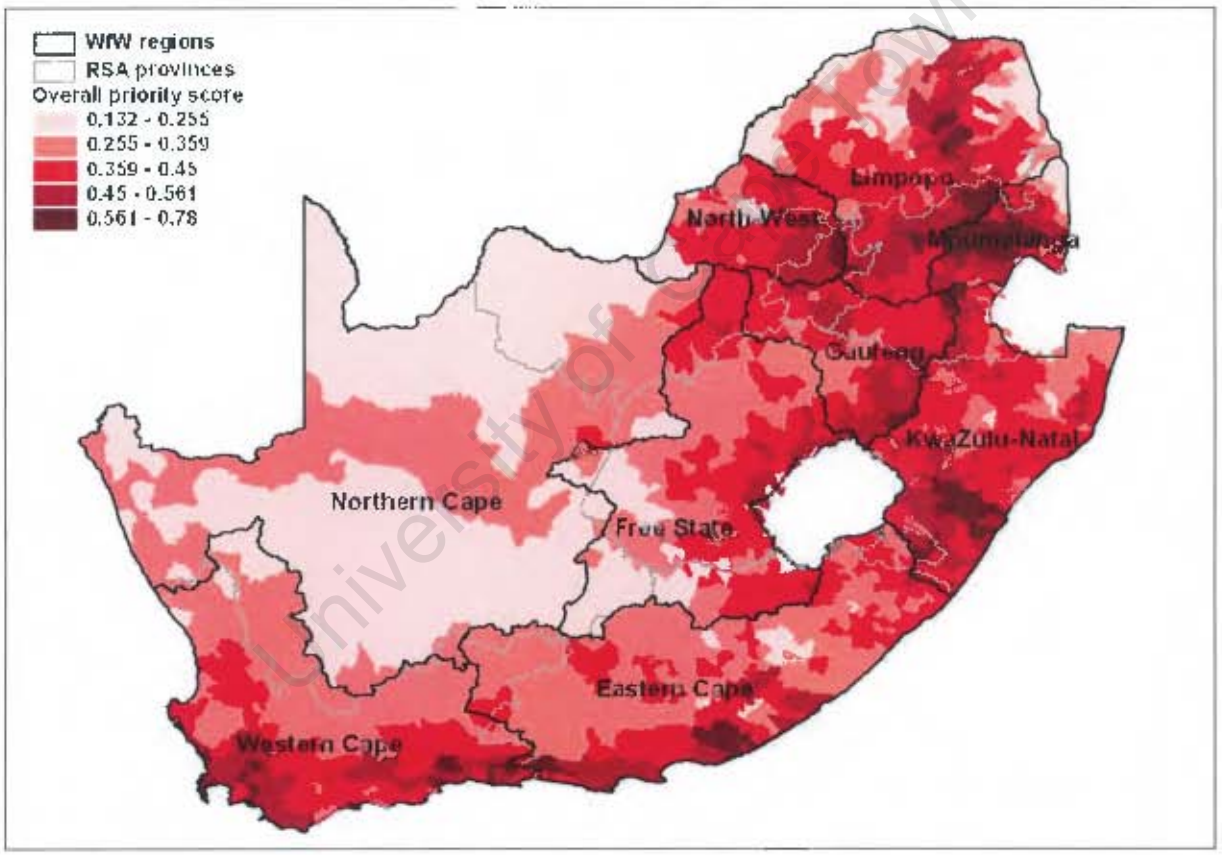

Figure 4.18 Systematic prioritisation composite showing overall priority scores per quaternary catchment (graduated colour classified by 5 natural breaks)

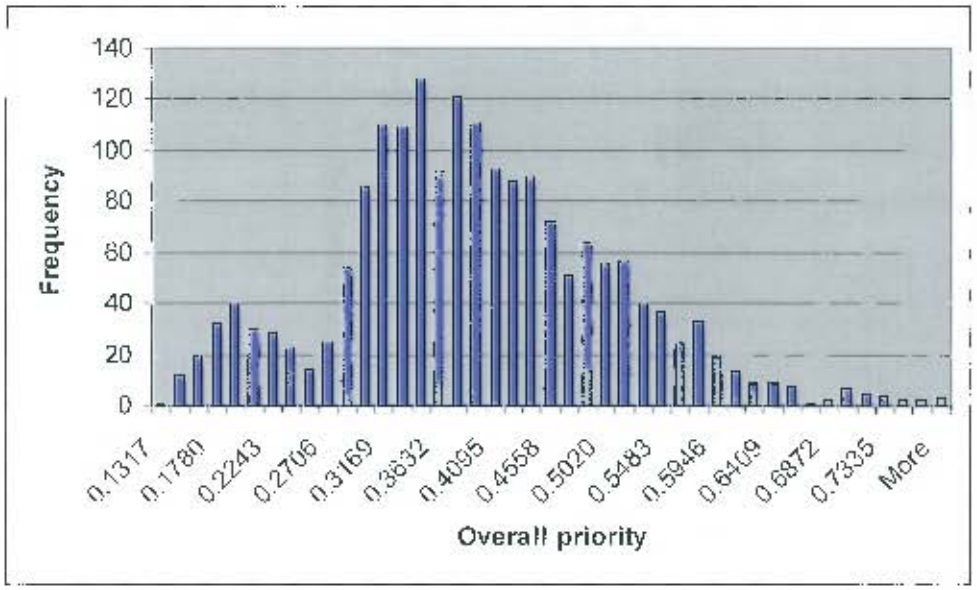

Figure 4.19 Frequency histogram for the overall priority scores per quaternary catchment

4.2 WfW prioritisation (B)

The WfW prioritisation per quaternary catchment is shown in figure 4.20. There was a mean of R529,565 for the 502 quaternary catchments included.

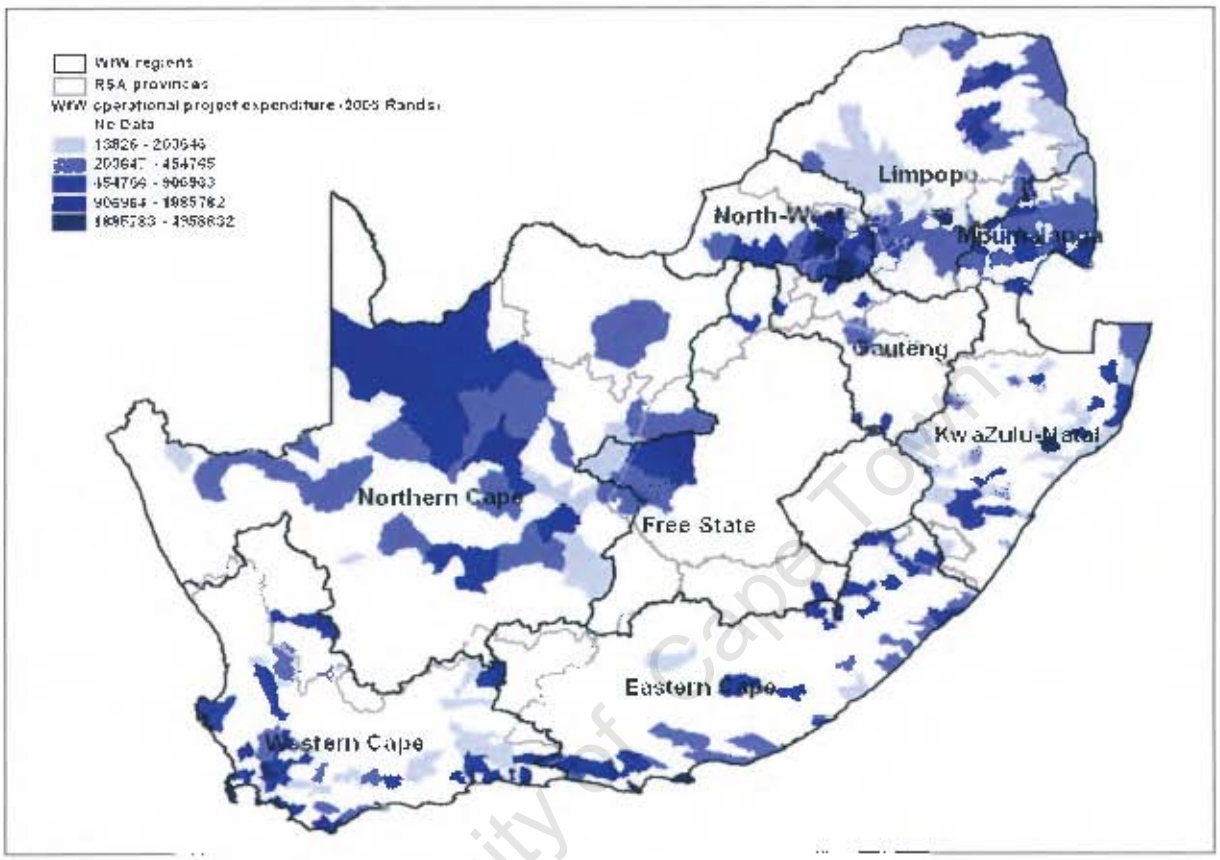

Figure 4.20 WfW prioritisation (B) (graduated colour classified by 5 natural breaks)

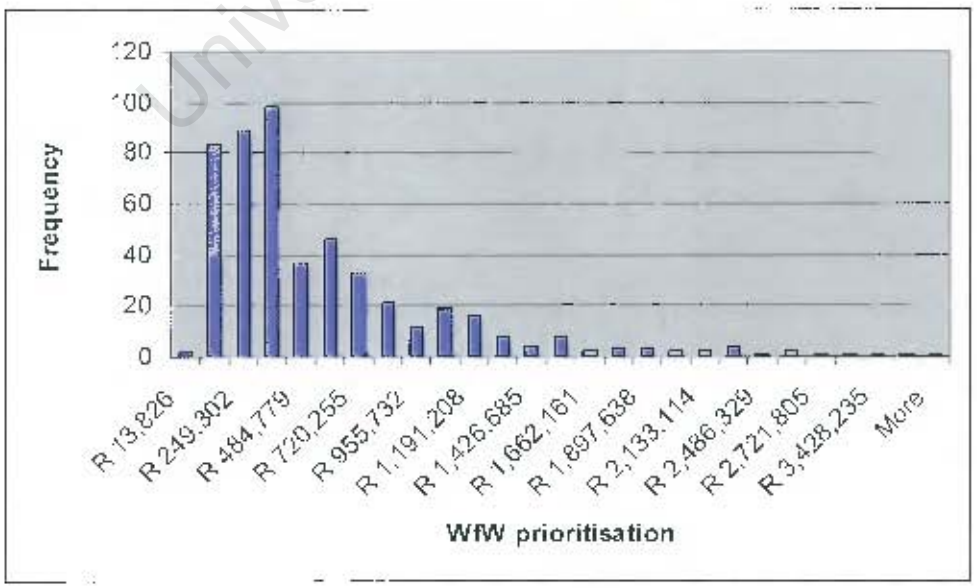

Figure 4.21 Frequency histogram for the WfW prioritisation per quaternary catchment

4.3 Systematic vs. WfW prioritisations (A vs. B)

The correlation matrix showing the relationships between all pairs of criteria within **South Africa** is shown in table 4.1. Since the study dealt with population and not sample data, all correlations will be statistically significant.

The systematic prioritisation (A) is weakly, yet positively, correlated (0.274) with the WfW prioritisation (B). A likely cause for the weakness of this correlation could be the fact that WfW projects have historically been initiated at locations where management capacity was available (Breen, 1997), opportunistically (WfW, 1998) and for political expediency and logistical convenience (Ractliffe *et al.*, 2003). The management capacity theory is perhaps supported by the fact that 15% of the total operational project expenditure is allocated to national (SANParks) and provincial protected area authorities (CapeNature and KZN Wildlife) when protected areas should mostly be free of invasive alien plants. Also, the WfW prioritisation could have been driven by socio-economically aspects, which were beyond the scope of this study.

It appears that despite the equal weightings given to each criterion before combination, a large proportion of the systematic prioritisation can be ascribed to the "range" (0.796), "abundance" (0.752) and "effect" (0.777) criteria. The explanation for this could be the fact that each of these criteria is strongly correlated with each other (0.883, 0.936 & 0.825) and this can possibly be considered a form of "triple counting". Factor or interaction effects are said to be confounded when the effect of one factor is combined with that of another. In other words, the effects of multiple factors on a response cannot be separated (Ott, 1988).

Table 4.1 Correlation matrix showing the relationships between all pairs of criteria within **South Africa.**

Systematic prioritisation criteria	WfW prioritisation	Range	Abundance	Effect	Distur-bance	Terrestrial	River	Water	Agri-culture	Overall priority
WfW prioritisation	1.000									
Range	0.325	1.000								
Abundance	0.328	0.883	1.000							
Effect	0.285	0.936	0.825	1.000						
Disturbance	-0.143	-0.452	-0.414	-0.440	1.000					
Terrestrial	0.076	0.226	0.228	0.193	-0.432	1.000				
River	0.032	-0.029	-0.032	-0.083	-0.029	0.132	1.000			
Water	0.069	0.176	0.193	0.208	-0.106	0.049	0.009	1.000		
Agriculture	0.134	0.518	0.446	0.563	-0.457	0.310	-0.248	0.162	1.000	
Overall priority	0.274	0.796	0.752	0.777	-0.349	0.419	0.400	0.337	0.571	1.000

The **"disturbance"** criterion has a very weak negative correlation (-0.143) with all other criteria. With respect to its negative correlation with the "range" (-0.452), "abundance" (-0.414) and "effect" (-0.440) criteria, this is in agreement with Nel *et al.* (2004a) who found that most major invasive alien species are confined to areas with a high proportion of transformed land, high rainfall and a high population density. This is also in agreement with Le Maitre *et al.* (2004) who found that alien plant species richness patterns in South Africa are largely the result of introduction patterns: alien species are concentrated in regions where humans have formed hubs of settlement over the past three centuries. Another possible explanation is the collection bias in the SAPIA data towards areas easily accessible by road or around areas where active SAPIA contributors live and work (Nel *et al.*, 2004a). Its negative correlation with the "terrestrial" and "river" biodiversity criteria can be explained by the strong correlation between indigenous species richness and human density in South Africa found by Richardson *et al.* (2005). And its modest negative correlation with agriculture can be explained by the fact that cultivated land and forest plantations are responsible for 15% of transformation in South Africa (Fairbanks *et al.*, 2000).

The very weak correlation of the **"river"** criterion with the "range" (-0.029) and "abundance" (-0.032) criteria might indicate that the terrestrial, transformer species selected are not associated with the loss of river biodiversity. River ecosystems are nonetheless very important, and several studies have found riparian zones to be more invaded by alien species than other plant communities and rivers may function

as dispersal corridors for the rapid spread of invasive alien plants across landscapes (van Wilgen *et al.*, in press).

A summary of overall correlations of systematic prioritisation criteria with WfW prioritisation for each **WfW region** is shown in table 4.2. Correlation matrices showing the relationships between all pairs of criteria within each WfW region are given in APPENDIX 3

Table 4.2 Overall correlations of systematic prioritisation criteria with WfW prioritisation for each **WfW region** and the number of quaternary catchments in each WfW region

	Western Cape	Eastern Cape	Limpopo	Mpumalanga	KwaZulu-Natal	Northern Cape	North-West	Gauteng	Free State
Overall priority	0.393	0.238	0.298	0.272	0.094	0.265	0.670	0.077	-0.016
No. quaternary catchments	396	326	227	92	284	183	58	91	168

Some WfW regions are better at assessing priority than others as reflected in the strong correlation scores of the North-West (0.670) region. This could be due to the surplus of expenditure received relative to the priority in that region and to the relatively small number of quaternary catchments in that region (58). The WfW regions of Free State, Gauteng and KwaZulu-Natal are the worst in assessing priority as demonstrated by the very weak correlation scores.

4.4 Use & limitations of this systematic prioritisation

Spatial analyses can take place at different spatial scales, from the global scale to the local scale. A national analysis is intended to be broad, and will not yield information about, for example, how to manage an individual parcel of land or a specific river or catchment. A national analysis does provide a national context for analyses at the sub-national scale, and points to broad priority areas where further investigation, planning and action are warranted (Driver *et al.*, 2005).

Prioritisation is a subjective exercise, and although the fundamental approach to prioritization may be guided by rational, factual information, priorities are also influenced by factors beyond the decision maker's control such as: political, funding, financial, technical and logistical (Versfeld *et al.*, 1998). In this study, priority setting is considered from the viewpoint of ecosystem and species values. It is however

recognized that political and public support and the availability of external support may drive an invasive alien species specific project that might not be a priority from this more rigorous viewpoint (Wittenberg & Cock, 2001). The study is scale sensitive and its resolution depends on the scales of the available datasets. However, at the broad scale at which this analysis is intended to inform management and planning, it is believed that none of these limitations will have a substantial effect on the overall accuracy or usefulness of the results.

The GIS shapefile created for this systematic prioritisation can be used as a decision support system by re-assigning weights in the summed field and even re-evaluating the criteria used.

5. CONCLUSIONS

5.1 Conclusions

Given the evidence presented and bearing in mind the issues considered in the results and discussion chapter, the main conclusion of this study in answer to the question set up at the start of this dissertation, is that a systematic data-driven prioritisation is weakly correlated with the prioritisation in use by WfW.

Also, while there has been good targeting of infestations of invasive alien species with clear ecosystem impacts, there is room for improvement in targeting these species in areas where the opportunities to meet individual goals are synergistic, particularly with regard to areas of low disturbance and high conservation or production value.

Furthermore, while the WfW North-West region is good at assessing priority, considerable improvement is required in the WfW Free State, Gauteng and KwaZulu-Natal regions.

5.2 Practical implications

This study identified priority areas that have not currently been identified as such, and should provide decision-makers with a transparent, systematic and objective means with which to prioritise areas for the control of invasive plants. This information can be used by decision makers to set priorities for which areas should get the most investment and for developing control strategies for individual species. It could be of assistance to the Department of Water Affairs & Forestry in helping to clarify the goals of WfW and how they relate to each other, should the criteria and weightings be accepted. It could assist the Department of Agriculture to prioritise areas for assistance and law enforcement for the appropriate management of the natural agricultural resources (RSA, 1995). And could also help the Department of Environmental Affairs & Tourism with the co-ordination and implementation of programmes for the control or eradication of invasive alien plants especially with regard to prioritising land under the control/jurisdiction of organs of state which are required to submit invasive species monitoring, control and eradication plans in accordance with Section 76 of the Biodiversity Act (RSA, 1997a).

At increasingly finer scales, the systematic prioritisation can be used to identify shortfalls in operational project expenditure between the 9 South African provinces, 9 WfW regions and 19 DWAF Water Management Areas (Figure1.1).

5.2.1 Priority RSA provinces

The shortfall identified in the KwaZulu-Natal province by this study is supported by the fact that the provincial government of KwaZulu-Natal, on their own initiative, has recently increased the budget for invasive alien plant control in that province by 250%. Other major shortfalls exist in the provinces of Eastern Cape and Free State. This study also identified a surplus in the provinces of Western Cape & Gauteng (Figure 5.1).

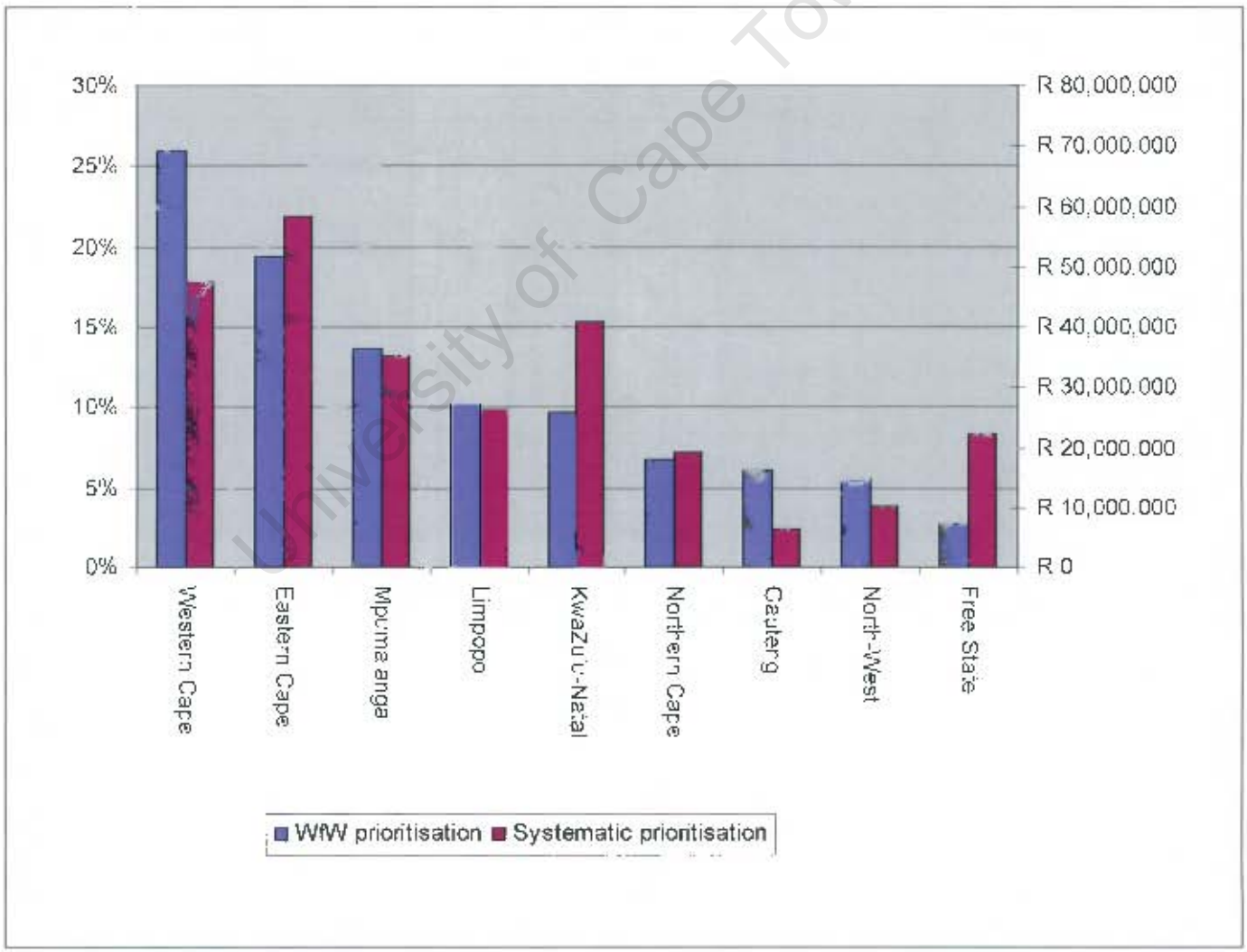

Figure 5.1 WfW prioritisation vs. the systematic prioritisation between provinces (arranged in descending order of WfW prioritisation)

5.2.3 Priority WfW regions

Major shortfalls exist in the WfW regions of KwaZulu-Natal, Northern Cape, Gauteng and Free State. This study also identified major surpluses in the WfW regions of Western Cape, Mpumalanga & North-West (Figure 5.2).

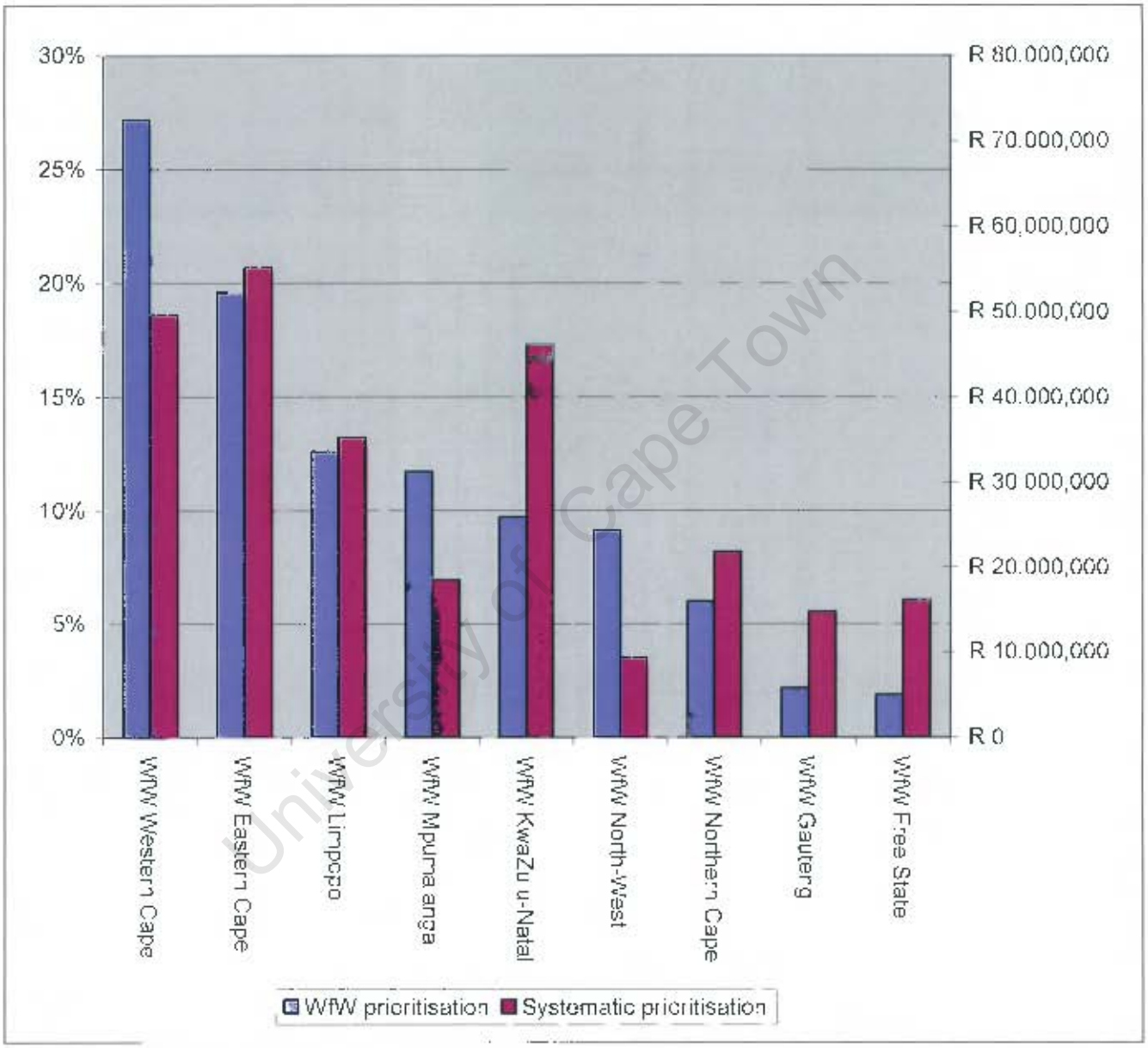

Figure 5.2 WfW prioritisation vs. the systematic prioritisation between WfW regions (arranged in descending order of WfW prioritisation)

5.2.3 Priority DWAF Water Management Areas

Major shortfalls exist in the DWAF Water Management Areas of Thukela, Upper Orange, Upper Vaal, Middle Vaal, Olifants, Limpopo, Usuthu to Mhlatuze and Mvoti to Umzimkulu. This study also identified major surpluses in the DWAF Water Management Areas of Berg, Inkomati, Levuvhu & Letaba and Crocodile (West) & Marico (Figure 5.3).

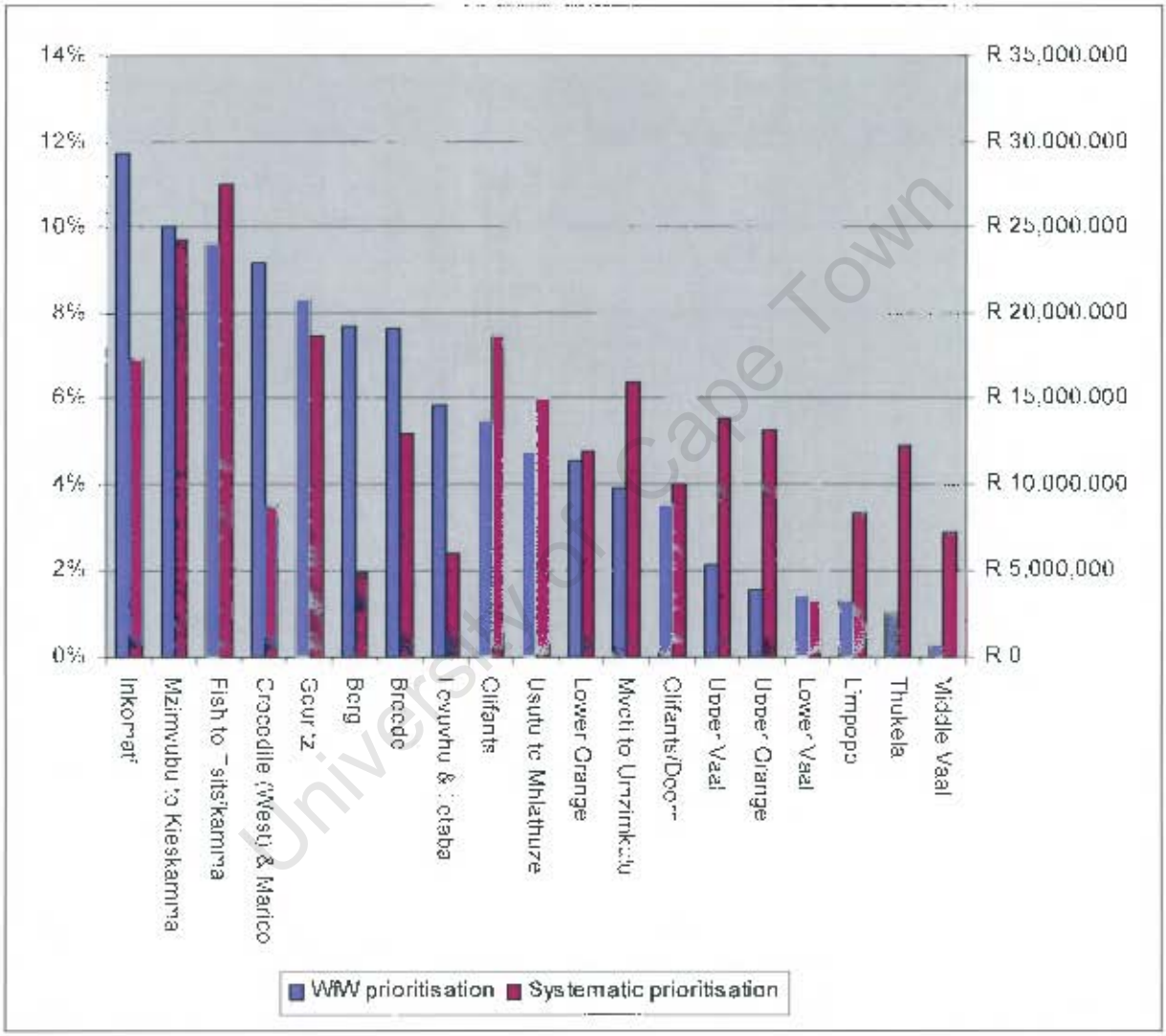

Figure 5.3 WfW prioritisation vs. the systematic prioritisation between DWAF Water Management Areas (arranged in descending order of WfW prioritisation)

5.2.4 Priority areas within South Africa

At a finer scale (quaternary catchments), the systematic prioritisation can be used to identify priority areas within South Africa as illustrated in figure 5.4 and assist in re-aligning funding either between existing projects (yellow hashed areas) or at new priority locations (darkest red areas not covered by a yellow hash).

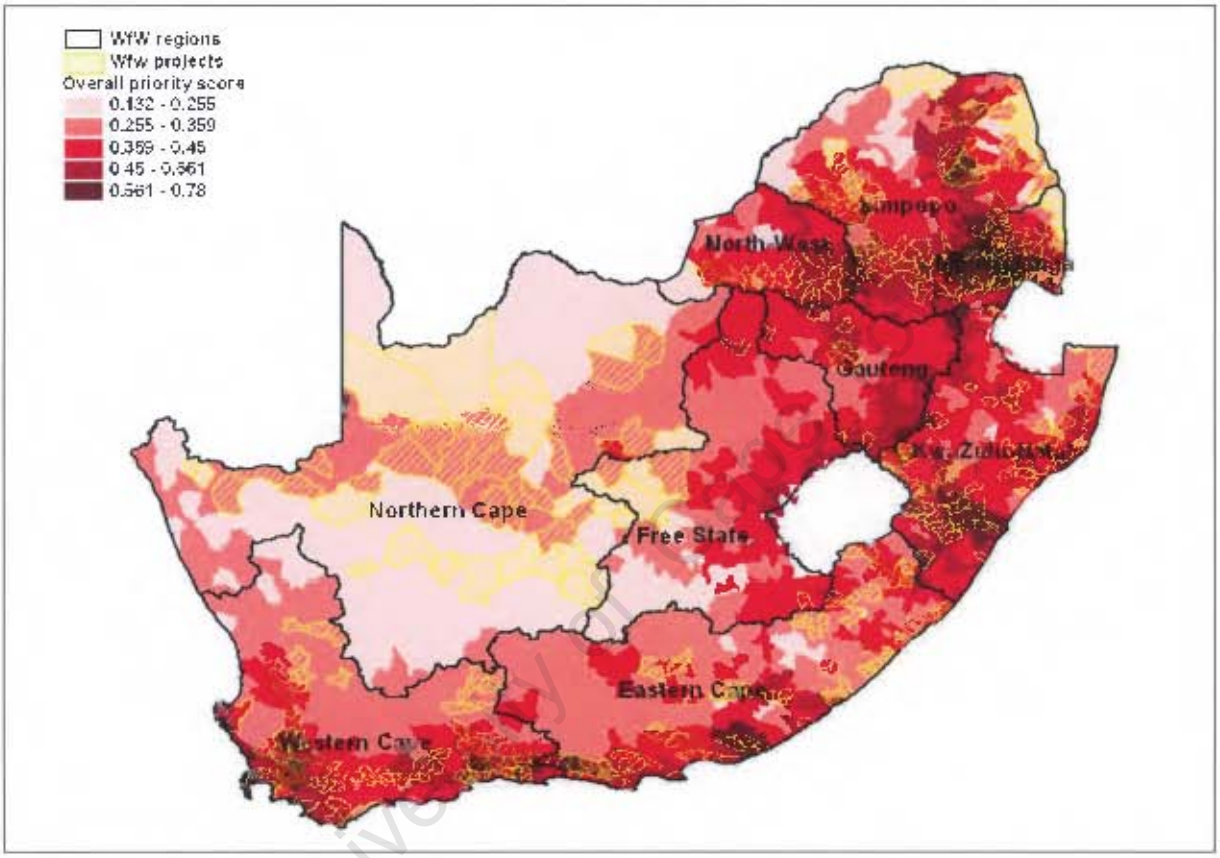

Figure 5.4 WfW projects (yellow hashed areas) vs. systematic prioritisation overall priority scores (graduated colour classified by 5 natural breaks)

WfW is also currently updating the Versfeld *et al.* (1998) map using remote-sensing imagery. If it proves to be impossible in the short-medium term to provide a comprehensive map of invasive alien plants for the whole country, it may be possible to phase this map by identifying a strategic subset of the country to target for comprehensive mapping, using this study.

5.2.5 Priority areas within WfW regions

At the finest scale, the systematic prioritisation can be used to identify priority areas within WfW regions as illustrated in the example for the WfW Free State region in Figure 5.5. The obvious cluster of projects (yellow hashed areas) in the western section of the Upper Orange DWAF Water Management Area compared to thepriority locations (darkest red areas not covered by a yellow hash) in the eastern section of the same DWAF Water Management Area, explain why the systematic prioritisation is very weakly correlated (-0.016) with the WfW prioritisation for the WfW Free State region. To remedy this situation either project funding needs to be re-aligned between the existing projects in the west and the east or allocated to the establishment of new projects in the east.

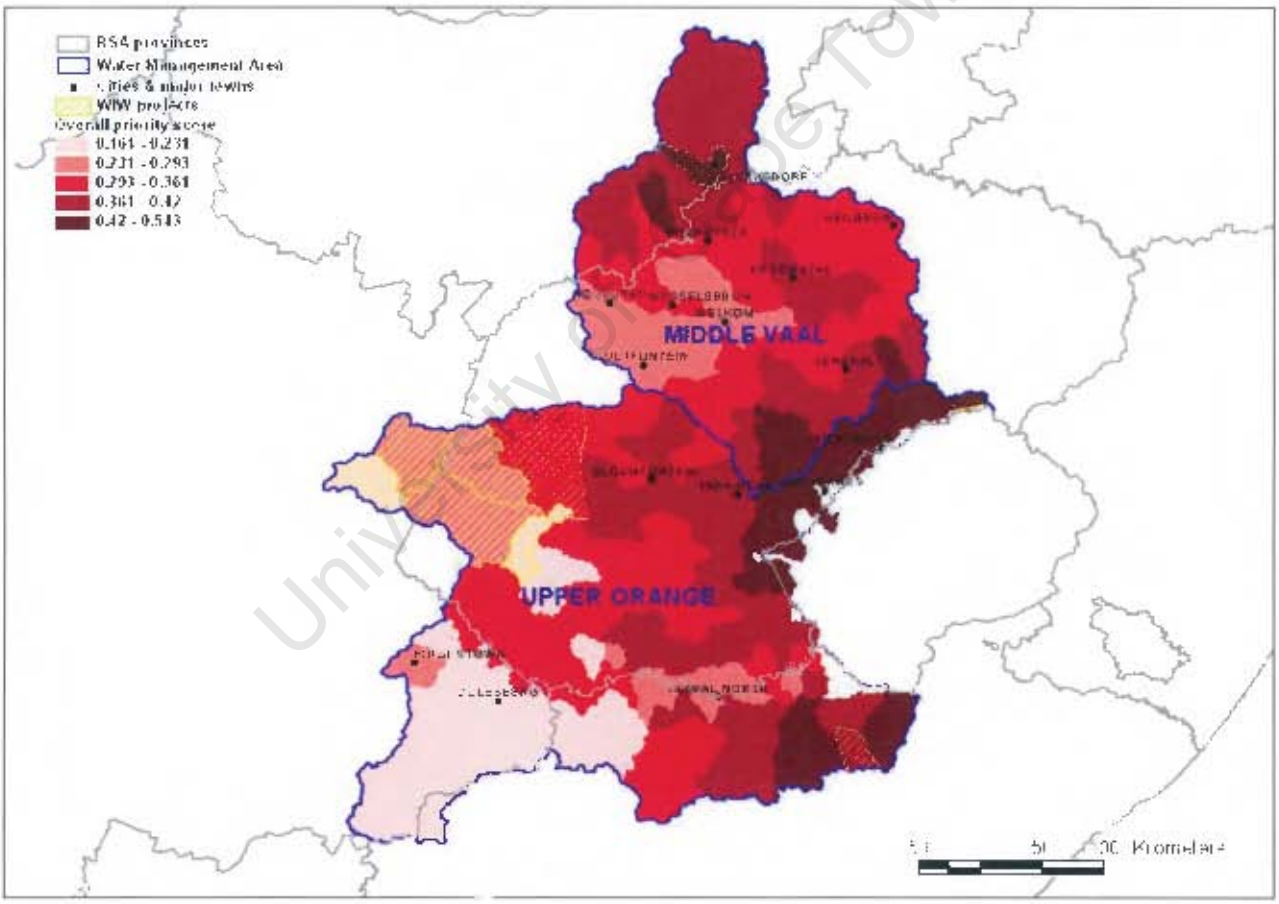

Figure 5.5 WfW projects (yellow hashed areas) vs. systematic prioritisation overall priority scores (graduated colour classified by 5 natural breaks) for the WfW Free State region

5.3 Desirable future research

Future research should concentrate on collecting species, water resource and natural agricultural resource values at finer scales to allow for more robust re-scaling to the quaternary catchment scale. The consequences of invasions for the delivery of goods and services (effects), with the notable exception of their influence on water resources, needs further study.

Data on total WfW operational project expenditure per WfW project since the inception of the programme in 1995 would also be useful.

Data on the proportion of quaternary catchments made up of State land would also assist in proving the assertion that projects were initiated where institutional capacity existed.

The ratio of present-day to natural mean annual runoff (MAR) for each quaternary catchment would provide an indication of ecologically stressed catchments, on the basis of present-day exploitation of the resource. For over-exploited rivers, the most severely affected component is generally the low flow, as a result of damming and run-of-river abstraction. Thus, the benefits of clearing for enhancing ecosystem integrity would be greatest in these catchments. Such a cover does not presently exist in DWAF (Watson, pers. comm.).

Assessment is a core component of planning, but there is more to planning than simply assessment. The identification of spatial priority areas through assessment should feed into the development of an implementation strategy and action plan, which may address non-spatial issues (Wittenberg & Cock, 2001; Driver *et al.* 2003).

REFERENCES

Blood, K. (2002). *Best Practice Management Guide for Environmental Weeds*, Co-operative Research Centre for Australian Weed Management (Weeds CRC), Australia. http://www.weeds.crc.org.gov.au

Breen, C., Erskine, J., Jelinek, E., Mbowa, S., Quinn, N. and Salomon, M. (1997) Evaluation of the *Working for Water* Programme for the Commission of the European Communities, Brussels & Government of South Africa, Department of Water Affairs & Forestry. Ingenieurbüro für Landentwicklung, Florstadt, Germany in association with Institute of Natural Resources, University of Natal, Pietermaritzburg.

Commonwealth of Australia (1999). *The National Weeds Strategy: A strategic approach to weed problems of national significance*. Agriculture and Resource Management Council of Australia and New Zealand, Australian and New Zealand Environment and Conservation Council and Forestry Ministers. 52 pp.

Corbett, B (1999) *Working for Water* Operational Manual: Volume 1, Policy Guidelines

Cronk, Q.C.B. and Fuller, J.L. (1995). *Plant Invaders. The Threat to Natural Ecosystems*. London: Chapman & Hall.

DEAT (2005). *South Africa's National Biodiversity Strategy and Action Plan (NBSAP)*. Department of Environmental Affairs & Tourism, Pretoria.http://www.deat.gov.za

DPLG (2001). *Integrated Sustainable Rural Development Programme*, Department of Provincial and Local Government. http://dplg.gov.za/html/progs/isrdp.htm

DPW (2006) Expanded Public Works Programme (EPWP). Monitoring and Evaluation Template Version 6.2e for 4th quarter of 2005/6 financial year. Department of Public Works, Pretoria http://www.epwp.gov.za.

DWAF (1999) Resource Directed Measure for Protection of Water Resources, Appendix R1: *Ecoregional Typing*. Prepared by Kleynhans, C.J. and Hill. L. Version 1.0. Pretoria, South Africa.

DWAF (2002) Water Resources Situation Assessment: Berg Water Management Area. Report No. P 19000/00/0101. Directorate: Water Resources Planning. Department of Water Affairs & Forestry

DWAF (2004). *National Water Resource Strategy: Our blueprint for survival*. First Edition. Department of Water Affairs & Forestry, Pretoria. http://www.dwaf.gov.za

Driver, A., Cowling, R.M. and Maze, K. (2003). Planning for living landscapes: perspectives and lessons from South Africa, Washington DC: Center for Applied Biodiversity Science at Conservation International; Cape Town: Botanical Society of South Africa. http://www.botanicalsociety.org.za

Driver, A., Maze, K., Rouget, M., Lombard, A.T., Nel, J., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas Z., Reyers, B., Sink, K. and Strauss, T. (2005). National Spatial Biodiversity Assessment 2004: Priorities for biodiversity conservation in South Africa. *Strelitzia* **17**, South African National Biodiversity Institute, Pretoria. http://bgis.sanbi.org/NSBA/index.asp

Eastman, J.R., Kyem, P.A.K., Toledano, J. and Jin, W. (1993). *GIS and Decision Making*, Explorations in Geographic Information Systems Technology, Volume 4, United Nations Institute for Training and Research, Geneva, Switzerland, 112 pp.

Eberhard, R., Goldblatt, M. and Middleton, J. (2003). *External Evaluation of the Working for Water Programme, Financial and Economic Theme*, Palmer Development Group, 33 pp.

ESRI (2002). *Using ArcView GIS*, Environmental Systems Research Institute, Inc. Redlands, California. 340 pp.

Fairbanks, D.H.K., Thompson, M.W., Vink, D.E., Newby, T.S., Van den Berg, H.M. and Everard, D.A. (2000). The South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science* **96:** 69-82.

Fourie, S., Fabricius, C. & Shackleton, C. (2002) An ecology research strategy for *Working for Water*. Final Report, Department of Environmental Science, Rhodes University, Grahamstown

Fowler, J., Cohen, L. & Jarvis, P. (1998). *Practical statistics for field biology*. John Wiley & Sons, Inc.

Gibson, D. and Low, B. (2003) *National Invading Alien Plant Survey Inception Report*. Steffen, Robertson and Kirsten (South Africa) (Pty) Ltd, Report No. 304201.

Görgens A.H.M. and Van Wilgen B.W. (2004). Invasive alien plants and water resources: an assessment of current understanding, predictive ability and research challenges. *South African Journal of Science* **100**, 27-33.

Henderson, L. (1998). Southern African Plant Invaders Atlas (SAPIA). *Appl. Plant Sci.* **12:** 31–32.

Henderson, L. (2001). *Alien weeds and invasive plants: a complete guide to declared weeds and invaders in South Africa.* ARC-PPRI, PPRI Handbook No. 12, Pretoria, South Africa

Hobbs, R.J. and Humphries, S.E. (1995). An integrated approach to the ecology and management of plant invasions. *Conservation Biology* **9:** 761-770.

Hobbs, R.J. (2004). The *Working for Water* programme in South Africa: the science behind the success. *Diversity and Distributions* **10:** 501-503.

Hoffman, T. and Ashwell, A. (2001). Nature divided. Land degradation in South Africa, University of Cape Town Press, 168pp.

Holmes, PM., Euston-Brown, D. and Richardson, DM (2003) *External Evaluation of the Working for Water Programme, Terrestrial Ecology Theme*, Cape Ecological Services, 45 pp.

Hulme, P.E. (2003). Biological invasions: winning the science battles but losing the conservation war? *Oryx*, **37:** 178-193.

Joubert, A.R., Leiman, A., De Klerk, H., Katua, S. and Aggenbach, J.C. (1997). Fynbos (fine bush) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis. *Ecological Economics* **22**: 123-140.

Kluge, R.L. and Erasmus, D.J. (1991). An approach towards promoting progress with the control of woody alien invasive plants in Natal, *Southern African Forestry Journal* **157**: 86-90

Laros, M, Leslie, K and Manaka, B (2003) *Working for Water* External Evaluation, Synthesis Report dated August 2003, Common Ground Consulting, 95 pp.

Laros, M. (2005). Review of progress toward implementing the recommendations adopted from the Common Ground external evaluation. Draft Project Closure Report. Project Number: 2004/118. Marlene Laros & Associates.

Le Maitre, D.C., Mgidi, T.N., Schonegevel, L., Nel, J., Rouget, M., Richardson, D.M. and Midgley, C. (in prep). Plant invasions in South Africa, Lesotho and Swaziland: assessing the potential impacts of major and emerging plant invader. *Ecosystems*

Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A. (2000). The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. *Water SA* **26**: 397–408. http://www.wrc.org.za

Le Maitre, D.C., Richardson, D.M. & Chapman, R.A. (2004). Alien plant invasions in South Africa: driving forces and the human dimension. *South African Journal of Science* **100**, 103-112.

Low, A.B. & Rebelo A.G. (1996). Vegetation of South Africa, Lesotho & Swaziland. Department of Environmental Affairs & Tourism, Pretoria.

Macdonald, I.A.W. and Jarman, M.L. (1984). Invasive alien organisms in the terrestrial ecosystems of the fynbos biome. South African National Scientific Programmes Report No. 85. CSIR, Pretoria. 72 pages.

Macdonald, I.A.W. and Jarman, M.L. (1985). Invasive alien plants in the terrestrial ecosystems of Natal, South Africa. South African National Scientific Programmes Report No. 118. CSIR, Pretoria. 88 pages.

Macdonald, IAW. (2004) Recent research on alien plant invasions and their management in South Africa: a review of the inaugural research symposium

of the Working for Water Programme, *South African Journal of Science* **100**: 21-26

Macdonald, I.A.W., Van Wilgen, B.W. and Mgidi, T.N. (2004). Towards a national strategy for dealing with invasive alien species. Final Report, CSIR Report No: ENV-S-C 2004-030

Maguire, L.A. (1991). Risk analysis for conservation biologists. *Conservation Biology* **5**: 123-125.

Maguire, L.A. (2004). What can decision analysis do for invasives species management? *Risk Analysis* **24**: 859-868.

Marais, C., Turpie, J., Mullins, D., Conradie, B., Khan, A., Goldin, J., van Zyl, H., Grobbelaar, E., Vink, N. & Ndzinge, V. (2001). A cost-benefit analysis framework for the national *Working for Water* Programme. Report No. SEGA 34: Socio-economic evaluation of *Working for Water* Projects.

Marais, C.M., van Wilgen, B.W. and Stevens, D. (2004). The clearing of invasive alien plants in South Africa: a preliminary assessment of costs and progress. *South African Journal of Science* **100:** 97-103

Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis*. John Wiley & Sons, Inc. New York. 392pp.

McNeely, J.A., H.A. Mooney, L.E. Neville, P. Schei, and J.K.Waage (eds.) 2001. *A Global Strategy on Invasive Alien Species*. IUCN Gland, Switzerland, and Cambridge, UK. x + 50 pp.

Midgley, D.C., Pitman, W.V. and Middleton, B.J. (1994). *The surface water resources of South Africa 1990*. Volumes 1 to 6. Report Numbers 289/1.1/94 to 298/6.1/94 (text) and 298/1.2/94 to 298/6.2/94 (maps), Water Research Commission, Pretoria. Also accompanied by CD-ROM with selected data sets.

Mgidi, T.N., Le Maitre, D.C., Nel, J., Rouget, M., Richardson, D.M., Midgley, C., Mdzeke, N., Van Wilgen., BW., Schonegevel, L. Henderson and Neser, S., Egoh, B. (2005). *An assessment of invasion potential of invasive alien plant species in South Africa*. CSIR Report Number ENV-S-I-2004-108. Stellenbosch: Council for Scientific and Industrial Research.

Mgidi, T.N., Le Maitre, D.C., Schonegevel, L., Nel, J., Rouget, M., and Richardson, D.M. (in prep.) Alien plant invasions – incorporating emerging invaders in regional prioritization: a pragmatic approach for South Africa. *Environmental Management*

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Mucina, L. and Rutherford, M.C. (2004). *Vegetation Map of South Africa, Lesotho and Swaziland: Shapefiles of basic mapping units*. Beta version 4.0, February 2004, National Botanical Institute, Cape Town

Nel, JL., Richardson, DM., Rouget, M., Mgidi, T., Mdzeke, N., Le Maitre DC., Van Wilgen., BW., Schonegevel, L. Henderson and Neser, S. (2004a) A proposed classification of invasive alien plant species in South Africa: towards prioritising species and areas for management action, *South African Journal of Science* **100**: 53-64

Nel, J., Maree, G., Roux, D., Moolman, J., Kleynhans,N., Silberbauer, M., Driver, A. (2004b). *South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 2: River Component*, CSIR Report Number ENV-S-I-2004-063. Stellenbosch: Council for Scientific and Industrial Research. Report and data available at http://bgis.sanbi.org/NSBA/index.asp

Ott, L (1988). *An introduction to statistical methods and data analysis*. 3rd edition. PWS-Kent Publishing Company, Boston, Massachusetts, 763 pp.

Owen, S.J. (1998) Department of Conservation Strategic Plan for Managing Invasive Weeds. Department of Conservation, Wellington, New Zealand. 87 pp.

Parker, I.M., Simberloff, D., Lonsdale, W.M., Goodell, K., Wonham, M., Kareiva, P.M., Williamson, M., von Holle, B., Moyle, P.B., Byers, J.E. and Goldwasser, L. (1999). Impact: towards a framework for understanding the ecological effects of invaders. *Biol. Invas.* **1**: 3-19

Parsons, T and Knight, P (1995). *How to do your dissertation in geography and related disciplines*. Chapman & Hall, London, 149pp.

Ractliffe, G., Ewart-Smith, J., Görgens, A. (2003) *External Evaluation of the Working for Water Programme, Aquatic Ecology & Hydrology Specialist Report*, Freshwater Consulting Group and Ninham Shand Consulting Services, 77 pp.

Richardson, D.M., Macdonald, I.A.W., Hoffmann, J.H. and Henderson, L. (1997). Alien plant invasions. In: Cowling, R.M, Richardson, D.M. and Pierce, S.M. (eds). Vegetation of Southern Africa. Cambridge University Press, Cambridge. pp. 534–570

Richardson D. M., Pysek P., Rejmanek M., Barbour M. G., Panetta D. F. & West C. J. (2000). Naturalization and invasion of alien plants – concepts and definitions. *Diversity and Distributions* **6**: 93-107.

Richardson, D.M. (2001) *Plant invasions*. In: Levin, S. (ed.), Encyclopedia of Biodiversity, Volume 4., pp. 677-688. Academic Press, San Diego.

Richardson, D.M., Moran, V.C., Le Maitre, D.C., Rouget, M. & Foxcroft, L.C. (2004) Recent developments in the science and management of invasive alien plants: connecting the dots of research, knowledge, and linking the disciplinary boxes, *South African Journal of Science* **100:** 126-128

Richardson, D.M. (2004). Plant invasion ecology - dispatches from the front line. *Diversity & Distributions* **10:** 315-319.

Richardson, D.M. and Van Wilgen, B.W. (2004). Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South African Journal of Science* **100**: 45-52

Richardson D.M., Rouget M., Ralston S.J., Cowling. R.M., van Rensburg B.J. and Thuiller W. (2005). Species richness of alien plants in South Africa: Environmental correlates and the relationship with indigenous plant species richness. *Ecoscience* **12** : 391-402.

Roberts, P., van Niekerk, P. and Dewey, S. (2000). Efficacy of the *Working for Water* Programme. In: Best management practices for preventing and controlling invasive alien species (edited by G Preston, G Brown and E van Wyk). *Working for Water* Programme, Cape Town, pp.118-128.

Robertson, M.P., Villet, M.H., Fairbanks. D.H.K., Henderson, L., Higgins, S.I., Hoffmann, J.H., Le Maitre, D.C., Palmer, A.R., Riggs, I., Shackleton, C.M. and Zimmermann, H.G. (2003). A proposed prioritization system for the management of invasive alien plants in South Africa. *South African Journal of Science* **99:** 37-43.

Rouget, M., Richardson, D.M., Nel, J., Le Maitre, D.C., Egoh, B., Mgidi, T (2004a). Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. *Diversity & Distributions* **10**: 475-484.

Rouget, M., Reyers, B., Jonas, Z., Desmet, P., Driver, M., Mazo, K., Egoh, B. and Cowling, R.M. (2004b). *South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component*, Pretoria: South African National Biodiversity Institute. Report and data available at http://bgis.sanbi.org/NSBA/index.asp

RSA (1995). *White Paper on Agriculture*, Department of Agriculture

RSA (1997a). *White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity*. Department of Environmental Affairs & Tourism

RSA (1997b). *White Paper on a National Water Policy for South Africa*, Department of Water Affairs & Forestry

RSA (1998). *National Water Act*, Act No. 36 of 1998. Republic of South Africa

RSA (2004). *National Environmental Management: Biodiversity Act*, No 10 of 2004

Schulze, R.E., Maharaj, M., Lynch, S.D., Howe, B.J. & Melvil-Thomson, B. (1997). *South African atlas of agrohydrology and climatology*. Water Research Commission, Pretoria.

Schoeman, J.L. van der Walt, M., Monnik, K.A., Thackrah, A., Malherbe, J. & Le Roux, R.E. (2002). *Development and Application of a Land Capability Classification System for South Africa Final Report to Directorate Agricultural Land Resource Management*, ARC Report No. GW/A/2000/57 ARC-Institute for Soil, Climate and Water, Pretoria

Shine, C., Williams, N., Gündling, L. (2000). *A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species.* IUCN, Gland, Switzerland Cambridge and Bonn. xvi + 139 pp.

Swarbrick, J.T. (1991). Towards a rating scheme for environmental weeds. *Plant Protection Quarterly* **6**:185.

Turpie, J.K., Heydenrych, B.J. and Lamberth, S.J. (2003). Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. *Biological Conservation* **112**: 233-251.

Turpie, J. (2004). The role of resource economics in the control of invasive alien plants in South Africa. *South African Journal of Science* **100:** 87-93.

Van Riet, W., Claasen, P., Van Rensburg, J., Van Viegan, T. and Du Plessis, L. (1997). Environmental Potential Atlas for South Africa (ENPAT), JL Van Schaik, 1064 Arcadia Street. Hatfield, Pretoria, 60 pp. Also accompanied by CD-ROM with selected data sets.

Van Wilgen, B.W. Cowling, R.M. & Burgers, C.J. (1996). Valuation of ecosystem services: a case study from the fynbos, South Africa. *Bioscience* **46:** 184-189.

Van Wilgen, B.W. and Van Wyk, E. (1998). The environmental impacts of invading alien plants in South Africa. Department of Environmental Affairs & Tourism, Pretoria, 19 pp

Van Wilgen, B.W., Richardson, D.M., Le Maitre, D.C., Marais, C. & Magadlela, D. (2001). The economic consequences of alien plant invasions: Examples of impacts and approaches for sustainable management in South Africa. *Environment, Development and Sustainability* **3**: 145-168.

Van Wilgen, B.W. (2004). Scientific challenges in the field of invasive alien plant management. *South African Journal of Science* **100**: 19-20

Van Wilgen, B.W., Nel, J.L. and Rouget, M. (in press). Invasive alien plants and South African rivers: A proposed approach to the prioritisation of control operations. *Freshwater Biology*

Versfeld, D.B. and van Wilgen, B.W. (1986). Impact of woody aliens on ecosystem properties. In *Ecology and Management of Biological Invasions in Southern Africa*, ed. I.A.W. Macdonald, F.J. Kruger and A.A. Ferrar, pp.21-35. Cape Town: Oxford University Press.

Versfeld, D.B., Le Maitre, D.C. and Chapman, R.A. (1998). *Alien Invading Plants and Water Resources in South Africa: A preliminary assessment.* Report No. TT 99/98, Water Research Commission. Pretoria.

Watson, M. (pers. comm.) Chief Engineer. Water Situation Assessment Model, Department of Water Affairs & Forestry

Wells, M.J., Balsinhas, A.A., Joffe, H., Engelbrecht, V.M., Harding, G. and Stirton, C.H. (1986a). A catalogue of problem plants in southern Africa. *Mem. Bot. Surv. S. Afr.* **53**.

Wells, M.J., Poynton, R.J., Balsinhas, A.A., Musil, C.F., Joffe, H., van Hoepen, E. and Abbot, S.K. (1986b). The history of introduction of invasive alien plants to southern Africa. In *Ecology and Management of Biological Invasions in Southern Africa*, ed. I.A.W. Macdonald, F.J. Kruger and A.A. Ferrar, pp.21-35. Cape Town: Oxford University Press.

WfW (1998). The *Working for Water* Programme. Annual Report, 1997/98. Department of Water Affairs and Forestry, Pretoria.

WfW (2001a). The *Working for Water* Programme Strategic Plan (2001-2004). April 2001

WfW (2001b) The *Working for Water* Programme. Planning Guidelines, Final Draft. Unpublished report.

WfW (2002) The *Working for Water* Programme. Draft Regional Strategic Planning Process. Unpublished report.

WfW (2004a). *The Working for Water Programme: Interim Strategic Plan: 2004/5 to 2007/8*, Draft 11 dated 16 March 2004.

WfW (2004b). The *Working for Water* Programme: Strategic Planning Policy, The use of incentives, disincentives, advocacy and research within the programme's overall planning and prioritisation for the prevention and management of invasive alien plants, WfW Executive Committee, 6 pp.

Wilson, PAS, Dennil, G, Erasmus, CF, Fourie, E, Gordon, T, Kluge, RL, Muller, K, Page, P, Richardson, DM and Rossouw, J (1985) Chapter 10: Control Strategies. In: Macdonald IAW, Jarman ML and Beeston P (eds). Management of invasive alien plants in the fynbos biome, South African National Scientific Programmes Report No. 111, 140pp.

Wittenberg, R. & Cock, M.J.W. (eds) (2001) Invasive Alien Species: A Toolkit for Best Prevention and Management Practices. CAB International, Wallingford, UK.

APPENDIX 1: Determination of documented species effects

Species	Kind of weed (Wells *et al.*, 1986a)	Significant water users (Versfeld *et al.* 1998)	Environmental effects (van Wilgen *et al.*, 2001)	Effects on agricultural production (Hoffman & Ashwell, 2001)	Ecological effect	Hydrological effect	Agricultural effect	No. of effects
Acacia cyclops	Pastoral (natural), hydrological?, industrial (tourist), flora, conservation	Yes		Yes	Yes	Yes	Yes	3
Acacia dealbata	Ruderal (general), silvicultural (natural), silvicultural (plantations), pastoral (natural), hydrological?, industrial (tourist), flora, conservation	Yes			Yes	Yes	Yes	3
Acacia decurrens	Ruderal (general), silvicultural (natural), pastoral (natural), hydrological?, industrial (tourist), flora	Yes			No	Yes	Yes	2
Acacia longifolia	Pastoral (natural), industrial (tourist), flora, conservation	Yes	Decreases streamflow		Yes	Yes	Yes	3
Acacia mearnsii	Ruderal (general), pastoral (natural), hydrological?, industrial (tourist), flora, conservation	Yes	Decreases streamflow	Yes	Yes	Yes	Yes	3
Acacia melanoxylon	Ruderal (general), silvicultural	Yes			Yes	Yes	No	2

	(natural), silvicultural (plantations), hydrological?, flora, conservation							
Acacia pycnantha	Ruderal (general), hydrological?, industrial (tourist), flora	Yes			No	Yes	No	1
Acacia saligna	Ruderal (general), pastoral (natural), hydrological?, industrial (tourist), flora, conservation	Yes		Yes	Yes	Yes	No	2
Albizia lebbeck/procera	Ruderal (general), pastoral (natural), flora				No	No	Yes	1
Arundo donax	Ruderal (general), hydrological?, recreational (water-sport), industrial (tourist), flora	Yes			No	Yes	No	1
Atriplex lindleyi subsp. inflata	Ruderal (general), pastoral (natural), flora				No	No	Yes	1
Caesalpinia decapetala	Ruderal (general), agrestal (general), silvicultural (plantations), pastoral (natural), hydrological?, flora	Yes			No	Yes	Yes	2
Campuloclinium macrocephalum					?	?	?	0
Cardiospermum grandiflorum	Ruderal (general), silvicultural (natural),				No	No	No	0

	silvicultural (plantations), flora							
Cereus jamacaru	Pastoral (natural), industrial (tourist)?, flora, health related (humans)			Yes	No	No	Yes	1
Cestrum laevigatum/parqui	Ruderal (general), agrestal (general), pastoral (natural), flora, conservation, health related (cattle)				Yes	No	Yes	2
Chromolaena odorata	Ruderal (general), agrestal (general), silvicultural (natural), silvicultural (plantations), pastoral (natural), industrial (tourist), flora, conservation	Yes		Yes	Yes	Yes	Yes	3
Eucalyptus camaldulensis	Flora	Yes			No	Yes	No	1
Eucalyptus lehmannii	Ruderal (general), industrial (tourist), flora	Yes			No	Yes	No	1
Hakea drupacea	Ruderal (general), pastoral (natural), hydrological, industrial (tourist), flora, conservation	Yes			Yes	Yes	Yes	3
Hakea gibbosa	Hydrological, industrial (tourist), flora, conservation	Yes			Yes	Yes	No	2
Hakea sericea	Ruderal (general), hydrological,				Yes	Yes	Yes	3

	pastoral (natural), industrial (tourist), flora, conservation							
Harrisia martinii	Ruderal (general), pastoral (natural), flora, health related (humans)				No	No	Yes	1
Hedychium coccineum/gardnerianum					?	?	?	0
Hedychium coronarium/flavescens					?	?	?	0
Ipomoea alba/indica	Ruderal (general), agrestal (general), flora				No	No	No	0
Jacaranda mimosifolia	Ruderal (general), pastoral (natural), industrial (tourist), flora, conservation	Yes			Yes	Yes	Yes	3
Lantana camara	Ruderal (general), silvicultural (natural), silvicultural (plantations), pastoral (natural), industrial (tourist)?, flora, conservation, health related (humans), health related (livestock generally)	Yes	Poisons livestock	Yes	Yes	Yes	Yes	3
Leptospermum laevigatum	Flora, conservation	Yes			Yes	Yes	No	2
Litsea glutinosa	Flora, health related (livestock generally)?				No	No	No	0

Macfadyena unguis-cati					?	?	?	0
Melia azederach	Ruderal (general), pastoral (natural), industrial (tourist)?, flora, conservation, health related (humans), health related (livestock generally)	Yes			Yes	Yes	Yes	3
Morus alba	Flora	Yes			No	Yes	No	1
Nasella trichotoma	Ruderal (general), agrestral (general), pastoral (other planted), pastoral (natural), flora, conservation, health related (humans)		Decreases pasture productivity	Yes	Yes	No	Yes	2
Opuntia aurantiaca	Ruderal (general), pastoral (natural), flora, conservation, health related (humans), health related (livestock generally)	Yes	Decreases pasture productivity	Yes	Yes	Yes	Yes	3
Opuntia ficus-indica	Ruderal (general), pastoral (natural), industrial (tourist)?, flora, conservation, health related (humans)	Yes	Decreases pasture productivity	Yes	Yes	Yes	Yes	3
Opuntia fulgida	Pastoral (natural), flora, health	Yes		Yes	No	Yes	Yes	2

	related (humans), health related (livestock generally)							
Opuntia imbricata	Ruderal (general), pastoral (natural), flora, health related (humans)	Yes		Yes	No	Yes	Yes	2
Opuntia stricta	Ruderal (general), pastoral (natural), flora, health related (humans)	Yes		Yes	No	Yes	Yes	2
Paraserianthes lophantha	Ruderal (general), agrestal (general), hydrological?, flora	Yes			No	Yes	No	1
Pinus elliottii	Flora	Yes			No	Yes	No	1
Pinus halepensis	Flora	Yes			No	Yes	No	1
Pinus patula	Pastoral (natural), industrial (tourist), flora, conservation	Yes			Yes	Yes	Yes	3
Pinus pinaster	Pastoral (natural), industrial (tourist), flora, conservation	Yes	Decreases streamflow		Yes	Yes	Yes	3
Pinus radiata	Pastoral (natural), industrial (tourist), flora, conservation	Yes	Decreases streamflow		Yes	Yes	Yes	3
Populus alba/canescens	Pastoral (natural), hydrological, recreational (water-sport), industrial (tourist), flora, conservation	Yes			Yes	Yes	Yes	3
Prosopis glandulosa var. torreyana/velutina	Ruderal (general), agrestal (general), pastoral (natural), hydrological?, industrial (tourist),	Yes	Decreases pasture productivity	Yes	Yes	Yes	Yes	3

	flora, conservation						
Psidium guajava	Ruderal (general), pastoral (natural), industrial (tourist), flora, conservation	Yes		Yes	Yes	Yes	3
Pyracantha angustifolia	Pastoral (natural), industrial (tourist), flora	Yes		No	Yes	Yes	2
Robinia pseudoacacia	Ruderal (general), pastoral (natural), flora	Yes		No	Yes	Yes	2
Rubus cuneifolius	Ruderal (general), agrestal (general), silvicultural (plantations), pastoral (natural), industrial (tourist)?, flora, conservation	Yes	Yes	Yes	Yes	Yes	3
Rubus fruticosus		Yes	Yes	No	Yes	Yes	2
Salix babylonica	Hydrological?, industrial (tourist), flora, conservation, health related (humans)	Yes		Yes	Yes	No	2
Salix fragilis				?	?	?	0
Sesbania punicea	Ruderal (general), pastoral (natural), hydrological?, flora, conservation, health related (sheep)	Yes	Decreases streamflow, poisons livestock	Yes	Yes	Yes	3
Solanum mauritianum	Ruderal (general), agrestal (general), silvicultural (natural),	Yes	Yes	Yes	Yes	Yes	3

	silvicultural (plantations), industrial (tourist)?. flora, conservation, health related (humans)							

APPENDIX 2: Comparison of species selected with other national invasive alien plant lists.

Species	Wells *et al.* (1986a)	Richardson *et al.* (1997)	Versfeld *et al.* (1998)	Robertson *et al.* (2003)	Holmes *et al.* (2003)	Nel *et al* (2004a)	No. of effects
Acacia cyclops	1	1	1			W	3
Acacia dealbata	1	1	1		1	W	3
Acacia decurrens	1	1	1		1	W	2
Acacia longifolia	1	1	1			W	3
Acacia mearnsii	1	1	1		1	WW	3
Acacia melanoxylon	1	1	1			W	2
Acacia pycnantha	1	1	1			L	1
Acacia saligna	1	1	1			W	2
Albizia lebbeck/procera						L	1
Arundo donax	1	1	1			WW	1
Atriplex lindleyi subsp. inflata						W	1
Caesalpinia decapetala		1	1		1	W	2
Campuloclinium macrocephalum						W	0
Cardiospermum grandiflorum		1				W	0
Cereus jamacaru	1	1				W	1
Cestrum laevigatum/parqui	1	1			1	W	2
Chromolaena odorata	1	1	1		1	W	3
Eucalyptus camaldulensis			0.5			W	1
Eucalyptus lehmannii	1	1	0.5		1	L	1
Hakea drupacea	1		0.333		1	L	3
Hakea gibbosa	1	1	0.333		1	L	2
Hakea sericea	1	1	0.333			W	3
Harrisia martinii						L	1
Hedychium coccineum/gardnerianum						L	0
Hedychium coronarium/flavescens						L	0
Ipomoea alba/indica						W	0
Jacaranda mimosifolia	1		1		1	W	3

Lantana camara	1	1	1		1	W	3
Leptospermum laevigatum	1	1	1		1	L	2
Litsea glutinosa		1				L	0
Macfadyena unguis-cati						L	0
Melia azederach	1	1	1		1	VW	3
Morus alba		1	1		1	W	1
Naselta trichotoma	1	1				L	2
Opuntia aurantiaca	1	1	0.2			W	3
Opuntia ficus-indica	1	1	0.2			VW	3
Opuntia fulgida			0.2			L	2
Opuntia imbricata		1	0.2			W	2
Opuntia stricta			0.2			W	2
Paraserianthes lophantha		1	1		1	L	1
Pinus elliotii		1	0.2		1	L	1
Pinus halepensis			0.2		1	L	1
Pinus patula	1	1	0.2		1	W	3
Pinus pinaster	1	1	0.2		1	W	3
Pinus radiata	1	1	0.2		1	W	3
Populus alba/canescens	2	2	1		1	VW	3
Prosopis glandulosa var. torreyana/velutina	2	1	1		1	VW	3
Psidium guajava	1	1	1		1	W	3
Pyracantha angustifolia	1	1	1			W	2
Robinia pseudoacacia			1			W	2
Rubus cuneifolius	1	1	0.5			W	3
Rubus fruticosus			0.5			W	2
Salix babylonica	1	1	0.5			VW	2
Salix fragilis			0.5			W	2
Sesbania punicea	1	1	1			W	3
Solanum mauritianum	1	1	1		1	W	3
TOTAL (from this study occurring on other lists)	36	40	30	36	24	56	
TOTAL (terrestrial, of other lists)	43	80	40	56	29	111	

APPENDIX 3: Correlation matrices showing the relationships between all pairs of criteria within each WfW region (B).

Table 1 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Western Cape region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.374	1.000								
Abundance	0.407	0.877	1.000							
Effect	0.333	0.972	0.862	1.000						
Disturbance	-0.106	-0.557	-0.478	-0.578	1.000					
Terrestrial	0.169	0.424	0.400	0.418	-0.473	1.000				
River	-0.102	-0.228	-0.245	-0.231	0.019	-0.058	1.000			
Water	-0.018	-0.224	-0.117	-0.208	0.023	-0.103	0.214	1.000		
Agriculture	0.332	0.779	0.721	0.740	-0.403	0.376	-0.332	-0.275	1.000	
Overall priority	0.393	0.881	0.865	0.863	-0.405	0.508	0.057	0.024	0.742	1.000

Table 2 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Eastern Cape region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.252	1.000								
Abundance	0.194	0.903	1.000							
Effect	0.249	0.943	0.859	1.000						
Disturbance	-0.116	-0.495	-0.512	-0.499	1.000					
Terrestrial	-0.042	0.315	0.359	0.323	-0.468	1.000				
River	-0.022	-0.162	-0.143	-0.185	0.403	-0.246	1.000			
Water	-0.065	-0.467	-0.451	-0.472	0.276	-0.191	-0.276	1.000		
Agriculture	0.181	0.483	0.455	0.483	-0.658	0.380	-0.622	-0.115	1.000	
Overall priority	0.238	0.862	0.850	0.831	-0.315	0.383	0.100	-0.288	0.405	1.000

Table 3 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Limpopo region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.328	1.000								
Abundance	0.374	0.874	1.000							
Effect	0.322	0.925	0.806	1.000						
Disturbance	-0.259	-0.373	-0.383	-0.329	1.000					
Terrestrial	0.210	0.210	0.221	0.146	-0.485	1.000				
River	0.003	0.292	0.256	0.301	-0.185	0.258	1.000			
Water	-0.033	-0.268	-0.257	-0.234	-0.103	0.081	-0.207	1.000		
Agriculture	0.347	0.619	0.577	0.632	-0.416	0.463	0.387	-0.071	1.000	
Overall priority	0.298	0.762	0.725	0.754	-0.375	0.507	0.618	0.094	0.784	1.000

Table 4 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Mpumalanga region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.298	1.000								
Abundance	0.211	0.892	1.000							
Effect	0.212	0.933	0.839	1.000						
Disturbance	-0.262	-0.519	-0.574	-0.441	1.000					
Terrestrial	0.288	0.302	0.262	0.225	-0.181	1.000				
River	-0.031	-0.058	-0.183	-0.026	0.246	0.028	1.000			
Water	0.046	-0.372	-0.439	-0.426	0.137	-0.041	0.011	1.000		
Agriculture	0.193	0.678	0.600	0.712	-0.508	0.281	-0.023	-0.253	1.000	
Overall priority	0.272	0.721	0.577	0.694	-0.181	0.511	0.388	0.090	0.596	1.000

Table 5 Correlation matrix showing the relationships between all pairs of criteria within the **WfW KwaZulu-Natal region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.162	1.000								
Abundance	0.102	0.836	1.000							
Effect	0.138	0.841	0.585	1.000						
Disturbance	-0.083	-0.350	-0.393	-0.256	1.000					
Terrestrial	-0.050	0.308	0.441	0.222	-0.284	1.000				
River	0.137	0.137	0.137	0.053	-0.091	0.056	1.000			
Water	-0.119	-0.240	-0.271	-0.080	0.147	-0.162	-0.109	1.000		
Agriculture	0.038	0.317	0.294	0.263	-0.276	0.226	0.198	-0.171	1.000	
Overall priority	0.094	0.658	0.621	0.595	-0.073	0.454	0.617	0.121	0.388	1.000

Table 6 Correlation matrix showing the relationships between all pairs of criteria within the **WfW North West region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Disturbance*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.672	1.000								
Abundance	0.669	0.933	1.000							
Effect	0.626	0.952	0.829	1.000						
Disturbance	-0.578	-0.664	-0.634	-0.629	1.000					
Terrestrial	0.237	0.522	0.442	0.521	-0.444	1.000				
River	0.213	0.295	0.245	0.347	-0.033	0.193	1.000			
Water	0.619	0.496	0.448	0.515	-0.532	0.200	0.214	1.000		
Agriculture	0.242	0.318	0.223	0.407	-0.336	0.096	0.168	0.518	1.000	
Overall priority	0.670	0.899	0.834	0.902	-0.557	0.535	0.556	0.696	0.473	1.000

Table 7 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Northern Cape region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Untransformed*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.178	1.000								
Abundance	0.292	0.195	1.000							
Effect	0.202	0.841	0.294	1.000						
Untransformed	0.048	-0.260	0.136	-0.262	1.000					
Terrestrial	-0.018	0.123	-0.171	0.126	-0.842	1.000				
River	0.140	0.255	0.085	0.247	-0.283	0.204	1.000			
Water	-0.007	0.246	0.038	0.206	-0.009	-0.044	-0.035	1.000		
Agriculture	0.051	0.330	-0.148	0.340	-0.679	0.589	0.119	0.139	1.000	
Overall priority	0.265	0.732	0.449	0.764	-0.390	0.282	0.655	0.357	0.441	1.000

Table 8 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Gauteng region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Untransformed*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.134	1.000								
Abundance	0.195	0.748	1.000							
Effect	0.125	0.922	0.670	1.000						
Untransformed	-0.050	-0.063	-0.045	-0.043	1.000					
Terrestrial	0.013	-0.117	0.123	-0.070	0.229	1.000				
River	0.026	-0.106	-0.047	-0.095	-0.049	0.082	1.000			
Water	-0.143	-0.333	-0.254	-0.272	0.298	-0.046	0.064	1.000		
Agriculture	0.107	0.060	0.302	0.105	0.469	0.329	0.081	0.107	1.000	
Overall priority	0.077	0.568	0.655	0.606	0.447	0.367	0.106	0.315	0.561	1.000

Table 9 Correlation matrix showing the relationships between all pairs of criteria within the **WfW Free State region**.

	WfW prioritisation	*Range*	*Abundance*	*Effect*	*Untransformed*	*Terrestrial*	*River*	*Water*	*Agriculture*	*Overall priority*
WfW prioritisation	1.000									
Range	0.048	1.000								
Abundance	0.099	0.521	1.000							
Effect	0.176	0.589	0.201	1.000						
Untransformed	0.085	0.276	0.232	-0.255	1.000					
Terrestrial	-0.022	0.181	0.080	0.453	-0.444	1.000				
River	-0.103	-0.072	0.087	0.168	-0.448	0.342	1.000			
Water	-0.134	-0.393	-0.305	-0.312	0.049	-0.130	-0.337	1.000		
Agriculture	0.032	0.297	0.422	0.415	-0.303	0.421	0.488	-0.477	1.000	
Overall priority	-0.016	0.523	0.594	0.539	-0.060	0.571	0.498	-0.060	0.618	1.000