ALIEN INVADING PLANTS AND WATER RESOURCES IN SOUTH AFRICA:

A PRELIMINARY ASSESSMENT

DB Versfeld · DC Le Maitre · RA Chapman

WRC Report No. TT99/98

Water Research Commission

ALIEN INVADING PLANTS

AND

WATER RESOURCES IN SOUTH AFRICA: A PRELIMINARY ASSESSMENT

Report to the Water Research Commission

by

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Water Research Commission Report

Alien Invading Plants and Water Resources in South Africa: A Preliminary Assessment

Foreword

Professor Kader Asmal, M.P.
Minister of Water Affairs and Forestry

August 1998

This critically important report has given us, for the first time, a picture of the extent to which South Africa has been invaded by alien plants, and the enormity of the challenge facing the Working for Water programme.

The picture is bleak. Invading alien plants have covered some 10 million hectares, an area larger than the province of KwaZulu-Natal, or about 8% of South Africa. If all of the invading plants were packed densely together, they would more than cover the whole of the province of Gauteng.

Invading alien plants are causing us to lose some 7% of the annual flow in South Africa's rivers each year - about 3 300 million cubic metres of water. (This excludes their severe impact upon groundwater reserves.) Were we to do nothing to redress the situation, then the plants would continue to invade at a rate of about 5% per year, doubling their impact every 15 years!

Our Working for Water programme is the world's most comprehensive initiative to clear invading alien plants. It is estimated that approximately 750 000 hectares will need to be cleared each year to win the battle over a 20-year period. The costs of doing so are huge (up to R600 million per year), and a great deal of innovative action will be needed to achieve this goal.

Aside from the necessary funding, there is a need to improve productivity in the programme; to develop secondary industries associated with the work; to utilize biological control agents to best effect; to develop and apply appropriate legislation regarding invading alien plants, and for a massive educational initiative.

The investment in the Working for Water programme is huge by any standards, and we need to consider the benefits carefully before committing ourselves to an increased level of expenditure. This report indicates that the worst-invaded areas are mostly in our high-yielding catchments, so the communities downstream (where it is usually far drier) will be severely affected. Furthermore, building dams to provide the same volume of water as used by alien plants is more expensive, and will not help if there is not enough water left to fill them.

The programme also has many socio-economic benefits. Current estimates are that it could provide on-going employment to about 50 000 people, directly and indirectly, and support a further 250 000 more, mainly among the poorest of the poor.

Together with the employment comes the many social benefits for an improved quality of life, as the programme strives to meet its reconstruction and development obligations.

What is more, the programme also contributes significantly to the conservation of our rich and diverse plant and animal life, and our vital river systems, in keeping with the far-reaching provisions proposed in the National Water Act.

Should we tackle this challenge? I do not believe we have a choice. To take on a challenge of this magnitude will require a joint commitment by government, the private sector, labour and the communities - and particularly the land-owners. We have made an exceptionally auspicious start. As I have said before, and now say with renewed urgency: Phambili! Forward!

Professor Kader Asmal, M.P.
Minister of Water Affairs and Forestry

ACKNOWLEDGEMENTS

The project has placed great demands upon a large number of people and organizations. It has been a truly participative information gathering exercise. Our thanks go out to all who willingly sacrificed time, effort and travel to attend workshops, complete maps and questionnaires and who in so many ways provided knowledge and expertise. Individuals and organizations are too many to single out in this acknowledgement but have been listed, to the best of our ability, under *the "Consultations and expertise list"* (Appendix 1).

Amongst our colleagues we are most indebted to Lynn Carelse and Reney Robyntjies for taking complete ownership of the digitizing of what was often very difficult data. This cost many long hours and weekends. Also to Francois van der Heyden, Tony Poulter and Greg Forsyth for organizing and facilitating workshops. Pieter Viljoen of Ekoserv in Mpumalanga also proved invaluable in locating knowledgeable people and gathering information.

Most important to this project has been the willingness of organizations to share not only expertise, but also to offer the use of existing data sets. The willingness of Rand Water to support the capture of data within the Rand Water Catchment area (50 000 km^2) and to make this data available, was invaluable - both in terms of information and experience. Western Cape Nature Conservation and Eastern Cape Nature Conservation both provided substantial GIS data bases, as did Umgeni Water, through their consultants Murray Biesenbach and Badenhorst (MBB). The Department of Agriculture (KZN) provided a set of 1 : 50 000 maps which was also included. Dave Richardson supplied references which form the basis of an appendix on *"Literature on alien plants and invasion processes"*.

Perhaps one can risk singling out the DWAF Working for Water Programme, and all of the field project managers, for input and support, not least in the gathering of data on costs of clearing, and for financial support for a revision of this report.

Finally we wish to extend our thanks to the Water Research Commission for supporting this study, and to all the members of the steering committee for scientific and technical guidance.

EXECUTIVE SUMMARY

INTRODUCTION

Alien plant invasions are recognised as a major threat to the natural resources of South Africa, and particularly to the water resource. A national programme 'Working for Water', under the auspices of the Department of Water Affairs and Forestry, is aimed at bringing the problem of plant invasions under control. This umbrella programme operates at a level of approximately R150 million per year and now includes a number of additional water management bodies such as water boards and city councils. The programme needs to operate at maximum efficiency by concentrating in those areas of greatest need and where the risks of invasion to the sustainability of the resource are highest.

Despite widespread recognition of the problem posed by plant invasions , and excellent local knowledge and understanding of risks in some regions and impacts on some sectors, there has never been a comprehensive assessment of the full extent of invasion, nor of the associated impacts and costs. This is partly explained by the biological dynamics - invasions are spreading at an exceptional rate and existing cover is likely to more than double over the next 20 years. Conventional survey methods have difficulty keeping pace.

This project has put in place a picture of the major known occurrences of alien invaders, at a scale of 1:250 000, based primarily upon the knowledge of natural resource experts from across South Africa. The survey concentrated on woody, alien species (particularly trees) which are likely to use more water than indigenous vegetation, but data on herbaceous and aquatic species have been included where they have been mapped. All the mapped data have been captured in a Geographic Information System (GIS) and includes details of species composition and density. From this information the nature and degree of invasion can be calculated for each province, water scheme, or catchment. The expected water-use of invaders has been calculated using a relationship between biomass and streamflow reductions. Costs to clear (in 1997/8 Rands) have been estimated from the current experience of managers in the field. Some guidelines for prioritizing the catchments requiring clearing operation have also been provided.

This project provides an active database. The potential of this data can only be partially realized through this report. The maximum benefits will be best achieved if the data itself is used as both baseline and management tool, and is regularly updated and improved. For consistency the scientific names of species have been used at all times. A list of recognised common and scientific names has been included in Appendix 1.

OBJECTIVES

The objectives of the project, as agreed to by the steering committee appointed by the Water Research Commission, are listed below:

- To determine the nature, extent and distribution of alien invaders in South Africa at a national scale.
- To assess the impacts which these invaders may have on the water resource.
- To assess the costs of managing the current problem of alien invaders (in bringing them under control) and the costs of maintaining the landscape in a condition where invasive species are kept under control.
- To assess the costs of failure to bring alien invaders under control, i.e. to assess the consequences and costs of unchecked further invasion.
- To determine how long it will take to achieve satisfactory control.
- To prioritise the areas which should be targeted first in a national programme to control alien invaders. Water is viewed as the primary issue upon which this prioritization will be based, but other implications must be considered.
- To identify gaps in the national knowledge base, and to determine research priorities.
- To use scenario planning in determining how to take the invader control programme forward into the long-term future (e.g. the clearing of lightly vs. densely invaded areas).
- To develop a vision for the future with regard to the clearing of alien invading plants.

METHODOLOGY AND RESULTS

Invasions of alien plants were mapped and digitised and stored within a GIS (*Arc/Info*) at a scale of 1:250 000 for almost the entire country. Mapping was on the basis of expert knowledge, along with the addition of existing databases for some limited areas. Species and densities were recorded for each of the more than 6 000 invaded areas (polygons) captured. The primary aim was to gather information on the woody species which are likely to use more water than the indigenous vegetation but a limited amount of data on herbaceous aquatic species has also been included. The water-use of herbaceous and aquatic invaders was not calculated in this analysis. From these GIS records it is possible to determine the extent and distribution of each species within each catchment and for each province. Incremental water use by invading species has also been determined at the level of tertiary catchment in addition to the total water costs to each province and the country. The results are summarised in Table 1.

Alien invaders occupy a total area of 10.1 million ha (6.82%) of South Africa and Lesotho. These invasions were often at low densities (<5% canopy cover) but if the plant invaders are 'condensed' (e.g. 100 ha with 5% cover of alien plants would be condensed to 5 ha with 100% cover), the occupied area is the equivalent of 1.7 million hectares, or 1.4% of the total landscape. To put this into perspective, the condensed invaded area is greater than that of Gauteng and about 20% greater than the total area of commercial plantations. Riparian invasions are found throughout all the provinces although extensive landscape invasions have also been mapped within the Western Cape. This has important implications for water use as riparian zone species generally have relatively free access to water and therefore are often consumptive users. The data on the invaded areas exclude plantations and woodlots but do include invaders occurring within them.

Table 1: **Summary by province of the areas invaded by alien plants, impacts on mean annual runoff and costs of clearing and control. The condensed area is the total area adjusted to bring the cover to the equivalent of 100%. The costs of control are based on a 20-year clearing programme, a rate of expansion of the total invaded area of 5% per year, an annual budget of R600 million, and have been discounted at 8.0% per year. (For more information see the text.)**

Province	Area (ha)	Invaded area (ha)		Mean annual runoff (millions of m³)	Incremental water-use		Estimated costs of clearing (millions of Rands)
		Total	Condensed		(millions of m³)	(%)	
Eastern Cape	16 739 817	671 958	151 258	9 998.76	558.19	5.58	564.36
Free State	12 993 575	166 129	24 190	3 546.10	86.19	2.43	99.13
Gauteng	1 651 903	22 254	13 031	551.97	53.93	9.77	44.97
KwaZulu-Natal	9 459 590	922 012	250 862	12 517.61	575.74	4.60	597.48
Lesotho	3 056 978	2 457	502	4 647.19	1.88	0.04	1.29
Mpumalanga	7 957 056	1 277 814	185 149	6 303.01	446.29	7.08	372.81
Northern Cape	36 198 060	1 178 373	166 097	910.94	150.86	16.56	869.77
Northern Province	12 214 307	1 702 816	263 017	3 383.63	297.70	8.80	410.13
North West	11 601 008	405 160	56 232	1 081.57	95.40	8.82	232.07
Western Cape	12 931 413	3 727 392	626 100	6 555.18	1 036.82	15.82	2 250.56
RSA+Lesotho	124 803 708	10 076 365	1 736 438	49 495.96	3 303.00	6.67	5 442.57

Terrestrial, woody, alien invaders are estimated to use a total of 3 300 million m³ of water over the entire country in a single year. This is approximately 6.7% of the estimated mean annual runoff (MAR) for the country or about 75% of the naturalised MAR of the Vaal River system. In contrast, commercial plantations occupy approximately 1.44 million hectares and use an estimated 1 399 million m^3 (3.2% of MAR). On a unit area basis the incremental water use of dense alien invaders is the equivalent of 1 900 m^3 per hectare per year compared with 930 m^3 for commercial plantations. Invading species therefore occupy a greater land area and also consume significantly more of the national water resource than the entire commercial forestry industry. The impacts could also be significantly higher, on a percentage basis, during drought periods, as the riparian invaders will still have free access to water. This would be particularly important for rural and urban communities which depend on river flow because they do not have the infrastructure needed to store water.

Water use by invaders also has been summarised into component water use by different species, and into water use for each tertiary catchment and each province. The most widespread genus is *Acacia* and it is the acacias, eucalypts, and pine species which use most of the water. *Prosopis* species are the sixth highest water users nationally and by far the greatest water users in the Northern Cape province. There are a number of instances where the estimated volume of water used by invaders exceeds the expected water production from a tertiary catchment, particularly in arid catchments where the MAR is often less than five mm. Although the water use estimates for these arid areas may be in excess of local production, they are realistic as the invaders are maintained by access to groundwater or water from riparian zones. This allows them to access water which is accumulated elsewhere and thus to maintain high water-use rates all year round.

Costs to clear terrestrial alien invaders have been determined for each of the major species and the data have been used to estimate the overall costs of clearing, if all the control operations could be completed 'instantaneously'. The cost of clearing dense stands of tall trees (invaders such as pines, eucalypts and acacias, identified as the country's major problem species) is in the order of R5 500 per hectare, although this may vary considerably depending on region, method employed, and accessibility. Applying these figures to all invading species countrywide suggests that the costs of mounting a one-year, 'once-off' eradication campaign would be in the order of R6.97 billion (including follow-up costs). This is obviously impossible in practice. If invaders are conservatively estimated to spread at a rate of 5% per year, a 20-year control programme would cost in the order of R600 million per year and the total cost (Net Present Value) would be R5.44 billion (Table 1). A delay of 10 years in launching this programme would increase these costs by at least 55%. Savings of the order of 20-30% could be achieved by successfully implementing biocontrol on a number of the major woody species, or by focussing only on water-using invaders. Long-term maintenance will always be necessary and will probably cost about R30 million per year.

These costs need to be seen in context. The high costs of the initial clearing and follow-up will be spread over a few years in a particular area but the additional water released will be available for alternative uses in perpetuity. When expressed on the basis of the amount of water that could be saved during the 20-year control programme alone, the total costs would be 45 cents per m^3. Other benefits include employment and the concomitant social and economic upliftment, the restoration of natural systems and their ecosystem services, and conservation of the natural biodiversity on which much of our tourism industry depends.

Nevertheless, the high direct costs of clearing emphasize the importance of prioritizing where and how funds are spent, ensuring maximum return on investment, and also the need to look for alternative approaches in dealing with the problem. Greater investment in biocontrol is one important strategy that is recommended, as is the need for the authorities to shift responsibility away from government programmes towards the individual land-owner and communities.

Which areas should be cleared first? There are so many variables which affect this decision that any one answer is decidedly risky. The highest priorities are undoubtedly in the high-yielding catchments of the Drakensberg escarpment from the Eastern Cape through to the Soutpansberg, and the mountain areas of the south-western Cape. The most significant impacts simply in terms of water are in the arid Namaqualand coastal region, the areas of the Karoo invaded by *Prosopis*, and the coastal lowlands of the south-western Cape. These areas, particularly the Karoo, cannot be ignored because the invaders will have an impact on groundwater which is the primary, or sole source of water for many communities. Some areas which appear lightly invaded in this assessment (e.g Gauteng) are critical because they lie on the watersheds of major river systems - in this case the Vaal, Limpopo and Olifants River systems.

Decisions on action must, however, be based on the principle of maximum return on investment taking into account the full costs and benefits. This may require more effort to be spent on lightly invaded catchments, which do not yet appear to be a problem, than on heavily invaded catchments where a water shortage is already being experienced. Catchments at risk of rapid invasion also become critical in such an assessment. Data on the rate of spread and the costs of clearing corroborates the argument that preventative measures must be taken to prevent the densification and expansion of currently lightly invaded areas. An analysis of the literature on the rates of invasion indicates that many important species can double in extent over the next 10-20 years and that for some species (e.g. *Mimosa pigra*) such a doubling can be as rapid as one to two years. The only real limit to expansion is the availability of land. With the cost of eradication increasing from R825 to R5875/ha between light and dense invasions the cost implications are obvious.

RECOMMENDATIONS

Our recommendations fall into two main groups:

- recommendations for action:
  - promoting and facilitating public awareness and fostering active public participation in alien plant control and mapping of invasions by creating a framework for community and public participation in the management of invaders; and
  - using this database as the foundation for establishing an effective and readily accessible information system on alien plant invasions, their impacts and what can be done to control measures.
- recommendations for research into:
  - key aspects of the biology of alien invaders and their control (including rehabilitation);
  - developing better models for the assessment of the impact of invaders on water and other natural resources, and evaluating the extent to which the water used by alien invaders may have been implicitly included in the recent (1990) estimates of naturalised mean annual runoff;
  - improving our understanding of rates of invasion;
  - improving existing, and developing new control methodologies and achieving better integration;
  - the costs of control and the factors that influence control in different situations; and
  - obtaining better information on the full social and economic costs and benefits of alien plant clearing operations to put the clearing costs into perspective.

Recommendations for action are focussed on the use of information, the need to maintain and update the database, and the establishment of an open information line. Specific tasks include the mapping of areas cleared of invaders, the standardization of data-capture methodology, and the use of the Internet as a mechanism for information sharing.

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1. INTRODUCTION

1.1 Background

Alien invading plants have a major impact on the natural resources, and particularly the water resources, of South Africa. The South African environment is particularly prone to invasions. The total land mass of South Africa is some 1 221 040 km^2 and all of this land is potentially subject to invasions - from giant eucalypts to scrubby cactus. The higher rainfall catchments, which are the primary source of our water supplies, tend to be the most readily invaded and can be considered the most important in terms of water supplies.

The management of 'the high yielding' catchment areas is certainly a key component in the protection of South Africa's water resources. The high rainfall catchment areas of the country cover some 150 000 km^2 and are responsible for a large proportion of the country's runoff (Van der Zel, 1981). Invasion by alien woody weeds displaces the indigenous vegetation, increases the biomass in catchment areas, and can substantially decrease the surface runoff (Van Wilgen *et al.*, 1990, Le Maitre *et al.*, 1996, Van Wilgen *et al.*, 1996, Umgeni Water, 1997). Concern over the impact of these invasions has led to renewed efforts by the Department of Water Affairs and Forestry to clear infestations.

Invasions must, however, be viewed both in terms of their impact on high-yielding catchments areas (impact on water production) and on low-yielding catchment areas (invasives as consumers of available water). Our concerns are therefore not only with the upland mountain catchment areas but with the drier downstream areas where invaders are also able to gain a foothold - notably within riparian zones. The question of water security has also come to the fore, and land management is no longer considered only in terms of large scale supply and demand (big dam supply culture), but also in terms of the needs of the local community and landowner. Alien invaders can have very important impacts at this scale of supply. What we are dealing with therefore is a **national** issue, affecting all land and all users of water.

The current recognized expenditure on invading alien plant clearing projects exceeds R100 million per year, having been stepped up to this level in 1995 in response to growing concerns. The cost incurred by farmers, foresters, landowners, local authorities, utilities and other individuals and institutions in clearing plant invasions must be added to this amount. Preliminary investigations have led to the generally accepted view that, if water alone is considered, the expense of clearing programmes can be financially justified (Van Wilgen *et al.*, 1996, Umgeni Water, 1997). It is accepted that the clearing of invasions at an early stage or, better still, the pre-emption and prevention of invasion, is the most cost-effective option, in view of the exponential increases in the costs of clearing, and the impact of their incremental water-use (and thus the reduced streamflow - see chapters 2 and 4), if invasion is allowed to continue unchecked. Finally, the added benefits of clearing, including the social benefits that arise from the implementation of a labour-intensive clearing programme and the conservation of biodiversity and maintenance of catchment stability, although not quantified, will further support the argument for clearing operations. These benefits can be substantial (Higgins *et al.*, 1997).

For the reasons outlined above, 38 major projects spread across all 9 provinces have been initiated to control alien invaders (DWAF, 1997). However, it was recognised that an overall assessment of the problem in the country would be necessary in order to establish its magnitude. Such an assessment is needed to answer questions such as:

- What is the extent of the problem in the country?
- What species are implicated?
- What impact do invading plants currently have, on water as well as on other elements of the environment?
- What will it cost to deal with the problem?
- Who would benefit from clearing, and how will the costs be covered?; and
- Can the invaded areas be prioritized in terms of importance for clearing?

1.2 Project Objectives

In order to provide preliminary answers to these questions, the Water Research Commission appointed the CSIR to conduct an initial assessment. The terms of reference for the study were as follows:

1. To determine the nature, extent and distribution of alien invaders in South Africa at a national scale.

2. To assess the impact which these invaders may have upon water resources.

3. To assess the cost of managing the current problem of alien invaders (in bringing them under control) and the cost of maintaining the landscape in a condition where invaders are kept under control.

4. To assess the cost of a failure to bring alien invaders under control, i.e. to assess the consequences and cost of unchecked further invasion.

5. To determine how long it would take to achieve satisfactory control.

6. To prioritise the areas which should be targeted first in a national programme to control alien invaders. Water is viewed as the primary issue upon which this prioritization will be based, but other implications must be considered.

7. To identify gaps in the national knowledge base, and to determine the research priorities.

8. To use scenario planning in determining how to take the invader control programme forward into the long term future (e.g. the clearing of lightly invaded vs. densely invaded areas and with or without biological control).

9. To develop a vision for the future with regard to the clearing of alien invader plants.

1.3 Time Frame

The urgency with which information is needed to properly direct the funding of alien clearing programmes resulted in the time frame for this work initially being limited to 15 months. The project timespan was of 1 January 1996 to 31 March 1997 was subsequently extended to June 1998 to allow for the addition of further data, corrections to the existing data and a re-analysis of the impact of alien invaders on water resources.

1.4 Study Area, Scope and Scale of Study

This study was restricted to the borders of South Africa, but given the importance of Lesotho to South Africa as a water resource, some consideration has also been given to catchments within Lesotho. The scale of the study is therefore vast - to gain a picture of the scope and extent of alien invaders **nationally**, to understand issues and consequences (particularly with regard to water), and from this national picture to offer direction to efforts to get the problem under control. Forest plantations, although sometimes a source of invasion, have not been mapped as invaders. Invading species within plantations have however been recorded where possible.

To assume that some provinces are more seriously invaded than others, or that some provinces are not really affected by alien invaders, would pre-empt the findings of this study. The approach has therefore been to try and look even-handedly at the entire country (see Figure 1.1), although certain areas, particularly the central Karoo and Kalahari regions, have been neglected. But it has been the study of areas relatively little known to the project team, and indeed to many 'experts' on invaders, that has turned up some of the biggest surprises.

The extent and consequences of alien invaders are described at a national level, but also at the level of the nine provinces. Data have been broken down further to the level of the tertiary catchment - considered the finest scale to which data of this nature could be applied. Methodologies are such, however, that at finer scales a certain level of error is unavoidable.

The scope is such that it has been obligatory for the project team to avoid becoming distracted by detail - and yet much of the information captured and collated is very detailed. It is important therefore to recognise that (i) the objective has been to capture data at a national scale and to provide information to advise decisions at a national level, and (ii) that far more information is available than can possibly be presented in this report, but that this data remains available for use. It is also important to recognise the constraints imposed by a study of this nature at a national scale. These are particularly apparent when looking at the implementation of the models. The models had to be kept very simple, even though more sophisticated approaches are available for studies using a fine resolution.

1.5 Achieving Objectives

How successful has this overview, data gathering and impact determination exercise been?

- In the first instance, and for the first time, a national snapshot of the situation with regard to alien invaders is available to planners and decision makers. We do now have some view of the national extent of the problem and how this is distributed across South Africa.

- Impacts on water resources have been computed down to the level of the tertiary catchment. Whilst these results lack precision they do add to our understanding of the problem and can be used to direct activity.

- Costs of managing invaders can be estimated from the extent and density - but there are significant uncertainties. Differences in terrain, species, density, method of clearing, wage structure, ease of access to invaded areas, and a host of other factors, make it very difficult to determine precisely what clearing might cost. This is reflected in the wide range of cost estimates offered by field managers. A good deal of experience is still required in the field. Nevertheless it is clear that the clearing of alien invaders is a costly exercise but, it would seem, cost effective. This last will certainly depend on the way resources are allocated to clearing projects.

- Attempting to estimate the rate of spread, and the cost of failure in bringing alien invaders under control, has proved a most difficult, and ultimately unsatisfactory, exercise. This is despite the development of models, and a good theoretical understanding of the invasion process, although the lack of data on actual spread dynamics is also a key factor. Expert opinion has been very variable. Species, site, land-use and management area available for invasion, and level of infestation play a major role in patterns of expansion and densification. That levels of invasion in some areas may double every 20 years (or faster) nevertheless gives a good indication of the implications of failure to act, and imparts a real sense of urgency.

- We have not been successful in estimating the time needed to achieve satisfactory control.

- A set of principles have been devised from which, together with the available and tabulated data, areas can be prioritised by decision makers. Areas have been prioritised on the basis of these principles. Prioritization is a difficult and often subjective process dependent on local needs and objectives. There is also an underlying set of principles, such as the prospect of keeping uninvaded areas clean as being the most cost effective approach, which can result in a very different set of priorities. These principles are discussed, and data with regard to extent and impacts presented so that decisions can now be taken.

- Gaps in the knowledge base, some scenario planning, and a vision for the future have been derived from our collective experience in studying the alien invasive situation over the past 20 months. These ideas are open to scrutiny and we trust that they will enjoy vigorous debate.

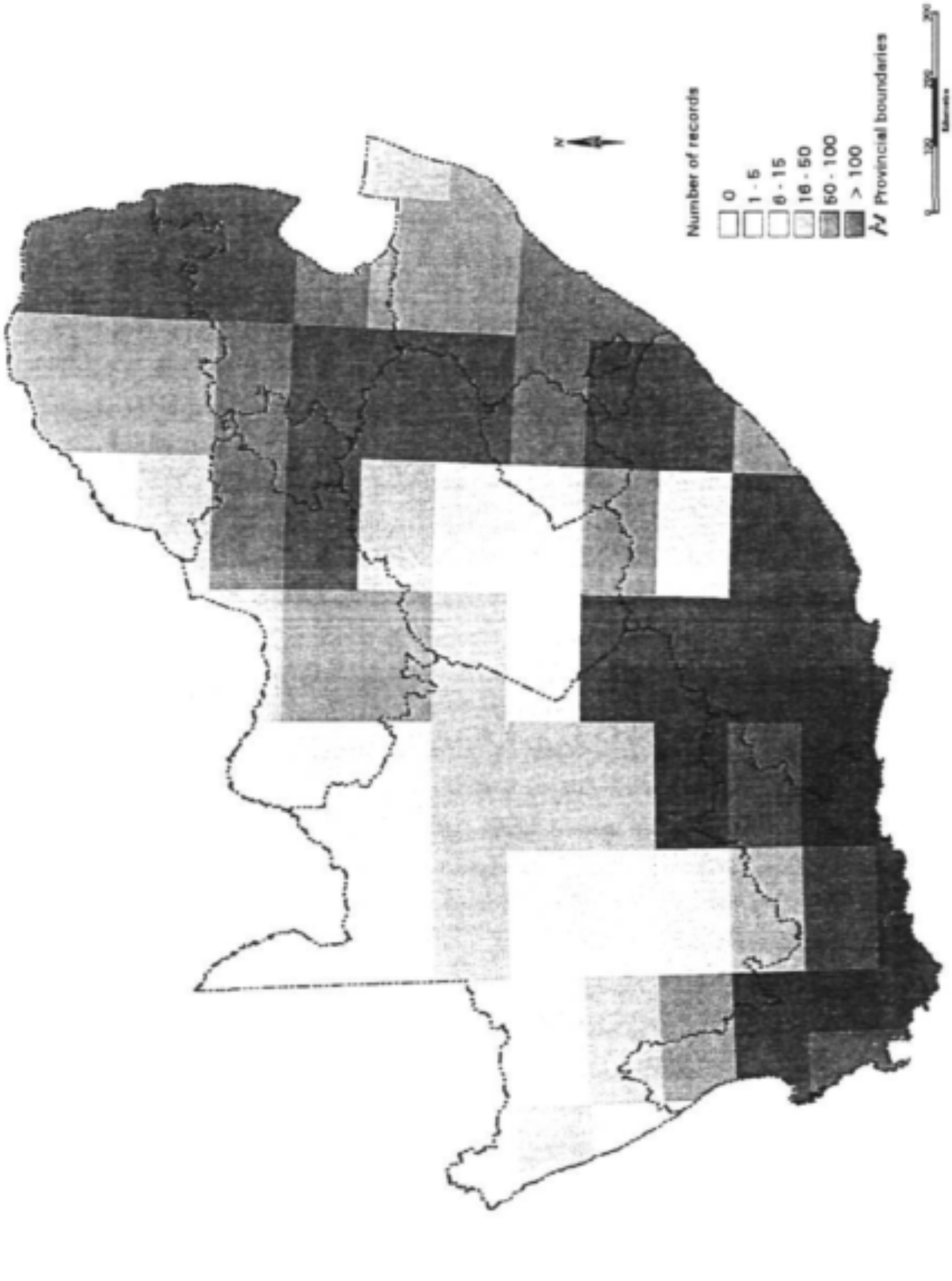
1.6 Literature Review

The brief for this study did not include compilation of a bibliography of the available literature on invading plants. As we have had numerous requests for literature, we have created a categorized reference list including the most useful and readily accessible literature on alien plants and invasive processes. This is included as Appendix 7. The core of this list was provided by Dr D.M. Richardson of the Institute for Plant Conservation, at the University of Cape Town.

1.7 Nomenclature

The names of species used in this report are based on those in Henderson (1995), Bromilow (1995) and Von Breitenbach (1989). A list of scientific names with the generally accepted common names is given in Appendix 1.

Figure 1.1: Areas which have been mapped, indicating also the intensity of mapping.



2. METHODOLOGICAL APPROACH

2.1 Approach to the Study

This study was required to provide a broad-brush estimate of the extent and magnitude of the problem of invading alien plants in the country. It was readily apparent that there is a great deal of individual knowledge, expertise, and information - but that this has never been put together in a broad conceptual picture. Given recent recognition of the seriousness of the problem, and the levels of funding directed at achieving control, this picture was required fast. This would then be used in informing control strategies at national level. The estimate needed to be based on an appraisal of the extent of invasion (which does not exist except for limited areas), and on models of water use and other impacts (which can be estimated from the observed effects of plantation forestry on streamflow). The scale of the appraisal would necessarily, at this stage, be coarse - but it should set the stage for more detailed work. Time and a limited budget did not allow for detailed field mapping of alien plant infestations, nor did it allow for the development of refined models of water use by alien plants. There is, however, a considerable wealth of knowledge about the distribution of alien plants which resides with local land managers, landowners, extension officers and conservation authorities. Several studies have also been conducted on the impact of alien plants on streamflow (Le Maitre *et al.*, 1996, Van Wilgen *et al.*, 1997, Umgeni Water, 1997). Our approach therefore comprised an attempt to gather all existing knowledge on the distribution of alien plants at a scale appropriate to national planning and decision making, to capture this on a Geographic Information System (GIS), and then to model the impact based on existing models of water use by vegetation. In this chapter, we outline the process and the methods employed to gather and analyse the data that forms the basis of this report. Detailed technical descriptions have been included within chapters where appropriate.

2.2 Assessing the Nature and Extent of Invasions

2.2.1 Baseline data

Baseline data have been kept to a minimum. Rainfall data were drawn directly from the Computing Centre for Water Research (CCWR) data base (Figure 2.1), and topography is available via the national digital terrain model. Rivers, at 1:500 000, were available from the CSIR, but this data set only includes major rivers and a far more detailed coverage would be required to get a full picture of riparian invaders (see section 4.2.2). Land Cover, which provides an indication of the land use, vegetation cover type, and condition of the landscape, is currently being mapped by a consortium, including the CSIR, for the Department of Agriculture. This survey (which does not include invaded land and is also not part of this baseline data set) will be of inestimable future value in determining both sources of invasion and areas of land available for, and most susceptible to, invasion. We are most indebted to Midgley *et al.*, (1994) for their work 'Surface Water Resources of South Africa 1990', a Water Research Commission report. This has proved a most valuable resource, particularly for data on catchment boundaries, and estimates of natural runoff from these catchments. Figure 2.2 is a map of the primary catchments and also shows the provincial boundaries.

2.2.2 Use of existing databases

The logical place to start in this study was with existing data sets, but the reason for the very fragmented South African picture of alien invasions has been the lack of both concerted effort and of consistency in approach. The dynamics of invasions - most particularly the very rapid expansion of the problem, but also clearing activities, also render mapping exercises quickly obsolete, although most useful in developing a picture of spread dynamics.

The advent of GIS has made the capture and use of spatial data not only a possibility but an imperative. The assembly of GIS data sets from different sources always offers difficulties in reconciling scale, specifications, accuracy and resolution. GIS data sets have, however, been assembled by a number of different roleplayers and wherever possible these have been included within this study. The most important contributions have been the mapping of alien invaders on Arc/Info for the Western Cape by Western Cape Nature Conservation, sections of the Eastern Cape by Eastern Cape Nature Conservation, KwaZulu-Natal (Department of Agriculture), and data sets held for Umgeni Water by MBB (Table 2.1). Very detailed data (at 1:10 000) has also come from the Cape Peninsula. Of inestimable value to this project has been the support from Rand Water for the mapping and digitizing of alien invaders within the Rand Water catchment area (circa 50 000 km^2), and Rand Water's willingness to have this incorporated within this WRC national aliens database. By far the biggest study of invaders undertaken in this country is the ongoing work of Lesley Henderson of the National Botanical Institute (NBI). This is an invasives atlas comprising a wide variety of point and area data. It has been used as a means of data verification - most particularly in determining areas and species occurrences for those parts of the country where 'expert knowledge' could not be tapped.

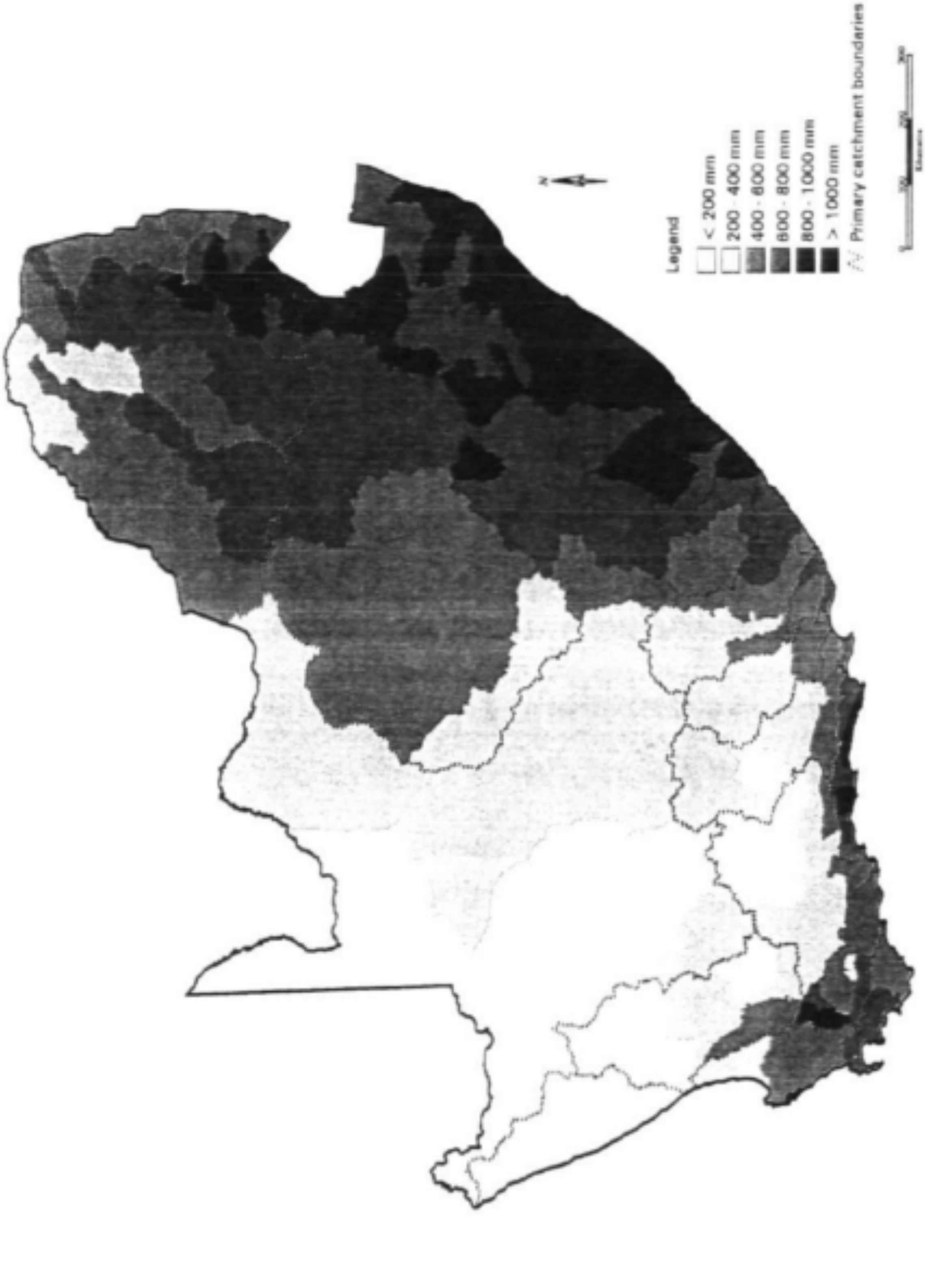


Figure 2.1: Mean annual rainfall for South Africa

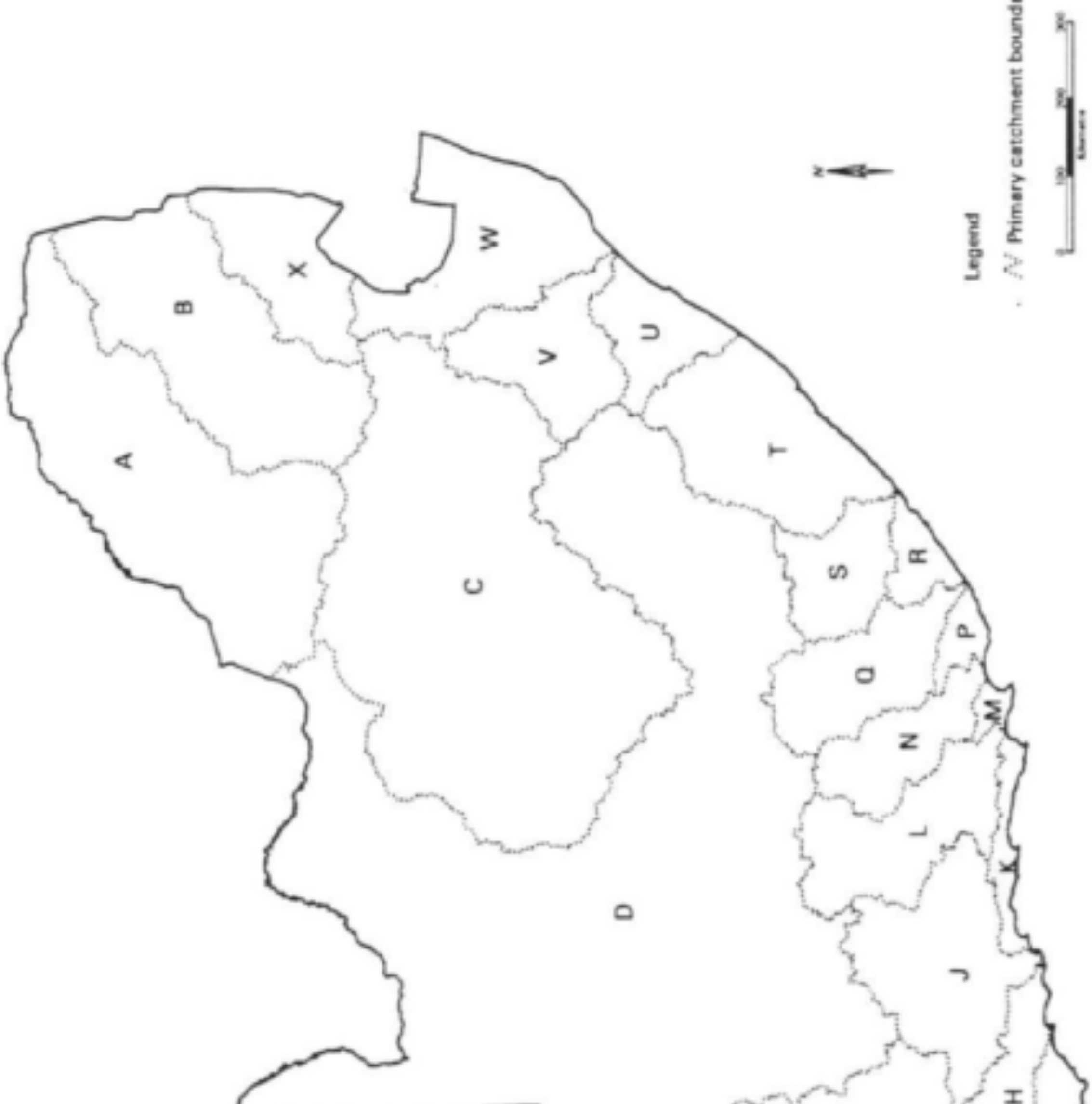


Figure 2.2: Primary catchments of South Africa and Lesotho

Table 2.1: Data sets included in the master data base used in this study

Data set	Description
1:250 000 aliens data set	Data collected for all the map sheets for South Africa and Lesotho and mapped according to the specifications in Appendix 3; density coded using the numbers 1-4 (occasional-dense) with 5 = rare in some cases. This includes data collected for the Vaal River catchment for Rand Water.
Cape Nature Conservation (Western Cape)	Mountain catchment areas of the southwestern and southern Cape mapped at 1:50 000 by C Marais using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Cape Peninsula	The non-urban areas of the Cape Peninsula mapped on 1:10 000 orthophotos using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Gauteng data	Additional data collected for the 1:250 000 maps comprising Gauteng by P. Brown using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Central Karoo	Additional data collected for the 1:250 000 maps comprising the central Karoo by D. Euston-Brown using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Eastern Cape	Additional data collected for the 1:250 000 maps of Port Elizabeth and Grahamstown by D. Euston-Brown using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Former Transkei, Kwa-Zulu-Natal, Western and Northern Cape	Additional data collected for the 1:250 000 maps of southern KwaZulu-Natal, former Transkei & Ciskei, Western and Northern Cape by D. Le Maitre using the mapping guidelines given in Appendix 3; density coded with five classes (rare-closed).

Table 2.1 (cont.)

Data set	Description
KwaZulu-Natal	Data mapped at a 1:50 000 scale for parts of the former Natal Province (KwaZulu was not mapped) by extension staff of the Department of Agriculture; a variety of methods and classifications were used as there was no overall standard method; density descriptions were converted to percent cover classes. Data mapped at 1:50 000 for the Natal Parks Board Reserves in the Drakensberg. Transcribed onto 1:250 000 maps by Arthur Chapman.
Eastern Cape Nature Conservation	Data mapped at a 1:50 000 scale from aerial photographs and field mapping for the Tsitsikamma, Kouga and Grahamstown areas; different density descriptions were used and these were converted to percentage cover classes. Some of the data contained errors (e.g. about 30% of the polygons were unclosed or had no species data). Erroneous data polygons were excluded as they could not be corrected in the time available and without the original data.
Riviersonderend	Data for the Riviersonderend catchment mapped at a 1:50 000 scale for the Working for Water Management Plan using the mapping guidelines given by Le Maitre & Versfeld (1994); density coded with seven classes (rare-closed).
Umgeni Water	Data mapped for Umgeni Water by MBB using aerial videography; includes parts of the Upper Tugela, Midmar, Umvoti and Lovu River systems; only rivers were mapped except in the Upper Tugela; density classes and species composition based on information given in the report (Umgeni Water, 1997).
Sabie-Sand River Catchment	Data mapped at 1:50 000 and 1:10000 scale for a management plan prepared by Rick van Wyk (CSIR).

2.2.3 Methods of capturing data

The following methods of capturing spatial information on alien invaders were considered:

(i) *Remote sensing*

The resolution from Landsat coverages does not allow for sufficiently accurate interpretation for a distribution map, particularly in the case of riparian invasions. SPOT technology would certainly be useful but remains prohibitively expensive. Remote sensing technology also does not allow one to determine areas of occasional, sparse and medium invasions which are of greatest concern in control management programmes.

(ii) *Aerial photography*

This is a very suitable methodology and was successfully applied to the Rand Water catchments, but recent aerial photographs are not available for the whole country, and the level of work in extracting data and then achieving verification would have been beyond the scope of this project.

(iii) *Videogrammetry*

This is a very promising technique now being used by Umgeni Water in KwaZulu-Natal. It is accurate but expensive, and limited to the scale of a particular catchment, clearing project or programme.

(iv) *Expert knowledge*

Given the 'failure' of technology to meet project needs, the project team decided that the only way to map the entire country in any meaningful way over a very short space of time would be to capture the knowledge of landowners and land managers familiar with the landscapes under their jurisdiction. This then became the primary method of approach, supplemented by existing mapped data where possible.

2.2.4 The expert approach

This approach was based on the premise that local landowners and managers are well acquainted with the situation within their catchments or landholdings, and would be able to map this with a reasonable degree of accuracy. As far as possible this mapping was done in workshop format, wherever more than one person familiar with an area was involved. This allowed for some immediate measure of peer review.

In practice the following steps were taken:

- Workshops were convened by province, region or district, as best as could be arranged by the project team. These workshops comprised as far as possible members of local conservation agencies, officials from the Departments of Agriculture and of Water Affairs and Forestry, landowners, research organizations, and any other identified knowledgeable individuals. A list of all persons who participated in these workshops, or who were otherwise approached or consulted, is included as Appendix 2.

- Standard 1:250 000 scale maps of the subject area were prepared for each workshop, with each map provided with an acetate overlay. Workshop participants were provided with an explanation of objectives, and with specifications for the nature of data required (e.g. species and density classes). These specifications are presented in greater detail in Chapter 4 and the guidelines are attached as Appendix 3.

- Participants were required to map the distribution of alien invaders on the acetate overlays to the best of their knowledge and ability. Each area, or patch, of invaders comprises a polygon which was then described in terms of species and density. Mixed stands added complexity to the data but were as far as possible described in terms of the different component species. Data could then be agglomerated for the polygon. These data sets were finally digitised as *Arc/Info*[1] datasets. For more information on the data capture procedure, the nature of the output, and an assessment of some of the difficulties encountered, refer to Chapter 3.

Workshop participants were also asked to complete a questionnaire (Appendix 3.3) indicating affiliation, area of interest/knowledge, perception of the problem in terms of size and potential and prospects for control, and to list the major problems (and benefits) associated with alien invaders, and the species viewed as most problematic. The outcome of this questionnaire is discussed in Appendix 4.

It must be noted here that the workshop format worked extremely well in areas of active conservation activity, but that there are also extensive parts of the country where surprisingly little "expert knowledge" could be extracted. At times it was necessary to work on a one-on-one basis with local roleplayers, but the lack of either knowledge or roleplayers in some areas has resulted in some inconsistency of output.

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1 *Environmental Systems Research Institute Inc., Redlands, California, USA*

In other areas the problem of invaders is so overwhelming that mapping proved too daunting a task, and this has resulted in sweeping statements as to the level of invasion.

2.2.5 Data extrapolation in KwaZulu-Natal

The mapping of alien invaders in KwaZulu-Natal proved significantly more difficult than we had anticipated. One of the major difficulties was in finding experts who could map areas with confidence. Time and resources were too limited to map the areas in the field. In the end we managed to assemble a number of data sets (see also Table 2.1). The main data sources were:

- 1:250 000 data collected for this study from experts, particularly for the KwaZulu-Natal Parks Board Reserves along the Drakensberg, and from field mapping;
- 1 : 50 000 data from the Department of Agriculture extension officers. This was available only for the former Natal (areas of KwaZulu-Natal were excluded) and only for about half of the 1 : 50 000 maps of the province. This data set included detailed mapping and generalised polygons;
- high-resolution video-based maps prepared by MBB for Umgeni Water for sets of quaternary catchments above Midmar Dam (U20A-U20C), in the Llovu (U70A, U70B in part), Mvoti (U40A, U40B) and upper Tugela catchments (V11A, V11C, V11D). Only a 30 m wide zone either side of the rivers was mapped except in the upper Tugela where non-riparian invasions of *Acacia mearnsii* were included; specific data were not available for the different polygons, therefore the summary information on species frequencies in the different density classes (from Umgeni Water 1997) was used to determine the percentage cover by species; and
- expert opinion which indicated broad geographic regions (largely climatic) where certain species were noted as present and information on density was provided.

The data covered a limited area, therefore a reasonable basis for extrapolation was needed. First the existing data were compared with the South African Plant Invaders Atlas (SAPIA) data for the province and the generalised regions based on expert opinion. A visual comparison of these data sets showed that there was a substantial degree of congruency. As the regions provided by the experts were only indicated crudely on the maps, a coverage based on Phillips (1963) Bioclimatic Regions was prepared. The Philips regions were grouped as follows, based on the similarity in composition and density of the alien invaders, (vegetation types from Low & Rebelo, 1996):

region 1 - the coastal belt or Coast Lowland (Coastal Bushveld);

region 2 - a broad belt between the coastal and the interior and including Coast Hinterland, Riverine, Lowland-Upland, Riverine Lowland and Lowland (Valley Thicket, Coast Hinterland Bushveld, Natal Lowveld Bushveld, Subhumid Lowveld Bushveld);

region 3 - the Mist Belt (Short Mistbelt Grassland);

region 4 - Upland (drier facies) including Tugela and Buffalo River valleys (Natal Central Bushveld);

region 5 - Upland (moister facies) and Highland Montane, including the Little Berg (Moist Upland Grassland, North Eastern Mountain Grassland); and

region 6 - the Drakensberg proper or Montane (Alti Mountain Grassland).

A list of the alien species and their densities was then compiled for each of these groups of regions and applied to a buffered river coverage based on the data set of the rivers of KwaZulu-Natal (1:500 000 scale). Since this river data set only includes a small proportion of all the rivers this will underestimate the extent of riverine invasions. On the other hand the nature and degree of invasions often differs between areas of the former KwaZulu and Natal Provinces, with the former areas often being less invaded because of harvesting of wood for fuel and construction. This data set still has significant deficiencies but we believe it is adequate for identifying priorities at national and provincial level.

2.2.6 Data storage

All mapped data have been digitised using the Arc/Info GIS system in order to facilitate later modelling and analysis exercises. Additional data sets mapped by other organizations have been imported into this system, and reconciled to provide one final coverage. For many areas workshop 'experts' merely indicated that "all the rivers within a district or zone are invaded by species x to y degree". In such cases the rivers within the baseline data set were buffered to a distance of 20 metres with the respective invader. Attribute data associated with each polygon (species and density) was also entered into the GIS. Digitizing and sorting of information has proved to be a major task - accounting for some 40% of the budget on this project.

2.2.7 Verification

It has not been possible to verify the accuracy of mapped data in the field except in very limited circumstances, but digitised data have been compared to original maps and all inconsistencies with regard to species names and densities have been clarified. It is believed that the existence of the resultant coverages will in itself allow for a level of participative and interactive interaction with roleplayers across the country - and for subsequent correction where necessary.

2.3 Modelling Impacts on Streamflow

This section is aimed at describing the broad background to the modelling of water use. Additional details and a description of the model itself and how it was applied are given in Chapter 4. The approach we adopted in this analysis was aimed at trying to keep the model simple to apply while keeping it scientifically robust. The only really accurate data available for tree water-use at the landscape scale of this study comes from catchment experiments which compared the streamflow from catchments with natural vegetation and with commercial plantations. The questions was: how could we relate the measured reductions in the streamflow from afforested catchments to the impacts of a range of different invading plant species?

A comprehensive review of catchment experiments worldwide found that there was a relationship between the change in forest or plantation cover and the change in the streamflow, whether the catchment was afforested or deforested (Bosch & Hewlett, 1982). There general finding was that a 10% change in the cover of pine or eucalypt forest would result in a 40 mm change in water yield (runoff) while for deciduous hardwood forest and scrub the change was 25 and 10 mm respectively. Other studies have also found that plant and forest water-use can be related to leaf area (e.g. Jarvis & McNaughton, 1986) and leaf area is related to biomass, growth and productivity (Waring, 1983). The idea that water-use could be related to biomass was developed further by Bosch *et al.* (1986) and Le Maitre *et al.* (1996) who related streamflow reductions to the biomass of fynbos and plantations using data from South African catchment experiments.

The model was developed using data from catchment experiments in the winter rainfall regions of the country. Data on the reductions in streamflow are available from similar catchment experiments elsewhere in the country but we could not obtain reliable data on the biomass of the plantations to use in developing a model for the summer rainfall regions. We recognise that extrapolation of a model based on data from the winter rainfall regions to the summer rainfall areas is risky, especially as most of the country lies in the summer rainfall regions. The catchment data do show that the reductions in streamflow after afforestation in both the summer and winter rainfall regions fall within a similar range (170-450 mm, Versfeld, 1993), therefore the errors are unlikely to be very large. Streamflow reduction curves developed by Scott & Smith (1997) suggest that reductions in the winter rainfall catchments are less than those in the summer rainfall catchments (on a percentage basis), suggesting that estimates from the biomass model may be conservative.

The way the model was applied in the summer rainfall areas meant that we did not distinguish between invaders growing in riparian and in landscape situations. Experimental data shows that riparian trees use substantially more water than those in landscape situations (Scott & Lesch, 1995). The model is based on data from afforestation of non-riparian situations, except for one catchment, and this would also make the estimates of water-use conservative. In addition, most of the invasions, except for the south-western and southern Cape are in riparian habitats, which would eliminate much of the site and climatic impact variability. One of the controversial issues is the water-use of aquatic weeds such as the Water Hyacinth (*Eichhornia crassipes*). There are some who believe that the water-use is high but we based our approach on the findings of a wide range of studies (see Chapman, 1990) which suggest that water-use, at least for a closed canopy, may be less than open water evaporation. There are a number of reasons why this should be so, including shading of the water surface, the albedo of the plants and internal resistances incurred during transpiration.

2.4 Assessing the Risks of Invasion

The initial aims of this project included developing models for predicting the rates of spread and of increases in density using models appropriate for the level of coarse scale and the national scope of the project. Scenario modelling at this scale proved impractical, so an attempt was made to identify the risks of invasion in terms of the factors that facilitate invasion, areas of particular risk and species which actually, or potentially, constitute the major problems. The aim was, therefore, to provide information - on invasion processes, factors facilitating invasions and the species that invade - that would help to answer the following questions: *What parts of the country are most at risk from invasions and how rapidly will invasions expand?* Details of this approach are provided in Chapter 5 of this report.

2.5 Prioritizing Catchment Areas

The prioritization of regions or catchments for clearing of alien invasions is ultimately a matter for the decision-maker. This project can, at best, offer useful information. Our approach has been to outline the issues considered most pertinent in making decisions and to provide the relevant data against which these decisions might be made. We have used the output from the 'issues' questionnaires, local workshopping, and the determinants arrived at through a workshop process with Rand Water, as the most likely factors in assessing priorities.

Data are presented at the level of the tertiary catchment. Prioritization at provincial level may require a different set of criteria. And there are also underlying principles which can influence or even reverse the outcome of any prioritization procedure. For example, the principle of prioritizing areas still relatively uninvaded as being the most cost-effective means of achieving results, conflicts with the need to re-establish water supplies from densely invaded areas. We attempt also to present these underlying arguments and to consider the situation and possible action strategies in this light (see Chapter 6).

Data for costs of clearing are is presented in Chapter 6. This data were gathered from a survey of Working for Water project managers actively engaged in field programmes to clear alien invasions. The data are biased towards the Western Cape because more comprehensive and detailed data was available from respondents in this province.

2.6 Ground Truthing

Much of the data gathered in this report is based on the field knowledge and recollections of people familiar with particular areas, with the weaknesses (e.g. inaccurate recall) that this necessarily involves. The mapping was done at a relatively coarse scale (e.g. using generalised polygons) to reduce the amount of time and detail involved. On the whole we believe that overestimates and underestimates probably balance out, and the mapped data do show the worst affected areas. One possibility will be to compare the mapped data with the 2nd phase National Land Cover Study (due to be completed by September 1998), especially for dense stands. Project planning for the Working for Water Programme will be based on more detailed mapping and this data should be included in the national data set as and when it becomes available.

3. NATURE, EXTENT AND DISTRIBUTION OF ALIEN INVADERS IN SOUTH AFRICA

3.1 Introduction

Alien invasions across South Africa have been mapped using the 'best expert knowledge' approach outlined in chapter 2 (section 2.2.4). This has been supplemented by information from existing GIS datasets, where available. All expert knowledge was mapped directly onto acetate overlays on 1:250 000 topo sheets. Associated with this exercise, participant experts completed questionnaires on problems and issues (see Appendix 4), and also tabulated knowledge on costs of clearing and risks of spread (see Chapters 5 and 6). Alien invaded areas were mapped as independent polygons with each polygon accompanied by attribute data giving species and density data. All data have been captured in a Geographic Information System (Arc/Info).

This process has been aimed at providing a spatial depiction of the full extent of alien invasions in all parts of the country. Data have been gathered to a set of fixed specifications determined by the project team and adopted as a standard by the DWAF Working for Water team (see section 3.2.1). The quality of data gathered remains somewhat variable, depending on the level of expert knowledge available, the nature of the terrain, but also upon the extent and complexity of the actual invasion. Where invasion is an overwhelmingly big problem it becomes very difficult to map, and it is under these situations that experts tended to resort to generalizations.

Most of the country has been surveyed in this way, and we have already argued (section 1.4) that to treat certain parts of the country as 'uninvaded' is a dangerous assumption. Nevertheless, not quite all areas have been covered, and some most certainly better than others. It has also happened that some participants in the mapping exercise have stuck very rigidly to the boundaries of their area of jurisdiction - and this has resulted in the mapping of invaders ending very abruptly along, for example, some or other administrative boundary. The data on the extent and impacts of invasions by alien plants have been analysed and presented at the scale of the province, primary and tertiary catchments.

3.2 Mapping Alien Invaders

The process of mapping invaders and our reliance on expert knowledge and a few additional data sets, has been introduced in Chapter 2. This section provides additional background details of the mapping approaches and data sources used in compiling this report.

3.2.1 Specifications for the capture of data

The data capture procedure was designed to standardize the approach and terminology and to ensure, as a far as possible, that consistent and comparable data have obtained from the wide range of people involved (see Appendix 3 for more details). Standard data forms for mapped data, control costs and estimated rate of spread were designed. These were used by virtually all the participants. The participants were also asked to complete a questionnaire on alien plants species and their concerns about them.

The map data were recorded using the standard 1: 250 000 base maps available from the Department of Surveys and Mapping. Guidelines were given to avoid overly detailed mapping (e.g. to get the mean cover for large areas rather than a point for each clump) and to ensure that participants attempted to map the boundaries reasonably accurately. The following data were recorded for each mapped invasion: each species, its canopy cover (%) or density in four classes and the duration of the invasion. Explanatory notes could be added. Invaded areas could be mapped as patches (polygons), which are typical of landscape invasions, or as lines following, for example, riparian zones (river valley bottoms or river beds and banks). Where only, or primarily, riparian zones were invaded we asked participants to mark sections of rivers and to indicate the approximate width of the invaded strip. In KwaZulu-Natal, Mpumalanga and parts of Northern Province some participants indicated broad zones (e.g. highveld, middleveld, lowveld) within which all the rivers were invaded by characteristic suites of species. In these cases all the rivers (in the river data layer for that area) were selected within the GIS, and then buffered and labelled as having the specified suites of species. All the data were recorded by participants on clear acetate overlays on 1:250 000 maps and each invaded area was given a number corresponding with a number on the map data form. The amount of data for each of the 1:250 000 map sheets, and how it was collected, is shown in Table 3.1 and is graphically presented in Figure 1.1.

Table 3.1: Status of data for each of the 1: 250 000 map sheets used in this study. (The number of records is an estimate of the number of invaded areas for that map excluding the data sets identified separately at the end of the table which covered one or more map sheets. Workshop = maps workshopped with experts. Expert = experts involved in mapping. Photo = maps based on aerial photograph interpretation. Field = mapping done in the field. Buffered = maps where rivers were buffered to represent invaded areas. Other data sets = data obtained from other sources; those marked with a # have been included in the count of records per map sheet).

Map No.	Map name	Number of Records	Work-shop	Expert	Photo	Field	Buffered	Other data sets
2228	Alldays	38		#			#	
2230	Messina	189		#			#	
2326	Ellisras	1		#				
2328	Pietersburg	71		#			#	
2330	Tzaneen	500		#			#	
2426	Thabazimbi	24		#			#	
2428	Nylstroom	351		#			#	
2430	Pilgrim's Rest	801	#	#			#	Sabie and Sand Rivers
2520	Nossob	0						
2522	Bray	1		#			#	
2524	Mafikeng	22		#			#	
2526	Rustenburg	162		#		#	#	
2528	Pretoria	386		#		#	#	
2530	Barberton	1 035	#	#			#	Sabie and Sand Rivers
2620	Twee Rivieren	9		#			#	
2622	Morokweng	9		#			#	
2624	Vryburg	7		#				
2626	West Rand	269		#	#	#	#	Rand Water#
2628	East Rand	330		#	#	#	#	Rand Water#
2630	Mbabane	223	#	#			#	
2632	Mkuze	57		#			#	
2720	Noenieput	7		#			#	
2722	Kuruman	3		#			#	
2724	Christiana	36		#			#	
2726	Kroonstad	44		#			#	
2728	Frankfort	855		#	#	#	#	Rand Water#
2730	Vryheid	174		#			#	
2816	Alexander Bay	11	#	#			#	

Table 3.1 (cont.)

Map No.	Map name	Number of Records	Work-shop	Expert	Photo	Field	Buffered	Other data sets
2818	Onseepkans	10		#			#	
2820	Upington	23		#			#	
2822	Postmasburg	12		#			#	
2824	Kimberley	19		#			#	
2826	Winburg	2		#				
2828	Harrismith	1 300	#	#	#	#	#	Rand Water#, Natal Parks Board
2830	Richards Bay	224		#			#	
2916	Springbok	16	#	#				
2918	Pofadder	4	#	#				
2920	Kenhardt	9		#			#	
2922	Prieska	28		#			#	
2924	Koffiefontein	21		#			#	
2926	Bloemfontein	3		#			#	
2928	Drakensberg	182		#	#		#	Umgeni MBB, Natal Parks Board
2930	Durban	227		#	#	#	#	Umgeni MBB
3017	Garies	19	#	#			#	
3018	Loeriesfontein	16	#	#			#	
3020	Sakrivier	19		#			#	
3022	Britstown	23		#				
3024	Colesberg	80						
3026	Aliwal North	52		#			#	
3028	Kokstad	328	#	#		#	#	Natal Parks Board
3030	Port Shepstone	151		#		#	#	
3118	Calvinia	96	#	#			#	
3120	Williston	8		#				
3122	Victoria West	115				#	#	
3124	Middelburg	189				#	#	
3126	Queenstown	22		#		#		
3128	Umtata	162		#		#	#	
3218	Clanwilliam	323	#	#			#	Olifants River
3220	Sutherland	7		#				
3222	Beaufort West	21		#				
3224	Graaf Reinet	217		#	#			
3226	King William's Town	240		#	#		#	
3228	Kei Mouth	29		#	#		#	

Table 3.1 (cont.)

Map No.	Map name	Number of Records	Work-shop	Expert	Photo	Field	Buffered	Other data sets
3318	Cape Town	205	#	#	#	#	#	
3319	Worcester	1732	#	#	#	#	#	Breede & Sonderend Rivers Management Plan#
3320	Ladismith	136	#	#	#		#	
3322	Oudtshoorn	397	#	#	#		#	Outeniqua Mountains#
3324	Port Elizabeth	251	#	#	#		#	
3326	Grahamstown	630		#	#			
3420	Riversdale	407	#	#	#		#	Breede River
	Christo Marais	1 325		#		#		Western Cape Mountain catchments
	CNC Eastern Cape	264		#	#	#	#	Southern Cape & Grahamstown
	Cape Peninsula	2 028		#		#		1:10 000 Orthophotos
	Mpumalanga	2825		#		#	#	1:10 000 & 1:50 000 mapping
	KwaZulu-Natal	±280		#		#	#	1:50 000 maps Dept. of Agriculture#
	KwaZulu-Natal	387				#	#	MBB Video based mapping

In some cases the experts did not map each species, or indicated only the total density of the mixture. This has been corrected as far as possible. In other situations the experts have grouped species where there was a mixture which they did not identify to species level, or where they were uncertain. This mainly applies to *Prosopis, Salix, Populus* and mixtures of the tall, rather similar tree-form *Acacia* species, notably *A. mearnsii, A. dealbata* and *A. decurrens* which we have called *Acacia* mixed species. We have also subsequently grouped species to facilitate the presentation of the data in the analysis but the raw data retains the individual species names where available. The main groupings used are as follows: *Eucalyptus, Prosopis, Pinus, Hakea, Populus, Salix,* and *Opuntia* species. We did not group together species which were likely to differ significantly in their water-use. One example is *Acacia*, where some species become large trees (*A. mearnsii, A dealbata, A. melanoxylon*) and others remain small to medium sized trees (*A. cyclops, A. saligna*) and are very likely to use less water because of their smaller canopy areas. In the data obtained from MBB only the mean percentage cover of different species was given for each density class (Umgeni Water, 1997). The data were converted to a percentage cover for each species for the purposes of this analysis.

A large proportion of the invaded areas contains more than one species and many contain several species (up to 13). The coarse density classes used led to problems in some cases. For example, an area of 100 ha could be invaded by four species with 3, 10, 30 and 40% cover respectively. The equivalent density classes are 1 (<5%), 2 (5-25%) and 3 (25-75%), respectively. The corresponding midpoints are 2.5, 15, and 50% cover and thus the equivalent areas are 2.5, 15 and 50 ha if the cover for each species is 'condensed' to 100%. The total condensed area invaded is 117.5 hectares which is more than the total area of 100 hectares. To correct this the condensed area for each species was adjusted downwards so that the sum of their condensed areas is equal to the total invaded area. In this example each species' condensed area would be multiplied by 100÷117.5 = 0.85.

3.2.2 Mapping rivers

The problem of alien invaders is primarily a riparian problem although extensive landscape invasions may be even more dominant in the Western Cape and also in parts of the Eastern Cape and KwaZulu-Natal. In many parts of the country (including the Western Cape) expert knowledge simply informs that 'all the rivers are invaded'. Other alien surveys within the Western Cape also show alien plants to be virtually ubiquitous in the rivers of the province. Unless these rivers are individually mapped, an impossible task at this scale in areas of broken topography and high rainfall, it is difficult to know how extensive such riverine invasions actually are. Certainly it is true that all perennial rivers are susceptible to invasion. Mapping along larger order rivers has been successfully achieved, but the reality is such that this probably comprises only a small fraction of the total invaded riparian zone. A coverage of all South African rivers to a scale of 1:50 000 (which would satisfactorily represent all riparian zones) is not available in digital format, although this is being prepared by the Department of Surveys and Mapping. At best we have a coverage at 1:500 000, with 1:250 000 for some areas (such as the province of KwaZulu-Natal) only. In a trial analysis we compared the lengths of river marked in maps at the scale of 1:500 000 with those marked on 1:50 000 maps. This was computed for two topographically and environmentally different areas (Table 3.2):

Table 3.2: Comparison of length of river mapped at a scale of 1:50 000 and at 1:500 000

Region	Map Scale		Ratio	Map Sheets
	1:50 000	1:500 000		
Drakensberg Escarpment	410 520	92 610	4.43	2828DB Witsieshoek & 2829CA Bergville
Southern Cape	777 604	262 942	2.96	3323DD, 3324CA-CD; Kouga & Kromriver, Baviaanskloof, Suuranys, Tsitsikamma

A visual comparison of river lengths at a scale of the 1:250 000 and 1:500 000 was done for the Rand Water Study (Versfeld *et al.*,1997). This determined that the ratio of river length for perennial rivers ranged from about 1.8 on the undulating highveld near the Vaal Dam to 2.5-3.8 in parts of the Upper Wilge River and Liebenbergsvlei catchments on the Drakensberg escarpment. To consider only invaders along the rivers mapped at these coarser scales could, therefore, lead to significant underestimates of the true extent of the problem.

Invasions along many river systems have been hand-drawn onto 1:250 000 sheets wherever possible. It is possible however that the hand-mapping of riparian invasions will lead to an overestimation of the invaded areas, simply because of the difficulty of drawing a polygon along a river fine enough to accommodate the scale in use. By the same token, where areas have been described simply as "all rivers are invaded" and a buffer of, for example, 20 m is used to locate invaders along all the rivers in the data base (recognizing the scale problem), then this may result in an overestimation of invaders if the buffer is too wide and not all the rivers are really invaded, or in an underestimation - where the river is braided or where the riparian strip is much wider than the estimated 20 m. Alternatively underestimation may be a result of the fact that most smaller rivers are as seriously invaded as larger rivers - but do not yet occur within the data base. Typical examples of these uncertainties are reflected in the data for Mpumalanga Province, where poplar (*Populus* species) appears to be an important invader, seemingly a consequence of generalized statements such as 'all rivers contain poplars', and in KwaZulu-Natal and Eastern Cape where wattle may be underestimated because the smaller rivers are not mapped.

3.2.3 Map joining and attribute data

The individually drawn and digitized maps were first joined to form provincial coverages, with further joining to create a national picture. Map joining is a singularly time-consuming process as all polygons extending over the edges of the maps have to match, and all polygons must be closed. Frequently polygons are drawn only to the edge of one map and then not continued on the next, resulting in an abrupt data discontinuity as the digitizer operator is forced to close the polygon at this point. A continuous mapping procedure therefore should be devised for any future exercise of this nature.

All species and density data (attribute data) for each polygon was entered into a simple text file and later converted into an *INFO* data base file. Variation in the use of species names (common and scientific, the use of group names such as wattle for different *Acacia* species), and a remarkable range of spelling forms, all resulted in very complex datasets, requiring a great deal of editing.

3.2.4 Interpreting 'expert' data and 'real' data

The first question which arises is "how good are the data?" Certainly there are some difficulties in merging 'expert' data with 'real' data (i.e. data which has been mapped directly in the field or from aerial photographs, photogrammetry, or other methodology). It is very important that 'expert' data should be seen for exactly what it is, i.e. **information** rather than **data**. The risk of merging these two very different sources of information is that one might be leading to a critical bias. In practice there has been little opportunity to compare the nature of the two information sources, as care was taken to avoid the duplication of collecting expert data where the situation with regard to invaders had already been mapped. The primary benefit of the data set is that it is immediate. It reflects the current situation as best it is known. It also provides an information baseline which can be used to guide future mapping work.

3.2.5 Areas of no invasion

As valuable as any coverage indicating areas of invasion, would be a coverage showing areas of no invasion or 'clean' areas. There are extensive areas such as much of the central and south-eastern Karoo, and a significant part of the Northern Province where invaders are clearly not a significant presence at this stage. We have not found it possible however, to declare any area 'invasive free'.

3.3 Results and Discussion

This report offers only a limited analysis and assessment of general issues and trends raised by the data. It must be remembered that the data on alien invader distribution is now within a GIS, and can be accessed for analysis at any time.

3.3.1 Species ranking

What is the most 'pervasive invader' in South Africa at present? From the 'Issues Ranking' questionnaire (Appendix 4) *Acacia mearnsii* was ranked as the number one invader in the country, but from here it becomes difficult to separate the most problematic species due to regional differences (see Appendix 4 section 4.9). From an analysis of the data, the most important species in terms of the total area invaded are *Melia azedarach* and the pines (mainly *Pinus pinaster* and *Pinus patula*) followed by *Acacia mearnsii* species and *Lantana*, each of which has invaded more than two million hectares (Table 3.3). The principal species in terms of condensed area are *Acacia cyclops*, which is found in the Western and Eastern Cape, and *Prosopis* species which are found mainly in the Northern Cape. *Acacia mearnsii* is ranked third on the basis of condensed area. It must be noted that separation of different *Acacia* species was often not possible, resulting in an additional category called *Acacia* mixed species. This category generally comprises *Acacia mearnsii* mixed with other species such as *Acacia dealbata*. Overall, *Acacia* species are the most important with three species in the top 10 and a further three species (notably *Acacia dealbata*) in the top 25 species. The importance of riparian invasions is shown by five species in the top 10 being primarily riparian invaders despite the relatively limited extent of riparian habitat in South Africa. The importance of the different species varies between provinces with *Prosopis* and *Opuntia* occurring mainly in the arid interior (Karoo and Kalahari) and the remaining species in the top 10 occurring in the region between the coast and the escarpment. Species in the top 10 based on total area (and which do not appear in Table 3.3) include *Eucalyptus* species, *Opuntia* species and *Jacaranda mimosifolia* with a further five species having invaded more than one million hectares.

Table 3.3: Top 10 invading species or groups of species in South Africa ranked by condensed invaded area.
('Habitat' indicates the main habitats invaded by the species: l = landscape, r = riparian, r(a) = alluvial plains. The condensed area is the total area adjusted to bring the cover to the equivalent of 100%. Density is the estimated mean cover in the total invaded area.)

Species	Habitat	Condensed invaded area (ha)	Total invaded area (ha)	Density (%)
Acacia cyclops	l	339 153	1 855 792	18.28
Prosopis species	r(a)	173 149	1 809 229	9.57
Acacia mearnsii	r,l	131 341	2 477 278	5.30
Acacia saligna	l,r	108 004	1 852 155	5.83
Solanum mauritianum	r,l	89 374	1 760 978	5.08
Pinus species	l	76 994	2 953 529	2.61
Opuntia species	l	75 356	1 816 714	4.15
Melia azedarach	r,l	72 625	3 039 002	2.39
Lantana camara	r	69 211	2 235 395	3.10
Hakea species	l	64 089	723 449	8.86

A more detailed breakdown of the distribution of all *Acacia* species (by far most pervasive genus if all species are taken into account) is given by province in Table 3.4. The Western Cape has the greatest total and condensed area of *Acacia* species, due mainly to the extensive areas of the coastal lowlands which have been invaded by *Acacia cyclops* and *A. saligna*. *Acacia* species are also widespread in Mpumalanga, the Eastern Cape and KwaZulu-Natal.

From a water-use perspective (see Chapter 4) the worst invaders are the acacias with *A. mearnsii* and *Acacia* mixed species (comprising primarily *A. mearnsii* and *A. dealbata*) accounting for 29% of invader water-use. The acacias are followed by *Eucalyptus* species (15%) and *Pinus* species (12%). This ranking might well change if actual water-use by different species was better known, and if added weighting was given to trees invading riparian zones.

Table 3.4: **Distribution of all *Acacia* species, both as total invaded area and by condensed area, for each province and Lesotho.**
(These areas exclude plantations but do include the invaded parts of plantation areas.)

Province	Area (ha)	Total invaded area		Condensed invaded area	
		(ha)	(%)	(ha)	(%)
Eastern Cape	16 986 940	571 772	3.37	117 822	0.69
Free State	12 993 572	25 383	0.20	8 001	0.06
Gauteng	1 651 904	13 487	0.82	6 443	0.39
KwaZulu-Natal	9 212 465	357 821	3.88	62 562	0.68
Lesotho	3 056 978	1 844	0.06	242	0.01
Mpumalanga	7 955 483	1 056 383	13.28	41 095	0.52
Northern Cape	11 602 581	123 126	1.06	27 726	0.24
Northern Province	36 198 066	267 884	0.74	3 321	0.01
North West	12 214 309	47 671	0.39	1 275	0.01
Western Cape	12 931 417	2 173 386	16.81	451 492	3.49
South Africa	124 803 715	4 638 756	3.72	719 981	0.58

3.3.2 Distribution and extent - South Africa and Lesotho

In this and the following sections the data is summarised for both South Africa and Lesotho and for the individual provinces using species (groups) and primary catchments within those provinces. More detailed data for the different tertiary catchments in each province can be found in Appendix 5. We have included Lesotho because it contains the headwaters of the Orange River, but Swaziland has been excluded. The Umzimkulu district has been included within KwaZulu-Natal for practical reasons.

Figure 3.1 is a map showing all areas of the country currently recognised as being invaded - this coverage accounts for density but makes no differentiation in terms of species. Riparian zones and all smaller patches are not easily visible at this scale and the reader is advised to make preferential use of the tables.

With this data in a GIS data set it is possible to home in on a particular site at an appropriate scale and to extract detail of species and density. The density of invasion across South Africa and Lesotho is expressed as a percentage invasion for each tertiary catchment (Figure 3.2). From this it can be seen, for example, that both the Western Cape and the Northern Province have a number of tertiary catchments invaded to a level exceeding 20% of total land area on a condensed area basis.

About 10 million hectares (8.28%) of South Africa and Lesotho has been invaded to some degree by a wide range of alien species. If the invaded area is 'condensed' to adjust the cover to 100%, then the equivalent of about 1.7 million hectares has been fully invaded. This is more than the current extent of commercial forestry at 1.4 million hectares and approximately the area of Gauteng province. The degree of invasion varies very markedly between provinces but the comparative figures must be treated with caution. For example, KwaZulu-Natal appears lightly invaded compared with Mpumalanga or Northern Province. This is a result of the relatively poor mapping of this province where only limited areas and the riparian zones have been mapped and only the major invading species have been included. This constraint also applies to the Eastern Cape Province where areas of the interior and the former Transkei have not been thoroughly mapped. The values for these provinces are probably much closer to those recorded for the provinces with similar climates, especially rainfall, such as Mpumalanga and the Western Cape. Data for South Africa and Lesotho is summarized below by province and primary catchment and then in more detail for each province (section 3.3.3).

Table 3.5: Areas invaded by alien plants in the different provinces both as hectares and as a percentage of the area of the provinces. (The condensed area is the total area adjusted to bring the cover to the equivalent of 100%.)

Province	Area (ha)	Total area invaded		Condensed invaded area	
		(ha)	(%)	(ha)	(%)
Eastern Cape	16 739 817	671 958	4.01	151 258	0.90
Free State	12 993 575	166 129	1.28	24 190	0.19
Gauteng	1 651 903	22 254	1.35	13 031	0.79
KwaZulu-Natal	9 459 590	922 012	9.75	250 862	2.65
Lesotho	3 056 978	2 457	0.08	502	0.02
Mpumalanga	7 957 056	1 277 814	16.06	185 149	2.33
Northern Cape	36 198 060	1 178 373	3.26	166 097	0.46
Northern Province	12 214 307	1 702 816	13.94	263 017	2.15
North West	11 601 008	405 160	3.49	56 232	0.48
Western Cape	12 931 413	3 727 392	28.82	626 100	4.84
RSA+Lesotho	124 803 707	10 076 365	8.07	1 736 438	1.39

Figure 3.1: Distribution of alien invasive plants in South Africa and Lesotho

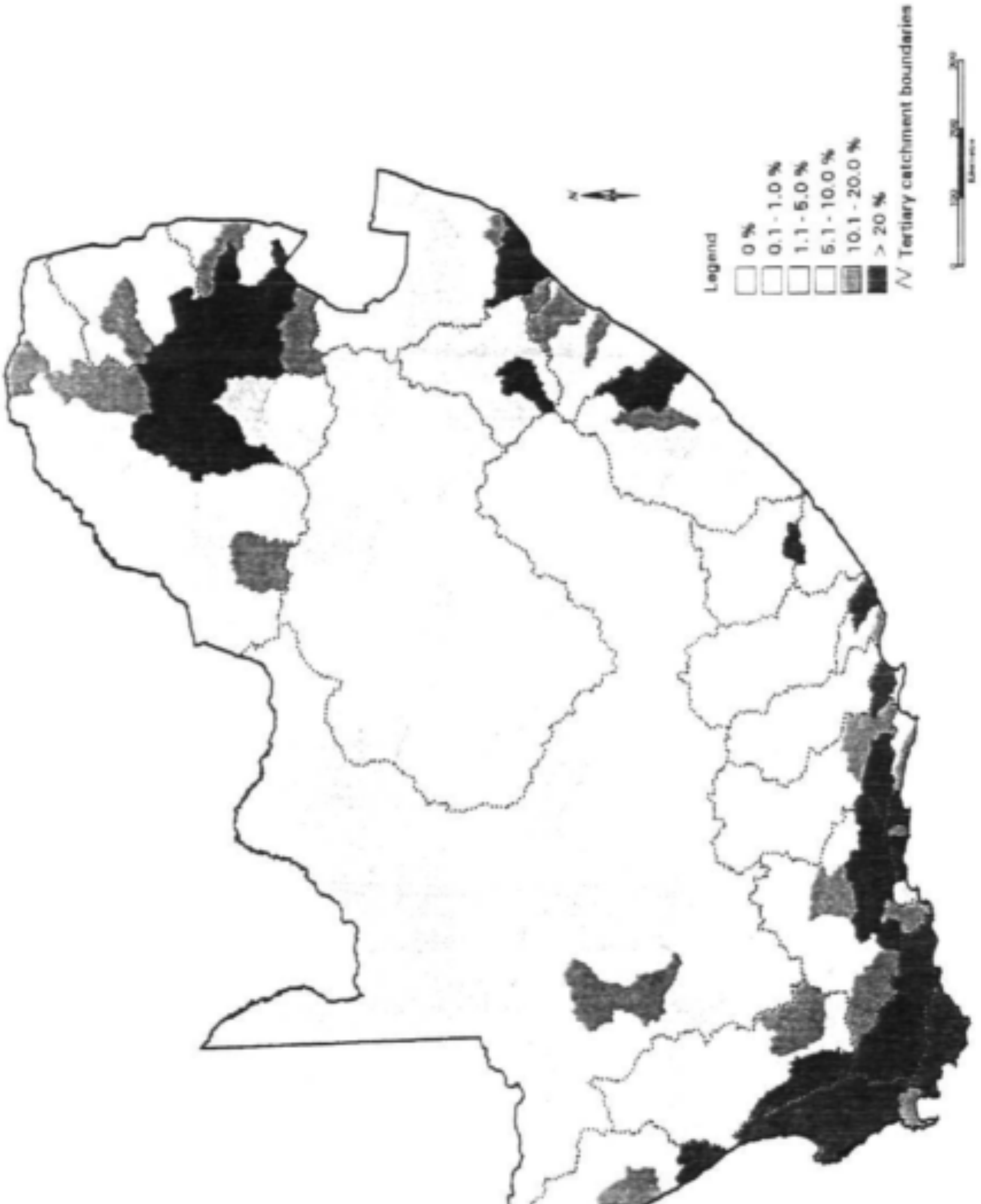


Figure 3.2: Percentage of alien invading plants cover per tertiary catchment across South Africa and Lesotho

The differences in the extent of invasion between the primary catchments are large (Table 3.6). The most heavily invaded are the catchments and coastal plains of the Western Cape (Catchments G and H) followed by the Mpumalanga escarpment (Catchment X), the Port Elizabeth region (Catchment M) and the Olifants River (Catchment B) in Mpumalanga and Northern Province. Some catchments appear relatively free of invasions, for example the Orange River. Because the invaded areas are located in the wettest catchments, they can have a marked impact on water resources.

Table 3.6: Areas invaded by alien plants in the different primary catchments both as hectares and as a percentage of the area of the catchments. (The condensed area is the total area adjusted to bring the cover to the equivalent of 100%.)

Primary catchment	River system	Area (ha)	Total invaded area		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A	Limpopo	10 873 288	726 084	6.68	122 457	1.13
B	Olifants	7 350 308	1 532 606	20.85	217 855	2.96
C	Vaal	19 629 440	362 351	1.85	64 632	0.33
D	Orange	40 876 535	1 045 393	2.56	141 012	0.34
E	Olifants (W Cape)	4 906 252	528 972	10.78	37 623	0.77
F	Namaqualand coast	2 850 621	237 244	8.32	46 618	1.64
G	W Cape & Agulhas coast	2 524 373	1 597 036	63.26	384 636	15.24
H	Breede & SW Cape coast	1 551 872	741 408	47.78	84 398	5.44
J	Gouritz	4 513 434	711 436	15.76	59 399	1.32
K	S Cape coast	716 816	132 030	18.42	52 993	7.39
L	Gamtoos	3 473 106	277 428	7.99	34 289	0.99
M	Port Elizabeth region	261 156	70 376	26.95	11 358	4.35
N	Sundays	2 122 532	25 191	1.19	3 964	0.19
P	E Cape coast	530 806	74 174	13.97	22 894	4.31
Q	Gt Fish	3 022 811	27 199	0.90	6 980	0.23
R	Border coast	791 830	24 781	3.13	12 483	1.58
S	Great Kei	2 048 307	57 196	2.79	30 694	1.50
T	Transkei region	4 662 380	302 131	6.48	68 493	1.47
U	S KwaZulu-Natal	1 829 337	151 747	8.30	46 442	2.54
V	Tugela	2 903 885	258 260	8.89	62 151	2.14
W	N KwaZulu-Natal & Mpumalanga highveld	4 507 461	341 362	7.57	100 574	2.23
X	Mpumalanga escarpment	2 857 157	851 962	29.82	124 494	4.36
	RSA+Lesotho	124 803 708	10 076 365	8.07	1 736 438	1.39

3.3.3 Distribution and extent - data for provinces and Lesotho

3.3.3.1 Eastern Cape Province

The most extensively invaded catchments are those in the coastal region from Port Elizabeth to the Kariega River catchment south of Port Alfred (Table 3.7), followed by the Gamtoos and the coastal region of the Tsitsikamma (catchment K). The low area given for condensed invaders in the Gamtoos River system is largely due to most of the catchment being situated in the sparsely invaded Karoo. Parts of this river system, particularly the Baviaanskloof and Kouga Rivers are heavily invaded. The low degree of invasion in the Orange River system is partly because much of it is arid Karoo and partly because of incomplete mapping.

Table 3.7: Areas invaded by alien plants in the Eastern Cape Province. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%).

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
D	Orange	2 189 478	563	0.03	266	0.01
J	Gouritz	178 179	1 750	0.98	44	0.02
K	S Cape coast	281 021	25 063	8.92	15 459	5.50
L	Gamtoos	1 865 615	239 683	12.85	24 095	1.29
M	PE Coast Swartkops & Coega	261 156	70 376	26.95	11 358	4.35
N	Sundays	2 097 259	25 191	1.20	3 964	0.19
P	Bushmans & Alexandria coast	530 806	74 174	13.97	22 894	4.31
Q	Gt Fish	3 018 253	27 199	0.90	6 980	0.23
R	Border Coast	791 830	24 781	3.13	12 483	1.58
S	Great Kei	2 048 307	57 196	2.79	30 694	1.50
T	Former Transkei	3 477 913	125 983	3.62	23 022	0.66
	Eastern Cape	16 739 817	671 958	4.01	151 258	0.90

Although pines have invaded the largest total area (Table 3.8), they are generally sparse, with a density of about 5%. The main species is *Pinus pinaster*, but *P. halepensis* and *P. patula* are also important.

Acacia species are the largest problem as they occupy large areas, are relatively dense and mainly occur in river courses where they can have a marked impact on water resources. The exception is *Acacia cyclops* which occurs mostly in the dune areas south-west of Port Elizabeth and eastwards along the coast towards Port Alfred. In the former Ciskei and Transkei there are many areas with old plantations and invading individuals of *A. dealbata* and *A. mearnsii*. In many of these areas invasions are confined to slopes and ridge tops. River valleys have not been invaded yet, perhaps because the grasslands are in relatively good condition and are burnt regularly.

Invaders are viewed in the Eastern Cape Province as bringing important benefits, notably as an alternative fuelwood resource important to the conservation of the indigenous forests of the region. These trees are often the only source of wood so clearing operations will have to be carefully planned.

Table 3.8: Most important invader species in the Eastern Cape Province based on condensed invaded area.
('Habitat' indicates the primary habitats invaded by the species (r = riparian, l = landscape). *Opuntia* was not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Acacia mearnsii	r,l	344 535	49 022	14.23
Acacia mixed species	r,l	36 640	20 378	55.62
Acacia dealbata	r,l	65 730	18 876	28.72
Acacia saligna	l	202 952	12 809	6.31
Eucalyptus species	l	163 121	9 515	5.83
Acacia cyclops	l	212 790	8 579	4.03
Pinus pinaster	l	295 346	7 283	2.47
Acacia longifolia	r,l	73 212	7 155	9.77
Solanum mauritianum	r,l	43 379	4 262	9.83
Schinus molle	r	82 799	2 061	2.49
Hakea sericea	l	14 760	1 927	13.06
Opuntia ficus-indica	l	47 374	1 885	3.98
Pinus sp.	l	14 112	1 317	9.33
Lantana camara	r,l	2 297	1 156	50.32
Acacia melanoxylon	r	22 151	963	4.35

3.3.3.2 Free State

At least 160 000 ha of the Free State has been invaded by alien plant species (Table 3.9), with by far the majority being riparian invasions. The data should be treated with caution because the coverage has been very uneven. The uneven mapping of alien plant species in the Free State is reflected in the variation in the degree of invasion between catchments. The Rand Water catchments in the Vaal River system have been mapped in detail and the degree of invasion ranges from 0.9-3.7%. Similar areas in the Caledon River system (e.g. Fouriesberg) have not been mapped but are known to be invaded to much the same extent.

Table 3.9: Areas invaded by alien plants in the different primary catchments in the Free State. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
C	Vaal	10 421 911	142 271	1.37	23 593	0.23
D	Orange	2 565 631	23 858	0.93	597	0.02
V	Tugela	6 033	0	0.00	0	0.00
	Free State	12 993 575	166 129	1.28	24 190	0.19

The most important invaders are *Prosopis* species (largely confined to the drier western areas), *Acacia* mixed species, *Acacia dealbata* and *Salix babylonica* species (Table 3.10). The only non-riparian invader in the top 10 is pine species, but even they can invade riparian zones. The *Acacia* species generally occur in dense stands (>20%) which is important because these stands can rapidly progress to complete cover if frequent fires, grazing or other factors do not limit further increases in density. These species are also able to disperse and colonise rapidly in riparian situations, therefore the situation could worsen rapidly.

Table 3.10: Most important invaders in the Free State based on condensed invaded area. ('Habitat' indicates the primary habitats invaded by the species (r = riparian, a= aquatic, r(a) = riparian and alluvial plains, l = landscape).)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Prosopis species	r(a)	116 606	4 834	4.15
Acacia dealbata	r,l	16 284	3 632	22.30
Acacia mixed species	r,l	6 301	3 433	54.49
Salix babylonica	r	15 249	3 240	21.25
Eucalyptus species	r,l	10 652	2 338	21.95
Pinus species	l	9 973	1 758	17.63
Salix species	r	8 298	1 235	14.88
Populus species	r	7 586	1 177	15.51
Acacia mearnsii	r,l	3 422	931	27.22
Populus canescens	r	1 100	642	58.37

3.3.3.3 Gauteng

Gauteng province appears to be relatively free of invading plants according to the available data (Table 3.11). These figures need to be viewed with great circumspection, however, because (a) the alien species in the extensive urban and peri-urban areas of the Pretoria-Witwatersrand-Vereeniging area generally have not been mapped, and (b) only the Vaal River catchments above the Vaal Barrage have been thoroughly mapped. Mapping at a scale of 1:50 000 or greater would significantly increase the invaded areas shown above. Large urban areas are often also major source areas for the introduction of new species. Invasions of areas in Gauteng are also important because it lies on a watershed which forms the headwaters of three key river systems: the Vaal, Limpopo and Olifants. Riparian and aquatic invaders which enter these rivers in Gauteng can readily spread downstream and result in major problems. Since it is logical to clear river systems by starting in the headwaters, clearing programmes should also be initiated by the relevant local authorities.

Table 3.11: Areas invaded by alien plants in Gauteng.
(The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A	Limpopo	604 796	4 415	0.73	3 814	0.63
B	Olifants	229 160	6 323	2.76	2 192	0.96
C	Vaal	817 946	11 516	1.41	7 025	0.86
	Gauteng	1 651 903	22 254	1.35	13 031	0.79

The most important invaders include *Acacia* species, *Eucalyptus camaldulensis*, *Acacia* mixed species and *Salix babylonica* (Table 3.12). All the top five species occur in medium dense stands (>25% cover), especially the *Acacia* species. Two aquatic invaders fall just outside the top 10 although they only occupy a relatively limited area. All these species are undoubtedly more widespread in the province and there are certainly many other species, such as *Rubus*, which are more widespread than is shown by these data.

Table 3.12: Most important invader species in Gauteng based on condensed invaded area.
('Habitat' indicates the primary habitats invaded by the species (r = riparian, l = landscape).)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Acacia mearnsii	r,l	9 962	2 966	29.78
Eucalyptus camaldulensis	r,l	8 086	2 300	28.44
Acacia mixed species	r,l	3 267	2 173	67.51
Salix babylonica	r	4 504	1 404	31.16
Populus canescens	r	4 044	1 109	27.42
Acacia decurrens	r,l	2 681	966	36.02
Eucalyptus sideroxylon	r,l	1 427	497	34.80
Salix species	r	1 507	377	24.99
Eucalyptus species	r,l	900	367	40.76
Acacia dealbata	r,l	1 324	330	24.94

3.3.3.4 KwaZulu-Natal

The Umzimkulu district[1] of the former Transkei, the coastal belt and the mistbelt are the most heavily invaded regions of KwaZulu-Natal. There are smaller densely invaded areas, for example the escarpment bordering on the Free State, but the drier parts of the province appear to be much less invaded. Although detailed data were obtained from limited mapping or 1:50 000 maps, and by MBB using videography, this covers only a small portion of the province. Personal observations and the comments of observers suggest that the total invaded areas may be as much as 2-3 times as extensive as shown below. The perceptions of the experts used in mapping are that there are "huge problems" in tropical Zululand and along rivers. The situation in the Drakensberg is described more optimistically as "controllable and even eradicable". The Coastal Zone and Midlands are recognized as major problem areas.

Table 3.13: Areas invaded by alien plants in KwaZulu-Natal. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total invaded area		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
C	Vaal	1 718	210	12.24	72	4.21
D	Orange	1 421	1	0.04	0	0.00
T	Former Transkei	1 182 537	176 148	14.90	45 470	3.85
U	S KwaZulu-Natal	1 829 156	151 747	8.30	46 442	2.54
V	Tugela	2 862 012	257 323	8.99	61 344	2.14
W	N KwaZulu-Natal	3 582 746	336 583	9.39	97 534	2.72
	KwaZulu-Natal	9 459 590	922 012	9.75	250 862	2.65

Although *Solanum mauritianum* is the most important invasive species in terms of condensed area and total area, the *Acacia* species, especially *A. dealbata* and *A. mearnsii*, are very important because they are widespread. They occur in all but the sub-tropical coastal belt except in the southern areas where *Acacia mearnsii* is becoming increasingly common in the river systems near the coast. *Chromolaena* is

1 *Technically this district falls under the Eastern Province but it has been grouped with KwaZulu-Natal because it falls geographically and climatically within the latter province.*

very widespread and common in the coastal belt, especially in Zululand, and is spreading inland along the river valleys, notably the Tugela River. The abundance of *Acacia* species, in particular, would increase if more detailed mapping were available because (a) large areas of the Midlands are heavily invaded and (b) personal observations and high resolution mapping show that they occur in dense stands even in minor streams and rivers that are not shown at a map scale of 1:250 000 (Umgeni Water, 1997). A study of three quaternary catchments (U20A-U20C) above Midmar Dam found that of the 2056 km of river mapped, 40% was invaded and 7.6% densely invaded, mainly by wattles (Umgeni Water, 1997).

Table 3.14: Most important invader species in KwaZulu-Natal based on condensed invaded area. ('Habitat' indicates the primary habitats invaded by the species (r = riparian, a = aquatic, l = landscape). *Opuntia* and *Pereskia* were not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Solanum mauritianum	r	404 999	44 265	10.93
Chromolaena odorata	r	326 139	43 178	13.24
Acacia mixed species	r,l	116 584	24 912	21.37
Acacia dealbata	r,l	136 004	22 115	16.26
Opuntia imbricata	r,l	133 344	16 645	12.48
Opuntia species	r	132 701	16 533	12.46
Acacia mearnsii	r,l	190 542	12 896	6.77
Melia azedarach	r	220 764	12 592	5.70
Rubus sp	r	163 475	11 845	7.25
Lantana camara	r	235 849	10 518	4.46
Caesalpinia decapetala	r	161 982	6 674	4.12
Psidium guajava	r	104 250	4 550	4.36
Pinus species	r,l	49 810	4 115	8.26
Eucalyptus species	r	153 103	2 658	1.74
Eucalyptus grandis	r,l	108 391	2 394	2.21

3.3.3.5 *Lesotho*

The low degree of invasion of catchments in Lesotho (Table 3.15) is partly because trees are removed for firewood and partly because the river valleys are cultivated wherever possible as there is so little arable land. There was also a problem mapping this area and we could only get data for parts of two of the major rivers. Only parts of the upper Orange River and the Sinqua River in eastern Lesotho have been mapped. The more densely inhabited western and southern areas have not been mapped at all, but are probably invaded to a similar extent. Overall though, Lesotho catchments are not densely invaded and the impacts on water resources will be limited.

Table 3.15: Areas invaded by alien plants in Lesotho. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
C	Vaal	1 030	0	0.00	0	0.00
D	Orange	3 052 351	2 457	0.08	502	0.02
T	Former Transkei	1 931	0	0.00	0	0.00
U	S KwaZulu-Natal	181	0	0.00	0	0.00
V	Tugela	1 486	0	0.00	0	0.00
	Lesotho	3 056 978	2 457	0.08	502	0.02

The short list of invader species (Table 3.16) is primarily due to the limited extent and the remoteness of the areas that were mapped (see above). Much of Lesotho is also at high altitude and the low temperatures and frost also limit the range of species that can exist in this area. *Salix* and *Populus* species were the most extensive followed by *Acacia* mixed species. As noted for Gauteng, the presence of *Acacia* species in catchment headwaters is a cause for concern because they are able to spread rapidly downstream.

Table 3.16: Most important invaders in Lesotho based on condensed invaded area. ('Habitat' indicates the primary habitats invaded by the species (r = riparian, l = landscape). *Opuntia* and *Nicotiana* were not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Acacia mixed species	r,l	410	197	48.03
Salix fragilis	r	2 359	93	3.94
Salix babylonica	r	2 434	61	2.51
Acacia dealbata	r	1 359	34	2.50
Populus canescens	r	1 359	34	2.50
Eucalyptus species	r	636	16	2.52
Nicotiana glauca	r	636	16	2.52
Pinus species	l	636	16	2.52
Populus species	r	636	16	2.52
Acacia mearnsii	r,l	461	12	2.60

3.3.3.6 Mpumalanga

Mpumalanga is one of the most heavily invaded provinces with 16% being invaded to some extent and the equivalent of 185 000 ha being completely covered (Table 3.17). The Olifants River and the rivers in primary catchment X, particularly the Crocodile, Sabie and Sand Rivers, are heavily invaded by a wide range of species.

Table 3.17: Areas invaded by alien plants in Mpumalanga. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total invaded area		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A	Limpopo	1 573	0	0.00	0	0.00
B	Olifants	2 797 606	419 548	15.00	56 597	2.02
C	Vaal	1 552 428	19 924	1.28	6 617	0.43
V	Tugela	34 354	937	2.73	808	2.35
W	N KwaZulu-Natal	924 715	4 780	0.52	3 040	0.33
X	Komati to Nwanedzi	2 646 380	832 625	31.46	118 086	4.46
	Mpumalanga	7 957 056	1 277 814	16.06	185 149	2.33

A wide range of invading alien plants has been reported from Mpumalanga and the top 20 out of the 68 different species are given in Table 3.18. The wide variety of species is due to the wide range of bioclimatic regions ranging from highveld to sub-tropical lowveld. The major species include *Solanum*, *Lantana*, *Acacia mearnsii*, *Psidium* and *Rubus* species. *Populus* species occur mainly on the highveld and in the south-eastern regions (Ermelo-Piet Retief). There are four *Acacia* species in the top twenty, making them a very important group of invaders. The *Acacia* species appear to occur at lower densities than in the other provinces, suggesting that the invasion may be relatively young and with a potential for rapid increases in density.

The opinions of the experts varied widely and are clearly dependent on the areas they knew. Some comments from local observers include: "A problem of alarming proportions; very severe, especially the rivers adjacent to forestry areas; extensive over all plantations; a major threat to rivers and mountains; big problem along the escarpment, *Lantana* in the lowveld rivers the real problem". In Mpumalanga the situation in rivers is highlighted for both the Highveld and the escarpment, although the situation for Highveld catchments is described as 'localized but severe in some catchments'. The Lowveld is also viewed as seriously threatened by species such as *Lantana*. Invaders are seen as the 'biggest biological threat to the Kruger National Park'. There is variability too, in reality and opinion. The Hazyview area was also described as 'moderate' and rivers as 'medium to serious'. At Graskop the situation is 'severe in some places but reasonable in others'. The curator of the Lowveld Botanical Garden reports spending R50 000 over two years but that this has been wasted due to lack of follow-up.

Table 3.18: Most important invaders in Mpumalanga based on condensed invaded area. ('Habitat' indicates the primary habitats invaded by the species (r = riparian, l = landscape). *Opuntia, Nicotiana* and *Eichhornia* were not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Solanum mauritianum	r,l	1 051 738	36 038	3.43
Lantana camara	r	1 069 605	31 768	2.97
Acacia mearnsii	r,l	1 048 013	27 928	2.66
Psidium guajava	r	616 954	16 114	2.61
Rubus sp	r,l	455 311	13 470	2.96
Melia azedarach	r	1 061 933	13 129	1.24
Acacia dealbata	r,l	386 702	9 846	2.55

Table 3.18 (cont.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Eucalyptus species	r	521 213	7 886	1.51
Caesalpinia decapetala	r	718 504	3 784	0.53
Pinus species	l	490 043	3 088	0.63
Acacia mixed species	r,l	8 908	2 754	30.92
Jacaranda mimosifolia	r,l	668 785	2 320	0.35
Nicotiana glauca	r	71 945	1 804	2.51
Opuntia species	l	70 319	1 758	2.50
Populus species	r	982 312	1 673	0.17
Salix species	r	12 523	1 477	11.80
Sesbania punicea	r	622 663	1 205	0.19
Opuntia stricta	l	41 153	1 032	2.51
Eichhornia crassipes	a	33 759	914	2.71
Opuntia ficus-indica	l	35 697	866	2.43

3.3.3.7 Northern Cape

More than one million hectares of the Northern Cape have been invaded by alien plant species but the average densities are very low so that the 'condensed' area reduces to 166 000 hectares (Table 3.19). Invasions remain particularly important, however, because most of the province is semi-arid to arid (see Chapter 5). The most densely invaded areas are in the Orange River catchment, mainly *Prosopis*, and the Namaqualand-Olifants River region along the West Coast where the coastal lowlands are heavily invaded by *Acacia cyclops*. The Orange River itself has been invaded by a number of species but we have only a very superficial idea of the extent (e.g. width) and density of the different species. We believe that we have captured the main concentrations (e.g. *Prosopis* in the Sak River system, Van Wyksvlei and Britstown-De Aar area) but the invasions could be more extensive than shown here.

Table 3.19: Areas invaded by alien plants in the Northern Cape. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total invaded area		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
C	Vaal	2 196 427	7 083	0.32	2 328	0.11
D	Orange	28 503 370	939 623	3.30	129 509	0.45
E	Olifants, Sout & Doring	2 529 995	98 131	3.88	5 144	0.20
F	Namaqualand coast	2 491 214	128 120	5.14	28 689	1.15
J	Gouritz	140 399	691	0.49	346	0.25
L	Gamtoos	330 500	4 724	1.43	81	0.02
N	Sundays	1 598	0	0.00	0	0.00
Q	Gt Fish	4 558	0	0.00	0	0.00
	Northern Cape	36 198 060	1 178 373	3.26	166 097	0.46

Prosopis species are the most important invaders in this province. They occur mainly on low-lying alluvial plains (Harding & Bate, 1991) where they have access to the groundwater they need to survive. *Acacia cyclops* has invaded large areas of the coastal sand plains. In the north-west it is apparently restricted to areas where there are regular fogs, especially on the Namaqualand coast. *Nicotiana glauca* is widespread but rarely currently abundant. It is likely to colonise all the river systems of the arid west coast and Karoo in the foreseeable future. River systems and river valleys, as in all the arid regions, are the worst affected areas.

**Table 3.20: Most important invaders in the Northern Cape based on condensed invaded area.
('Habitat' indicates the primary habitats invaded by the species (r = riparian, r(a) = riparian and alluvial plains, l = landscape). *Bromus*, *Nicotiana* and *Opuntia* were not included in the water-use calculations.)**

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Prosopis species	r(a)	1 047 135	134 495	12.84
Acacia cyclops	l	123 101	27 722	22.52
Bromus species	l	1 890	1 654	87.50
Nicotiana glauca	r	2 700	1 224	45.34
Populus species	r	3 317	476	14.35
Opuntia species	l,r	259	227	87.50
Nerium oleander	r	376	147	39.15
Salix fragilis	r	554	56	10.19
Salix babylonica	r	575	35	6.01
Eucalyptus species	r/l	1 967	24	1.22

3.3.3.8 Northern Province

The Northern Province is the second most extensively invaded province with about 1.7 million hectares in total but most invasions, except in the rivers, are at low densities with about 260 000 hectares of condensed invasions (Table 3.21). The problem has been described as "huge". The river systems draining the highveld and the escarpment are the worst affected with the Nyl & Sterk, Elands, Steelpoort and Olifants Rivers being the most heavily invaded.

Table 3.21: Areas invaded by alien plants in the Northern Province. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A	Limpopo	7679990	576745	7.51	97544	1.27
B	Olifants	4323541	1106734	25.60	159065	3.68
X	Komati to Nwanedzi	210776	19337	9.17	6408	3.04
	Northern Province	12214307	1702816	13.94	263017	2.15

More than 80 species have been mapped as invaders in the Northern Province and the top 25 are given in Table 3.22. The high diversity of species is due to the wide range of environments, ranging from temperate, high-rainfall grassland to moist subtropical to arid savannah. *Opuntia* species are the most widespread but are quite sparse and, with *Cereus* and *Agave*, are the only landscape invaders that have been mapped. The others are primarily invaders of riparian systems or of the forest and scrub vegetation found in the river valleys. Three species have invaded more than a million hectares and a further 15 more than 180 000 hectares, but most of them are relatively sparse as shown by the ranking based on condensed areas. There is exceptional potential for increase by densification. This province has by far the greatest invasion by *Melia azedarach*, highlighting the need to find an effective control strategy for this species. An important species is *Mimosa pigra* which has shown exceptional invasion rates in sub-tropical Australia (Lonsdale, 1993). It was formerly thought to be indigenous (L. Henderson pers. comm., 1997) and is known to occur in the Letaba and Sabie River systems.

Table 3.22: **Most important invaders in the Northern Province based on condensed invaded area.**
('Habitat' indicates the primary habitats invaded by the species (r = riparian, a = aquatic, l = landscape). *Opuntia, Ricinus, Cereus, Eichhornia, Agave, Nicotiana, Cedrela* and *Argemone* species were not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Melia azedarach	r	1 637 283	43 009	2.63
Opuntia ficus-indica	l,r	1 195 450	29 886	2.50
Lantana camara	r	872 569	24 077	2.76
Jacaranda mimosifolia	r	972 201	18 971	1.95
Eucalyptus species	r,l	863 652	18 166	2.10
Sesbania punicea	r	635 274	15 714	2.47
Cereus jamacaru	l,r	623 399	15 585	2.50
Eichhornia crassipes	a	622 342	15 569	2.50
Ricinus communis	r,l	591 512	15 281	2.58
Agave sp	l	573 341	14 333	2.50
Caesalpinia decapetala	r,l	418 890	12 977	3.10
Solanum mauritianum	r	258 940	4 842	1.87
Nicotiana glauca	r	182 595	4 629	2.54
Opuntia species	l,r	181 608	4 540	2.50
Psidium guajava	r,l	36 159	2 774	7.67
Argemone ochroleuca	r	11 297	2 403	21.27
Acacia melanoxylon	r	36 881	2 211	6.00
Xanthium strumarium	l	6 474	2 193	33.88
Quercus accutissima	l	24 494	2 128	8.69
Pinus patula	l	17 658	1 956	11.07
Cedrela toona	l	17 635	1 955	11.09
Rubus species	r,l	20 922	1 371	5.55
Acacia mearnsii	r,l	248 425	1 292	0.52
Pinus sp.	l	229 029	1 203	0.53
Argemone mexicana	r	8 737	1 203	13.77

3.3.3.9 North West Province

This province appears to be more lightly invaded than some others and the levels of invasion are generally sparse with some districts still being little affected. Problems are viewed by local managers as "controllable with a concerted, dedicated effort". The arid western parts of the province, in the Orange River catchment, have not been thoroughly mapped and this needs to be borne in mind when interpreting this data.

Table 3.23: Areas invaded by alien plants in the North West Province. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A	Limpopo	2 586 929	144 924	5.60	21 099	0.82
C	Vaal	4 637 984	181 347	3.91	24 996	0.54
D	Orange	4 376 095	78 890	1.80	10 137	0.23
	North West Province	11 601 009	405 161	3.49	55	0.48

The most important invader in this province is *Prosopis* which has invaded some 210 000 hectares, mainly along the seasonal river systems found in the upper Limpopo and the Vaal River catchments (Table 3.24). *Melia azedarach, Eucalyptus* species and other riparian invaders were surprisingly abundant in the wetter eastern parts of this province, where they are restricted, by and large, to perennial river systems. *Melia* is viewed as the problem species to watch. Some of the experts who provided data for this mapping survey included large areas as invaded by indigenous species such as *Acacia mellifera, Tarchonanthus camphoratus* and *Rhus lancea*. These areas of 'bush encroachment' have not been included in this analysis although they are in the database. Bush encroachment (viewed by agriculturalists as a major problem) is also likely affect to water resources, but this has not been quantified. *Chromolaeua* was not thought to be present in this province, but it was recorded at the Lost City complex during construction. These observations need to be confirmed.

Table 3.24: Most important invaders in the North West based on condensed invaded area.
('Habitat' indicates the primary habitats invaded by the species (r = riparian, a = aquatic, r(a) = riparian and alluvial plains, l = landscape). *Cereus, Opuntia, Agave, Azolla* and *Eichhornia* were not included in the water-use calculations.)

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Prosopis species	r(a)	210 968	27 371	12.97
Cereus jamacaru	l,r	85 238	5 440	6.38
Melia azedarach	r	81 401	3 787	4.65
Eucalyptus species	r,l	74 514	3 057	4.10
Jacaranda mimosifolia	r	73 321	1 833	2.50
Lantana camara	r	53 893	1 684	3.12
Opuntia species	l	63 889	1 597	2.50
Populus canescens	r	3 189	1 412	44.26
Arundo donax	r	47 948	1 303	2.72
Nerium oleander	r	51 413	1 285	2.50
Salix babylonica	r	14 758	1 276	8.65
Acacia mearnsii	r,l	47 671	1 275	2.67
Azolla filiculoides	a	5 148	1 225	23.80
Populus species	r	48 096	1 210	2.52
Sesbania punicea	r	8 315	1 091	13.13
Eucalyptus camaldulensis	r,l	729	439	60.21
Agave sp	l	14 310	358	2.50
Eichhornia crassipes	a	2 442	143	5.84
Schinus sp	r,l	3 877	97	2.50
Robinia pseudoacacia	r	554	83	15.00

3.3.3.10 Western Cape

The Western Cape differs from much of the rest of the country in that the problem of invaders is one of both landscapes (i.e. the entire catchment area) and rivers, whereas riparian invasions tend to dominate as an issue through most of the rest of the country. From the data the Western Cape appears to be the most heavily invaded of all the provinces, especially the wetter catchments of the coastal mountain ranges and the broad coastal lowlands in the west and south (Table 3.25). The worst affected catchments are the Berg and Breede River systems where more than 20% of some of the sub-catchments are covered by condensed invaders. Very large areas of the sandy soils on the coastal lowlands have dense thickets of acacias as is shown by the high condensed invaded area in catchment G. The most poorly mapped areas are in the Great Karoo. The coastal lowlands from about Malmesbury through to False Bay and eastwards to Somerset West have not been mapped. It is the perception of observers that rivers are the major problem, with 'well managed' indigenous forests in a reasonable condition - although *Acacia melanoxylon* is a significant problem in these forests. The catchments are very threatened. *Acacia mearnsii* is the primary riparian invader, with *Hakea* and *Pinus pinaster* the invaders of mountains and foothills. Potential problems are particularly pertinent in the inland catchments (Swartberg, Kouga) which are vast and remote and currently still in a good condition.

Table 3.25: Areas invaded by alien plants in the Western Cape. (The condensed invaded area is derived by adjusting the total invaded area to the equivalent value if the alien plant cover were 100%.)

Primary catchment	River system	Area (ha)	Total area invaded		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
D	Orange	188 187	1	0.00	1	0.00
E	Olifants, Sout & Doring	2 376 257	430 840	18.13	32 479	1.37
F	Namaqualand coast	359 406	109 124	30.36	17 930	4.99
G	W Cape & Agulhas coast	2 524 373	1 597 036	63.26	384 636	15.24
H	Breede & Riversdale coast	1 551 872	741 408	47.78	84 398	5.44
J	Gouritz	4 194 856	708 995	16.90	59 010	1.41
K	Southern Cape coast	435 795	106 967	24.55	37 534	8.61
L	Gamtoos	1 276 991	33 021	2.59	10 114	0.79
N	Sundays	23 675	0	0.00	0	0.00
	Western Cape	12 931 413	3 727 392	28.82	626 100	4.84

A wide variety of species have been mapped as invasive in the Western Cape (some 72 taxa in all) but many come from the Cape Peninsula data set where the mapping was very intensive (1:10 000 scale). In contrast to all the other provinces, a large proportion of the top 10 species are landscape invaders, *Pinus* species (mainly *P. pinaster*) and *Hakea* species in the montane areas and *Acacia cyclops* and *A. saligna* on the coastal lowlands. Overall, *Acacia* species are the biggest problem, with a total invaded area of more than 1.6 million hectares and a condensed area of more than 500 000 hectares. Biocontrol is having a significant impact on a number of the top invader species (e.g. *Acacia saligna, A. longifolia, Hakea* and *Sesbania*). According to reports, a number of aquatic weeds are invading the Breede River system and they could rapidly become a serious threat.

Table 3.26: Most important invaders in the Western Cape based on condensed invaded area.
('Habitat' indicates the primary habitats invaded by the species (r = riparian, l = landscape). Western Cape. *Bromus* was not included in the water-use calculations.

Species	Habitat	Total invaded area (ha)	Condensed invaded area (ha)	Density (%)
Acacia cyclops	l	1 519 901	302 852	19.93
Acacia saligna	l,r	1 649 179	95 191	5.77
Hakea sericea	l	703 202	58 929	8.38
Pinus pinaster	l	878 837	43 779	4.98
Acacia mearnsii	r,l	584 224	35 214	6.03
Atriplex lindleyi	l	171 434	12 929	7.54
Acacia longifolia	r,l	98 421	12 835	13.04
Eucalyptus species	l	606 599	12 112	2.00
Pinus radiata	l	456 576	6 482	1.42
Prosopis species	r,l	417 924	6 245	1.49
Bromus species	l	24 435	5 214	21.34
Pinus sp.	l	545 426	4 647	0.85
Sesbania punicea	r	32 495	4 122	12.68
Leptospermum laevigatum	r,l	118 900	3 817	3.21
Acacia melanoxylon	r,l	83 795	3 138	3.74
Populus species	r	93 884	2 948	3.14
Nerium oleander	r	56 522	2 308	4.08
Hakea gibbosa	l	59 654	2 258	3.79
Populus canescens	r	5 929	1 401	23.63
Acacia mixed species	r,l	1 938	1 059	54.65

The problem is variously described as *"huge; very large; spreading; underestimated; severe if no action taken; very big in rivers; large outside the wilderness area."*. One agricultural perspective is that the problem is only severe *outside* the cultivated areas and another rates the problem as *'very big in relation to staff and money'*. Aquatic invaders are seen as a real threat, especially in the Breede River system.

3.3.4 Patterns of species distribution

Figures 3.3 to 3.7 are used to illustrate the geographic distribution of some of the major species of invaders in South Africa. These maps are not precise and give no indication of density but do show the presence or absence of particular species by tertiary catchment.

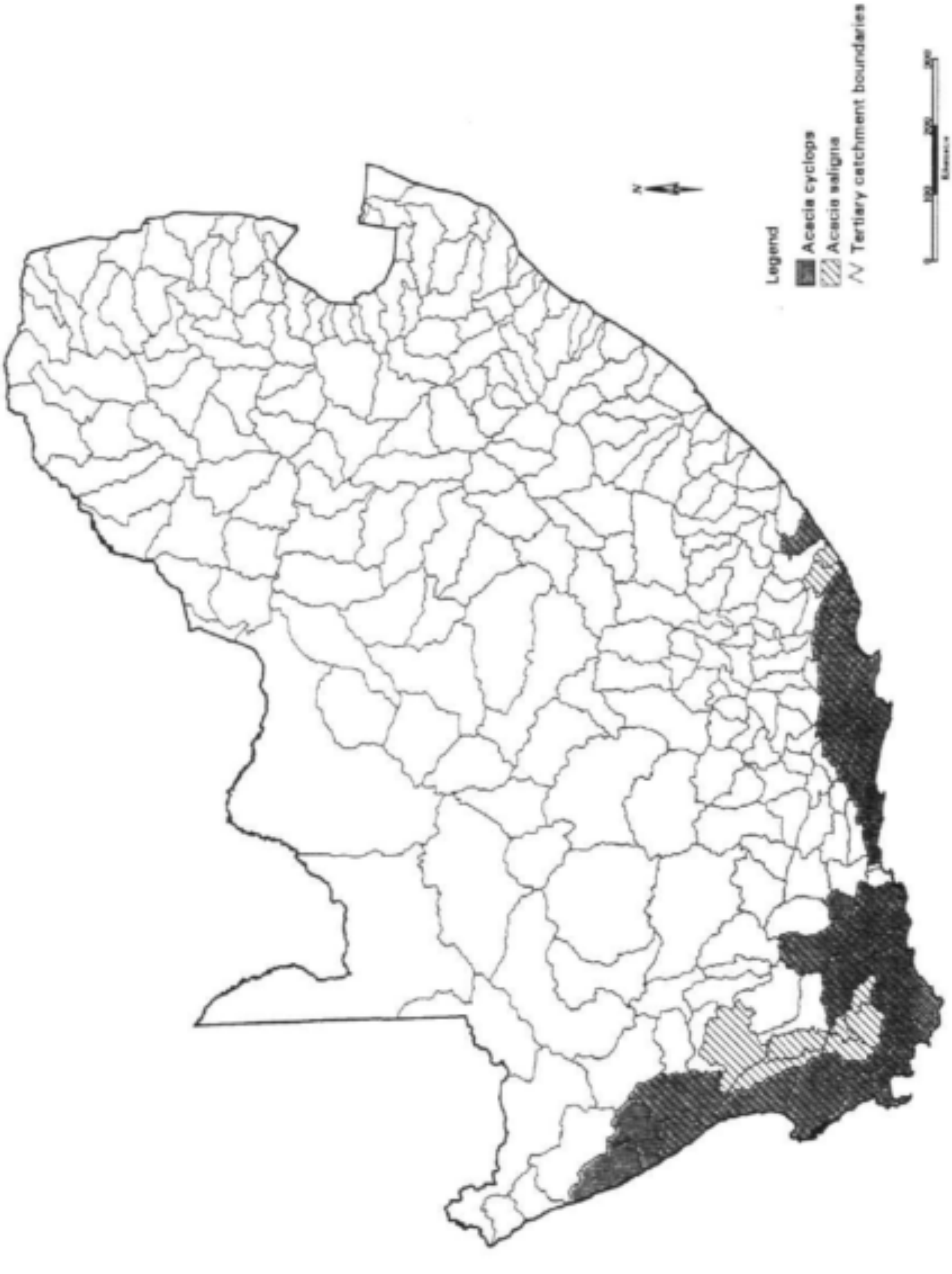


Figure 3.3: Presence by tertiary catchment of *Acacia cyclops* and *Acacia saligna* as invasive trees across South Africa and Lesotho

Figure 3.4: Presence by tertiary catchment of *Pinus spp.* as invading trees across South Africa and Lesotho

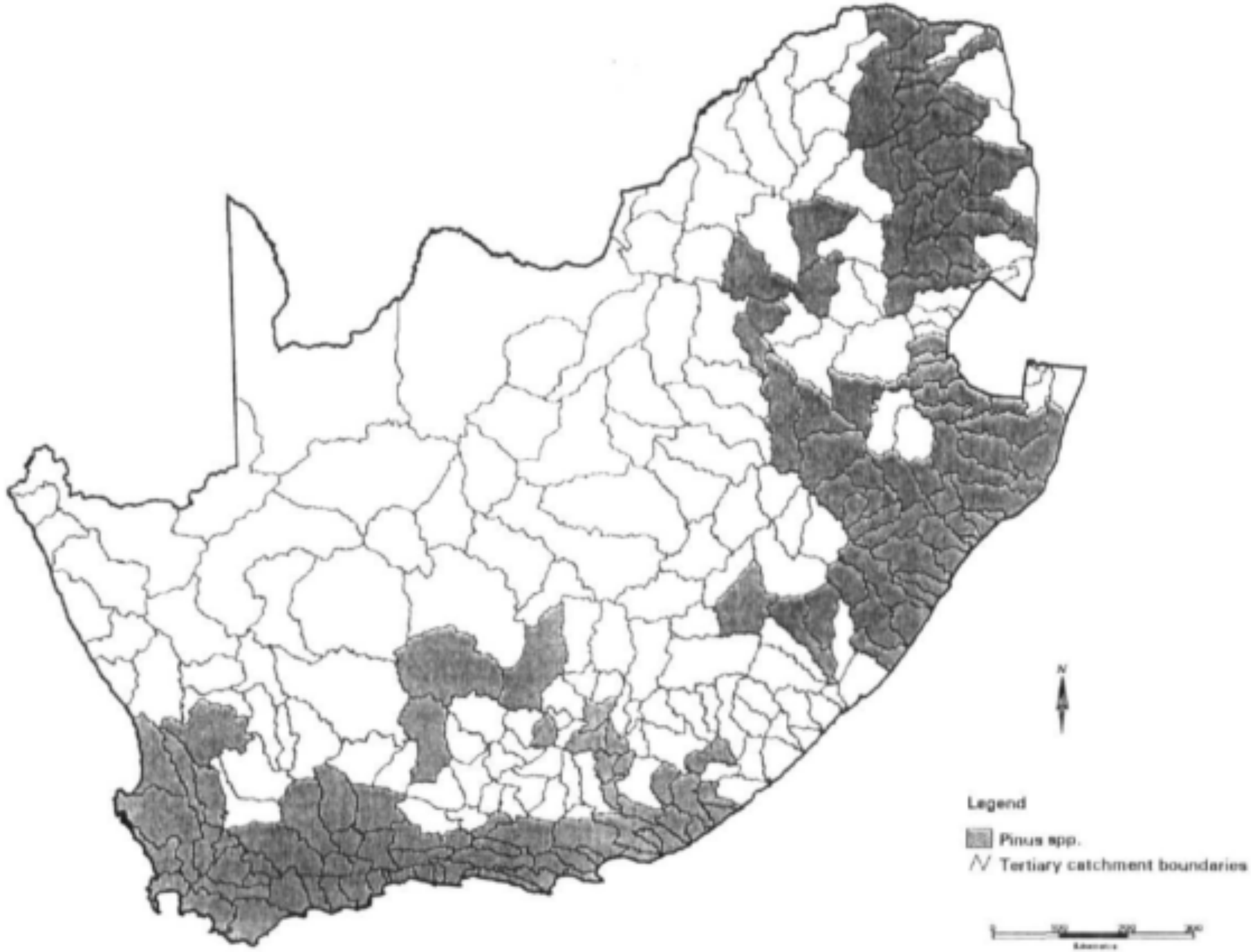


Figure 3.5: Presence by tertiary catchment of *Eucalyptus spp.* as invasive trees across South Africa and Lesotho

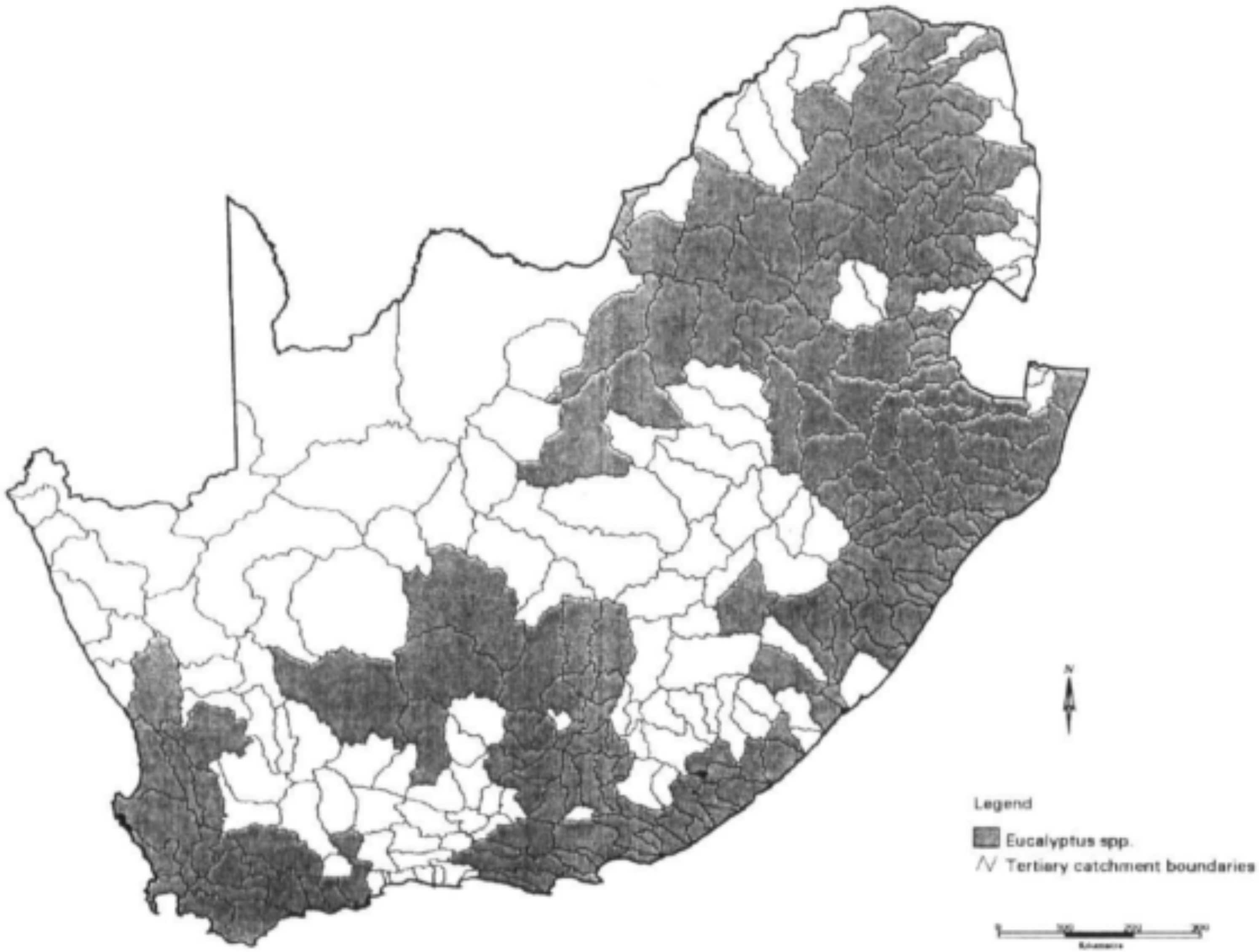


Figure 3.6: Presence by tertiary catchment of *Prosopis spp.* as invasive trees across South Africa and Lesotho

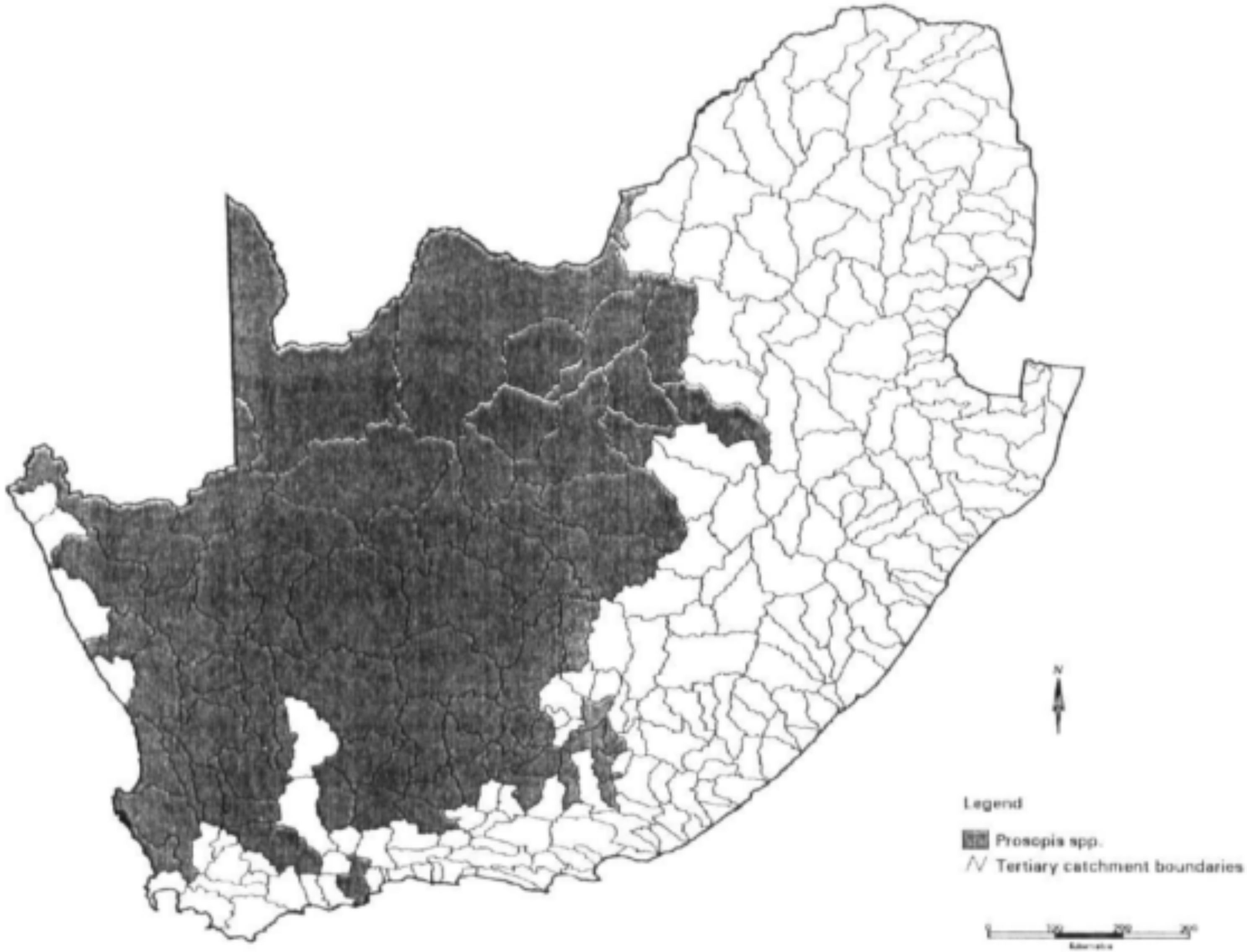
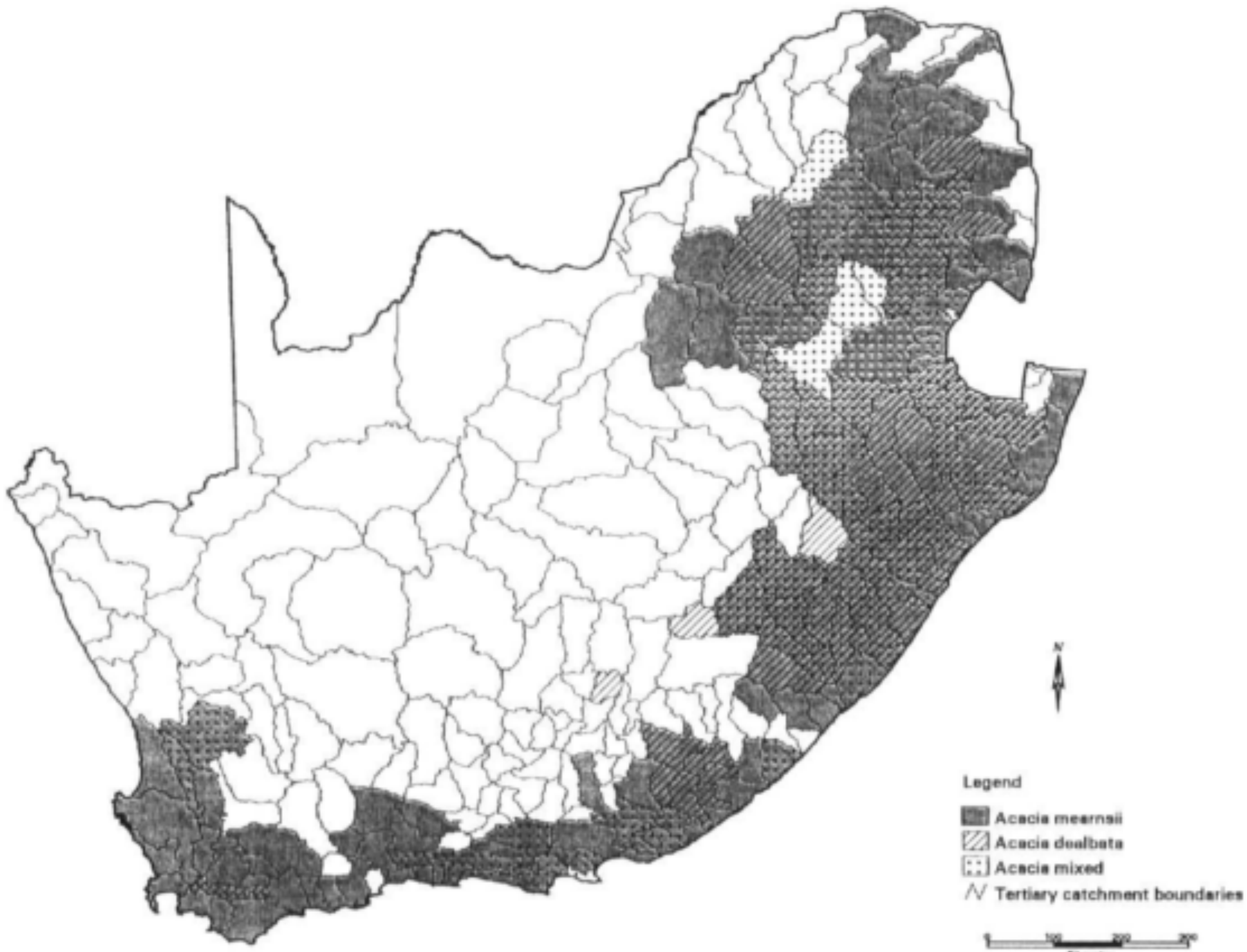


Figure 3.7: Presence by tertiary catchment of *Acacia mearnsii* and mixed *Acacias spp.* as invasive trees across South Africa and Lesotho



From this the very widespread distribution of *Prosopis* in the arid north-western half of the country can be observed. The expansion of *Prosopis* southward into the Karoo as far south as the Gouritz River, and also down the west coast towards Cape Town is an obvious cause for concern. So too *Acacia cyclops* and *A. saligna* are currently limited to the western and southern coastal regions. Both pine and eucalypt species are widespread in the wetter parts of the country, eucalypts being very noticeable also in the North West Province and all the coastal catchments of KwaZulu-Natal. The principal wattle species (*A. mearnsii and A. dealbata)* can be seen to have a very wide distribution but have not yet penetrated the arid interior. Each species can be examined in this way, or in greater detail based upon the actual distribution by mapped polygons.

3.3.5 Correlations with rainfall

The degree of invasion is not strongly correlated with rainfall *per se* when the country is viewed as a whole. This is mainly due to the following factors:

- Many invasions are of riparian zones so that the degree of invasion is largely independent of the rainfall in the surrounding areas. For example, perennial or seasonal rivers running through arid areas can be heavily invaded by species unable to invade the surrounding landscape.

- There are several invaders which have invaded large areas of the landscape in the semi-arid and arid catchments such as the Cactaceae and a number of herbaceous species. *Prosopis* species are a 'bridging' group as they invade arid landscapes but are generally confined to situations where their root systems, which can be very deep, can reach groundwater. Thus they are confined primarily to alluvial plains locally termed 'leegtes' (Harding & Bate, 1991). Landscape invasions by other species (pines, acacias, eucalypts) do seem to be confined to the moister regions of the country. *Acacia* species appear to be the most drought tolerant landscape invaders but all these species probably require more than 400 - 500 mm of rain to invade landscape areas.

- In many cases landscape invasions are also related to land-use practices with invasion rates being directly related to the degree of degradation of the natural vegetation. Exceptions are fynbos and dune systems where the invaders appear to be able to invade healthy vegetation under natural disturbance regimes. Forest vegetation also appears to be susceptible to some species (e.g. *Rubus, Acacia melanoxylon, Caesalpinia decapetala*) even under natural disturbance regimes.

While the overall correlation between invasion and rainfall may be weak, it is highly likely that invasions are initiated more readily in high rainfall areas. This is particularly true of riparian invasions in South Africa where many invaders were introduced in high rainfall areas of the upper catchments and have subsequently spread rapidly downstream. Degradation of riparian habitats due to inappropriate land-use practices has also facilitated invasion as these zones are naturally prone to invasions (see chapter 5).

Rainfall, together with temperature, is related to the diversity of species that can invade. Areas with moist sub-tropical climates appear to have the greatest range of invader species with a more limited suite of species being found in fynbos and grasslands and especially on the highveld and in the dry interior. Once again riparian situations prove the exception, probably because ready access to water enables a number of species to invade, which could not survive in the drier surrounding areas.

3.4 Impact of Clearing Initiatives

Can the efforts of current or past clearing programmes be observed in any way?

A retrospective "what if?" scenario on the impact of clearing seems to be more difficult to construct than a future scenario on the potential benefits. There can be no doubt that the major effort to clear the Western Cape mountains in the 1970s, and the continued efforts to keep some mountains free of invaders (such as the Swartberg and the Cederberg) have had a very important impact. No attempt has been made to map "cleared" areas. Recently cleared areas would, in any event, still classify as 'invaded' and would currently be (one would hope) part of a follow-up programme. This is the detail covered by management plans - but would be a useful addition at national scale - offering not just a view of the extent of the problem, but a picture of the size and achievements of the effort currently being mounted in the face of the problem.

4. IMPACT OF ALIEN INVADERS ON SURFACE WATER RESOURCES

4.1 Introduction

The key question which this chapter seeks to address is: how much water is being lost through needless interception and transpiration by invading alien vegetation?

Our approach to quantifying the hydrological impact of invading alien vegetation was influenced by several constraints:

- The scope of this project was at a national scale, requiring simple models and data input.
- The task had to be completed in a short time, therefore the method had to be easy and quick to apply.
- There also was very little information on the amount of water used by the different invader species and species mixtures found in this country. Most of the data on the way in which vegetation affects streamflow came from experiments involving afforestation with plantations of pines and eucalypts. Therefore, we were obliged to use an index of water-use which enabled us to relate the water-use of various species to that of eucalypts and pines.

4.1.1 The model

The model used to simulate streamflow reductions was based on a relationship between biomass and streamflow reduction calculated from catchment data which was developed and applied by Le Maitre *et al.* (1996) and modified by Van Wilgen *et al.* (1997). This model was developed from data for fynbos and pine-afforested catchments in the winter rainfall region of the Western Cape. The data are too sparse to develop a similar model for the all-year rainfall and summer rainfall regions, therefore the winter rainfall model has been applied across the whole country. The cardinal hypothesis therefore was that the greater the biomass of the vegetation, the more water it will consume. This appears to be a reasonable hypothesis for fast-growing vegetation types, but may not hold for mature vegetation. Invasion by alien species generally results in a significant increase in biomass over the original indigenous vegetation (primarily grassland or fynbos).

The model is based on data on the reductions in stream flow after afforestation, i.e. the change in the amount of water reaching the stream in catchments under the natural vegetation and in catchments under an established, mature plantation of pines or eucalypts (see Dye, 1996). The reduction in stream flow is not directly related to water-use because it varies from year to year depending on the amount and timing of rainfall and changes in the amount of water which the plants remove from the water stored in the catchment (e.g. in the soil profile). The decrease in streamflow therefore is an indirect estimate of how much more water is used by the plantation trees and is termed the incremental water-use. This amount is less than the total water-use, or the evaporation plus transpiration, which is the difference between the mean streamflow and the mean rainfall calculated over enough time for the changes in the amount of water stored in the catchment to average out.

The model does not allow for the impact of drought years and for the possibility that reductions in dry season (low) flows may be proportionately greater than for total annual flows. The streamflow reduction has also been estimated directly from the biomass and this does not allow for the effects of limited water availability. A partial solution for this problem is described in the next section.

4.1.2 Allowing for limited water availability

In most of South Africa invasions by alien woody plants are confined to the riparian strips. The main exception to this generalisation occurs in the high-rainfall mountain catchment areas of the Cape mountains and the mountains along the escarpment, for example the Drakensberg (Chapter 3). Many of the streams and rivers in these areas are perennial, so the riparian plants will have free access to water. The rainfall is also generally sufficient to ensure that landscape invaders will not experience much moisture stress. There are two special cases which do not conform to this generalisation, both situated in areas where surface runoff is often highly seasonal or ephemeral: the invasions of *Prosopis* species in the arid interior and invasions by *Acacia cyclops* and *A. saligna* on the coastal lowlands of the Cape west coast and to some extent the Agulhas plain. In these areas the plants probably are using shallow groundwater and thus will not have a direct impact on the surface runoff.

The model we used is based on data from catchment experiments in areas where moisture supplies are seldom limiting or, if they are, this occurs only for a small portion of the year and does not have a significant impact on tree water-use. The most straightforward method of allowing for limited water availability was to adjust the model's estimates using a simple index of availability proposed by Prof. Andre Görgens (pers. comm. 1998). The index was calculated as the proportion of the months with zero flow in the synthesised monthly flow records for each quaternary catchment. The synthesized flow records were obtained from data sets provided by the WR90 study (Midgley *et al.*, 1994). The estimated flow reduction for each quaternary catchment was then reduced by the proportion of the time in which there was zero flow. A similar process was used to adjust the estimated incremental water-use by each species. These adjusted figures are used throughout the report unless otherwise specified.

The adjusted water-use may well underestimate the amounts used where the plants occur along perennial rivers sustained by flow from upstream catchments. The adjustments also will not hold in situations where plant roots could still access water stored in the soil profile, river banks and shallow aquifers. The approach also does not allow for the fact that currently invaded areas upstream (and future increases in the invaded areas) may reduce water availability downstream. Nevertheless, we believe that it does provide more reasonable estimates of the actual incremental water-use by invading exotic plants than the unadjusted biomass model, particularly in the semi-arid and arid regions of the country.

4.2 Methodology

The model converts estimates of biomass into estimates of streamflow reduction in millimetre rainfall equivalents using the following equation where streamflow reduction is a function of biomass (Le Maitre *et al.*, 1996; Van Wilgen *et al.*, 1997):

$$\textit{Streamflow reduction (mm)} = 0.0238 \times \textit{biomass } (g.m^{-2})\ (r^2 = 0.75,\ n = 9) \qquad \textbf{(1)}$$

As this equation was based on data from mature plantations with a closed canopy, the canopy cover in areas with less than 100% had to be adjusted to equate to a canopy cover of 100%. This was done by reducing the size of the invaded area to its equivalent, had there been 100% cover. For example, an area of 100 ha with 50% cover is equivalent mathematically to an area of 50 ha with 100% cover (see Table 4.1).

Table 4.1: Density classes for four vegetation types and the scaling factor for the invaded area as a fraction of a closed canopy.

Density class	Canopy cover (%)	Scaling factor
Rare	«0.1	0.0001
Occasional	< 5	0.0250
Scattered	5 - 25	0.1250
Moderate	25 - 75	0.5000
Dense	> 75	0.8750

4.2.1 Estimating the biomass

The biomass of plants is related to their age and typically increases in a sigmoidal fashion, but Le Maitre *et al.* (1996) simplified this to an asymptotic curve. They also developed models which related biomass to plant age for each of the three biomass classes: tall shrub, medium tree and tall tree (Table 4.2). All the important invader species identified in this study were assigned to one of the three different biomass classes based on its growth form and likely water use relative to pines and eucalypts (Table 4.3).

Table 4.2: Above-ground biomass (b) and growth curves (Le Maitre *et al.*, 1996) for three categories of vegetation based on post-fire age (a = age in years).

Equation number	Vegetation structure	Biomass ($g.m^{-2}$)
1	Tall alien shrubs	$b=5\ 240 \log_{10}(a) - 415$
2	Medium alien trees	$b=9\ 610 \log_{10}(a) - 636$
3	Tall alien trees	$b=20\ 000 \log_{10}(a) - 7060$

Table 4.3: Alien species and associated biomass equations used in calculating the impact of invaders on water resources. (Deciduous species are indicated with a #. Biomass equations are based on species growth form (see Table 4.2).)

Invading alien species	Biomass equation no.	Invading alien species	Biomass equation no.
Acacia baileyana	2	*Leptospermum laevigatum*	1
Acacia cyclops	2	*Melia azedarach #*	2
Acacia decurrens	2	*Morus alba #*	2
Acacia elata	3	*Nerium oleander*	2
Acacia longifolia	2	*Opuntia* species	1
Acacia mearnsii	3	*Paraserianthes lophantha*	1
Acacia melanoxylon	3	*Pinus* species	3
Acacia pycnantha	2	*Pittosporum undulatum*	1
Acacia saligna	2	*Populus* species #	3
Acacia mixed species	3	*Prosopis* species	2
Alnus viridis	3	*Psidium guajava*	1
Arundo donax	2	*Pyracantha* sp	1
Caesalpinia decapetala	1	*Quercus robur #*	2
Chromolaena odorata	1	*Robinia pseudoacacia #*	2
Cupressus glabra	2	*Rubus* sp	1
Eucalyptus species	3	*Salix* species #	2
Ficus species	3	*Sesbania punicea*	2
Gleditsia triacanthos #	2	*Solanum mauritianum*	1
Hakea species	1	*Tamarix* species	2
Jacaranda mimosifolia #	2	Uncertain	3
Lantana camara	1		

The species not considered to be significant water users or which are minor invaders were excluded from the analysis. This is unlikely to have a significant impact on the water-use estimates because the most important of the excluded species were the *Cactaceaes*, grasses and aquatic invaders.

4.2.2 Estimating the age of invaders

The mean post-fire vegetation age differs between landscape and riparian areas because of the frequency with which the areas are disturbed, primarily by fire. In the winter rainfall region (Western Cape province), fires occur during the dry summers, either as a result of veld management or as wild fires, every 8 - 20 years. If the typical period between successive fires in any one place is once in every 15 years, and fires are evenly distributed, the mean vegetation age of a large catchment will be 7.5 years. Riparian vegetation burns more rarely so that the plants frequently attain greater ages (30-40 or more years) as well as growing larger and more rapidly. To compensate for this we have doubled the water-use of the tall acacia species which primarily invade riparian zones (e.g. *Acacia mearnsii*, *Acacia dealbata*).

No information on, or estimates of, the mean age of invading alien vegetation could be found for the summer rainfall regions. Veld fires in grassland and savanna areas, although normally occurring with a periodicity of 1-4 years, often do not burn through invaded areas such as riparian zones, allowing large trees to grow there. Trees invading the grassland and savannah typical of landscapes in this region are also able to survive fires by sprouting or through the protection of thick bark. Information obtained during mapping, and general observations have indicated that most invasions occur in riparian habitats and that the trees are typically mature. Therefore a mean age of 20 years has been used for invading vegetation in the summer rainfall region.

4.2.3 Plantation water-use

In this report we have compared the water-use estimates from the biomass model with those from an analysis of the impact of commercial plantations taken from Le Maitre *et al.* (1997) and Scott *et al.* (1998). These studies were based on the use of runoff reduction models developed from the same catchment data, and relate the plantation age to the percentage reduction in streamflow compared with the natural vegetation. Rainfall-runoff relationships were used to estimate the mean annual runoff (in millimetres) in plantation areas and these were then reduced by the mean annual reduction over the rotation period (time from planting to clear felling) of the plantations. These curve models therefore take the actual runoff into account and reduce it by a percentage. This differs from the biomass model which calculates the reduction directly in millimetres. The reduction curve models also take site conditions into account. The Scott *et al.* (1998) approach does provide more accurate estimates of the water-use but it would not be easy to use their approach in this analysis because it is far more data-intensive (e.g. data on the growth potential would be needed) and there is insufficient data on the relationship between biomass and percentage streamflow reductions over time to parameterise the curves properly. The curves were also developed for high-rainfall areas and set up for non-riparian situations and would need to be redeveloped for use in a study like this one.

The results are also compared with those from a study using the ACRU model (Smithers & Schulze, 1995) which is physically based and simulates evaporation and transpiration on a daily time step using parameters derived for plantations and for the Umgeni catchments themselves (Umgeni Water, 1997). The ACRU model was used to estimate the incremental water-use of riparian invasions, mainly wattle and eucalypt, in the catchments of the Midmar Dam, and the estimates were compared with those from the biomass model.

4.3 Verification and Validation of the Models

The adjusted results obtained from the models were tested to determine whether they were within the right range by dividing the volume of the estimated streamflow reduction by the area of invaders and converting it to rainfall equivalents in millimetres. In the winter rainfall areas, a value of 110-250 mm was obtained for tall alien vegetation at an age of 7.5 years, while in the summer rainfall areas, the value was 200-450 mm for an age of 20 years. These values are reasonable when compared with the results of studies of afforested catchments (Dye, 1996) and with the finding that riparian pine and eucalypt trees can use two, or more, times as much water as non-riparian trees (Scott & Lesch, 1995). Studies of the water-use of large trees with access to abundant water show that their total water-use can be as much as 1 600 mm per year (Dye, 1996), about 500 mm more than that of the native vegetation. The incremental water-use of riparian invasions, mainly wattle and eucalypt, in the catchment of the Midmar Dam was estimated at 11 million m^3 per year using the ACRU model (Umgeni Water, 1997). This is equivalent to about 560 mm per year (on a condensed area basis), which is higher than the biomass model's estimate of 368 mm for the same catchments.

4.4 Results

The impact of invaders on surface runoff is discussed firstly as a national overview and then by province. The data on streamflow reductions presented in the tables in this chapter and elsewhere are obtained from the biomass model and adjusted according to the data on seasonal streamflow patterns (see section 4.1.2), unless explicitly stated otherwise. The use of the term streamflow reduction, while technically correct, leads to some confusion, especially for catchments where streamflow is ephemeral. As discussed earlier, the reduction in streamflow can be equated with the incremental water-use when measured over a number of years. Therefore we have used the term incremental water-use in the text. The summary tables in this chapter only deal with the incremental water-use for provinces and primary catchments and the data for the tertiary catchments and for each species in each of the provinces are given in Appendix 6.

4.4.1 National overview

The greatest impact on water resources country-wide, on a volume basis, is along the eastern escarpment where rainfall is higher than in the rest of the country (Table 4.4). This is to be expected, as invading aliens grow and increase more rapidly where the water is available.

Over the entire area of South Africa and Lesotho the mean annual runoff has been reduced by about 6.67%. The greatest impact (as a percentage) was recorded in the Northern Cape where water-use by invaders, primarily *Prosopis*, is equivalent to about 17% of the mean annual runoff (MAR, Table 4.4), or the equivalent of 91 mm per year for densely invaded areas. A similar situation is found in the North West province but here a greater proportion of the invasions are by riparian species such as *Melia azedarach* and wattles. Northern Province also has large areas with a low rainfall but most of the invaded areas are located in the high-rainfall catchments (Drakensberg escarpment, Soutpansberg and similar areas) and thus have a disproportionate impact on the surface runoff in the province as a whole. The Western Cape has the greatest reductions in terms of volume mainly because large areas of the mountain catchments are invaded by pines, and most river systems are invaded by wattles.

The total water-use before adjustment was about 4 010 million m^3 per year (8.10% of the MAR). The largest adjustment of the estimates from the biomass model was in the Northern Cape where there is only surface runoff (at a quaternary catchment scale) for about 33% of the time, followed by the North West Province at 67% and Northern Province at 73%. The mean adjustment factor for the whole area was 82%. The water-use of invading plants in Gauteng, Free State and KwaZulu-Natal was not adjusted downwards as there is perennial surface runoff in all their quaternary catchments. The impact of invaders is equivalent to 190 mm per year (1 900 m^3 per ha) on a condensed area basis and 33 mm over the total invaded area of 10.1 million ha. To put this in perspective, this is equivalent to about 72% of the virgin mean annual runoff of the Vaal River which was about 4 567 million m^3 (Midgley *et al.*, 1994), and about 98% of the virgin MAR of the Northern Province.

Table 4.4: Impact of the water-use of invading alien plants on the mean annual runoff (MAR) in each of the provinces and in Lesotho.

Province	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded area (ha)	Water-use in rainfall equivalents (mm)
Eastern Cape	9 998.76	558.19	5.58	151 258	369
Free State	3 546.10	86.19	2.43	24 190	356
Gauteng	551.97	53.93	9.77	13 031	414
KwaZulu-Natal	12 517.61	575.74	4.60	250 862	230
Lesotho	4 647.19	1.88	0.04	502	374
Mpumalanga	6 303.01	446.29	7.08	185 149	241
Northern Cape	910.94	150.86	16.56	166 097	91
Northern Province	3 383.63	297.70	8.80	263 017	113
North West	1 081.57	95.40	8.82	56 232	170
Western Cape	6 555.18	1 036.82	15.82	626 100	166
South Africa	49 495.96	3 303.00	6.67	1 736 438	190

An analysis of the impact on the runoff in the different primary catchments also highlights some of the worst affected areas (Table 4.5; Figure 4.1). The highest impact, on a percentage basis, is found in the arid Namaqualand coastal region (catchment F) which has very low surface runoff. The main invading species are the wattles, especially *Acacia cyclops*, which are probably exploiting groundwater and fog, thereby utilising more water than is directly available as surface runoff. A similar situation is found in the relatively dry coastal catchments from Port Elizabeth to Port Alfred (catchments M-P) where dense invasions of wattles are found in the extensive coastal dune-fields. The substantial impact of invading plants on the amount of runoff in the Olifants (catchment B, Mpumalanga) and Limpopo River (catchment A) systems also stands out clearly. The relatively wet catchments of the southwestern Cape (catchment G) have also been severely affected at 31% of MAR, mainly because of extensive landscape invasions by pines and riparian and landscape invasions by *Acacia* species.

Table 4.5: Impact of water-use by invading alien plants on the mean annual runoff (MAR) in primary catchment areas of South Africa and Lesotho. See the text for a discussion of why certain catchments have such high reductions.

Primary catchment	River system	Mean annual runoff (millions of m³)	Incremental water-use (millions of m³)	Water-use (% of MAR)	Condensed invaded area (ha)	Reduction in rainfall equivalents (mm)
A	Limpopo	2 381.82	190.38	7.99	122 457	155
B	Olifants	2 904.1	290.44	10.00	217 855	133
C	Vaal	4 567.37	190.53	4.17	64 632	295
D	Orange	7 147.76	141.40	1.98	141 012	100
E	Olifants, Sout & Doring	1 008.35	35.52	3.52	37 623	94
F	Namaqualand coast	25.01	22.76	91.00	46 618	49
G	W Cape & Agulhas coast	2 056.75	646.50	31.43	384 636	168
H	Breede & Riversdale coast	2 088.35	181.63	8.70	84 398	215
J	Gouritz	670.63	74.79	11.15	59 399	126
K	S Cape coast	1 297.3	134.46	10.36	52 993	254
L	Gamtoos	494.71	96.53	19.51	34 289	282
M	PE Coast, Swartkops & Coega	150.04	40.18	26.78	11 358	354
N	Sundays	279.89	8.34	2.98	3 964	210
P	Bushmans & Alexandria coast	172.92	73.08	42.26	22 894	319
Q	Gt Fish	520.72	21.12	4.06	6 980	303
R	Border Coast	578.91	55.58	9.60	12 483	445
S	Great Kei	1 042.35	138.22	13.26	30 694	450
T	Former Transkei	7 383.76	217.38	2.94	68 493	317
U	S KwaZulu-Natal	3 121.2	126.37	4.05	46 442	272
V	Tugela	3 990.88	104.67	2.62	62 151	168
W	N KwaZulu-Natal	4 741.74	229.86	4.85	100 574	229
X	Komati to Nwanedzi	2 871.4	283.26	9.86	124 494	228
	RSA	49 495.96	3 303.00	6.67	1 736 438	190

The largest adjustments of the water-use estimates from the biomass model were in catchment F where there was surface runoff for only 20% of the time (at a quaternary catchment scale) followed by catchment D with 36% and E with 58%. All the catchments of the well-watered eastern parts of South

Figure 4.1: Water use by alien invading plants as a percentage of MAR for tertiary catchments across South Africa and Lesotho

Africa, from catchment R (Eastern Cape) through to catchment W (Northern KwaZulu-Natal) had surface runoff for 100% of the time as did catchment K in the George-Tsitsikamma region.

The top twenty tertiary catchments in terms of the percentage loss of MAR are as follows (by province and within province):

- Western Cape: F60 southern Namaqualand coast; G50 Agulhas plain; G30 Sandveld; J13 Groot River; E33 Sout River; L81 Baviaanskloof River; H90 Kafferkuils River; F50; G21 Diep River to Yserfontein; J34 Kammanassie River
- Northern Cape: D57-D58 Sak River; F40 Namaqualand Coast; D54 Van Wyksvlei district
- Northern Province: B51 Middle Olifants
- Eastern Cape: P20 Alexandria coast; P30-P40 Kariega & Cowie Rivers; S40 Thomas & Middle Kei River; S60 Kubusi River; M30 Lower Sundays.

A small sub-set of the invading species is responsible for most of the water use by invaders in this country. The most important species, by this standard, is *Acacia mearnsii* (Table 4.5) followed by *A. cyclops*. The impact of the latter species on surface runoff is limited because of its coastal distribution pattern except where communities depend on groundwater supplies, for example the town of Atlantis in the Western Cape. As a group the acacias, with 7 species in the top 25, notably *A. mearnsii*, *A. cyclops* and *A. dealbata* (*Acacia* mixed species also includes *A. decurrens*), are the prime water users, accounting for 55% of the total water-use. They are followed by pines, eucalypts, *Prosopis* species and *Melia azedarach*. The top 10 account for 81% of all water-use due to invading aliens. Water-use by pines could be higher because they are found primarily in the Western Cape mountain catchments where their water-use is reduced by the mean age of 7.5 years compared to the greater ages, and greater water-use, estimated for riparian species. The greatest adjustment in water-use was for *Prosopis* species, which occurs mainly in semi-arid areas, where the adjusted value is only 40% of that predicted from its biomass, followed by *Sesbania punicea* with 67% and *Acacia cyclops* with 73%.

Table 4.6: Estimated mean annual water-use of the top 25 invader species for the whole country, ranked according to their relative water-use.

Species	Water-use (millions of m^3)	Cumulative percentage of the total water-use
Acacia mearnsii	576.58	17.46
Acacia cyclops	487.63	32.22
Acacia dealbata	248.32	39.74
Acacia mixed species	242.63	47.08
Pinus species	231.53	54.09
Eucalyptus species	213.98	60.57
Prosopis species	191.94	66.38
Acacia saligna	171.13	71.56
Melia azedarach	164.91	76.56
Solanum mauritianum	139.97	80.79
Lantana camara	97.14	83.73
Chromolaena odorata	68.26	85.80
Hakea species	66.30	87.81
Populus species	53.83	89.44
Jacaranda mimosifolia	48.40	90.90
Sesbania punicea	42.57	92.19
Rubus species	41.33	93.44
Acacia longifolia	38.73	94.62
Psidium guajava	37.31	95.75
Caesalpinia decapetala	33.82	96.77
Salix species	33.21	97.78
Acacia melanoxylon	32.20	98.75
Acacia decurrens	9.83	99.05
Quercus species	7.24	99.27
Nerium oleander	6.95	99.48
Other species	17.27	100.00

4.4.2 Provincial overview

Eastern Cape

The mean annual rainfall in the Eastern Cape (at a quaternary catchment scale) ranges from 135-1 277 mm (mean 588) and the MAR from 1-480 mm (mean 73). The rainfall-runoff ratio ranges from 135.5 to 2.1 with a mean of 19.4, i.e. on average only 5% of the rainfall ends up as surface runoff. The wide range of climates from semi-arid to alpine results in a wide variety of biomes: Forest, Thicket, Savanna, Grassland, Nama Karoo and Fynbos (Low and Rebelo, 1996). Most of the invaded area occurs in the higher rainfall regions of these biomes where vigorously growing plants can flourish.

The total water-use of invading alien species in the Eastern Cape province is approximately 558 million m^3yr^{-1}. All the most severely affected catchments are in the relatively dry interior and coastal belt where the rainfall, and thus surface runoff is relatively low. The exception to this is the Tsitsikamma region (primary catchments J & K), especially the Kouga region which are severely invaded. The impacts of invading aliens in primary catchment K are in addition to those caused by the extensive plantation areas, although the extent of the impacts is mitigated by the relatively low water demand in these areas. A number of tertiary catchments are particularly badly affected. The top 10 are located in the coastal regions east of Port Elizabeth (P20-P40), near Port Elizabeth (M30), Kouga-Baviaanskloof (L81, L70), Tsitsikamma (K60), Albany (R50) and the Keiskamma region (S40, S60).

Table 4.7: Impact of invading alien plants on surface runoff in the primary catchment areas of the Eastern Cape.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Reduction (mm)
D	1 024.41	0.57	0.06	266	214
J	10.07	0.04	0.40	44	91
K	552.80	57.17	10.34	15 459	370
L	348.95	76.53	21.93	24 095	318
M	150.04	40.18	26.78	11 358	354
N	275.73	8.34	3.02	3 964	210
P	172.92	73.08	42.26	22 894	319
Q	520.08	21.12	4.06	6 980	303
R	578.91	55.58	9.60	12 483	445

Table 4.7 (cont.)

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Reduction (mm)
S	1 042.35	138.22	13.26	30 694	450
T	5 322.50	87.36	1.64	23 022	379
Total	**9 998.76**	**558.19**	**5.58**	**151 258**	**369**

The large wattles (*Acacia mearnsii, A. dealbata, A. melanoxylon, Acacia* mixed species) account for 68% of the total water-use of invading aliens. With the addition of pines, *A. cyclops, A. saligna* and eucalypts the cumulative water-use is 92% of the total for the province.

Free State

The Free State is located primarily in the Grassland Biome, with dry sandy Highveld Grassland in the west and moist cool Highveld Grassland in the east (Low and Rebelo, 1996). The mean annual rainfall in the Free State (at a quaternary catchment scale) ranges from 300 mm in the west to 1 223 mm in the east (mean of 636 mm) and the MAR from 2-611 mm (mean of 68 mm). The rainfall-runoff ratio ranges from 2.0-161.5 with a mean of 25.9, i.e. on average about 96.2% of the rainfall evaporates or is transpired.

Table 4.8: Impact of invading alien plants on surface runoff in the primary catchment areas of the Free State.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
C	2 723.40	85.32	3.13	23 593	362
D	804.04	0.86	0.11	597	144
V	18.66	0.00	0.00	0	0
Total	**3 546.10**	**86.18**	**2.43**	**24 190**	**356**

Invading alien species in the Free State use approximately 86 million m^3 per year (Table 4.8) more than the native vegetation. Almost all the tertiary catchments affected by alien invaders occur in the Vaal River System which has extensive riparian invasions, particularly catchments C21, C81-C83 and C91 and in the Orange River system (D33). The Caledon River system (secondary catchment D2) has not been adequately mapped and the water-use by invaders has been underestimated. Six species groups account for about 86% of the total water-use, namely *Acacia*, *Salix*, *Eucalyptus*, *Populus* and *Pinus* species in decreasing order of impact.

Gauteng

The natural vegetation is predominantly grassland on the highveld with its occasional rocky outcrops, with mixed bushveld in the north. The mean annual rainfall (at a quaternary catchment scale) ranges from 574-718 mm (mean of 658 mm) and the MAR from 9-115 mm (mean of 68 mm). The rainfall-runoff ratio ranges from 6.1-65.2 with a mean of 21.1, i.e. on average about 4.7% of the rainfall becomes surface runoff. Invading alien species in Gauteng Province use approximately an additional 54 million m^3 per year (Table 4.9) compared with the native vegetation. The worst affected catchments are situated in the Vaal (catchment C) and Limpopo (A) River systems, notably the upper Olifants (B32), Wilge (B20), Klip and Vaal Barrage (C22) and the Crocodile River (A21). The tall *Acacia* species account for half the total water-use by woody alien plants. Other important water-users are eucalypts, *Salix* species and *Populus* species which mostly occur within the riparian zones.

Table 4.9: Impact of invading alien plants on surface runoff in the primary catchment areas of Gauteng.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
A	217.88	16.18	7.43	3 814	424
B	78.20	9.08	11.61	2 192	414
C	255.89	28.67	11.20	7 025	408
Total	**551.97**	**53.93**	**9.77**	**13 031**	**414**

KwaZulu-Natal

KwaZulu-Natal is the wettest province: the mean annual rainfall (at a quaternary catchment scale) ranges from 553-1353 mm (mean of 817 mm) and the MAR from 20-678 mm (mean of 155 mm). The rainfall-runoff ratio ranges from 2.0-32.2 with a mean of 7.4, i.e. on average about 13.5% of the rainfall becomes surface runoff. The natural vegetation of KwaZulu-Natal is composed of a number of biomes. The uplands consists of extensive grasslands, where frequent frosts and fire limit the establishment of trees. This changes to savanna and then thicket towards the coast, interspersed throughout with patches of forest. The presence of several biomes in the province facilitates extensive invasions by a wide variety of invading species, particularly in the river valleys.

Invading alien plant species in KwaZulu-Natal use approximately 576 million m^3 per year more than the natural vegetation they have invaded or replaced. Primary catchment C is the most affected, on a percentage basis, but the area is very small as only a small part of the Vaal catchment falls within the borders of KwaZulu-Natal. The river systems of the southern region (catchment T), which includes the Umzimkulu District of the Eastern Cape Province, the southern midlands region (catchment U)and catchment W (including the northern coastal plains) are particularly badly affected. The impact of alien water-use in this province is underestimated because much of the area is inadequately mapped, notably the former KwaZulu districts.

As noted earlier, independent estimates suggest that invaders in the riparian zones of the Umgeni River system above the Midmar Dam use about 11 million m^3 per year more than the natural riparian vegetation - equivalent to about 560 mm on a condensed area basis (Umgeni Water, 1997). The worst affected tertiary catchment in KwaZulu-Natal is in the Mhlatuze River system (W12 at 15.6%) followed by the Kaneka (T33), upper Pongola (W52), Umzimvubu (T32), Mvoti (U40), lower Umzimkulu (T52) and Mkuzi River (W31) systems.

Table 4.10: Impact of invading alien plants on surface runoff in the primary catchment areas of KwaZulu-Natal.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
C	1.81	0.30	16.57	72	415
D	3.26	0.00	0.00	0	0
T	2 057.90	130.02	6.32	45 470	286
U	3 120.44	126.37	4.05	46 442	272
V	3 900.67	101.02	2.59	61 344	165
W	3 433.53	218.03	6.35	97 534	224
Total	**12 517.61**	**575.74**	**4.60**	**250 862**	**230**

Acacia species account for about 48% of the total water-use, followed by *Solanum mauritianum*, *Melia azedarach*, pines and eucalypts. *Chromolaena* has a high water-use (68 million m^3) but it is not known how much of this would be incremental water-use given that the natural vegetation in the coastal belt where *Chromolaena* is most abundant would probably have much the same water-use. The same is probably true of *Lantana* (16.6 million m^3) and *Rubus* (18.7 million m^3).

Lesotho

Lesotho has a high mean annual rainfall of 922 mm (range 539-1353 mm) at a quaternary catchment scale, a mean annual runoff of 289 mm and a rainfall-runoff ratio of 4.7 or about 21% of the rainfall. The natural vegetation is Moist Cold Highveld Grassland (Low and Rebelo, 1996). The total incremental water-use of invading alien species in Lesotho is estimated at 2.0 million m^3 per year. This is an underestimate of the impact because only parts of the Orange River system itself have been mapped. Only a very limited area of the Caledon River system, which drains the more densely inhabited and developed western parts of Lesotho has been mapped. Observations during earlier trips through this area suggest that invasion levels are more typical of the north-eastern Free State catchments where reductions are about 3-5%. Nevertheless, large areas of Lesotho are comparatively free of invaders because of the high demand for wood for fuel for construction, and because of intensive cultivation of the very limited arable soils along the rivers.

Table 4.11: Impact of invading alien plants on surface runoff in the primary catchment areas of Lesotho.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
C	1.34	0.00	0.00	0	0
D	4 632.58	1.88	0.04	502	374
T	3.36	0.00	0.00	0	0
U	0.76	0.00	0.00	0	0
V	9.15	0.00	0.00	0	0
Total	**4 647.19**	**1.88**	**0.04**	**502**	**374**

Only seven genera of invasives contribute to this loss, with *Acacia* species contributing about 57%, *Salix* spp a further 23% and *Populus* spp most of the rest.

Mpumalanga

Mpumalanga is the second wettest province with a mean annual rainfall of 793 mm (range 460-1 334 mm) at a quaternary catchment scale, a mean annual runoff of 113 mm (4-543 mm) and a rainfall-runoff ratio of 16.8 (2.3-109.3 mm) or about 6.0% of the rainfall. Natural vegetation along the high-rainfall escarpment region is North-eastern Mountain Grassland where invading acacia and pine species occur in both riparian and landscape areas. The lowveld falls within the Savanna Biome. In the high-rainfall areas, both along the escarpment and in the lowveld, grasses grow vigorously, leading to plentiful fuel supplies for veld fires. These fires aid the spread of acacia species in particular.

Table 4.12: Impact of invading alien plants on surface runoff in the primary catchment areas of Mpumalanga.

Primary catchment	Mean annual runoff (millions of m³)	Incremental water-use (millions of m³)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
A	0.14	0.00	0.00	0	0
B	1 332.47	132.83	9.97	56 597	235
C	903.23	26.89	2.98	6 617	406
V	62.40	3.65	5.85	808	452
W	1 308.21	11.83	0.90	3 040	389
X	2 696.56	271.09	10.05	118 086	230
Total	**6 303.01**	**446.29**	**7.08**	**185 149**	**241**

The total incremental water-use of invading alien species in the Mpumalanga province is approximately 446 million m^3 per year or 7.1% (Table 4.12). The Olifants River system (catchment B) and the Crocodile and Sabie River systems (catchment X) are the worst affected. Among the worst affected areas are the riparian zones in the plantation areas which have been heavily invaded by a wide variety of species while pines have spread in some of the grassland areas. The forestry companies have made substantial progress in clearing riparian zones of invading trees but there still is a considerable backlog. The decrease in the amount of water in the rivers undoubtedly aggravates the low- and no-flow problems that are having a negative impact on the river systems of the Kruger National Park. The worst affected tertiary catchments are in the Spekboom (B42), Blyde (B60), Sabie-Sand (X31-32), Crocodile and Kaap (X21-24) and Steelpoort (B41) River systems.

Acacia species account for about 42% of the total water-use, *Acacia mearnsii* alone uses some 126 million m^3, with the other large tree species (e.g. eucalypts, *Melia azedarach*, poplars) accounting for a further 20%. *Solanum mauritianum*, *Lantana camara*, *Caesalpinia decapetala* and *Rubus* species also account for a substantial volume of water in the moist eastern escarpment areas. The water use of these species may be overestimated because they typically displace similar indigenous vegetation or occur in the understorey where they may use little additional water.

Northern Cape

The Northern Cape is the driest province with a mean annual rainfall (at a quaternary catchment scale) of 226 mm (range 29-433 mm) and a mean annual runoff of 4.5 mm (0.0-43.5 mm). The mean rainfall-runoff ratio is 134.6, i.e. only 0.7% of the rainfall becomes surface runoff. Many catchments can be dry for extended periods and there is surface runoff for an average of only 33% of the time. Almost all of the province falls within the Karoo, ranging from the winter rainfall, Lowland Succulent Karoo vegetation in Namaqualand and the Richtersveld (catchments E and F) to the summer rainfall Nama Karoo Biome with its grassy, dwarf shrublands where the fuel load is insufficient to carry fires. Invasions are confined largely to the perennial rivers, the kalahari dunes and the low-lying 'leegtes' favoured by *Prosopis* probably because of easy access to shallow groundwater.

The total incremental water-use of invading alien species in the Northern Cape province is approximately 151 million m^3 per year (Table 4.13) more than that used by the natural vegetation. The greatest impact on a percentage basis is in the arid Namaqualand and Richtersveld region (catchment F, notably F60, F40) but the largest volumes are in the Orange River system (catchment D). At a tertiary catchment scale seven of the top 10 invaded catchments are those invaded primarily by *Prosopis*. These are the Modder (C52), lower Fish (D58), Sak (D54, D57, D58) and middle Orange River system (D71, D72). *Prosopis* invasions in the Van Wyk's Vlei area (D62) also use the equivalent of more than 15% of the mean annual surface runoff.

Table 4.13: Impact of invading alien plants on surface runoff in the primary catchment areas of the Northern Cape.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
C	116.58	3.08	2.64	2328	132
D	608.85	126.16	20.72	129 509	97
E	115.79	5.20	4.49	5 144	101
F	22.62	15.32	67.73	28 689	53
J	19.65	0.93	4.73	346	269
L	26.62	0.18	0.68	81	223
N	0.19	0.00	0.00	0	0
Q	0.64	0.00	0.00	0	0
Total	**910.94**	**150.87**	**16.56**	**166 097**	**91**

Prosopis species are responsible for 89% of the incremental water-use (1 100 m^3 per densely invaded hectare per year) and with *A. cyclops* (found in catchment F on the arid west coast) account for 99% of the estimated water-use. *Prosopis* species are found mostly on the alluvial plains where they can utilise the groundwater up to a depth of 50 m (Phillips 1963). The adjusted water-use probably still overestimates the direct impact on surface runoff but the adjustments do not allow for groundwater use which could be much higher than that of the Karoo shrubs and grasses they replace. Calculations using the unadjusted biomass model suggest that *Prosopis* species in this province could be using as much as 380 million m^3 per year or about 2800 m^3 per densely invaded hectare per year more than the natural vegetation.

Northern Province

The Northern Province has a relatively high rainfall (at a quaternary catchment scale) with a mean of 610 mm per year (range 288-1334 mm) and a mean annual runoff of 52.0 mm (1.9-542.9 mm), i.e. about 2.6% (0.6-42%) of the rainfall ends up in the rivers. The vegetation of the Northern Province falls mainly in the Savanna Biome, although grasslands occur along the north eastern escarpment areas (Low and Rebelo, 1996). Invader species occur primarily along the riparian zones, especially around the plantation and fruit farming areas along the escarpment and near Tzaneen.

Table 4.14: Impact of invading alien plants on surface runoff in the primary catchment areas of the Northern Province.

Primary catchment	Mean annual runoff (millions of m^3)	Incremental water-use (millions of m^3)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
A	1 715.36	136.99	7.99	97 544	140
B	1 493.43	148.53	9.95	159 065	93
X	174.84	12.18	6.97	6 408	190
Total	**3 383.63**	**297.70**	**8.80**	**263 017**	**113**

The incremental water-use of invading alien species in the Northern Province is approximately 298 million m^3 per year or the equivalent of 8.8% of the mean annual runoff (MAR, Table 4.14). The greatest impact occurs in the Olifants River system (catchment B), including the Elands and the Olifants

Rivers where the incremental water-use is more than 30% of the MAR. The impact exceeds 10% of MAR in roughly a third of all the tertiary catchments in Northern Province. Most of these comprise the headwaters of the Limpopo (A) and Olifants (B) primary catchments. In the Olifants the worst affected tertiary catchments are the middle Olifants (B32, B51, B52), Elands (B31) and lower Olifants (B71). In the Limpopo system the water-use in the Sand (A71) and Magalakwa (A61) Rivers is equivalent to more than 10% of the MAR. *Melia azedarach* (syringa) accounts for about 28% of the total amount of water used, followed by eucalypts (found mainly in the major rivers draining the escarpment), *Jacaranda, Sesbania, Lantana, Caesalpinia* and *Solanum mauritianum*.

North West Province

This province is the second driest with a mean annual rainfall (at a quaternary catchment scale) of 545 mm (range 200-718) and a mean annual runoff of 16.1 mm (0.4-100.0). The mean rainfall-runoff ratio is 85.8 with about 1.2% of the rainfall becoming surface runoff. The natural vegetation in the North West Province consists mostly of the Savanna Biome Mixed Bushveld types, especially towards the west and the Kalahari region (Low and Rebelo, 1996). In the east, the vegetation changes to Rocky Highveld Grassland in the headwaters of the Harts River. The low rainfall limits the spread of alien invaders, except along the river banks where most of the invaders occur at present.

The total incremental water-use of invading alien species in the North West Province is approximately 95 million m^3 per year (Table 4.15). The relatively dry catchments of the lower Orange (catchment D) (catchment C) are the most severely affected, on a percentage basis, both by extensive invasions of *Prosopis* and by riparian invasions along the Orange River itself. A similar situation applies to the Limpopo River (catchment A) where a number of the major tributaries have become invaded, especially those that arise in Gauteng such as the Crocodile (secondary catchment A2) and Marico (A3) rivers. Five groups of species account for about 90% of the impact, namely *Prosopis* species (43%), *Eucalyptus* species, *Melia azedarach, Populus, Acacia mearnsii* and *Jacaranda mimosifolia*.

Table 4.15: Impact of invading alien plants on surface runoff in the primary catchment areas of the North West Province.

Primary catchment	Mean annual runoff (millions of m³)	Incremental water-use (millions of m³)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
A	448.44	37.21	8.30	21 099	176
C	565.12	46.27	8.19	24 996	185
D	68.01	11.92	17.53	10 137	118
Total	**1 081.57**	**95.40**	**8.82**	**56 232**	**170**

The additional water-use by alien invaders is more than 10% pf the MAR in half of the tertiary catchments in the province. Catchments C22, C32 and C25 in the Vaal River system are particularly badly affected as are the Elands and Hex Rivers (A22) and lower Crocodile River (A24) north-west of Pretoria and the Kuruman/Molopo area (D41).

Western Cape

Vegetation from a number of biomes occurs in the province including Succulent Karoo, Nama Karoo, Fynbos and Forest. The shrubby Fynbos vegetation is particularly susceptible to invasion by tall shrubs and trees and a number of species have invaded very large areas of the mountain catchments. The mean annual rainfall at a quaternary catchment scale is 424 mm and varies from 1 895 mm in the Franschhoek-Stellenbosch area to 98 mm on the arid West Coast. The mean annual runoff also varies widely from 0.2-1 206.8 mm with a mean of 86.0 mm and a rainfall-runoff ratio of 33.5 (range 1.32-514.8).

The total incremental water-use of invading alien plants in the Western Cape is about 1 037 million m³ per year (Table 4.16). The worst affected (as a percentage of MAR) is the arid west coast (catchment F) with extensive areas of *Acacia cyclops* and *A. saligna*. These species depend mainly on fog and groundwater, therefore the effect of invasives on surface runoff may still be overestimated in this catchment despite the adjustment of the predictions from the biomass model. The greatest impact, in terms of volume, is in the catchments (E, G, H-K) which supply the major towns and the important agricultural areas which sustain the deciduous fruit, wine and citrus industries. The most important species are *Acacia cyclops* (44% of the total) and *A. mearnsii* (15%), followed by *A. saligna* (13%), *Pinus* species (13%), and *Hakea* species (6%). Together with eucalypts and *A. longifolia* they account for 95% of the total water-use.

Table 4.16: Impact of invading alien plants on surface runoff in the primary catchment areas of the Western Cape.

Primary catchment	Mean annual runoff (millions of m³)	Incremental water-use (millions of m³)	Water-use (% of MAR)	Condensed invaded areas (ha)	Water-use (mm)
D	6.61	0.00	0.00	1	0
E	892.56	30.32	3.40	32 479	93
F	2.39	7.44	311.30	17 930	41
G	2 056.75	646.50	31.43	384 636	168
H	2 088.35	181.63	8.70	84 398	215
J	640.91	73.82	11.52	59 010	125
K	744.50	77.29	10.38	37 534	206
L	119.14	19.83	16.64	10 114	196
N	3.97	0.00	0.00	0	0
Total	**6 555.18**	**1 036.83**	**15.82**	**626 100**	**166**

Tertiary catchment E33 comprises the lower end of the Olifants River and the Sout River, and terminates in the Atlantic ocean. Aliens here are found on the sandy coastal plains, comprising *Acacia cyclops*, *A. saligna* and eucalyptus species along the river banks. The interior is very arid and supports only the Succulent Karoo type of vegetation (Low and Rebelo, 1996). Similarly, F60 is also extremely arid, although *A. cyclops* occurs mostly along the coastal dunes where the plants capture additional water from the Atlantic fogs. The impact of aliens on water resources is unlikely to be important in this catchment area. Invaders in the Agulhas plain area (G50) and Sandveld (G30) are estimated to be using more water than the mean surfcae runoff but little is known about the extent to which they are using groundwater.

In some tertiary catchments - G10 (the Berg River), G21 (the Swartland), G30 (the Sandveld around Clanwilliam) - there are both landscape and riparian invasions, with *A. saligna* and *A. cyclops* being the primary landscape invaders, and with eucalypts and *A. mearnsii* occurring along the river banks. The rivers in this environment are very noticeable from the air because of the distinct linear features created by the continuous riparian thickets of invading vegetation. In the southern Cape area between False Bay and the Breede River mouth (G40 and especially G50 - Bredasdorp area), the rivers are similarly heavily invaded by the acacias and eucalypt species.

4.5 Discussion

In some cases the percentage of MAR utilised by invaders was estimated to be more than 100%. This is not true, because there is still some water left in those rivers. There could, however, be a number of reasons for this discrepancy:

- The models are overestimating water-use by alien plants;
- The water-use data are presented as a percentage of the mean flow, but the actual flow in a given year is likely to be more, or less, than the mean;
- There is an over-estimation of the extents or density, or both, of invaders in the catchments;
- We are estimating the impact of aliens on naturalised flow estimates (Midgley *et al.*, 1994) which have already been adjusted to implicitly include the impact of invaders; therefore there may be some double accounting; and
- in some cases, too, it is probable that individual catchments are particularly severely affected by invaders but the water observed in the rivers is supplied by other catchments upstream. Water from upstream catchments is not included in the surface runoff estimates for downstream catchments in Midgley *et al.*'s (1994) analysis.

The models we have used are empirical, based on catchment experiments, albeit from a forestry perspective. The lack of explicit data on water-use by the different invading species is a problem and will require special research. It is also likely that in some places the extent of invaded areas has been underestimated, especially in KwaZulu-Natal. Whatever reservations there might be about either data or calculations, the impact of invading aliens on the water resources of South Africa is significant, at about 6.7% of the total surface runoff or about 75% of the mean annual runoff of the Vaal River. The impact can also be put into perspective by comparing it with estimates of the water-use of plantations (data from Le Maitre *et al.*, 1997; Scott *et al.*, 1998):

Water-use by commercial forestry:	1 399 million m^3 per year
Water-use by invading aliens:	3 303 million m^3 per year
Area covered by commercial forestry:	14 389 km^2
Area covered by invading aliens:	17 364 km^2 (condensed area)

In millimetre rainfall equivalents this equates to about 93 mm per year for plantations compared with 190 mm for invaded areas, therefore the incremental water-use of alien invaders (per unit area) may be substantially greater than that of commercial plantations. As discussed at the beginning of this chapter (see section 4.2.3), there are a number of factors which could account for this, the most important being that:

- Most of the alien invaders mapped for this study occur in the riparian zone along riverbanks. It should be remembered that plantation forestry is expressly kept out of riparian zones in South Africa because of the recognized consumptive use of water from this zone which may be two or more times that of non-riparian trees planted at the same time (Scott & Lesch, 1995).
- We have used an age of 20 years for invasions, except in the Western Cape (see section 4.2.3). This is substantially greater than the typical mean age of plantations which is of the order of 10 years.

As pointed out earlier, the independent study for Umgeni Water (Umgeni Water, 1997) which used a completely different model gives an estimated incremental water-use of about 560 mm per year (5 600 m^3), which is higher than the 368 mm estimated for the same catchments in this study. There are various studies under way which will provide more information on the water-use of invading plants and will help to refine the estimates provided by this study.

5. PROCESS AND RISKS OF INVASION

5.1 Introduction

The aims of this project, in addition to assessing the current extent and impact of alien invasions, included providing information and developing models to address the following questions:

- What area of the country could be invaded if nothing were done to limit the spread of woody alien plant species?
- How rapidly would this area be invaded?

In order to address these questions we need to understand (a) what species invade, how they invade, what factors facilitate and limit such invasions, and (b) how rapidly different species are able to invade and increase in density. When this part of the study was initiated the plan was that the rates of spread and increases in density would be modelled. The model outputs would then have been used to develop scenarios for setting priorities and determining the costs of controlling invasive plants. The scenario modelling could not be implemented in the available time, so the thrust of this chapter has shifted to the process and dynamics of invasions and to identify areas and species which are important risks. The literature review, assessment of potential modelling approaches, and summary of what is known about invasive species in South Africa are given in Appendix 5. In this chapter the term *seeds* is used as shorthand for all propagules - parts of the plant that can grow and become new individuals.

5.2 Factors Determining the Approach

This section discusses the constraints that the nature of the project and the available information placed on the approaches that could be used to assess the levels of risk of invasion and to identify the species that could constitute serious risks.

5.2.1 The nature of the project

The aims of the project include providing an assessment of the extent and potential impact of alien plant invasions within South Africa, to help in determining priorities for the funding of alien plant control. This work had to be completed in a period of about 15 months, although it was later extended by a further

15 months. These requirements introduced some constraints:

- The information had to be suitable for use by national and provincial decision makers in determining overall priorities for the allocation of funds for alien plant control.

- The base maps for mapping aliens had to use a standard map scale which was readily available, provided a consistent level of detail and facilitated rapid mapping either in the field or from expert knowledge. The scale adopted was 1:250 000 as this is compatible with the level of detail required (national-provincial). This also limited the number of maps to a reasonable quantity compared with the more detailed 1:50 000 maps.

- An explicitly spatial approach (e.g. Auld and Coote, 1980, 1990; Le Maitre *et al.*, 1996) has the advantage of modelling the key processes (e.g. dispersal, recruitment) directly. However, a spatially explicit model would have resulted in complex and time-consuming calculations involving hundreds of individual polygons. This was not possible within the time and logistical constraints on the project. Thus the data were aggregated into larger units which provide information at the scale required by decision makers.

5.2.2 The limited amount of information available on invasion rates

There have been remarkably few studies which have quantified in detail the physical invasion process of plants in space and time compared with animals and diseases (see for example Drake *et al.*, 1988; Hengeveld, 1989; see also Appendix 7). This is in marked contrast to the numerous theoretical and empirical studies of seed dispersal and studies of the factors which may prevent, limit or facilitate invasions. Although there have been a few South African studies which have analysed changes over time (Boucher, 1984; Smit & de Kock, 1984; Taylor *et al.*, 1985; Moll & Trinder-Smith, 1992), only four South African studies could be found which provided sufficient data for parameterising a model of spread over time: Brownlie (1982) for various species (mainly *Acacia*), Richardson & Brown (1986) for *Pinus radiata*, Harding & Bate (1991) for *Prosopis* species, and for *Acacia cyclops*, Macdonald *et al.* (1989). The study of the invasion of Western Cape lowland fynbos site by Brownlie (1982) could not be included because it will require more detailed analysis than was possible in this study.

One additional relevant study was found. This is of *Mimosa pigra*, which was previously considered indigenous. The study analysed its invasive potential in Northern Australia (Lonsdale, 1993) and it is relevant because there are similar habitats in southern Africa, especially Mozambique. The species is known to occur in the former Cape Province, KwaZulu-Natal and the former Transvaal (Arnold & De Wet, 1993), especially in the Tzaneen area and the Letaba River system (L Henderson, pers. comm., 1996).

5.2.3 The role of disturbance

Rapid colonisation and increases in density of invasive plants are often tightly linked to disturbances. For example, fires, floods and overgrazing create areas of open soil, or reduce competition from other plants, providing open space which is ideal for colonisation by invasive plants (Hobbs, 1988; Noble, 1988; Richardson & Cowling, 1992). Colonisation continues between disturbances for most species, but at a much slower rate than shortly after disturbances. Fires typically initiate expansions and increases in the density of invasive alien plants in fynbos (Richardson & Cowling, 1992), but the same may not necessarily be true of grasslands. The frequent fires which occur in grasslands in good condition may actually prevent regeneration, and factors which reduce fire frequencies, or exclude fires (e.g overgrazing), may be needed to initiate invasion. Floods or good rainfall years may stimulate recruitment in many invasive aliens. For example, there is some evidence that recruitment in *Prosopis* depends on good rainfall years (Harding & Bate, 1991) and that floods increase invasions by *Sesbania* (Hoffman & Moran, 1988). The scale of this study does not allow for detailed interpretation of disturbances or disturbance regimes, even if hard data were available. The lack of spatial realism also makes it impractical to attempt to assess the patchiness of disturbance. Thus disturbance regimes can only be discussed in broad terms.

5.3 Estimating Rates of Spread and Densification

A large body of information on invasions by plant species and their impact on natural systems has been assembled (MacDonald *et al.*, 1986; Drake *et al.*, 1988; Hengeveld, 1989). These studies have shown that there are some patterns to the invasion process. In general, the process of invasion of an area in both space and time can be divided into two phases:

- *expansion* - dispersal from the existing patches as an expanding front and by establishing satellite colonies (which later become patches); and

- *densification* - increases in the density of populations within the colonised patches.

Although a number of these studies have provided insights into which species can invade particular areas and habitats, there have been very few studies which have documented and quantified invasion rates, particularly of large areas (greater than 10 km^2). There have also been relatively few studies which have documented the factors that limit invasions, i.e. why certain species will not invade specific areas, vegetation types or habitats. The experts and others who took part in the mapping for this study were given a questionnaire on rates of expansion and increases in density. The responses confirmed that there is very little hard data on these aspects; estimated rates of spread and increases in density were based on expert opinion. Nevertheless our results (Table 5.1) tended to fall in the same range as those found in the literature (see below), suggesting that the estimates are sound.

5.3.1 Expansion

The most promising models of expansion use information on seed dispersal to predict expansion (Higgins & Richardson, 1996). This approach requires spatially explicit models and is, therefore, not suitable for this study. This means that data on the rate of expansion in area has to be used. There have been very few studies of this at the regional scale that is required (see Appendix 1) so the available data are sparse, from disparate situations, and data for invasions in grassland or savanna are lacking. This makes it very difficult to give a single value for the expansion rate (r) used in the typical exponential model. The expansion rates of fitted models range from 0.01-0.65, while values in the range of about 0.10-0.30 are probably reasonable for the most important and aggressive species with short generation times (see Tables 6.1 and 6.2). The rates for *Mimosa pigra* of about 0.65 (Lonsdale, 1993) are very high but may be close to the rate for species such as *Chromolaena* which has spread extremely rapidly since introduction (J. Goodall, pers. comm., 1996). The review found little evidence that invasions of riparian areas are more rapid than those in landscapes but observations do suggest that they are more rapid for species such as *Acacia mearnsii* (D. Versfeld, pers. obs.). Estimates for the Rand Water Catchments (Vaal River system above the Vaal Barrage) gave expansion rates of about 0.12-0.15 for both landscape (area in ha) and riparian (length in km) situations (Versfeld *et al.*, 1997). An important factor which affects expansion rates is the dispersal mode. The most aggressive landscape invaders are wind-dispersed species such as pines, hakeas (Table 5.2) and a number of the herbaceous invaders. Bird and animal dispersed species spread relatively slowly across landscapes but much more rapidly in woodlands and forest like those found in river systems in the moister areas; these include *Acacia* species, *Rubus, Lantana, Melia* and *Prosopis*. Water dispersed species include those dispersed as seeds (e.g. *Acacia, Sesbania, Nerium*) and those dispersed as complete plants or parts, especially during floods (e.g. aquatic weeds, *Salix, Populus*).

5.3.2 Densification

The information available from the literature suggests that increases in density are initially slow and then accelerate rapidly. There is little hard evidence that the rate of increase in density slows as the cover approaches 100%, therefore an exponential rate of increase to a maximum of 100% can be assumed.

Studies by Boucher (1984), Richardson & Brown (1986) and others (see Appendix 7) suggest that transitions from initial invasion to complete cover take of the order of 40-160 years over a wide range of situations. This is equivalent to a rate of increase coefficient ranging from 0.045-0.194 per year. For the analysis in this study a mean cover increase (densification) rate of 0.11, or about 70 years from first invasion to 100% cover in landscape areas and 0.15 (about 50 years) in riparian situations, has been used.

5.3.3 Available space or habitat

The next requirement is to define the available space and/or the preferred habitat. The constraints suggested below are first approximations and will need to be re-examined and refined using the mapped data. The areas invaded by aliens can be broadly grouped into two major categories: landscapes where plants invade the entire area and riparian habitats where species primarily, or only, invade river banks and alluvial plains. Some broad generalisations on distributions, habitats invaded and climatic factors are given below (see also Table 5.2). More detailed information on alien plant species and their distribution in South Africa is given in Appendix 7.

5.3.3.1 Landscapes

There are a number of succulent and herbaceous invasive species, such as the Cactaceae, which invade landscapes in arid areas (Henderson, 1995). These are believed to have little impact on water resources and are not covered in much detail in this chapter. In South Africa a key constraint on landscape invasions for many species is rainfall, particularly the frequency and intensity of dry seasons and droughts. The only tree species which rapidly invades landscapes in the semi-arid and arid interior are in the genus *Prosopis* and, being phreatophytes, even they are largely confined to alluvial plains where groundwater stores are easily accessed and reliable, for example the valleys of the major rivers. Otherwise landscape invasions by woody shrub and tree species appear to be restricted to areas with at least 500-600 mm per year. Exceptions are the southern Cape coastal lowlands and the west coast lowlands where the cut-off is about 300 mm per year except for a strip near the coast (extending as far north as Hondeklip Bay) where regular fog is an important source of moisture. Only a few species appear to be successful as landscape invaders on a large scale. These include: *Pinus pinaster* and *P. radiata* in the mountains of the winter and all-year rainfall regions, and *P. patula* and *P. halepensis* in the summer rainfall regions; *Hakea* species in the western and southern Cape mountains; *Acacia cyclops, A. saligna* and *A. pycnantha* on the coastal plains and dune fields on the Western and Eastern Cape coasts, *Acacia mearnsii* in KwaZulu-Natal, especially in the midlands, and *Acacia dealbata* in the highveld and high altitude grasslands of the Eastern Cape.

In many areas landscape invasions are restricted by regular burning (e.g. *Acacia* species in grasslands used as pastures) or by agricultural practices such as intensive cultivation. Land cover maps could be used to define limits to invasion but unfortunately this study is not yet complete for all of South Africa. The Water Resources 1990 data sets (Midgley *et al.*, 1994) do have land-use categories but they only include forestry (pine, eucalypt, wattle, indigenous), sugar-cane and urban areas and are too limited to use in this study. The lack of suitable data for reliably defining the limits on invasion means that it is not possible to estimate invasion risk based on the potentially invadable areas, other than to recognise the limitations placed by rainfall.

5.3.3.2 Riparian zones

Previous studies have emphasized the vulnerability of riparian zones to invasion (see Appendix 7). South Africa is no exception and expert opinions and the mapped data (see Chapter 3) show that most, and probably all, river systems have been invaded to some degree. The most heavily invaded seem to be those in the wetter regions from the Western Cape through to the Northern Province. The rivers of the moist subtropical coastal belt and the lowveld appear to be the worst affected. Extensive invasions and the formation of dense stands in riparian zones appear to be largely limited to perennial rivers. The exceptions are species such as *Nicotiniana glauca*, which survives as seeds even in ephemeral river systems, and *Prosopis*. *Prosopis* is a phreatophyte and, therefore, appears to be limited largely to major river systems (e.g. those with regular seasonal flow) and their alluvial plains, except for areas with > 300 mm per year (SJ Milton, pers. comm., 1996). Prominent invaders of riparian zones include *Acacia mearnsii, A. dealbata* and *A. decurrens* which are primarily confined to river systems except in the moist grasslands (e.g. mist-belt grasslands and the highveld). Species such as *Lantana, Melia azedarach, Caesalpinia decapetala, Salix, Populus, Sesbania, Jacaranda* and *Rubus* are also widespread and important invaders. In the Western Cape *Nerium oleander* is an important riparian invader (Bruwer, 1983). For riparian species dispersal is primarily unidirectional and downriver, especially during floods, although most are dispersed upriver as well by some means or other. Thus areal expansion should be lower than species which invade omnidirectionally across landscapes. This may be compensated for by the relatively long-range dispersal during floods and high flows. Although the evidence from the available studies is inconclusive, the limited anecdotal information does suggest that it is reasonable to assume that expansion and densification rates are more rapid than those of landscape invaders. All river systems will be invasion prone, with perennial river systems, especially in the high-rainfall areas, being susceptible to invasions by numerous species.

5.4 Synthesis

A key aim of this project was to provide information to address the following questions:

- What area of the country could be invaded if nothing were done to limit the spread of woody alien plant species?
- How rapidly would this area be invaded?

This chapter has attempted to provide some insights by collating and synthesising information on (a) what species invade, how they invade, what factors facilitate and limit such invasions, and (b) how rapidly different species are able to invade and increase in density. The available information is insufficient to estimate invasion risk using quantitative models of invasion and densification. Thus we can only highlight the major risk areas and the important species in terms of their invasive potential in relation to what we now know about the extent of invasions and the major invasive species (Chapter 3).

5.4.1 Riparian zones

The literature review and the mapping exercise have confirmed that riparian zones are high-risk areas as they are particularly vulnerable to invasions. Riparian zones are physically dynamic areas with changes in flows, especially floods, altering river beds and exposing bare soil for colonisation by weeds. They also are invasion prone because they are long and narrow and vulnerable to the impact of changes in land-use and cover in adjacent areas. They also have extensive ecotones, transition areas between water and land and riparian vegetation and adjacent vegetation which often are important for their high biodiversity. Ecotones are particularly sensitive to invasions by species such as *Rubus*, *Chromolaena* and *Lantana* which readily colonise these habitats. Plants growing in riparian zones have direct access to water and can use water at substantial rates (see Chapter 4), therefore it is very important to control and minimise invasions. Riparian zones are also critical environments for maintaining water quantity because the aquatic communities play a key role in cleaning the water of impurities and riparian plants maintain the stability of the banks (Davies *et al.*, 1993).

Many species invade riparian zones with those that are dispersed as seeds (e.g. *Acacia* species) and those that are dispersed in the form of vegetative parts such as roots and branches (e.g. *Populus, Salix*) being particularly important (Chapter 3). South Africa experiences pronounced cycles of wet and dry periods, with floods being common during wet cycles. This is a key invasion opportunity for species that are dispersed by water. Another important feature of riparian invaders is that dispersal downstream is rapid and effective, resulting in rapid expansions and the 'sudden' appearance of thickets in formerly pristine areas. This means (a) that the headwater catchments of river systems should preferably be cleared first; and (b) that areas with a high risk of new introductions into headwater catchments (e.g. large urban areas) are major source areas for future invasions. Many of the worst affected areas have warm or sub-tropical climates where plants grow very rapidly and will, therefore, also invade and increase in density very rapidly.

A number of other species specialize in invading forest and woodland rather than riparian zones, including *Melia azedarach, Rubus, Lantana, Caesalpinia* and *Acacia melanoxylon* (see Table 5.2, Biome No 4). Recruitment of these species is not directly related to floods and they are able to colonize the margins or even relatively undisturbed forest and woodland, especially the ecotones. This makes them very difficult to monitor and control as the invasions are subtle and difficult to predict.

Prosopis species constitute a special problem. They mainly invade flat alluvial flood plains rather than river banks *per se* (Harding & Bate, 1991). They also do not seem to be really successful in areas with high rainfall but spread rapidly during years with above average rainfall, and following floods. In moist situations they are able to form totally impenetrable thickets, so timeous control while stands are sparse is important.

The generally high degree of invasion of riparian habitats in Northern Province, Mpumalanga and KwaZulu-Natal is a source of concern. The information reviewed in this chapter and the opinion of experts (Table 5.1) suggest that invaded areas expand at about 10% (5-20%) per year. At that rate a 100 ha invasion will become 200 ha in less than ten years, with an ever-decreasing doubling time if no factors limit expansion. Rates of increase in density are of the same order, or higher, therefore transitions from sparse to dense stands could be very rapid.

5.4.2 Landscapes

Landscape invasions, other than by certain Cactaceae and herbaceous species, appear to be limited primarily to areas with at least 500 mm of rainfall, except where coastal fogs are common. *Prosopis* species require access to groundwater and so are not able to invade the upland areas in the arid zone. Landscape invasions in the form of extensive and dense invasions of natural vegetation which is in good condition, are generally only found in areas with fynbos and, to a lesser extent, dune thicket vegetation. The major vegetation types that are at risk are the temperate grasslands (pines, acacias, eucalypts) and the fynbos of the Cape mountains and the deep sands and limestones of the coastal lowlands (pines, hakeas, acacias). Both fires and veld degradation can facilitate invasions by these species so that correct veld management is going to be critical to successful control and to reducing maintenance costs in the long term.

In the arid areas the Cactaceae are an important group of invaders, with *Opuntia* being by far the most important although there is concern about *Cereus* species in the savanna biome. Invasions by these species are facilitated by veld degradation and areas with degraded vegetation are therefore particularly at risk, so sound veld management is, again, a critical element in successful control. The importance of *Prosopis* species on the national scale is clearly shown by its rank of the seventh most important species (Chapter 3). It is also very important because its ability to tap groundwater meant that it can have a significant impact on the groundwater resources on which many rural communities and farmers depend (see Chapter 4).

5.4.3 Additional risks

The emphasis in this review has generally neglected the short-lived herbaceous species because their water-use is believed to be little more than that of the natural vegetation they replace. While this may be a reasonable assumption, these species can have a significant impact on the productivity of the land (e.g. unpalatable grasses) and on biodiversity. Most of these species invade areas with good rainfall, but a number are widespread and locally abundant in the semi-arid and arid areas. A factor that has not been addressed in this chapter, but which is important, is the ability of some species, many of them among the top invaders, to persist and recolonise. Examples are the acacias where the long-lived seed banks and rapid maturation rates (Table 5.2) necessitate frequent follow-up, and the poplars where repeated felling and spraying with herbicides is required for effective control. This makes them very expensive to control so that it is important to identify them before they become dense stands. Finally, there is the ongoing risk of species that are currently only found in limited areas, suddenly becoming aggressive invaders. This is known to have happened with a number of invaders, notably leguminous species. Species such as *Leucaena* are known to be aggressive invaders elsewhere and should be controlled or, preferably, eradicated, before they become severe problems. *Mimosa pigra* is known to be highly invasive and every effort should be made to bring it under control while it has only invaded a relatively limited area.

Unfortunately, species well suited to growing in degraded environments and often, therefore, selected for land rehabilitation and agroforestry projects are also often invasive. There needs to be more co-ordination of the different organisations involved to ensure that well-meaning efforts do not result in significant control costs at later stages.

Table 5.1: Rates of expansion (spread) and increasing density (densification) estimated by experts.
(These rates assume that suitable habitat is available and no control measures are being taken. Values we believe to be extreme are included in parentheses. Density classes are: occ = occasional (<5%), scat = scattered (5-25%), med = medium (25-75%) and dense (>75%).)

Species	Expansion (%/year)	Transition between density class		Notes
		Class transition	Time period (years)	
Tree and shrub species				
Acacia cyclops		occ-scat	10	
		scat-med	20	
Acacia dealbata & A. decurrens	10	occ-scat	10	
		scat-med	10	
Acacia mearnsii	5-10; high rates downstream	occ-scat	(1)5	high rates possible following a fire
		scat-med	10-20	
Acacia melanoxylon	5	occ-scat	10-20	
Acacia saligna		scat-med	5	high rates possible following a fire
Eucalyptus spp	5-10	occ-scat	4-20	North West and Northern Provinces in moist areas
		occ-med	8	
		occ-dense	15	
		scat-med	20	
Hakea spp		occ-scat	5	
		scat-med	15	

Table 5.1 (cont.)

Species	Expansion (%/year)	Transition between density class		Notes
		Class transition	Time period (years)	
Jacaranda mimosifolia	10	occ-scat	20	
Leptospermum laevigatum		occ-scat	10	
Leucaena leucocephala	5-10	?	?	flood plains
Melia azedarach	10-20(75)	occ-scat	(2)10-20	ranked next fastest after *Lantana*
		occ-med	8-10	
		occ-dense	10-30	
		scat-med	5-10	
Morus alba	5-50(75)	occ-scat	(2)5-20	
		occ-med	8	
		occ-dense	10	
Nerium oleander	50	?	?	
Pinus patula	5-10(15-20)	occ-scat	4-20	most rapid in grassland at >1000m altitude
		occ-med	8	
		occ-dense	15	
		scat-med	20	
Pinus pinaster		scat-med	5	
Poplars	5-15	occ-scat	5-20	
		occ-dense	1	very high rate of densification possible if burnt
		scat-med	10	
Prosopis spp	(50)	occ-scat	5	capable of rapid spread in overutilized areas as it is dispersed by livestock
		occ-med	10	
		med-dense	15-20	
Psidium guajava	10	scat-med	10	
Sesbania punicea	20	occ-scat	5-10	

Table 5.1 (cont.)

Species	Expansion (%/year)	Transition between density class		Notes
		Class transition	Time period (years)	
Solanum mauritianum	10-20	occ-scat	2-7	
		scat-med	5	
		med-dense	10	
Semi-woody scramblers and thicket forming weeds				
Caesalpinia decapetala	20	scat-med	5-10	
Chromolaena odorata	10	occ-scat	2	ranked as next fastest spreading after aquatic species
		occ-med	5	
		occ-dense	10	
Lantana camara	10-20	occ-scat	3-10	ranked as having a medium rate of spread
		occ-med	8	
		occ-dense	15	
		scat-med	5	
		med-dense	5-10	
Rubus spp	20	occ-scat	2	
		occ-med	5	
		occ-dense	10	
		scat-med	5	
Semi-woody and herbaceous species				
Argemone spp		med-dense	1-2	
Arundo donax		occ-scat	2	
		occ-med	4	
		occ-dense	6	
Cardiospermum halicacabum		scat-dense	2-5	
Cortaderia spp		occ-scat	10	
Datura spp		scat-med	5	

Table 5.1 (cont.)

Species	**Expansion (%/year)**	**Transition between density class**		**Notes**
		Class transition	**Time period (years)**	
Ricinus communis	20	occ-scat	5-10	
Xanthium spp		med-dense	2-5	
Aquatic species				
Aquatic weeds		occ-scat	1	considered fastest spreaders
		occ-med	3	
		occ-dense	5	
Azolla filiculoides		occ-dense	1	in eutrophic conditions
Eichhornia crassipes	20	occ-scat	5-10	
Pistia stratiotes		med-dense	5	
Salvinia molesta		med-dense	5	
Cactaceae				
Cereus spp	5-10	occ-scat	3-15	
		occ-med	10	
		occ-dense	20	
Opuntia spp	(1)15-20	occ-scat	5-10	
		med-dense	5-10	

Table 5.2: Summary of information on prominent weed species in South Africa after Dean *et al.* (1986) & Henderson (1995). (National ranking is based on the estimated impact on water resources (Chapman *et al.*, 1996, 100 = worst invader, blank = not ranked). Biomes: 1 = Fynbos, 2 = Grassland, 3 = Savanna, 4 = Forest, 5 = Karoo and Desert, 6 = Riparian (in order of invasiveness of the species in the different biomes). Riparian: whether the species transforms riparian zones or landscapes or both. Dispersal mode: b = bird, m = mammals, wa = water, wi = wind; (in order of importance). Sprouter: x = non-sprouter, c = coppice, s = sucker. Generation time = how long it takes to produce seeds.)

Name	Common name	National ranking (scaled)	Biome invaded	Riparian / Landscape	Dispersal	Seed storage, Longevity	Sprouter	Generation time (years)
Acacia baileyana	Bailey's Wattle	17	1,2,3	r, l	wi, m	soil, long	x	
Acacia cyclops	Rooikrans	26	1,5	l	b, m	soil, medium	x	2
Acacia dealbata	Silver Wattle	43	6,1,2,3,4	r, l	wa, b	soil, long	c	5+
Acacia decurrens	Green Wattle	24	1,2,3,6	r, l	wa, b	soil, long	c	
Acacia longifolia	Long-Leaf Wattle	16	1,4	r, l	wa, b, m	soil, long	x	2
Acacia mearnsii	Black Wattle	100	6,1,2,3,4	r, l	wa, b, m	soil, long	c	5
Acacia melanoxylon	Blackwood	22	4,6,1	r, l	b, wa	soil, long	c	5
Acacia podalyriifolia	Pearl Acacia	5	1,2,3	l	wa, b	soil, long	x	
Acacia pycnantha	Golden Wattle	2	1	r, l	wa, b	soil, long	c	3
Acacia saligna	Port Jackson	20	1,4	l, r	wa, b, m	soil, long	c	2
Caesalpinia decapetala	Mauritius Thorn	18	3,6,4	r, l	wa, m	soil?	c	
Chromolaena odorata	Triffid Weed	6	4,6,3	l	wi	short	c, s	1
Eucalyptus species	Gums		2,3,1,4,5	r, l	wi	canopy	c	
Hakea drupacea	Sweet Hakea	1	1	l	wi	canopy	x	6
Hakea gibbosa	Rock Hakea	1	1	l	wi	canopy	x	2-3
Hakea sericea	Silky Hakea	2	1,4	l	wi	canopy, long	x	1-2
Jacaranda mimosifolia	Jacaranda	27	3,6,4	r	wi	short-lived	c	
Lantana camara	Lantana	32	4,6,3,5,1	r, l	b, m, wa	soil stored	c, s	1+
Leptospermum laevigatum	Australian Myrtle	2	1	l, r	wi	canopy	x	4-5
Melia azedarach	Syringa	77	6,4,5,2,3,1	r, l	b, wa	short-lived	c, s	
Mimosa pigra	Sensitive Plant		6,3,4	r	wa, m	soil, medium	x	1-2
Morus alba	White Mulberry	15	2,3	l	b	short-lived	c	

Table 5.2 (cont.)

Name	Common name	National ranking (scaled)	Biome invaded	Riparian / Landscape	Dispersal	Seed storage, Longevity	Sprouter	Generation time (years)
Nerium oleander	Oleander		5,6	r	wi, wa	soil	c	
Nicotiana glauca	Wild Tobacco		5,6,2,3	r	wi, wa	soil	c	1
Paraserianthes lophantha	Stinkbean	3	1,6,4	l	wa, b	soil, medium	x	1
Pinus elliottii	Slash Pine	3	2,1	l, r	wi	canopy	c	8
Pinus halepensis	Aleppo Pine	13	2,1	l	wi	canopy, medium	c,s	8
Pinus patula	Patula Pine	9	2	l	wi	canopy, medium	x	7
Pinus pinaster	Cluster Pine	9	1	l	wi	canopy, medium	x	5-10
Pinus pinea	Stone Pine	2	1	l	m	short-lived	x	15
Pinus radiata	Radiata Pine	8	1	l	wi	canopy, long	x	5-10
Populus canescens	Grey Poplar	48	6,2,1	r, l	wa	none	s	n/a
Prosopis spp	Mesquite	19	5,6,2,3	r, l	m, wa	soil, long	c	
Psidium guajava	Guava	12	4,6,3	r, l	b, m	soil, medium	c, s	1+
Pyracantha species	Firethorns		2,6	l	b	soil		
Rubus cuneifolius	Bramble		4,3,6,2,1	r, l	b, m	soil	c, s	1+
Salix babylonica	Weeping Willow	29	6,2	r, l	wa	none	s, d	n/a
Salix fragilis	Crack Willow	5	6,2	l	wa	none	s	n/a
Schinus molle	Pepper Tree		5,6,2,3	r, l	b	soil	c	2+
Schinus terebinthifolius	Brazilian Pepper Tree		4,6,3	l	b	short-lived	c	
Sesbania punicea	Sesbania	25	6,5,3,1	r, l	wa	soil, long	x	1
Solanum mauritianum	Bugweed	28	4,6	r, l	b, m	soil, long	c, s	2-4
Tamarix ramosissima	Pink Tamarisk		5,3(6)	r	wi, wa	soil		

6. COST IMPLICATIONS AND PRIORITIZING CATCHMENTS FOR THE CLEARING OF ALIEN INVADERS

6.1 Introduction

Prioritization is a subjective exercise. It is for this reason that we have chosen, in this report, to present the principles and issues which would be used in guiding decisions of this nature, together with the information which we perceive as being useful in making decisions. This forms the basis of a flexible tool-kit which should then be applied under the guidance of decision makers. The guiding principles are not, and should not, be fixed - but must be determined for each situation in consultation with all relevant parties. It is very important that the process underlying prioritization is transparent and easily understood.

The process of prioritization can thus be viewed as having three steps. Firstly, the guiding principles must be determined by all the relevant decision makers. Secondly, the rules for decision-making must be clearly spelt out within this framework. Then only can the analysis be performed using all relevant information.

In this chapter we offer a prospective set of issues of principle, which may critically influence decision making. We then discuss more practical issues for which data or information is available, and around which decision making rules can be built. We present these factors and suggest rules, together with a table of catchment and invasive related data for the decision maker.

Further to this we also offer, as an example, a scheme for prioritization at the level of tertiary catchment based on water yield, water demand, water use by invaders, and the presence/absence of a government water scheme. This scheme provides for a set of answers, or priorities, but - in line with our contention that it is the decision maker who must define the critical factors and set the rules for decision-making - this should be seen only as an example of how this information can be used to inform decisions and not as a prescription.

6.2 Principles Guiding Prioritization

The fundamental approach to prioritization may be guided by rational, factual information, but priorities are also influenced by factors beyond the decision maker's control, such as the political demands of government or, perhaps, of foreign donors. Typically such considerations include:

Political objectives:

The need to create jobs, the need to distribute benefit to particular regions or provinces, the need for high profile activity, and the need to be visibly 'delivering the goods'.

Funding objectives:

The need to meet the requirements of the donor agency and the need to maximize the benefits by using funds efficiently and effectively.

Financial/ Technical considerations:

The most effective way of keeping invaders in check. This could mean that all money should be spent on managing areas not yet invaded at all (prevention), or on clearing areas which are as yet only very lightly invaded but likely to see rapid expansion (also prevention), or on clearing only the headwater areas of river systems.

Maximizing short-term benefits (clearing of densely invaded areas) vs maximizing long-term benefits (clearing sparsely invaded areas). This is not an altogether simple situation. An Australian study (Auld & Coote, 1990) suggested that a balance of effort between dense and sparse areas proved to be optimal. The clearing of sparse stands costs least in terms of R/ha. Existing dense stands produce large numbers of seeds to infest new areas - which is of particular importance where species have good dispersal mechanisms. Teams also work very effectively in dense stands where progress is more obvious.

Logistical considerations:

Management practicalities. The principle of working in relatively lightly infested areas increases the logistical complexity of operations and requires a relatively high management to worker input ratio.

6.3 Factors for Prioritization

Factors which are important for effective prioritization were identified through a series of workshops and discussion groups. In practice the application of these functions is determined by the availability of suitable data.

Factors for which information is available. Possible rules for application are suggested:

- The importance of the catchment in terms of runoff
  - the greater the runoff per unit area, the more important the catchment and the higher the priority

- The extent of alien invasion (in terms of area and density)
  - prioritize the most severely invaded catchments
  - prioritize less invaded catchments
  - prioritize catchments where invasions are at low densities or of limited extent
  - prioritize areas of riparian invasion

- The species involved
  - prioritize 'explosive' species
  - prioritize recognised high water users

- The water consumption attributed to these invaders
  - the higher the water use the greater the priority

- The level of demand for water (current and future). How important is the catchment in terms of the volume of water delivered? Can this demand be met in other ways?
  - The greater the demand the higher the priority.

- Is the invaded area within the catchment of a water supply scheme?
  - Prioritize areas supplying a water scheme.
  - Lower priority given to areas without capacity to harvest or utilize runoff.

- What is the risk of this invasion getting worse, the potential extent, and the likely rate of this

happening? (How rapidly will invasions happen if clearing does not take place?).
- Prioritize areas of risk

- Importance of the area in terms of ecology and species diversity.
  - Prioritize high diversity areas and biodiversity 'hotspots'.
  - The use and resource productivity of the land (water and other resources such as grazing). Is this being reduced through invasion?
  - Prioritize high value, high production, high potential land.
  - Protected areas, whether they be state, local government or privately owned and managed.

- 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.

Factors for which no information is available at the scale of this study:

- Is community water supply threatened?
- Will the invasion have a negative impact on catchment stability (riparian zone stability, soil erosion)?
- How difficult will it be to eradicate or control invaders from the catchment? To be evaluated in terms of cost and time. Sub-issues include control methods and costs, accessibility, availability of implementing agents, infrastructure and workforce.
- What is the realizable potential of the land for use/production?
- Are communities dependent on invaders - particularly as a fuelwood resource?
- What will the benefits of clearing be in terms of local job creation, community upliftment and other socio-economic aspects?
- How sustainable/achievable is it?

6.4 A Scheme for Prioritization of Catchments

We use, in this example, a limited set of data inputs in the prioritizing of tertiary catchments for clearing operations. These are inputs for which data is readily available:

- Water yield of the catchment,
- Water demand by irrigation schemes, municipalities and other users in a tertiary catchment,
- Water use by invasive aliens, and
- Presence of water schemes in the catchment.

Water-use by the invasive alien plants was modelled using the approach outlined in Chapter 4. Information on the location of dams and water schemes (government, municipal and private), water yields and water demand data for tertiary catchments was obtained from the WR90 report (Midgley *et al*., 1994).

The cumulative inflow, demand and alien water-use was calculated for tertiary catchments with water-supply dams and schemes. This proved to be a fairly complex operation as many schemes are downstream of others, therefore the accumulated water yield, demand and alien water-use data for schemes excludes that for dams situated higher up in the same river system. The tertiary catchments were then ranked based on the relative need for water R_n which is cumulative demand for water (a) as a percentage of the cumulative water yield of the catchment (b), such that:

$$R_n = a / b \times 100\%$$

Next, the relative use of water by invasive aliens R_a was calculated from the cumulative water-use by invasive aliens (c), as a percentage of the cumulative yield from the catchment (b), such that:

$$R_a = c / b \times 100\%$$

Finally, the catchments were ranked by summing the relative need and the relative water use:

$$P_r = R_n + R_a$$

where the greater the value of P_r, the greater the priority for clearing operations. This simple approach offers a sensitivity ranking for tertiary catchments with water-supply schemes and provides an example of a guideline for prioritization.

Table 6.1: Example of the results of prioritizing tertiary catchments with dams or irrigation schemes based on the cumulative demand for water for irrigation and municipal use, and on the estimated cumulative water-use of alien plant invasions in that catchment expressed as a percentage of the cumulative virgin MAR entering the dam or scheme. (For more details see the text.)

Tertiary catchment	Dam or irrigation scheme	River system	Irrigation and municipal demand (a)	Water-use by aliens (b)	Total demand (a+b)
C91	Vaalharts Weir	Vaal	7.20	890.92	898.12
D34	Vanderkloof	Orange	0.45	672.47	672.93
X31	Da Gama	Sabie	84.67	51.84	136.51
W12	Goedertrouw	Mhlatuze	31.34	102.40	133.74
W53	Jericho	Ngwempisi	0.08	114.20	114.28
B41	Vlugkraal	Steelpoort	0.00	91.11	91.11
A91	Albasini	Luvuvhu	64.45	25.22	89.67
X22	Witklip	Crocodile	8.58	80.10	88.67
W44	Pongolapoort	Pongola	5.89	74.79	80.68
C24	Kleinplaas	Skoonspruit	1.64	77.52	79.16
L82	Kouga	Kouga	42.61	19.29	61.90
V20	Craigieburn	Mooi	1.18	58.80	59.98
A21	Roodekopjes	Crocodile	6.31	53.17	59.48
S60	Wriggleswade	Kubusi	49.15	3.66	52.81
B31	Rust Der Winter	Elands	27.37	23.60	50.97

Although this simple prioritization scheme has shortcomings, it does help to identify priorities once these are understood. For example, the high human demand for water at both Vaalharts Weir and Vanderkloof Dam is well in excess of the MAR, but in both cases this is a shortcoming of the method used to calculate the cumulative virgin MAR at the dam itself which excludes excess flow from dams higher up in the system: the Vaal and Bloemhof Dams above the Vaalharts Weir and the Gariep Dam above the Vanderkloof Dam. At the Gariep Dam the water-use by aliens is much less than one percent and the demand is about 22%. A high percentage of the MAR is used by invasive alien plants for a number of the dams or schemes. Some of the them are situated in arid areas where the water resources are very limited and consequently even a small reduction in the runoff from a catchment has a significant impact (e.g. Albasini, Rust der Winter). Others are situated in high rainfall areas (Da Gama, Witklip, Craigieburn, Kouga) and are clearly very heavily invaded. *High human demand for water is the driving* force behind the high ranking of several catchments in the arid Free State and Northern Province.

6.5 Calculating Costs of Control

Cost information was obtained largely from projects launched with the Working for Water Programme. At that stage the most detailed and reliable data was that from the Western Cape where people had substantial experience in alien plant control before the Working for Water Programme was launched. The data are based primarily on the operating costs of the projects although some managers did explicitly include the capital costs in their calculation of costs per hectare.

6.5.1 Background on costs

The quoted costs for alien plant control from various centres and clearing operations across South Africa vary very widely. This is to be expected given the differences in the nature of the problem, accessibility, labour costs, methods used, management style, and accounting methods. Despite these differences there are very clear patterns and a surprising uniformity in outcome once some of the key factors are identified and used to define sub-sets within the data. For example, established stands of big trees (such as wattle, pine and eucalypt) all cost in the order of R6 000/ha to clear if stands are dense, whilst a low biomass cover (such as *Rubus, Lantana, Solanum*) costs in the order of R1 200/ha.

Some of the key factors are:

- Different approaches make big differences to costs (e.g. kill standing vs clear felling).
- It costs up to 30% more to clear in riparian areas as material must be carried out to prevent if blocking the river channel.
- Difficult access and rugged terrain increase costs.
- The variations may also reflect different methods of accounting for overheads.

The cost data suggests the advantages of prioritizing control programmes to prevent the establishment and development of high biomass stands and to take first action against the fastest growing and spreading species. The other important message lies in the difference in cost when employing different methods of clearing (recognizing that managers may often not have a choice). The clearing of invaders through killing of trees standing, if the example of *Eucalyptus* is anything to go by, can reduce costs by almost 70%. *Acacia mearnsii* is also being dealt with in this way in KwaZulu-Natal. The implications for the ecology and with regard to long-term follow-up need to be closely monitored. It may be that the killing of standing trees is highly effective in open stands but becomes impractical above a certain threshold density. This supports the case for prioritizing the clearing of less densely invaded areas where far larger tracts can be cleared for the same amount of money or at a faster rate than would otherwise be possible, and for the clearing of species currently at low density but known for their rapid expansion and densification.

6.5.2 An approach to calculating the costs

6.5.2.1 *Calculating costs per hectare*

Data and estimates of the costs per hectare for different control treatments were obtained from managers working for the Working for Water Programme (see Appendix 9). As noted earlier, an analysis of this data set revealed that the costs of different operations and for different species varied widely. The data therefore were simplified by grouping the species and reducing the range of density classes to three classes (Table 6.2). The cost of burning operations has been excluded from the summarised data because burning is not a standard treatment throughout the country. In addition, the only available information on the cost of burning was for fynbos catchments and the cost of burning grassland, for example, may differ significantly. Long-term maintenance will form part of the general costs of any control programme but these costs have not been considered in this analysis.

Table 6.2: Summary of cost data used to calculate the cost of different treatments for each compartment.

Species group	Treatment	Costs by density class (R/ha)		
		Light (<25% cover)	Medium (25-75% cover)	Dense (>75% cover)
Acacia	Initial (clearing)	486	1 505	2 063
	1st follow-up	310	746	1 403
	2nd follow-up	169	428	694
Eucalyptus	Initial (clearing)	525	4 518	4 786

Table 6.2 (cont.)

Species group	**Treatment**	**Costs by density class (R/ha)**		
		Light (<25% cover)	**Medium (25-75% cover)**	**Dense (>75% cover)**
	1st follow-up	275	429	802
	2nd follow-up	145	323	441
Pinus & *Hakea*	Initial (clearing)	585	1 112	3 844
	1st follow-up	249	512	818
	2nd follow-up	200	300	400
Other tall trees	Initial (clearing)	413	1 801	2 938
	1st follow-up	276	1 206	1 968
	2nd follow-up	136	594	969
Tall shrubs and other species	Initial (clearing)	350	456	582
	1st follow-up	235	305	390
	2nd follow-up	116	150	192

The grouping of the different species is based on the similarity of control methods, and on their growth form: (a) *Acacia* species including *A. mearnsii, A. melanoxylon, A. dealbata, A. cyclops*; (b) *Eucalyptus* species; (c) *Pinus* species; (d) other tall trees (e.g. poplars, oaks); and (e) tall shrubs and other species. The cost for pines was also used for *Hakea* species because *Hakea* stands are difficult to work in, are time-consuming to clear and have high plant densities per unit area at a given percentage canopy cover (or density class) because of their small crown diameters. The treatments were simplified to: (a) initial treatment or clearing, (b) first follow-up, (c) second follow-up and (d) third follow-up. The cost of the third follow-up is calculated only for *Acacia* species and as half the cost of 2nd follow-up. The mean cost for each of the treatments was then calculated for each of these groups and the commonly used density classes (Table 6.2).

The data for the last two species groups (other tall trees, tall shrubs and other species in Table 6.2) were too sparse and variable to divide costs according to treatments. The data were therefore summarised as the total cost, as if all treatments were done simultaneously, and then sub-divided according to the following rules: initial = 0.5×total cost; 1st follow-up = 0.5×0.67×total cost; and 2nd follow-up = 0.5×0.33×total cost.

6.5.2.2 *Modelling cost*

The relationships between cost and densities are non-linear. An analysis of the effects of different transformations of the density and cost data showed that the best fit was given by a power relationship $y=ax^b$. The raw data were transformed and the models were fitted using a linear transformation of the power model:

$$Ln(y) = Ln(a) + b \times Ln(x)$$

where Ln = the natural logarithm, y = cost in R per ha, x = the percentage cover (density) and *a* and *b* are the constant and coefficient respectively. The models were fitted to the data using the regression fitting routines in the *Quattro-Pro* Spreadsheet (version 6.0). The parameter values given in Table 6.3 are for the log-transformed relationship (y' = Ln(y)). The outputs from the formulae (y' = Ln (costs)) need to be back transformed to get the cost in R per ha using an exponent function ($e^{y'}$) or EXP(y') in most computer packages.

Table 6.3: Formulae used to calculate cost per ha for each treatment for the different species groups.

Species group	Treatment	Constant (a)	Coefficient (b)	Coefficient of determination (r^2)
Acacia	Initial	4.2931	0.7567	0.99
	1st follow-up	3.8097	0.7488	0.98
	2nd follow-up	3.3092	0.7153	0.99
	3rd follow-up *			
Eucalyptus	Initial	3.2989	1.2151	0.93
	1st follow-up	4.2802	0.5064	0.89
	2nd follow-up	3.5316	0.5728	0.99
Pinus	Initial	4.0439	0.8715	0.83
	1st follow-up	3.9945	0.5939	0.99
	2nd follow-up	4.4133	0.3441	0.98
Other tall trees	Total	4.1549	1.0191	0.99
Tall shrubs and other species	Total	5.9084	0.2474	0.95

* 3rd Follow-up costs were calculated by halving the 2nd follow-up costs; they were calculated only for *Acacia* species.

Areas or sites (polygons) invaded by alien species typically have a mixture of species with each occurring at a different density. We needed, therefore, to find a way to calculate the cost which took this into account. The calculations also had to allow for the fact that a proportion of the cost per hectare for each species was involved in simply getting to the site and in the clearing process, regardless of the species. Thus the cost of clearing each species for a mixture of two or more species cannot simply be added to get a total cost per hectare. It is not a simple job to disaggregate the available cost data. The method which gave the most reasonable estimates was to calculate (a) the cost per hectare for each species (according to which group it fell into) and (b) the weighted mean cost per hectare where the cost per hectare for each species was weighted according to its condensed area - a measure of its relative density. The condensed area is the area occupied by a species if the cover is adjusted to 100%. For example, if the total area invaded by a species is 100 ha and its percentage cover is 50% then the condensed area is 50 ha. The estimated cost per hectare is thus weighted by both the cost of controlling the constituent species and by their relative densities. The weighted mean cost per hectare was then multiplied by the total invaded area (i.e. polygon area) to give the total cost for each species group within a polygon. The total cost for each invaded polygon in each compartment was then summed to give the total cost per compartment.

There is no direct way to estimate the cost for each species individually because they typically occur in mixtures as noted above. The best method of estimating how much of the total cost (calculated as described in the previous paragraph) is due to each species was found to be as follows. The cost for each species was calculated for each polygon and then summed for all the polygons in which that species occurred. In effect this gives the total "cost" as if each species always occurred on its own. The "cost" for each species was then summed to give a grand total "cost" for all the species. The "cost" for the individual species was then expressed as a proportion of the grand total "cost". The proportion of the grand total "cost" for each species was then multiplied by the total costs (calculated as described in the previous paragraph) to give an estimate of how much it costs to control each species. This will not give the actual cost for a species but is the best estimate we can get and takes into account the differences in control cost between species, the importance of the species and the density at which it occurs.

6.6 Costs to Clear South Africa

The models and approaches described above were used to estimate the costs of controlling invading plants for the provinces and the country as a whole. The data are based on some important assumptions, including that this is a once-off cost (i.e. all operations are completed in one year or less), that all species are cleared everywhere (no priorities are set), that there are no improvements in the efficiency of the clearing operations, and that biocontrol does not reduce control cost. On the basis of these assumptions the best estimate is that it would cost about R6.97 billion to control invading alien plants in 1997 rands. The mean cost per hectare for alien clearing on a national scale (based on the cost data given earlier) appears to be relatively low at about R 690; this is largely the result of the extensive, low-density invasions in much of the country. Although the once-off cost provides a basis for comparison with the potential benefits of biocontrol operations, it cannot be achieved in practice because it will take many years to complete a control programme of this magnitude, if we assume that -

- the programme will take about 20 years (to 2018) to complete,
- the total invaded area invaded by aliens (10.1 million ha) is expanding at about 5% per year with the net density remaining constant, and
- we use the 1997 cost data adjusted to R800 per hectare to allow for, for example, expenditure on the social requirements of the programme, including creches.

Table 6.4: Estimated costs of controlling invading alien plants in the different provinces, Lesotho and South Africa based on the following assumptions: a 20-year clearing and follow-up programme; a rate of expansion of the total invaded area of 5% per year with the mean density remaining constant; and a real discount rate of 8.0% for the annual cost used to calculate the total cost.

Province	Total area (ha)	Total invaded area (ha) [a]	Condensed invaded area (ha)	Total cost of control (millions of R) [b]	Mean cost per ha (R) [using a and b]
Eastern Cape	16 739 817	671 958	151 258	564.36	840
Free State	12 993 575	166 129	24 190	99.13	596
Gauteng	1 651 903	22 254	13 031	44.97	2 037
KwaZulu-Natal	9 459 590	922 012	250 862	597.48	648
Lesotho	3 056 978	2 457	502	1.29	524
Mpumalanga	7 957 056	1 277 814	185 149	372.81	292
Northern Cape	36 198 060	1 178 373	166 097	869.77	2 147
Northern Province	12 214 307	1 702 816	263 017	410.13	348
North West	11 601 008	405 160	56 232	232.07	136
Western Cape	12 931 413	3 727 392	626 100	2 250.56	604
RSA+Lesotho	124 803 708	10 076 365	1 736 438	5 442.57	540

The annual expenditure will be about R600 million and the total cost of the 20-year programme (in 1998 rands) will be about R10.1 billion. If the annual expenditure is discounted using a real rate of 8.0% (assuming inflation of 6.0% and an interest rate of 14.0%) the net present value of the 20-year programme would become R5.44 billion (Table 6.4). If the mean cost per hectare of the different control operations could be reduced by 10%, the annual expenditure for a 20-year programme would be R550 million and the total cost (NPV) would be R5.05 billion. If the annual expenditure was kept at R600 million the 10% reduction in cost per hectare means that the programme would be completed in 17 years at a total cost (NPV) of R5.02 billion. If the programme was delayed by 10 years the cost (in 1997 rands) of the 'once-off' operation would increase by 55% to R10.8 billion because the invaded area would increase to 15.6 million ha. If the rate of increase in the extent of alien invasions was raised to 10% per year the 'once-off' cost would increase to 23.8 million ha and the total cost would increase to R16.4 billion.

The Western Cape accounts for almost half of the total cost (Table 6.4). The next most expensive province is the Northern Cape with its extensive and often dense invasions of *Prosopis*. The most expensive province on a costs per unit area basis is Gauteng where the invading species are dominated by acacias, eucalypts and poplars, all of which are expensive to control and generally occur in dense stands.

The cost data provided above needs to be put into perspective. Invasions by alien plants also carry other costs which need to be taken into account:

- Invading alien plants have occupied large areas of formerly productive farmland;
- they are a major threat to the biodiversity of many of our natural vegetation types;
- they can disrupt the functioning of ecosystems and the services they provide;
- they are the major threat to many of the rare and endangered plant and animal species listed in the Red Data Books; and
- they have colonised river banks where they obstruct the flow of water and can be washed out during floods, increasing the extent of flooding and causing extensive damage to infrastructure such as bridges, and resulting in the loss of soil.

Clearing of alien invaders will reduce or cancel out these costs and also has other direct and indirect benefits. The water that is released is made available in perpetuity and can be gainfully redeployed. The Working for Water Programme has resulted in a wide range of social and economic benefits. For example, it provides meaningful and productive employment and training in practical and entrepreneurial

skills. The programme has also been instrumental in establishing properly equipped facilities for day-care for children and in training staff to run these facilities.

6.7 Potential Benefits of Biocontrol

Biocontrol, when successful, can be an extremely cost-effective way of controlling invasive alien plant species. The successful implementation of biocontrol for *Hakea sericea* (seed-eating insects), *Acacia longifolia* (seed production limiting insects) and *A. saligna* (fungal disease) has severely reduced their invasive potential. For *A. saligna*, in particular, the most effective control is simply to introduce the biocontrol fungus to a stand, with no further action apparently being needed (M. Morris, pers. comm., 1997). As the assessment of the benefits of biocontrol is purely illustrative the relative savings have been based on the 'one-year' expenditure of R6.97 billion to keep the calculations simple. If biocontrol is successful the cost savings on the 20-year programme will be of the same magnitude and could even be greater, depending on how they are phased in over time.

6.7.1 Assessing the potential for biocontrol

A list of the invading species identified in this study was compiled and submitted to Dr H. Zimmerman of the Plant Protection Research Institute. The species on this list were discussed and assessed by experts at the Institute. The potential for successful biocontrol was divided into two types: (a) agents which would limit or prevent seed production but would not kill the plant itself; and (b) agents which would attack and kill the plant itself. Type (a) biocontrol is required where the species is grown commercially or has other socially and/or economically beneficial uses. Examples are *Acacia mearnsii, Pinus radiata, Eucalyptus grandis* and *Psidium guajava*. Type (b) biocontrol would be used to aid in the eradication of species with little or no beneficial use, for example *Solanum mauritianum, Caesalpinia decapetala, Lantana camara* and *Acacia decurrens*. The potential for biocontrol of each type was scored using the following four criteria, each scored on a scale of 0-5:

1. **Conflict of interest**: No conflict of interest = 5 points, very high conflict of interest = 0 points - applies particularly to type (b) biocontrol above.

2. **Availability**: If host-specific biocontrol agents are available the score is 5. The taxonomic relationships between the invader and economic and native plants are crucial in this case. Another important factor is the ease of access to study and collect suitable biocontrol agents in the country of origin. For example, the chances of gaining entry to Iran or Algeria to collect biocontrol agents are presently not very good. The score for this criterion was multiplied by 1.5.

3. **Effectiveness**: The key factors are the expected effectiveness of biocontrol based on the known availability of insects and/or pathogens and an established history of biocontrol of related or similar invaders. The score was again multiplied by 1.5.

4. **Time factor**: If the biocontrol project is likely to take very long because of host specificity problems, problems with access to potential biocontrol agents, wide genetic variability (e.g. *Lantana*), closely related economic plants (and similar issues), the score was 0 or 1 point. The conflict factor has already been considered under the first criterion. The score was multiplied by 0.5.

A list of all the species considered in this exercise, and their scores, is given in Appendix 10 and a summary table with selected examples and their final scores are given in Table 6.5. The final scores were rescaled to make the maximum score equal to one with the other species having values between zero and one. For the scenarios in section 6.9 the biocontrol score for vegetative control was used except for species with a strong conflict rating (0 or 1) where the seed agent score was used (e.g. *Acacia mearnsii*). The impact on the cost of control was based on a proportion of the scaled score times the control cost. For species with no conflicts the proportion was 50% and for species with conflicts the proportion was 25% because seed attacking agents only limit spread and regeneration.

Table 6.5: Biocontrol potential for a selection of the most important weed species in South Africa for seed attacking and whole plant attacking (vegetative) agents. (The higher the score, the greater the potential. The conflict potential is scored from 1-5 where 0 = direct conflict and 5 = no conflict. Species with no score for seed-attacking agents do not produce seeds.)

Species	Final score (weighted)		Conflict potential	
	Seed	Vegetative	Seed	Vegetative
Acacia cyclops	20	10.5	5	2
A. dealbata	21.5	14	5	1
A. decurrens	21.5	15	5	2
A. mearnsii	19	11	5	0
A. melanoxylon	21.5	9.5	5	0
A. pycnantha	21.5	17	5	4
Arundo donax	0	8.5		3
Caesalpinia decapetala	21.5	17.5	5	4
Chromoleana odorata	22	20	5	3
Hakea sericea	18	15	5	5
Jacaranda mimosifolia	18.5	15	4	2
Lantana camara	20.5	16	5	5
Melia azedarach	17	13.5	5	2
Mimosa pigra	22	18	5	5
Morus alba	8.5	11.5	1	1
Nerium oleander	19	15.5	5	3
Pinus pinaster	17.5	16	4	3
Populus alba/canescens	0	10.5		3
Prosopis spp	19	15	4	2
Salix spp	0	15.5		5
Sesbania punicea	21.5	19	5	4
Solanum mauritianum	18.5	21	5	5

The effectiveness of existing biocontrol was also given a rating as follows: 1 = the present agents are providing some biocontrol but their impact is limited (e.g. *Cereus jamacaru*); 2 = a promising agent has been released but has not become widely established yet (e.g. *Azolla filiculoides*); 3 = there is a substantial degree of biocontrol already (e.g. *Acacia saligna).* For the scenarios the effectiveness ratings were converted to reductions of 10%, 20% and 75% respectively. Areas with all the species under effective biocontrol will not need clearing, therefore polygons which met this criterion were deleted to reduce the total area requiring control operations.

6.8 Species' Impacts on Water Resources

Two main factors influence the impacts of plant species on water resources: the growth form and physiology, and the habitats it colonises. The first case includes species such as the invader grasses and herbs whose water-use is limited by their small size as well as species such as the Cactaceae which by nature are conservative water users. Invasions by these species are unlikely to have a greater impact on surface runoff than the native vegetation. The second case includes species which have invaded habitats where they have little direct impact on the runoff in the rivers draining the catchments where they occur. Again this would include the Cactaceae which invade arid landscapes, and to a limited extent the rivers. Species such as *Acacia cyclops* and *Acacia saligna* also would be included in this group because they mainly invade the coastal lowlands of the Western Cape where they can reduce the amount of water recharging the local aquifer systems but probably have little direct impact on the river systems over much of the area they have invaded.

6.9 Scenarios

In this section we have tried to take some of these factors into account by examining what the impacts would be if we focussed our efforts on species most needing clearing. The data are summarised as both the decrease in the area that needs clearing and the reduction in the cost of controlling the current invasion problem (Table 6.6).

Table 6.6: Possible reductions in the 'instantaneous' cost of alien plant control operations through biocontrol (see section 6.8) and by leaving out areas invaded only by species classified as non-waterusers (see section 6.9).

Option	Cost of control (R billions)	Cost saving (%)	Area needing clearing (ha)
1. Baseline	6.974	0.0	10 076 365
2. Leave non-water users	5.042	27.7	8 233 715
3. Existing biocontrol	5.593	19.8	10 076 365
4. Potential biocontrol	5.073	27.3	10 076 365
5. 3 + 4	4.084	41.4	10 076 365
6. 3 + 4 + 2	2.889	58.6	8 233 715

The reductions in cost for scenarios including biocontrol would come mainly in the form of lower follow-up costs once the initial invasion is cleared. As the combined costs of all the follow-up operations often exceeds the cost of the initial clearing, these reductions (especially scenarios 3-5) may be reasonable. On the other hand this approach may overestimate the reductions because most species occur in mixtures with others that would have to be cleared anyway.

There is no doubt that the implications of these and other scenarios need to be modelled and analysed in substantially greater detail so that we can gain a deeper appreciation of the effects of different factors and choices. A more balanced picture that takes in all the costs and benefits is also needed to put the cost data into their proper context. Analyses like these will provide the sound basis that is needed to develop an effective and efficient strategy for tackling the enormous challenges alien invaders place before the people of South Africa.

7. SUMMARY

7.1 Introduction

Decision-makers recognised the need for a broad picture of the extent, distribution dynamics and impact of alien invaders to help to prioritize the expenditure of funds for control operations. This project was aimed at meeting that need by summarising the situation from a national perspective and the outcome is summarized in this chapter. We also address issues relating to the methodology used in this project in order to identify areas which need attention. We recognise, however, that there is far more useful information in the data set (mapped and otherwise) than we have been able to evaluate and present in this report and trust that managers and decision makers will make further use of the data now available.

7.2 The Approach and Methodology

During the course of the project we have benefited from the support of a wide range of organisations and individuals and also discovered a number of ways in which the approach and methodology could be improved.

7.2.1 Participation

At least 140 persons were consulted in the establishment of a national database of expert knowledge on the distribution and extent of alien invaders in South Africa. Several existing GIS databases for specific areas were added to this pool of knowledge. Reliance on the use of expert knowledge has allowed for the very rapid capture of a vast array of data. This has, by its nature, been a very participatory approach, and has demanded inputs and goodwill from a wide range of participants. The information has gaps and flaws, and is not a definitive snapshot of the current (1996/97) situation, but rather the start of an ongoing process in the establishment and maintenance of a national aliens database.

Not all South African expertise has yet been used to maximum effect. More can still be made of the work of Lesley Henderson (NBI), who is co-ordinator of the South African Plant Invaders Atlas (SAPIA). The SAPIA data could be re-interpreted and put into a GIS. This would involve a significant amount of work but it would enhance the value of this data set significantly. Data for the distribution of key species was obtained from the SAPIA set for comparison with the data collected for this study (see Chapter 3). This comparison did not identify any major gaps in our species distribution data (for the top 30 species) with data showing consistently similar distributions across the full range of densities and also where species were not recorded in areas mapped during this study.

7.2.2 Mapping approach

Data has been successfully gathered for all the provinces of South Africa, and partially for eastern Lesotho, with the exception of data for one 1:250 000 map in the far Northern Cape (Nossob). In total more than 7 000 polygons have been mapped. The mapping approach was generally successful once people had grasped the basic principles and the scale at which we were working. We have identified refinements and these should be incorporated in future mapping work of this kind whatever the scale.

Except for the Western Cape and the Rand Water Catchments (Vaal System above Vaal Barrage) landscape invasions have not been thoroughly mapped and there still are many gaps. The data in this report does show the major problem areas, except possibly for KwaZulu-Natal, but at a more detailed level there are deficiencies which need to be addressed before we can have a really complete picture of the situation.

There is always a high level of uncertainty in data gathered in this way. It is possible that where expert informants have drawn in polygons of invasion that this has led to an overestimation of alien invaders. We believe however that there has also been an important underestimation through the failure to map many areas, either as too small, or simply by omission. Most notable here is the invasion of many minor rivers and tributaries, especially in KwaZulu-Natal.

7.2.3 Water-use estimates

The water-use estimates have only been calculated for a subset of the invading species that have been mapped. Herbaceous species, the Cactaceae (except *Opuntia*) and aquatic herbs have not been included because they probably use little more than the indigenous vegetation they replace and possibly even less. A number of other species have been excluded because they occupy very small areas. The species included in the water-use model are divided into three sets (following Le Maitre *et al.* (1996): high water users such as the eucalypts, pines, Prosopis, poplars and the tall acacias (e.g. *A. mearnsii, A. dealbata*); medium water users including willows, jacaranda, syringa and the smaller acacia trees (e.g. *A. cyclops, A. saligna*); and low water-users which includes shrubs such as hakea and woody climbers such as *Rubus, Caesalpinia* and *Lantana* (Table 4.1). The assumptions involved in assigning species to these groups need to be tested, at least for the important invaders, as this could have a significant impact on the estimated streamflow reductions.

The calculated mean reduction in runoff from this model is high at 1 900 m³ per year per hectare of invaded land, compared with about 930 m³ per hectare per year for plantations (Le Maitre *et al.*, 1997; Scott *et al.*, 1998). This is, in part, because we used a single age class for invaders in contrast to plantations which are felled regularly, and also because most invaders are riparian and therefore have free access to water. The rotation lengths of plantations range from 5-30 years and the mean age (assuming an even age distribution) of plantations would be about 10 years compared with the 20 years used for most of the country in this study. Data provided in a report (Umgeni Water, 1997) and based on the ACRU model, gives an incremental water-use of about 5 600 m³ per hectare per year (on a condensed area basis) for riparian vegetation in the Midmar Dam area, a value which is much higher than our estimates of 3 680 m³ per ha for the same catchments.

If tall invading trees - notably pines, eucalypts and wattles - use as much water as commercial plantations, and given that tall trees comprise a significant proportion (42%) of the condensed invaded area, then the impact on water resource results in significant economic costs. Invading species rarely offer much in the way of economic returns although there are sometimes social benefits such as fuel and construction wood.

The actual water-use, as determined for each tertiary catchment, exceeds the estimated mean annual runoff (MAR) for a few catchments. This tends to be in situations where the rainfall is low, and where MAR naturally tends to be very low or almost negligible and highly seasonal or ephemeral. It is possible that in these situations even the adjusted biomass model (which is based on data from high rainfall catchments, see chapter 4) may be unreasonable, and yet with many of these trees growing in riparian zones, water-use may be even higher than estimated, especially in hot, dry climates with a high evaporative demand. It is however true that catchments where invaders are estimated to use >100% of MAR usually still deliver some water, although this may only be in the case of extreme events. Downstream invaders may also be using the equivalent of the contribution of a particular tertiary catchment, while the flow in the major rivers in that catchment is sustained by water from further upstream. New work by Le Maitre and Scott (1997) points to the exceptional contribution of upstream catchments to the total runoff in large catchments.

7.3 Results

7.3.1 Extent

Alien plants have invaded a total of 10.1 million hectares to some degree. If the total area is 'condensed' to its equivalent at a cover density of 100% then the total is about 1.7 million hectares of dense invasions (Table 7.1). To put this into perspective, the total 'condensed' area of alien plants is about 1.2 times the area under commercial plantations (DWAF, 1997) and much the same size as Gauteng Province. The largest area is in the Western Cape which has almost 37% of the total invaded area in South Africa, followed by Northern Province with 17% and Mpumalanga with 13%. These figures hide some important differences between the provinces. In all the provinces except the Western Cape, invasions of the riparian zones (the river beds and banks) are far more important than landscape invasions in terms of the area invaded, the density of the invasions, and the impacts on water resources. KwaZulu-Natal is also a province with a very high level of invasion but further mapping will be needed to gain an accurate picture of the situation.

Table 7.1: Summary by province of the areas invaded by alien plants, impacts on mean annual runoff and costs of clearing and control.
(The condensed area is the total area adjusted to bring the cover to the equivalent of 100%. The costs of control are based on a 20 year clearing programme, an annual budget of R600 million, a rate of expansion of the total invaded area of 5% per year, and have been discounted at 8.0% per year.)

Province	Area (ha)	Invaded area (ha)		Mean Annual Runoff (millions of m^3)	Incremental water-use		Estimated costs of clearing (millions of Rands)
		Total	Condensed		(millions of m^3)	(%)	
Eastern Cape	16 739 817	671 958	151 258	9 998.76	558.19	5.58	564.36
Free State	12 993 575	166 129	24 190	3 546.10	86.19	2.43	99.13
Gauteng	1 651 903	22 254	13 031	551.97	53.93	9.77	44.97
KwaZulu-Natal	9 459 590	922 012	250 862	12 517.61	575.74	4.60	597.48
Lesotho	3 056 978	2 457	502	4 647.19	1.88	0.04	1.29
Mpumalanga	7 957 056	1 277 814	185 149	6 303.01	446.29	7.08	372.81
Northern Cape	36 198 060	1 178 373	166 097	910.94	150.86	16.56	869.77
Northern Province	12 214 307	1 702 816	263 017	3 383.63	297.70	8.80	410.13
North West	11 601 008	405 160	56 232	1 081.57	95.40	8.82	232.07
Western Cape	12 931 413	3 727 392	626 100	6 555.18	1 036.82	15.82	2 250.56
RSA+Lesotho	124 803 708	10 076 365	1 736 438	49 495.96	3 303.00	6.67	5 442.57

7.3.2 Most important invading species

The most important invaders are undoubtedly the Australian *Acacia* species, which have invaded some 4.6 million hectares to some degree and covered the equivalent of 720 000 hectares in dense stands. The acacias fall into two distinct groups: small to medium trees (mainly *Acacia cyclops*, *A. saligna*) which have invaded coastal areas in the Western and Eastern Cape, and tall trees (mainly *A. mearnsii, A. dealbata*) which readily invade riparian situations and have also become landscape invaders in temperate grasslands in, for example, KwaZulu-Natal. All the species except *Acacia cyclops* are difficult to control because of their long-lived seed banks. They are also bird and water dispersed and can, therefore, expand their ranges very rapidly. *Prosopis* species have invaded a condensed area of about 170 000 ha and the pines have a condensed invaded area of about 77 000 ha. The next most important group is the eucalypts which cover a condensed area of about 63 000 ha. They are particularly well known for their ability to use large volumes of water (Dye, 1996). Eucalypts are very aggressive invaders in the moist grassland areas of Mpumalanga and Northern Province, where they invade riparian zones, and in the sub-tropical coastal belt of KwaZulu-Natal. They are also hard to control because most species sprout vigorously. Pines are relatively easy to control as they do not sprout or have long-lived seeds, but the long range dispersal (several kilometres) of their seeds by wind means that continuous monitoring of uninvaded areas is needed for effective management. *Prosopis* species are the most aggressive water using invaders of the semi-arid and arid interior of South Africa.

7.3.3 Impacts on water

Estimates of water-use by alien invaders have been calculated for each Province (Table 7.1), each tertiary catchment and for the entire country. Water used by invading aliens results in an estimated 6.67% reduction in the mean annual runoff of the entire country. The condensed invaded area is greater than the 1.44 million hectares currently under commercial plantations and the estimated water-use of 6.67% of the MAR is about 1.7 times that due to plantations (3.16% (Scott *et al.*, 1988)) or about 75% of the mean annual runoff of the Vaal River. The impacts of the water-use of alien invaders may be less than that of plantations because the water used by plantations is in the high-yielding head water catchments while the aliens often occur in low-yielding catchments lower down. Thus the economic significance may be less than the water-use figures would indicate. It is also possible that some of this impact has already been accounted for in the figures for mean annual runoff provided by the Water Resources 90 study (Midgley *et al.*, 1994) as this analysis did not explicitly allow for water-use by invading species. In some cases the WR90 study may have included them as indigenous riparian vegetation and this issue needs to be investigated.

The Northern Cape has the greatest estimated percentage water-use (Table 7.1), primarily because of the low MAR in this largely semi-arid to arid province. This is particularly important because the province has very limited water resources and a growing population. The Western Cape is the next most badly affected in terms of water-use from the total resource. The remaining badly affected provinces (>5% MAR) are better-off as they do have more water available, but the reductions are still very large. As noted above, KwaZulu-Natal's invasions have not been adequately mapped and we would expect the true impacts on water resources to be more in line with those of Mpumalanga given that they have similar climates, natural vegetation, suites of invading species and patterns of land-use.

7.3.4 Costs of clearing and control

Costs of control have been estimated using data provided by managers in the Working for Water Programme and were converted to a form that could be used to estimate the costs of clearing. The best estimate at present is that if we were able to clear all the aliens and complete all the follow-up operations so rapidly that there was effectively no expansion (e.g. within a year), then the total cost would be about 6.97 billion Rand. This is obviously only a theoretical estimate but it does give us some basis for comparisons. The costs vary very widely between provinces, with the Western Cape accounting for about 40% of the total cost followed by the Northern Cape (16%), KwaZulu-Natal (11%) and the Eastern Cape (10%). If we allow for existing biocontrol this cost is reduced to about 5.6 billion Rand and if non-water users (e.g. herbs, *Cactaceae)* were left uncleared the cost would be about 5.0 billion Rand.

In reality it is more likely to take a considerable period of time to achieve successful control, and a reasonable timespan would be 20 years. If an alien plant expansion rate of 5% per year is assumed then a 20-year programme would require an annual investment of about R600 million with a total cost (NPV) of R5.44 billion using a discount rate of 8.0% per year. If the programme were to be delayed by 10 years then the 'once-off' costs of the control programme would increase by 55% because of the increase in the extent of the alien invasions. These costs must be put into perspective though. The costs of clearing and control in a given area will be high during the first 3-5 years and all that will be needed after that is long-term maintenance at a cost of about R25 per hectare per year. The water that will be released will be released in perpetuity for maintaining the ecological and human reserve as well as for direct economic benefits. When expressed on the basis of the water that would be saved during the 20-year control programme alone, the total costs would be 45 cents per m^3 . There are also many other benefits such as the restoration of land for other uses, restoration of natural ecosystem functions and the conservation of biodiversity and the upliftment of communities both directly and indirectly through the employment generated through clearing programmes. These benefits have not yet been quantified but they could be substantial.

7.3.5 Risks of invasion

A review of the literature, especially the available data for South Africa, and the results of this study have confirmed that riparian zones are the areas which are most susceptible to invasion and have becomes most densely invaded. In most of the drier areas the riparian zones and alluvial plains are the only areas which are invaded by water-using species. The current degree of invasion of riparian zones, notably in Northern Province, Mpumalanga and the Western Cape is such that the invaded areas are likely to increase by at least 50% in the next 10 years and double in the next 20 years. The rates of invasion and densification will be slower in landscape situations but the risks remain high, especially in the Western Cape where the fynbos vegetation is particularly susceptible to invasion.

7.3.6 Prioritizing Catchments

Some approaches and guidelines for prioritization are given in Chapter 6. The initial plan for the project included some prioritization modelling using various criteria. We concluded that, in the end, it is best that the criteria and weighting of the factors used in determining priorities are decided by managers within the Working for Water Programme. We have identified the particularly heavily invaded and affected catchments (see Chapters 3 and 4) and those factors should also be taken into consideration.
Invasions by alien plants have other impacts (costs) which need to considered: the loss of productive farmland; threats to the biodiversity of plant and animal communities and rare and endangered plant and animal species; the disruption of the functioning of ecosystems; and destabilising of river banks which can cause extensive damage to infrastructure such as bridges and farmlands. Clearing of alien invaders will annul these costs and also has other direct and indirect benefits. The Working for Water Programme has resulted in a wide range of social and economic benefits including employment, training, and the establishment of infrastructure such as creches.

7.4 Knowledge gaps

In this section we have highlighted some of the key knowledge gaps identified in the course of this study. These should be addressed in any future work.

- Our information on rates of spread and increases in density, and on how these relate to the species biology and the environment being invaded, is very limited and restricted to a couple of situations.

- Little is known about what factors limit invasions (e.g. bioclimate, land-cover and land-use) and how important these are in different regions of the country

- A more sophisticated basis for modelling water-use which can be used at this scale and across a range of environments (e.g. the 'oasis' situation where there are invaded riparian environments in dry regions so that evaporative demand can be almost unlimited) is needed. This includes a better understanding of: vegetation structure (vertical and horizontal) and its influence on evaporative demand; accessibility of groundwater in and outside riparian zones; getting comparative data on alien versus indigenous water-use where water-use may, in fact be little more than the indigenous vegetation they replace, e.g. *Rubus, Chromolaena, Lantana*.

- Data on control costs. Costs are highly variable and we need a much better understanding of the different factors involved. We also need to know the timing and costs of different operations in order to model future cost scenarios over the lifetime of control programmes.

8. THE WAY FORWARD

8.1 Introduction

The brief for this project included developing scenarios to determine how to take the invasives control programme forward, while also developing a vision for the future with regard to the clearing of alien invading plants. We have not modelled specific scenarios, but the information that has been gathered does provide a foundation for suggesting ways to tackle the problem, and for making specific recommendations. The new Water Act, which is currently going through the parliamentary process, envisages the establishment of Catchment Management Agencies. The responsibilities of these agencies will include ensuring that water resources are efficiently used and this, in turn, will involve clearing and controlling invading alien plants. The structure and functions of these agencies still need to be worked out by the parties involved. We cannot go into detail because this chapter focusses on setting out the vision and broad approach that need to be taken, much of which can be adopted and adapted by the agencies as they are established.

8.2 The Problem

The scale and extent of the problem of alien invasions in South Africa is vast. About 10.1 million hectares of land are invaded to some degree, with many areas likely to experience rapid densification, and a prognosis for very rapid expansions in susceptible landscapes and habitats. If considered as dense stands, alien invasions occupy the equivalent of 1.7 million hectares of the country, an area greater than the total area occupied by commercial and non-commercial plantations (about 1.5 million ha). Alien plants also use more water than the entire forest industry. Forestry is carefully managed and strictly regulated to minimise the impact which it has on water resources, yet aliens have been allow to expand almost unimpeded, and most significantly in water courses. Very little income is generated from these invaders and most of this utilization of water can be considered to be entirely unproductive.

More than 140 species have been mapped in this exercise as recognizably invasive at the scale of 1:250 000. There are more species recognized as problems, and other potential problem plants are still being imported and propagated. The cost to the country in terms of water is estimated at 3 300 million m^3 or about 75% of the mean annual runoff of the Vaal River. There are many additional costs such as those to biodiversity, to land for production, recreation potential, and water quality. We are likely to see a doubling of the problem over the next 10-20 years unless radical control measures are taken.

To control alien invaders at the current level of infestation, and using conventional means would cost about R600 million per year over 20 years, with the total cost being about R5.44 billion based on an 8% real discount rate. Although control rather than eradication is the objective and not all areas will need to be cleared, there will always be follow-up costs which may be as high as R30 million per year.

The enormity of the challenge of achieving control does not mean that we should abandon conventional approaches, but that we should strive for a sound set of principles in our approach, and should always seek to maximize efficiencies and find innovative ways and means. A radical problem requires both radical and innovative solutions. In the remainder of this chapter we present a vision for alien plant management and control, some prerequisites, and discuss an overall strategy. Recommendations for future work and research are discussed in the following chapter (Chapter 9).

8.3 A Vision

- That all South Africans are fully aware of the problem of alien invaders, of the impact and their implications, and of every individual's ability to influence the outcome.

- That all the people of South Africa are involved in some way in programmes to manage the problem of alien invaders.

- That appropriate information should be readily available to assist at the levels of both decision making and implementation.

- That alien invader control operations become a part of the integrated management of catchments by the relevant authorities.

- That control of invaders is achieved, and that this is effective and economic.

8.4 Basic Prerequisites

- All people must accept their responsibilities and fully support the thrust to bring alien invaders under control as their support is the key to success. Political support is also essential in achieving this nationally. The benefits of the programme must be recognized, and the potential costs of failure to act must be understood.

- Catchment boundaries typically do not coincide with administrative boundaries, nor do administrative boundaries often respect catchments. This problem will be resolved during the formation and establishment of the Catchment Management Agencies which will have the necessary jurisdiction to bridge administrative divisions.

- An integrated approach to control is indispensable. This is not a new idea. It has a long history but, unfortunately, many of the basics are often neglected due to lack of knowledge or understanding. The aim of integrated control is to achieve effective control by using the best combination of treatments in the correct sequence and in the appropriate places. The basic concepts include:

  - Using every control method that is available, including biocontrol, where appropriate for the particular species, the area that is invaded and the available resources (manpower, skills, equipment, etc.).
  - Recognising that in most cases control is achievable but eradication is not.
  - The problem requires a long-term approach and long-term commitment. It is generally better not to begin unless there are sufficient resources to complete the control operations, including all the follow-up work.
  - Organisations undertaking control operations must provide for training of staff in integrated control.
  - The clearing of lightly infested areas, where invaders are spreading fastest, is usually far more effective than the clearing of areas already fully invaded.
  - Begin with the source areas first wherever possible - therefore clearing of riparian zones should begin in the headwaters of the rivers.
  - Follow-up always has higher priority than new clearing operations.

The Plant Protection Research Institute has amassed a substantial body of knowledge and expertise in alien plant control and should be consulted wherever there is doubt.

- Information with regard to control methodologies must be readily available; there must be easy access to advice and assistance.

8.5 Strategies

An effective strategy for alien plant control will have to take these prerequisites into account and must therefore include the following elements:

- An effective co-ordinating system and a network to market the programme, and a support system to provide relevant information to researchers, planning and implementing agencies.

- Community involvement, particularly that everyone should accept responsibility for the problem of alien invasions.

- An approach which can achieve 80% of the objective whilst using 20% of the resources. Examples of this approach are:

    - The preventative clearing of sparsely invaded areas.
    - Recognising that biocontrol will be a key factor in dealing with invasions of the magnitude described in this report, also that biocontrol usually requires time to become effective. Biocontrol rarely results in eradication of the species but, when successful it can significantly reduce control and follow-up costs.
    - Recognizing that the maintenance of areas in an uninvaded state is as important as the clearing of invaded areas.

- Integrated control operations to ensure that there is close liaison between projects and that effective alien plant control procedures are applied within projects.

8.5.1 Co-ordination and networking

The Working for Water Programme has managed to achieve a high profile in the news and many people are now aware of the programme and its aims. The next step must be to gain willing support. This can be facilitated by encouraging the belief that everyone can make a difference and by providing tools, technologies and approaches which will give substance to this belief. A co-ordinating and networking effort will be needed to ensure that an operation of this magnitude is conducted efficiently and effectively. This national overview of the extent of the problem and its impact could be used as a central coordinating and information base and must incorporate the current South African Plant Invaders Atlas (SAPIA) database and invader mapping initiatives being co-ordinated by the Plant Protection Research Institute (Leslie Henderson, Pretoria).

8.5.2 Community involvement

We believe that South Africa must generate a culture of acceptance of responsibility for the problem of alien invaders. This would include the following elements:

- Recognition of the size and scope, costs and potential costs of the problem and that this can only be achieved through a sense of common purpose.
- Recognition of the fact that invasions can be controlled, particularly if tackled early, and that the power to achieve this often lies in the hands of the landholder or custodian.
- Recognition of the responsibility of the landholder or custodian towards managing their land, and that the problem of alien invaders cannot be left solely to the State.
- Education and awareness raising are critical in growing an understanding of the problem which alien invaders present, knowledge of what needs to be done, and in building the necessary culture of joint responsibility.

Education will play a key role in raising awareness from schools level through to adults. The implementation of this programme needs to involve landowners and communities to a much greater extent than has already been achieved by the Working for Water Programme.

8.5.3 An information system

Knowledge and understanding of the extent of the problem, of the management initiatives in place, and of progress achieved, are essential to success in control. It is our vision that this exercise in understanding the relationship between alien invaders and the environment should become the basis of an up-to-date information and management system. Modern information technology can make this available to all managers and decision makers, providing both information for decisions and a continuous evaluation of the situation in South Africa. Ready access to relevant and up-to-date information will play a key part in raising and maintaining community awareness.

8.5.4 Integrated control

With a secure budget over the next 20 years, an initiative like the Working for Water Programme may solve the problem. Two of the key elements in any successful control programme will be (i) to raise the level of expertise of project managers in implementing agencies in the field and (ii) fully integrated biocontrol. Key issues which have arisen during this project include:

- how to manage and convert the current information into an **active database** which will be easy to update;
- the need for more research into biocontrol, and for more information and publicity about biocontrol;
- the need for greater understanding of what the best control methods are and how they can be combined most effectively; and
- control over the importation of new species and also the seeds of species which have already shown themselves to be (potential) problems.

Much of this need can be met by ensuring that people are fully aware of existing methodologies, and also by making effective use of modern information technology such as the World Wide Web (see Appendix 11).

An increasing emphasis on, and investment in, biocontrol is the only means of securing long-term success. This must be accompanied by stiff regulations to control the importation and propagation of new species which may have invasive potential, more effective customs procedures to prevent illicit imports, and by a rapid response mechanism when a new problem species is identified. The established position of certain problem species in industry and elsewhere, and the threat which bio-control may pose, must be evaluated in terms of the cost incurred elsewhere as a consequence of invasion by that species.

8.6 Integrating Current Reality with the Vision

The overall aim of this project is to provide the information needed by the Working for Water Programme to set priorities and establish an effective and efficient clearing programme for alien invading plants. Ideally, the Working for Water Programme should have been initiated with good information already in hand, then used this information to identify the highest priority catchments, developed management plans for those catchments, and implemented control operations. The plans should also have formed part of an Integrated Catchment Management (ICM) plan aimed at managing all the water resources in a catchment to the maximum benefit of all the water users. Alien invader control operations would then have become one of the activities coordinated by the Catchment Management Agencies as proposed in the Water Act.

In practice, the urgent need both for the RDP to generate employment and for alien invader plant control to begin as soon as possible resulted in many Working for Water projects being established first, and in the overall priorities and catchment management plans following later. This has led to some problems, notably a lack of proper management, a low priority being given to indispensable follow-up operations, and the lack of a broader, long-term perspective to focus and prioritise activities. These problems have been aggravated by a shortage of skilled managers in the project agencies within the Working for Water Programme. Some of these organisations have continued retrenching staff or have not expanded their staff to support the programme despite significant increases in their budgets. Although the skills of those employed in the Working for Water programme are being improved, many of these problems cannot be resolved in the short term. Model management plans have been prepared for some catchments (Riviersonderend [Western Cape], Keurbooms [W Cape], Sabie-Sand [Mpumalanga] and Upper Wilge [Mpumalanga]). These plans incorporate the basic concepts and principles (see section 8.4) and the priorities for control operations within those particular catchments. They will provide the framework for management plans for the other projects (there are currently 38) but will take time to produce and implement.

If the strategy proposed here is to succeed, the Working for Water programme - and all the implementing agencies engaged in the clearing and management of alien invaders - will have to find effective solutions to a number of significant challenges:

- Addressing the critical shortage of managerial staff, especially middle-management which is the key to ensuring that projects are properly managed, funds spent wisely, control operations followed up and that the necessary monitoring (hydrological, ecological, economic, social) is done.

- Ensuring that management plans are produced for each catchment in which projects are situated, that these plans are implemented and that progress is audited.

- Ensuring the participation of all water users in the development and implementation of these catchment management plans, and in this way pioneering the implementation of ICM by the proposed Catchment Management Agencies. In this way the different user groups can also be educated about why invader control operations should be given a high priority both now and in the future.

- Establishing an ongoing research programme to:
  - gain a detailed understanding of water-use by different invader plants in different situations, and of the processes, dynamics and rates of invasion (expansion and densification) of different species in different habitats, especially riparian zones;
  - quantify the various direct and indirect benefits of the programme;
  - determine the best methods and combinations of methods for controlling invader plants, including biocontrol (see section 9.5.3); and
  - gain insight into the need for rehabilitation of invaded areas, and of the procedures that need to be followed to ensure successful rehabilitation of these areas, especially in riparian ecosystems.

- Establishing an effective communication and education service to inform decision makers and the wider public about the need, and the urgency to ensure that invading plants are controlled and that further introductions are minimised.

These challenges are formidable but we believe they can be met, especially with the increasing recognition and support the programme is receiving. The ICM approach proposed in the draft Water Act provides both the broader perspective and the framework needed to help the Working for Water Programme to succeed in achieving its aims.

9. RECOMMENDATIONS

Our recommendations fall into two main groups:

- recommendations for action:
  - establish an effective and readily accessible information system on alien plant invasions, their impact and what can be done to control them;
  - promoting and facilitating active public participation in alien plant control; and
  - find ways to enhance the database by adding new and more accurate data; make this the focus of an ongoing mapping project in close co-operation with the SAPIA initiative of the NBI (Lesley Henderson).

- recommendations for research into:
  - key aspects of the biology of alien invaders and their control (including rehabilitation);
  - developing better models for the assessment of the impact of invaders on water and other natural resources;
  - improving our understanding of rates of invasion;
  - improving existing and developing new control methodologies and achieving better integration;
  - the cost of control and the factors that influence control operations and their cost in different situations; and
  - the extent to which reductions in streamflow due to alien invaders have already been incorporated in the estimated virgin MAR data provided by the Water Resources 90 study of Midgley *et al.* (1994).

9.1 Recommendations for Action

9.1.1 Information

Using information

- Information on alien invasions should be treated as public property.
- The database needs to be kept updated and active.

- Maps should be distributed as they stand at present to experts on alien invasions for participative updating.
- Maps should also be used to stimulate clearing operations.
- Standards for information capture should be improved.

Strategy

- Establish a full-time portfolio for the updating and improvement of aliens information (link to the Plant Invader Atlas project).
- Expand this to an open information line - this could be achieved through the establishment of an aliens information 'desk'. This information should be used in awareness raising and sensitizing (such as the production of annual situational bulletins).
- The information gathering and sharing process should be continued. Immediate emphasis on the capture of missing areas and areas for which data is weak (notably to improve the data coverage for KwaZulu-Natal).
- Establish a standardized methodology with regard to information/data capture.
- Initiate mapping of areas cleared - to give a picture of the extent of activity, and the extent of follow-up required.
- The scale of information should now be improved to serve in regional and local management planning.
- Get data onto the Worldwide Web.

9.1.2 Public participation

The clearing of all invading aliens in South Africa is beyond the reach of any reasonable budget. It is imperative to look to other ways of solving the problem.

- One option is to devolve responsibility from government to the land owner and custodian - but at the same time making the task possible through the transfer of both knowledge and technology.
- Create a climate of, and framework for, community and public participation in the management of the problem of alien invasions.
- Determine the barriers to transferring responsibility to landholders and custodians and how these can best be overcome.
- Determine and establish the role and responsibilities of (for example) local councils.
- Establish a process of education, awareness and understanding to all custodians of the land.

- Conduct research into public education and awareness and how this can be best achieved.
- Develop technology transfer (information transfer) mechanisms.
- Develop principles of how to approach the problem (dense vs sparsely invaded areas etc) - use cost data and rate of spread information. Tackle the cost-effective areas first! Do not wait for areas of uninvaded or sparsely invaded veld to become dense before taking action.
- Typical immediate strategies could include working in partnership with landowners - either in joint operations or through contributions from landowners. One suggested clearing approach is to use DWAF Working for Water teams to work dense areas (where management is more manageable); but at the same time to get volunteers, farmers, and individuals to tackle the sparse areas (these groups are more likely to be efficient and motivated and much more cost-effective under conditions of sparse invasion).
- The options and issues around the question of cash incentives and the sustainability of clearing operations need to be reviewed as this has become a thorny issue in soil and water conservation projects under the auspices of the Land Care initiatives.

9.2 Recommendations for Research

9.2.1 Extent and biology

- Rehabilitation biology - dynamics of disturbance and replacement
- Biology of invasions - seedbank dynamics
  - invasive biology and mechanisms, particularly in arid areas
- Rate of spread - studies of rates of spread to provide a sound basis for models of spread for different species in different habitats are required (e.g. from photo interpretation)
- Bioclimatic zones of invasion - determining areas of risk and susceptibility
- Comparison of data collected for this study with information from the satellite images and maps produced for the National Land Cover Project. This comparison, if successful, could provide a robust method for extrapolating the existing data to unmapped areas.

9.2.2 Impact and modelling of water-use

Riparian zones, ie. the river banks, floodplains and associated wetlands, are dynamic landscape features which are naturally highly susceptible to invasions. Data from catchment studies also indicates that plants in riparian zones may use substantially more water than those in the adjacent areas. Research into the water-use of invaders should concentrate on studies of species in these situations.

- Impact of invaders on water resources - improvement of methods and of estimates (species dynamics, age and biomass, riparian vs landscape). These studies should include an analysis of the extent to which reductions in streamflow due to alien invaders have already been incorporated in the estimated virgin MAR data by the WR 90 study (Midgley *at al.,* 1994).
- Methodologies for estimating water-use at larger scales (e.g. the biomass model) must be improved to allow for, *inter alia,* limited water availability.
- How much water is used by invading species? Determinations for different growth forms and habit. Water use by *Prosopis* spp and *Acacia mearnsii* should be seen as priorities.
- Determine the impact of invaders on the water security of rural communities.
- More practical examples are needed to demonstrate the impact of the clearing of invaders on the water resource.
- Assessments of the real cost of invaders (e.g. loss of productive land, flood damage to infrastructure, loss of biodiversity) and the real benefits of clearing both direct (e.g. the water released) and indirect (e.g. community upliftment, training in entrepreneurial skills).
- Review of long-term gains of clearing alien invaders, i.e. into the sustainability of the benefits.

9.2.3 Invading plant control

- Biocontrol: Importation of control agents for problem species. This programme is essential to long-term success and sustainability. The biocontrol programme should be strongly pro-active and must include the early identification of potential problem species.
- Clearing and follow-up. Determining best methods for specific species in specific climate zones. Costs and effectiveness of different approaches (e.g. clear felling versus killing of trees standing).
- River bank rehabilitation (post-clearing recovery).
- Managing invasions for fuelwood production as part of a control strategy.

9.2.4 Quantifying the costs of invaders

- Cost and effort required in controlling different invaders (especially different follow-up requirements).
- Costs of seed pollution.
- The costs to biodiversity and what this means in hard currency.
- The cost in terms of loss of land (to agricultural production - commercial and community).
- The costs to agriculture in clearing or reclaiming land for agricultural use.
- Costs to Telkom and to Eskom in terms of clearing lines, downtime through damage caused by falling trees.

9.2.5 Monitoring and evaluation

- Develop a set of indicators for establishing/measuring levels of success in control.
- Establish a set of long-term catchment experiments to complement the short-term portable weir studies and assess the long-term benefits of clearing invading alien plants.

9.2.6 Getting more from the data

- Identify special problems (species, areas of maximum sensitivity) - What really deserves priority? These can now be evaluated in the context of the national framework.
- Look more closely at distribution patterns for species and suites of species in the data set. From these and other data determine areas available and suitable and ready for, and likely to be, invaded.
- Determine the relationship between invasions, rainfall (bioclimatic modelling), and between invasions and other forms of land use.

9.2.7 Benefits of alien plant species

- The value and benefits which a number of alien plant species can provide must be recognised, for example timber and fibre for paper. There is a need to manage some stands for sustainable fuelwood provision, where this is beneficial to the community and with acceptable costs to the environment.

10. DATA STORAGE AND AVAILABILITY

This chapter describes the data, how it is stored, and its accessibility and ownership.

10.1 Description of Data

Data have been catalogued as follows:

Raw data

(i) Spatial distribution of aliens mapped at 1: 250 000 scale by experts or in the field.

(a) *A series of map overlays* (transparencies) prepared to match 1:250 000 topographical survey maps. Polygons of invasion are numbered for linking to attribute data.

(b) *Attribute data associated with the polygons of invasion on the map overlays*. Attribute data include a description of the invasion within each polygon in terms of species and density. All attribute data are on field forms.

A number of other data sets have been included in the national data set. These are described in Chapter 2 (see Table 2.1) in some detail. The data for these studies are stored only in electronic form (spreadsheets & text files) except for the data for the 1 : 50 000 mapping of KwaZulu-Natal where the maps and attribute data are currently housed at Environmentek in Stellenbosch.

(ii) Rate of spread and estimated cost to clear are stored as the raw data on field forms as completed by knowledgeable experts.

(iii) Questionnaires on "issues" completed by knowledgeable experts.

Processed data

Processed data comprises:

(i) Spatial data coverages on GIS (Arc/Info) stored by province with an INFO (*.DAT) file with all the polygon attribute information and programmes to process the data, produce maps and output text data for analysis.

(ii) Attribute data in ASCII text files as raw data and also converted into the correct format where necessary.

(iii) Tabulated information on rate of spread, costs to clear, and questionnaire outputs.

(iv) Spatial and attribute data sets provided by conservation and water management authorities.

10.2 Data Storage

The map overlays, raw attribute data, original data for rate of spread and costs to clear, and the original questionnaires have been classified and stored in the GIS lab of the Programme for Natural Resources and Rural Development, Environmentek CSIR, PO Box 320, Stellenbosch 7599. (Tel 021 - 8875101, Fax 021 - 8875142. Contact person - Mr D. Le Maitre (dlmaitre@csir.co.za).)

All processed data has been catalogued and stored on disk or backup tapes at the CSIR in Stellenbosch. Copies will be forwarded both to the Water Research Commission and to the Working for Water Offices for safekeeping.

It is hoped that the output of this project will be seen in the form of an active database, and the establishment of a management responsibility and portfolio is recommended (see also Recommendations, Section 9.1). Use of the World Wide Web is seen as one means of sharing and disseminating information (see Appendix 11).

10.3 Ownership of Data

This project has been supported by the provision of additional data sets from Western Cape Nature Conservation, Eastern Cape Nature Conservation, Rand Water, and Umgeni Water (through Murray Biesenbach and Badenhorst). All these data sets are presented in this report and have been used in the analysis. Coverages provided by Rand Water (the Rand Water catchments) and by Umgeni Water remain the property of these water boards. While the data will be curated as part of the national data set, permission will be required before release to the general user.

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Appendix 1 :
List of scientific species names with their recognised common names

Scientific and common names of alien invader plants recorded during the course of this project. Names taken from Henderson (1995), Bromilow (1995) and Von Breitenbach (1989).

Scientific Name	Common Name
Acacia baileyana	Bailey's Wattle
Acacia cyclops	Rooikrans
Acacia dealbata	Silver Wattle
Acacia decurrens	Green Wattle
Acacia elata	Peppertree Wattle
Acacia longifolia	Long-leaved Wattle
Acacia mearnsii	Black Wattle
Acacia melanoxylon	Blackwood
Acacia podalyriifolia	Pearl Wattle
Acacia pycnantha	Golden Wattle
Acacia saligna	Port Jackson Willow
Acacia spp	Wattle species
Acanthospermum hispidum	Upright Starbur
Agave americana	American Agave
Agave sisalana	Sisal
Agave spp	Sisal species
Ageratum conyzoides	Mexican Ageratum
Alnus viridis	European Green Alder
Anthemis spp	Camomile
Argemone mexicana	Yellow-flowered Mexican Poppy
Argemone ochroleuca	White-flowered Mexican Poppy
Argemone spp	Mexican Poppy
Arundo donax	Giant Reed, Spaansriet
Atriplex lindleyi	Sponge-fruit Saltbush
Atriplex nummularia	Old Man Saltbush
Atriplex semibaccata	Australian Saltbush

Scientific Name	Common Name
Azolla filiculoides	Red Water Fern
Bidens pilosa	Common Blackjack
Bromus spp	Brome grasses
Caesalpinia decapetala	Mauritius Thorn
Callitris glauca	White Cypress Pine
Canna indica	Canna
Cardiospermum grandiflorum	Balloon Vine
Cardiospermum halicabum (C. spp)	Balloon Vine
Carica papaya	Pawpaw
Cassia didymobotria	Peanut-butter Cassia
Cassia occidentalis	Cassia
Cassia pendula	Cassia
Cassia spp	Pod Bushes, Cassias, Sennas
Castanea dentata	American Chestnut
Casuarina cunninghamiana	Casuarina, Beefwood
Catharanthus roseus	Catharanthus
Cedrus deodara	Deodar Cedar
Cereus jamacaru (C. peruvianus)	Queen-of-the-Night
Cestrum laevigatum	Yellow/Orange Cestrum
Chamaesyce prostata	Hairy Creeping Milkweed
Chenopodium carinatum	Green Goosefoot
Chromolaena odorata	Paraffin/Triffid Weed
Cinnamomum camphoratus	Camphor Tree
Cirsium spp	Thistles
Conyza bonariensis	Flax-leaf Fleabane
Cortaderia sp	Pampas Grass
Cupressus glabra	Blue Cypress
Cupressus spp	Cypress
Datura ferox	Large Thorn Apple
Datura innoxa	Downy Thorn Apple
Datura stramonium	Common Thorn Apple
Datura spp	Thorn Apples
Delonix regia	Flamboyant
Echinosis spachiana	Torch Cactus

Scientific Name	Common Name
Eichhornia crassipes	Water Hyacinth
Eucalyptus camaldulensis	Red River Gum
Eucalyptus cinerea	Florists Gum
Eucalyptus cladocalyx	Sugar Gum
Eucalyptus delegatensis	Alpine Ash Gum
Eucalyptus diversicolor	Karri
Eucalyptus globulus	Blue Gum
Eucalyptus grandis	Saligna Gum
Eucalyptus lehmannii	Spider Gum
Eucalyptus macarthurii	Woolly Butt
Eucalyptus melliodora	Yellow Box Gum
Eucalyptus pellita	Large-fruited Red Mahogany
Eucalyptus polyanthemos	Red Box Gum
Eucalyptus robusta	Swamp Mahogany Gum
Eucalyptus sideroxylon	Black Ironbark
Eucalyptus spp	Eucalypts, Gums
Flaveria bidentis	Smelter's Bush
Gleditsia triacanthos	Honey Locust
Grevillea robusta	Silky Oak
Hakea gibbosa	Rock Hakea
Hakea sericea	Silky Hakea
Hakea suaveolens (H. drupacea)	Sweet Hakea
Hakea spp	Needle Bushes
Homolanthus populifolia	Bleeding-heart Tree
Hypericum perforatum	St John's Wort
Ipomoea spp	Morning Glories
Jacaranda mimosifolia	Jacaranda
Jatropha spp	Physic Nut
Lantana camara	Lantana
Leptospermum laevigatum	Australian Myrtle
Leucaena leucocephala	Giant Wattle
Ligustrum japonicum	Japanese Privet
Ligustrum lucidum	Chinese Privet
Ligustrum ovalifolium	Californian Privet

Scientific Name	Common Name
Macfadyena unguiscati	Cat's Claw Creeper
Mangifera indica	Mango
Melia azederach	Syringa, Indian Lilac
Metrosideros excelsus	New Zealand Bottlebrush
Mimosa pigra	Sensitive Plant
Morus alba	White Mulberry
Myoporum serratum	Manatoka
Myriophyllum aquaticum	Parrot's Feather
Nerium oleander	Oleander
Nicotiniana glauca	Wild Tobacco
Opuntia ficus-indica	Sweet Prickly Pear
Opuntia imbricata	Imbricate Prickly Pear
Opuntia rosea	Rosea Cactus
Opuntia stricta	Australian Pest Pear
Opuntia spp	Prickly Pears
Paraserianthes lophantha	Stink Bean, Albizzia
Passiflora edulis	Granadilla
Passiflora sp	Granadilla, Passion Fruit
Passiflora subpeltata	Granadina
Pereskia aculeata (P. sp)	Barbados Gooseberry
Phoenix sp	Date Palms
Phytolacca octandra	Belhambra
Pinus canariensis	Canary Island Pine
Pinus elliottii	Slash Pine
Pinus halepensis	Aleppo Pine
Pinus patula	Patula Pine
Pinus pinaster	Cluster Pine
Pinus pinea	Umbrella or Nut Pine
Pinus radiata	Radiata Pine
Pinus roxburghii	Chir Pine
Pinus taeda	Loblolly Pine
Pinus spp	Pines
Pistia stratiotes	Water Lettuce
Pittosporum undulatum	Sweet Pittosporum

Scientific Name	Common Name
Populus alba	White Poplar
Populus canescens	Grey Poplar
Populus deltoides	Match Poplar
Populus nigra var. italica	Lombardy Poplar
Populus wislizenii	Valley Match Poplar
Populus spp	Poplars
Prosopis glandulosa	Mesquite
Prosopis velutina	Velvet Mesquite
Prosopis spp	Mesquites
Psidium guajava	Guava
Pueraria lobata	Kudzu Vine
Pyracantha angustifolia (P. spp)	Firethorns
Quercus robur	English Oak
Quercus rubra	Red Oak
Quercus suber	Cork Oak
Quercus spp	Oaks
Ricinus communis	Castor-oil Plant
Robinia pseudoacacia	Black Locust
Rosa sp (R. eglanteria)	Sweet Briar
Rubus spp	Brambles
Salix babylonica	Weeping Willow
Salix fragilis	Crack Willow
Salix spp	Willows
Salvinia molesta	Kariba Weed
Schinus molle	Pepper Tree
Schinus terebinthifolia	Brazilian Pepper Tree
Schinus spp	Pepper Trees
Sesbania punicea	Red Sesbania
Setaria sp	Setaria Grasses
Solanum mauritianum	Bugweed
Solanum seaforthianum	Potato Creeper
Sorghum halepense	Sorghum
Stenocarpus sinuatus	Firewheel Tree
Syncarpia glomulifera (S. laurifolia)	Turpentine Tree

Scientific Name	Common Name
Tamarix ramossisima (T. sp)	Pink Tamarisk
Tecoma stans	Yellow Bells
Thevetia peruviana	Yellow Oleander
Tithonia diversifolia	Mexican Sunflower
Ulmus sp	Elm
Verbena bonariensis	Wild Verbena
Xanthium spinosum	Spiny Cocklebur
Xanthium strumarium	Cocklebur
Xanthium spp	Cockleburs
Zinnia peruviana	Redstar Zinnia

Appendix 2 : Alien plant invasions in South Africa: Consultation and expertise list

RESOURCE PERSONS AND ACKNOWLEDGEMENTS

PERSON	ORGANISATION	TEL & FAX	POSTAL ADDRESS	GEOGRAPHIC AREA & NATURE OF EXPERTISE
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Dawid Stonestreet	Maluti Water Matatiele			Mt Fletcher & Maluti Districts
Avis, Ted	Botany Dept. Rhodes University	T : (0461) 22023 F : (0461) 25524	P O Box 94 Grahamstown	E Cape : Grahamstown
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Kameni, Cariot	DWAF Indigenous Forests	T : (0436) 3-1537 F : (0436) 3-1126	Private Bag X32 Stutterheim, 4930	Stutterheim, Amatola Mountains
Lubke, Roy	Rhodes University	T : (0461) 31-8111 F : (0461) 2-5524		E Cape
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Van der Merwe, Theo	DWAF (Forestry Extension)		Private Bag X313 Pretoria, 0001	E Cape
Van Tonder, H W	Eastern Cape Nature Conservation			Uniondale, George & Knysna Districts
FREE STATE				
Collins, Nacelle	Free State Nature Conservation	T : (05861) 2-3520		Eastern Free State
Mooiman, Lucius	Free State Nature Conservation	T : (05861) 2-3520		Free State Costs of clearing, especially Salix
Oosthuizen, Piet	Dept of Agriculture Resource Conservation (Free State)	T : (05214) 2274/2309		Free State : Kroonstad, Kimberley
Pietersen, Koos	Dept of Agriculture Resource Conservation (Free State)	T : (05214) 2274/2309		Free State
Theron, Piet		T : (0148) 294-3343		
Van Dyk, Sarel				Free State
GAUTENG				
De Fontaine, Marc	Rand Water (Working for Water)	T : (011) 68-20911 F : (011) 68-20444	PO Box 1127 Johannesburg, 2000	Rand Water catchment area & Upper Tugela
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Roodt, Pieter	Alien Clearing Project for Resource Conservation	Cell : 082 268 5738		Distribution of invasives
Vorster, Tom				Pretoria
KWAZULU-NATAL (see also E. Cape)				
Bennet, Ron	KwaZulu-Natal Dept of Agriculture	T (0331)43-3371x294 F (0331) 43-3634	Private Bag X9059 Pietermaritzburg, 3200	KwaZulu-Natal, GIS
Brodie, James Meier, Kevin (GIS)	MBB Consulting Engineers Inc Pietermaritzburg	T : (0331) 45-3530 F : (0331) 42-7728	P O Box 2821 Pietermaritzburg, 3200	Umgeni Water Catchments
Charlton, Stuart	DWAF Kokstad	T : (037) 727-3620 F : (037) 727-3239	Private Bag 3522 Kokstad, 4700	Former Transkei & Sthn KwaZulu-Natal Plantations

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Le Roux, Peter	Natal Parks Board			KwaZulu-Natal : Coast, Drakensberg, Midlands
Matthee, Maryna				Vryheid
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Pitchford, William	Working for Water	T : (0332) 30-2051 F : (0332) 30-2101	Private Bag X24 Howick, 3290	KwaZulu-Natal : Frankfort
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MPUMALANGA				
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Bijl, Arrie	SAFCOL			Mbabane
Brown, D M	Mondi Forests			Hazyview Area
Clure, Carl	SAPPI	Cell : 082 568 0110		
Deall, G	Private			Between Usutu & Crocodile Rivers Escarpment & Highveld only
De Wet, F	Mpumalanga Parks Board			Lowveld : Sandriver southwards to Pongola River (excl. Swaziland)
Engelbrecht, J	DWAF			Former Transvaal
Eksteen, J	Mpumalanga Parks Board			Lydenburg / Dullstroom / Belfast / Middelburg / Loskop / Groblersdal
Green, Richard	DWAF	T : (013) 755-1674		Mpumalanga Escarpment Mbabane
Kirsten, Frikkie	PPRI	T : (013) 764-2164		
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McCartney, Sean	MONDI	T: (031) 764-1011		Mpumalanga & Northern Province
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Onderstall, J	Author Botanical			Mpumalanga (Escarpment/Lowveld)
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Poulter, Tony	CSIR (Working for Water)	T: (013) 74-13864 F: (013) 74-13869	Private Bag X11227 Nespruit, 1200	Mpumalanga
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Rossler, C	Mondi Forests			Graskop Area
Tourien, Lou	DWAF	T: (013) 752-4183		
Viljoen, Pieter	Ekoserv	F: (013) 74-14488		Pilgrims Rest, Sabie, Nelspruit, Witriver, Barbeton Districts
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NORTHERN CAPE				
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Smit, Pete	Upington Municipality	T : (054) 2-6911	Lower Orange	
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Syphus, Joel	DWAF (Forestry Extension)	T : (0236) 31-1188		Twee Rivieren
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NORTHERN PROVINCE				
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De Beer, GCO	Dept. Agriculture Land & Environment	T : (0152) 291-1403 F : (0152) 291-1517	P O Box 3556 Pietersburg, 0700	Crocodile River area
Rautenbach, George				N Province : Alldays / Pietersburg
Snyders, Marius	DWAF (Working for Water)	T : (015) 516-0201 F : (015) 516-1062	Private Bag X2413 Louis Trichardt, 0920	Costs of clearing
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Van Rooyen, Pieter	ex TPA		Brits	
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NORTH WEST PROVINCE				
Ashley, L	North West Parks Board			N W Province Natal : Zululand Drakensberg, Mafikeng, West Rand
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Van Heerden, Piet				
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Wills, Alf				
WESTERN CAPE				
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Carstens, Mike	Overberg RSC	T : (02841) 51157 F : (02841) 51014		Overberg District
Cattell, P	Cape Nature Conservation	T : (0445) 83-0042 F : (0445) 83-0042	Goukama Nature Res PO Box 331, Knysna, 6570	W Cape - George, Langkloof, Humansdorp, Knysna Mountains
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Coetzee, Ken		T : (0441) 74-2160		
Donian, Ivan	Cape Nature Conservation	T : (0441) 74-2160 F : (0441) 74-1567	Private Bag X6546 George, 6530	Gouritzriver - Bloukrantzriver (East Cape Border & north of Outeniqua Mountains
Du Plessis, C	Cape Nature Conservation			Cederberg - Wilderness Area

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Du Plessis, J	Cape Nature Conservation			Cederberg - Boland
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Jonker, Corrie	SAFCOL			
Kok, Reynard	DWAF			Tsitsikamma : Keurboomriver - Witelsbos
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Le Roux, Piet	DWAF	T : (0423) 5-1180 F : (0423) 5-2745	Humansdorp	Tsitsikamma
Le Roux, Piet	SAFCOL			Tsitsikamma Forestry
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Martens, Chris	Cape Nature Conservation	T : (02934) 2-2412 F : (02934)2-2838	Grootvadersbosch	Gourits - Breede River
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Stehle, T	DWAF (Conservation Forestry)			Southern Slopes of Outeniqua Mountains and foothills and coastal plateau between Kaaimansriver and Keurboomsriver
Swart, Paul		T : (028) 4-6705	Elim Community	
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Van Dyck, Sybrand				Citrusdal
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Van Eeden, Frans	Dept of Agriculture Resource Conservation	T : (021) 96-8136 F : (021) 96-1889		Western Cape Resource Conservation
Van Zyl, Piet	Cape Nature Conservation	T : (02353) 621 F : (02353) 674	Robertson	Breede River Valley : Worcester - Swellendam
Van Zyl, Piet	SAFCOL	T : (0441) 850-1153 T : (0441) 85-1283		W Cape - George
Vermeulen, Wessel	DWAF(Knysna)	T : (0445) 82-5466 F : (0445) 82-5461		George : Southern slopes of Outeniqua Mountains and foothills and coastal plateau between Kaaimansriver and Keurboomsriver
Vlok, Jan		T : (0443) 29-1739 F : (0443) 22-8110	De Rust	Southern Cape and Little Karoo
Wessels, Nigel	Cape Nature Conservation		Velddrift	Cederberg

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Henderson, Lesley	Plant Protection Research Institute SAPIA Co-ordinator	T : (012) 804-3200 F : (012) 804-3211	Private Bag X104 Pretoria, 0001	Plant Invader Atlas
Klein, Hildegard	Plant Protection Research Institute	T : (012) 32-9327		Biocontrol
Richardson, Dave	IPC, UCT	T : (021) 650 2440	IPC Botany Department University of Cape Town Private Bag Rondebosch, 7700	Biology of Invaders
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Appendix 3 :
Methodology and information gathering. Methods for mapping, data recording form, and questions of incidence and issues

METHODOLOGY FOR MAPPING POPULATIONS OF INVADING PLANTS

The aim of this project is to produce a map, and database, of South Africa at a scale of 1:250 000 to show the relative importance of different weed species across the country. This information will be used to determine national priorities for allocating funds for clearing of exotic plants in the "Working for Water" Programme of the Department of Water Affairs and Forestry.

The mapping approach and methodology described below is based on a manual for mapping aliens at a 1:50 000 scale for a fynbos catchment management system (Le Maitre & Versfeld 1994). The focus of the project is on the impacts of alien plants on water resources and more especially on species which have significant impacts on water resources such as trees and 'woody' thicket forming species (e.g. bramble, lantana, mauritius thorn).

A consistent method for mapping and describing areas invaded by alien plant species is needed to ensure that the data are collected in a standardised format that is (a) easy to map in the field or in workshops and (b) provides clearly defined classes for use in decision making. The approach is intended to:

- reduce confusion by introducing a standard terminology,
- introduce a standard method for mapping,
- provide a systematic procedure for collecting data, and
- provide a basis for making decisions about alien control operations.

To facilitate this process we have developed a set of standard forms for those who are doing the mapping to complete (see the end of this document). There are four forms:

- A questionnaire aimed at gathering general information on aliens and the issues relating to alien invasions in the area/region the person is familiar with.
- Mapped invasion information.
- Information on the costs of controlling alien invasions.

- Information on increases in stand density and the rate of spread of alien plants.

The data required for each invaded area consists of three items: species, plant canopy cover (%) or density, and the duration of the invasion. The data should be mapped according to the following guidelines:

- The map scale is 1: 250 000 so 1 mm on the map = 0.25 km and 1 mm² = 6.25 ha. This is still much too detailed and impractical to use for this study. An example may help. Picture a section of a river (30 km+) and mentally average out the aliens over that section of river. Parts may be densely invaded, and others may only have occasional plants but the average may be scattered (see the forms for definitions of the classes). If however a large section (e.g. 20 km) is densely invaded but the upper 10 km and the tributaries only have scattered plants then two classes can be distinguished. The final decision on how many (sub-)units to map is really a matter of judgement.

- Each invaded area must be recorded directly onto clear plastic overlays on 1:250 000 map sheets. Data can be mapped as lines (e.g. invasions along river courses) or as areas (e.g. landscapes that are invaded). Where invasions extend across two or more maps please try to ensure that the lines meet when the maps are positioned correctly next to each other.

- When a mixture of species is mapped, the density/cover class must be recorded separately for each species in the mixture. This is important. Although the density class of a **mixture** of two species may be *dense*, the **individual** density classes of species A and species B may be *medium*.

- Number each mapped invasion using a unique number on that map and record the data and treatments on the map data form against the same number.

The map data forms have the classes expressed as canopy cover (%) or as **apparent density**. True, or absolute, density is based on plants per unit area and is independent of plant size. Apparent density is strongly influenced by plant size. Thus, a stand of seedlings will **look** much less dense than a stand of larger plants with the same number of plants per ha (Figures 1-3). This study uses the canopy gap width method, where the gaps between shrubs are estimated as the number of canopy diameters. This gives the **apparent** density which is easily estimated in the field. The following information may help you to understand the density classes better:

Occasional: generally widely spaced plants; canopy cover 1-5%; 3-10+ canopy diameters apart.

Scattered: the plants average 1-3 canopy diameters apart; canopy cover 5-25 %.

Medium: this covers a wide range from where there are *clear and plentiful gaps between the canopies* to where there are only small gap but no overlaps; canopy cover 25-75%; plants average 0.3-1 canopy diameter apart.

Dense: *plant canopies are closed, touching or overlapping* in most places and *other vegetation is generally suppressed, sparse or lacking*; canopy cover > 75 %; the plants average less than 0.1 canopy diameter apart.

Our experience to date is that the mapping is more efficient and is completed more rapidly if we can get groups of people who have a good knowledge of the weeds in their areas to work together. Thus we prefer to "workshop" the mapping rather than working with each individual in isolation as working with groups also saves money it is very important to accept that the final map will not be perfect, for example boundaries will not be accurate, density estimates require much mental averaging. The point is that the aim of the mapping is to determine the **relative** importance and extent of the different weed species in different regions of the country. At this level errors in the estimates of a hundred hectares become a fraction of a percent on the national scale. The production of the map and database will, in itself, also provide an incentive to improve on the quality of the maps in future.

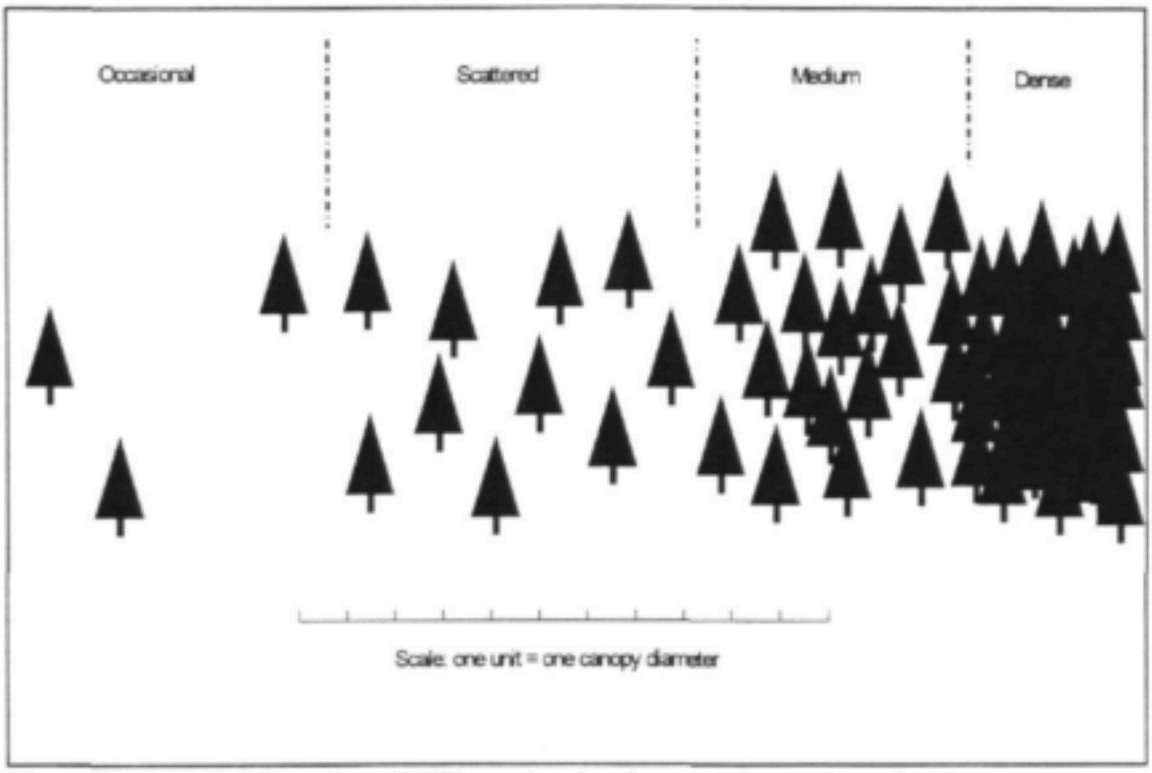

Figure 1: An illustration of different density classes with a scale marked in canopy diameter units.

Figure 2: The effects of plant size on apparent density. The true density (plants/unit area) is the same but the size differs as shown by the canopy diameter scales. The density class ranges from occasional (top) to medium (bottom).

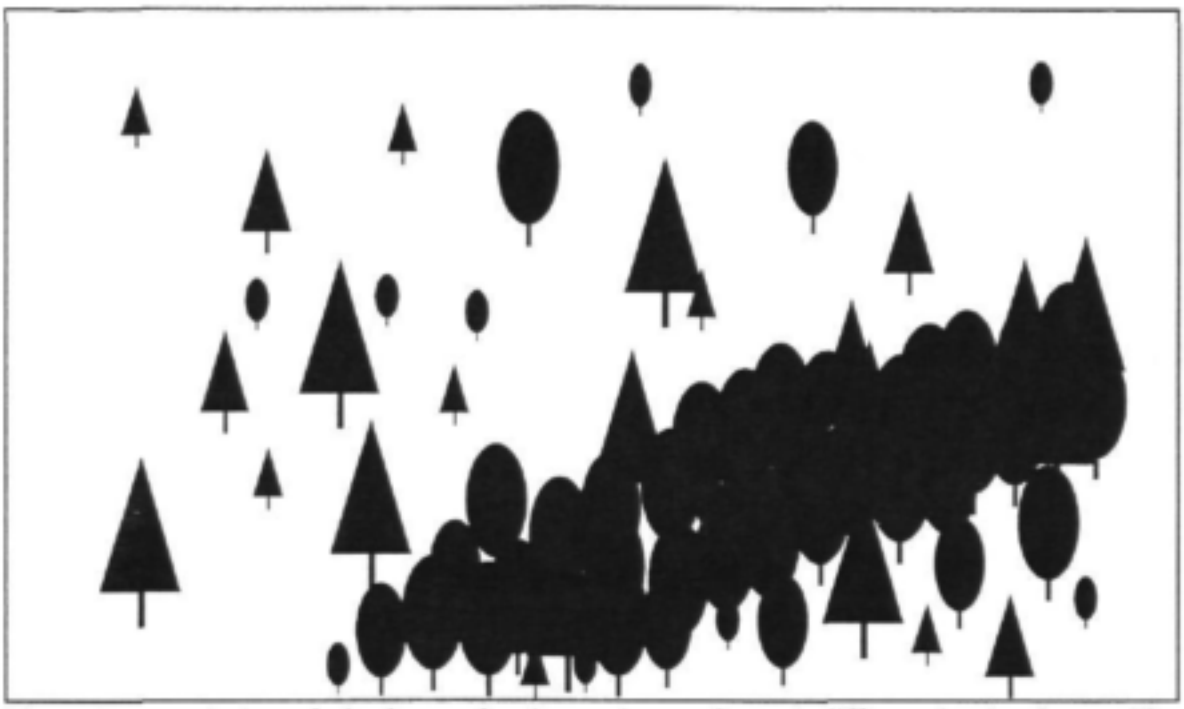

Figure 3: A view of a landscape showing a mixture of trees in different density classes. The densities are scattered over the landscape and medium to dense along the stream.

ALIEN INVADERS IN SOUTH AFRICA - 1996/97

INCIDENCE AND ISSUES IN SOUTH AFRICA - WHAT DO YOU KNOW?

Name:	Organization: ....

Assessments should be phrased in terms of
- → *Certainties*
- → *Uncertainties*
- → *We don't know*

1. Geographic area covered by your experience ....

2. How big is the problem? Give your perceptions.

....

....

....

3. To what extent are aliens still likely to spread ? What areas will be invaded and how quickly?

....

....

....

4. What do you see as the problems resulting from invaders (already experienced or expected problems)? Rate from 0 to 5 (0=no problem, 5 = major problem)

Water yield to dams
Water security (community and local agricultural water supply)
Water quality
Siltation (of rivers and dams)
Erosion of landscape

Bank and channel stability
Loss of land (eg for grazing, agriculture)
Loss of recreation value
Damage to fences
Damage to telephone lines
Damage to power lines
....
....
....
....

5. Can the invasion be controlled ?

- by Government/RDP/Conservation bodies?
- by individuals or community?
- other means ?

6. How do you see the problem being most effectively tackled? In your area? Regionally? Nationally?

- mechanical clearing
- herbicides
- biocontrol
- legislation/regulation
- subsidies
- other

7. What past initiatives have there been to keep aliens under control?

....

....

8. What is the extent of current effort to control aliens ?

....

....

9. What are the biggest gaps in our knowledge ?

....

....

10. Are there any **benefits** accruing from alien invaders?

- value of benefits (for use or cash)
-

- what are the necessary alternatives should communities be negatively affected given the control of aliens.

11. What, in your view are the top ten invaders in your area of concern (based on current levels of invasion and the potential for future invasion if unchecked) ?

1 ....
2 ....
3 ....
4 ....
5 ....
6 ....
7 ....
8 ....
9 ....
10 ....

Alien Study: Map Data Recording Form

Map Number:____________________ **Observer Name:** ___________________________ **Date:**___/___/___ **Page No** ___ **of** ___

Density class: Occasional: <5% cover or >3 canopy φs apart; Scattered: 5-25% cover or 1-3 canopy φs apart
Medium: 25-75% cover or 0.1-1 canopy φ apart; Dense: >75% cover or 0-0.1 canopy φ apart
Duration of invasion: 1 = <1 year; 2 = 1-5 years; 3 = 5-10 years; 4 = 10-20 years; 5 = > 20 years; or specify period

Poly No	Species (list each species in a mixture separately)	Density class				Duration of invasion	Notes (e.g. preferred habitat, factors affecting spread, impacts on water or the environment)
		Occ	Scat	Med	Den		

Alien Study: Map Data Recording Form (partially completed example)

Map Number:__________________ **Observer Name:** ______________________________ **Date:**__/__/__ **Page No** ___ **of** ___

Density class: Occasional: <5% cover or > 3 canopy φs apart; Scattered: 5-25% cover or 1-3 canopy φs apart
Medium: 25-75% cover or 0.1-1 canopy φ apart; Dense: >75% cover or 0-0.1 canopy φ apart
Duration of invasion: 1 = <1 years; 2 = 1-5 years; 3 = 5-10 years; 4 = 10-20 years; 5 = > 20 years; or specify period

Poly No	Species (list each species in a mixture separately)	Density class				Duration of invasion	Notes (e.g. preferred habitat, factors affecting spread)
		Occ	Scat	Med	Den		
1	Pinus pinaster		✓			4	
1	Hakea sericea			✓		3	
1	Acacia longifolia	✓				4	biocontrol is 100% successful
2	Acacia mearnsii				✓	5	requires floods to increase in density

Aliens Study: Control Cost Data Form

Name:____________________ **Province:**____________________ **Catchment Name:**____________________________ **Page No** ____ **of**______

Natural vegetation: e.g. fynbos, forest, grassland, karoo	Locality: e.g. riparian, mountain slope, whole catchment	Species or species combination: sp A 80% sp b 15% sp c 5%	Size class: - seedling - young - mature - all	Control method - Biocontrol - Felling - Herbicide - Burn - Hand pull	Control stage: - initial control - follow-up	Control costs by density class (R/ha to the nearest R10)			
						Occasional (<5%)	Scattered (5-25%)	Medium (25-75%)	Dense (>75%)

Alien Study: Information on the expected increase in the problem

Observer Name: ______________________________

Density class: Occasional: <5% cover or > 3 canopy φs apart; Scattered: 5-25% cover or 1-3 canopy φs apart
Medium: 25-75% cover or 0.1-1 canopy φ apart; Dense: >75% cover or 0-0.1 canopy φ apart

Anticipated increase: density = time to go from one class to another in years;
rate of expansion = typical mean increase in % per year (e.g. ha/ha/year or km of river/km/ year)

Species	From density class (tick 1)				To density class (years)				Rate of expansion	Notes (e.g. what causes increases; preferred habitats)
	Occ	Scat	Med	Den	Occ	Scat	Med	Den		

Appendix 4 :
Plant invasions - incidence and issues in South Africa: a scoping exercise

Introduction

Fifty-nine respondents completed a questionnaire entitled *"Incidence and Issues in South Africa - What do you know?"*. A sample copy of this questionnaire is attached as Appendix 1, together with a record of respondents.

Questions sought the understanding of respondents on the size of the alien invader plant problem, the likelihood of spread and expected rate of spread, a rating of consequent problems, past efforts at control and ways of achieving control, gaps in knowledge, community reliance on products derived from aliens, and finally a listing of the perceived most prevalent or problematic invader species. For the most part this questionnaire proved suited to meeting its objectives and questions were well understood by respondents. While the formulation of the questionnaire may have biased the answers (e.g. sequence of questions or the choices provided), we believe that the results do capture the major consensus and issues.

The questionnaires are a mine of information, often at a scale too detailed for a national study, but always useful. The responses have been analysed and summarized in the following pages - with original data retained in the project archive for further consultation by the interested reader seeking the detail pertinent to a particular area.

Some areas have been very thoroughly covered by means of this survey, and some poorly. This is partly a consequence of our ability to contact and involve knowledgeable people, partly a consequence of the lack of expert knowledge in some areas, and partly one of emphasis. Despite these gaps the questionnaire provides valuable information, especially when read alongside the results of the mapping exercise.

How big is the problem? A summary of perceptions

A more detailed breakdown of perceptions of the size of the alien invader problem is presented in Chapter 3 ('Nature, extent and distribution') with comment incorporated into section 4.3.3. Inputs to the questionnaire are therefore only summarised below.

The problem is certainly recognized as being very, very big. In some areas however, the control of alien invaders is still viewed as manageable at extensive scale (e.g. the KwaZulu-Natal Drakensberg) and others are being successfully managed (e.g. the Swartberg mountain range in the Western Cape). Rivers are clearly the focus of most problems - but very different species are responsible in different areas. *Acacia mearnsii* is the most extensive invader, but *Melia azederach* and *Prosopis* dominate in drier areas. Comments received urged the need for immediate action, and two respondents note the immensity of the problem alongside both lack of awareness and public indifference. Whilst aquatic invaders were not addressed specifically clear concerns have also been voiced with regard to a number of river systems.

What are the problems resulting from invasions?

A list of 11 pre-identified problems were presented to 'experts' for rating in terms of severity. Respondents could also list and rate other problem issues. The listed problems were ranked as follows (See also Table 3.1).

1. Water yield to dams
2. Water supply security
3. Loss of recreation value
4. Loss of land
5. Bank and channel stability
6. Erosion of landscape
7. Water quality
8. Siltation

Damage to fences, power and telephone lines were listed as prevalent problems but of relatively low consequence.

Of the problem issues raised by respondents themselves by far the most important was given as the **impact on biodiversity** (noted by 20 of the 59 respondents as a major problem). These items may have been underrated because of the natural tendency to emphasize, or only indicate, the ones provided in the questionnaire.

Table 4.1: **A rating of the importance of problems resulting from invaders based on returns from knowledgeable experts from all parts of South Africa. The rating scale used was 0=no problem to 5=major problem.**

	Rating frequency									
PROBLEM	**no rating**	**0**	**1**	**2**	**3**	**4**	**5**	**N ***	**total score**	**rank**
Listed in Questionnaire										
Water yield to dams	1	0	1	1	11	12	30	55	234	1
Water supply security	2	0	2	3	10	8	31	54	225	2
Water quality	6	3	5	15	10	12	5	50	124	7
Siltation	5	5	7	11	19	8	1	51	123	8
Erosion of landscape	4	6	9	12	10	10	6	53	133	6
Bank and channel stability	3	4	2	8	16	13	10	53	168	5
Loss of land	3	2	5	7	11	10	18	53	182	4
Loss of recreation value	1	1	7	5	11	17	14	55	188	3
Damage to fences	5	15	20	8	5	2	1	51	64	9
Damage to telephone lines	6	15	23	8	2	1	1	50	54	11
Damage to power lines	6	14	2	2	5	2	0	25	55	10
Added by Respondents									0	
Threat to biodiversity	0	0	0	0	0	6	14	20	234	
Ecological problems	0	0	0	0	0	1	1	2	9	
Degradation of natural ecosystems	0	0	0	0	0	0	2	2	10	
Threat to tourism	0	0	0	0	0	1	0	1	4	
Fire Hazard	0	0	0	0	0	0	1	1	5	
Loss of Aesthetic value	0	0	0	0	0	0	1	1	5	
Environmental change	0	0	0	0	0	0	1	1	5	
Land transformation	0	0	0	0	0	0	1	1	5	
Reduced carrying capacity	0	0	0	0	0	0	2	2	10	
Barrier - access to river	0	0	0	0	0	0	2	2	10	
Reduced sustainable yield	0	0	0	0	0	0	2	2	10	
Toxicity	0	0	0	0	2	1	0	3	10	
Loss of wildlife habitat	0	0	0	0	0	1	1	2	9	
Loss of indigenous species	0	0	0	0	1	0	1	2	8	
Loss of income	0	0	0	0	0	1	0	1	4	

* *N is the number of times this issue was allocated a score.*

Can invasions be controlled?

Few respondents felt "no" or expressed doubt, although there was recognition of the immensity of the problem. This question was further phrased in terms of mechanisms for control - could control be achieved by (i) Government/RDP Conservation bodies, (ii) by individuals or community, and (iii) by other means. Most indicated that control (or some degree of control) could be achieved through all of the above mechanisms. There were no clear regional patterns to responses. Almost all highlighted the role which government and conservation bodies have to play, with the RDP receiving several positive mentions. RDP was used here to refer to the DWAF Working for Water Programme. Some doubted that individuals or communities could contribute significantly, citing apathy together with lack of money, knowledge, incentives and legislation. Other respondents suggested that there was no other way but to get individuals and community involved. The need for the forestry companies to take responsibility was noted more than once. A number of respondents argued the urgency of getting the public involved, and some for legislation and enforcement (some dichotomy here, with others completely disbelieving in the powers of legislation). **Biocontrol** was added to the list by at least 50% of respondents as being critical to the process and especially to long-term success. Half the respondents also stressed that no programme or sector could go it alone - and that an **integrated approach** was the only way. **Government commitment** was seen as critical, as was the infusion of funds and incentives.

How do you see the problem being most effectively tackled? In your area? Regionally? Nationally?

Approaches highlighted by respondents are tabulated (Table 3.2). Although not solicited, some respondents also weighted approaches *(5 = most important, 1 = least important)*. This table is presented by province but few respondents considered different approaches for local, regional or national scales. Approaches offered should be read as applicable to wide scale clearing, but obviously influenced by the experience of respondents at local or regional level.

Responses to this question were fairly even. The majority of respondents recommended that all, or most, of the suggested approaches were appropriate, and laid a strong stress on the **integration** of approaches, and the selection of the best combination of approaches to suit particular circumstances. **Biocontrol** received the strongest support, and significant mention as the only long-term solution.

The value of legislation and of subsidies were more variously rated, with a number of respondents seeing a limited role for legislation, and strongly critical of the fact that existing legislation is not enforced, thus also questioning the value of new legislation. The use of subsidies implies farmer, landowner, community involvement in clearing programmes, and received good support in all but the Eastern Cape. **Education and awareness** were singled out as additional needs, along with initiatives on the DWAF Working for Water model.

What are the biggest gaps in our knowledge?

Responses to this question fall into two basic categories: (i) gaps in knowledge, and (ii) a strong expression of need to put knowledge into action, with operational suggestions. We have further classified responses below (if greater than one then the number of respondents on a particular issue is given in parentheses):

Gaps in our knowledge

Situation Analysis

Exact nature and extent of the problem (9); Geographical distribution;
Situation on private land
The cost of control/eradication (4); Costs of not taking action

Biological

Reproductive biology
Aliens in arid areas (invasive biology)
Seedbank dynamics (3); How to destroy seed banks
Rate of spread (4); Spread potential and dynamics; Geographical and environmental range into which species can spread
Effect and spread of garden plants
Vegetation dynamics following clearing (indigenous succession and re-colonization by same or different species); Restoration of rivers

Methodological

How to prevent the importation of new weeds
Biological control (introduction of biocontrol agents) (11); biocontrol of *Nerium oleander*; Effectiveness of biocontrol

Impacts of chemical control on other crops; correct application of herbicides.

Integrated control methods

Methods of control for specific invaders (2)

When it is necessary to take action against an invasion?

Follow-up (2)

Impacts

Impacts of annual weeds

Water use - effects on runoff (5); water use by particular species; practical examples demonstrating impacts of clearing on water

Impacts on water quality

Impacts on catchment stability

Impacts on biodiversity (2)

Putting knowledge into action

Needs and suggestions

"Enough knowledge - urgent attention must now be given to the problem"

Enough of research - need for a regional plan and coordinated, collective implementation

Enough knowledge - need for funding (2), for awareness (1), to spread the knowledge (2)

Need for information

Need for education of landowners

Need for motivation

To know how to convince the landowner that aliens are not an affordable luxury

Practical problems/issues

Community involvement and community lack of knowledge of impacts on water etc.

Roleplayer involvement

Coordination between roleplayers

Lack of leadership

Lack of public awareness

Lack of information

From this classification one of the biggest gaps in our knowledge has been a broad understanding of the nature, extent, and distribution of the problem of alien invaders. That is what this project has attempted to address. We need better to understand our situation in terms of cost, also as related to different species. Despite the strong call to down research tools and spring into action, there are clearly a number of other areas where our knowledge is inadequate and these have been classified as "biological', 'Methodological', and "Impacts'. Issues to highlight include **seedbank dynamics**, the need for more work on **biocontrol** (a dominant theme), and the need to better understand how best to tackle **control** methodologically. It is apparent too, that impacts on **water use** and **runoff** either contain too much uncertainty or are still inadequately demonstrated.

In terms of putting knowledge into action, the expressed gap with regard to methodologies of control can probably be met through the gathering and transfer of existing technologies. Under needs and problems we find **education, awareness, people's knowledge and involvement** to be the dominant theme. This would seem to express the need to broaden the base for implementation to be far **more inclusive of landowners and of community as potential roleplayers.**

The beneficial use of alien invading plants

The following is a list of suggested beneficial use as provided by questionnaire respondents. These indicate that alien invaders do often also serve as a resource, and that clearing programmes must take this into consideration.

List of direct benefits (with number of respondents in parentheses)

Firewood (33)		
Charcoal (11)		
Building material (6)		
Poles (3)	....	especially eucalypts
Fencing (3)		
Shade and shelter (2)		
Ornamental (1)		
Furniture timber (2)	....	*Acacia melanoxylon*, other species
Carving/curios (3)	....	especially *Melia* and *Jacaranda*
Woodchips/pulp (4)		
Tannin (1)	....	*Acacia mearnsii*
Mine props (1)		

Fodder (3) .... *A. cyclops, Prosopis, Atriplex*
Soil stabilization (1) .... *Atriplex*

Indirect benefits included:

Job creation (4)

Protection of the indigenous resource through provision of fuelwood (2)

Several respondents suggested that there were zero, or minimal, beneficial uses to be had from invaders. Some of these responses were linked to specific situations such as the Tsitsikamma where fuelwood is cheap and there is little need to resort to invader species. Most of the responses arguing that there is no benefit to be had from invaders came from Mpumalanga. In one case it was argued that "the benefits cannot come near the costs". In many other instances beneficial uses are limited to one or two species only, and all other species are viewed negatively. But it must be remembered that respondents were often answering for the situation within a specific area and not with regard to invaders as a whole.

To what extent are aliens likely to spread? What areas will be invaded and how quickly?

The following is a precis of responses:

Western Cape - South western region

Rivers are largely invaded but there is still scope for spread in the mountain catchment areas and those remaining uninvaded streams. The Olifants River is now being rapidly invaded. Disturbance exacerbates the situation. Several respondents gave a 10-15 year timespan either as a doubling time or for complete invasion, with the degree of control exercised very important in containing spread rates. Several rivers are expected to become totally clogged with water hyacinth.

Southern Cape coast and mountain ranges

Problems are apparent within mountain catchments, the indigenous forest and the riparian zones. Invasions are expected to double with catchments the worst affected. Farming areas are seen as the worst, especially where underutilised. Annual change in the level of invasion is visible on some farms. Control programmes are also noted as critical in slowing the rate of spread.

Little Karoo

In the Swartberg range invasions are under control thanks to constant vigilance and follow-up. In the Southern Karoo there is 'rapid' spread of *Tamarix* and *Nerium* while *Atriplex* invades heavily grazed land.

Northern Cape

Nicotiana is invading the dry riverbeds of Namaqualand and the Knersvlakte and is expected to spread to all Namaqualand rivers over the next 20 years. *Prosopis* in riverbeds is the major problem in the province.

Eastern Cape

Wattle is proving to be a faster invader than other aliens, totally covering new areas in 5-10 years. Other projected rates of spread are given as 1-2% per year; a doubling rate of 10-20 years. There remains great potential for spread - especially in the high rainfall areas.

KwaZulu-Natal

Rivers are at highest risk. Waterways, riverbanks, floodplains, road verges, drainage lines are being overrun. Coastal and inland forests at risk of being transformed. The potential for transformation (to alien vegetation) is viewed as explosive, with the environment perfect for invaders.

Northwest Province

Seedbed exists for further spread (*Melia*, wattle). Waterways will be invaded.

Northern Province and *Mpumalanga*

Wattle and gum are major problem species, with riverine areas most vulnerable and invaders spreading 'like wildfire'. The homeland areas are relatively uninvaded due to use. Elsewhere spread of invaders can be discerned annually, with the forest margins and drainage lines invaded fastest. The current rate of spread is much faster than the current rate of control. Wattle is now seen to be spreading over the landscape and not only in the riparian zones. Overall the rate of spread is described as 'very rapid', and the potential for further spread as high.

Note on spread and control:

On spread and control invasions often involve a subtle 'creeping' - a situation which changes abruptly when a fire or other disturbance triggers recruitment. Some respondents suggest that farmers "cannot afford" to practice control measures. The real difficulty may be that farmers simply don't see the problem when it is still manageable - but only recognize it (if at all) when difficult to control. What is therefore most required is that a process be initiated whereby farmers, owners and all custodians of the land receive the necessary education, awareness and understanding of invaders and the invasion process.

What species are the worst invaders?

This question was phrased as "What in your view are the top 10 invaders in your area (based upon current levels of invasion and the potential for further invasion if unchecked."

A tabulation of responses of experts queried through the questionnaire (not included in the text) is summarized briefly here. There are obvious regional differences but ***Acacia mearnsii*** is outstanding as the biggest and most widespread recognised national problem. *Pinus* and *Eucalyptus* are also almost ubiquitous invaders. Pines are considered likely to spread to all areas, especially in the wetter mountain catchments of the Cape mountains and in the Drakensberg and eastern escarpment from the Eastern Cape to Tzaneen (D.M. Richardson pers. comm. 1997). *Chromolaena, Lantana, Solanum, Prosopis, Sesbania, Hakea*, various other *Acacia* species, and a vast array of further invaders all appear on the list of critical problem species. Some provincial distinctions follow:

Eastern Cape Province

Acacia mearnsii ranks worst. Responses are very dependent further on regional differences, with *Hakea, Pinus spp, Acacia dealbata, Acacia melanoxylon* and other *Acacias* (*A. longifolia and A. saligna*), and *Eucalyptus* all ranking as important. Other species include *Solanum, Sesbania, Caesalpinia* and *Rubus*.

KwaZulu-Natal

The response base for this province is too limited to allow conclusions but *Rubus, Chromolaena, Acacia mearnsii/dealbata*, and *Lantana* are clearly identified. So too are aquatic weeds.

Mpumalanga and Northern Province

Acacia mearnsii and *Acacia dealbata* rank as by far the most problematic grouping of species (with 34 species listed in all). *Lantana camara* and *Solanum mauritanum* receive very high mention with *Lantana* probably viewed as the bigger problem. The distribution of *Pinus* spp is more limited but it nevertheless ranks as one of the major problem species. This also applies to *Eucalyptus*. Additional high ranking species are *Melia azederach*, *Populus*, *Caesalpinia decapetala*, *Jacaranda*, *Sesbania*, *Psidium guajava*, and *Rubus*. *Opuntia* is a problem in the arid areas.

Northern Cape

Prosopis, followed by *Nicotiana*.

North West Province

Acacia mearnsii rates highest, followed by *Melia azederach* and then *Prosopis*. Other particular problem species (of 14 identified) are *Cereus*, *Populus*, *Sesbania*, *Lantana*, *Chromolaena* and *Arundo donax*. Bush encroachment was identified as a major issue in this province.

***Western Cape Province* (western and south-western Cape)**

22 species are listed amongst the 10 worst. *Acacia mearnsii* is recognised in almost every instance as the 'worst' invader, scoring far higher than any other species. From there it is hard to separate between *Hakea*, *Acacia saligna*, *Acacia cyclops*, and *Pinus* spp. *Sesbania* is viewed as the major problem in some areas, and *Eucalyptus* also ranks high.

***Western Cape Province* (southern Cape)**

20 different species were listed. Again the top-scorer by far was *Acacia mearnsii*, ranking as number 1 or 2 in almost every instance. This was followed by *Pinus* spp. Problems with *Acacia melanoxylon*, *Hakea* and *Acacia cyclops* are hard to separate, followed by *Eucalyptus*, *Sesbania* and *Cortaderia* (pampas grass). It is interesting that *Populus* did not receive a mention.

***Western Cape Province* (Little Karoo)**

Nerium oleander, *Hakea*, and *Acacia mearnsii* are followed by *Sesbania*, *Pinus*, *Tamarix* and *Atriplex*, but this rating is from a very limited response base.

Appendix 5:

Table 1: Area of alien invasion for each species within each Province and Lesotho. A key to the province abbreviations is provided at the end of the table

Species	EC		FS		GA		KZ		LE		MP		NC		NP		NW		WC		RSA	
	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond
Acacia baileyana	6 958	30	151	4	49	1	0	0	0	0	0	0	0	0	0	0	0	0	180 585	32	187 743	67
Acacia cyclops	212 790	8 579	0	0	0	0	0	0	0	0	0	0	123 101	27 722	0	0	0	0	1 519 901	302 852	1 855 792	339 153
Acacia dealbata	65 730	18 876	16 285	3 632	1 324	330	136 004	22 115	1 359	34	386 702	9 846	0	0	7 700	193	0	0	67	4	615 171	55 030
Acacia decurrens	0	0	0	0	2 681	966	42 985	1 497	0	0	386 129	68	0	0	7 554	5	0	0	1 797	731	441 146	3 267
Acacia elata	0	0	0	0	38	1	0	0	0	0	0	0	0	0	0	0	0	0	62	1	100	2
Acacia longifolia	73 212	7 155	0	0	0	0	28 527	595	0	0	0	0	0	0	0	0	0	0	98 421	12 835	200 160	20 585
Acacia mearnsii	344 535	49 021	3 421	931	9 962	2 966	190 542	12 896	461	12	1 046 482	27 890	24	1	248 425	1 097	47 671	1 275	584 225	35 214	2 475 748	131 303
Acacia melanoxylon	22 151	963	0	0	0	0	72 390	543	0	0	986 200	537	0	0	36 881	2 016	0	0	83 795	3 137	1 201 417	7 196
Acacia podalyriifolia	0	0	0	0	60	5	40 830	4	0	0	0	0	0	0	0	0	0	0	378	38	41 268	47
Acacia pycnantha	218	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7 383	398	7 601	409
Acacia saligna	202 952	12 809	0	0	0	0	0	0	0	0	0	0	24	4	0	0	0	0	1 649 179	95 191	1 852 155	108 004
Acacia mixed species	36 640	20 378	6 301	3 433	3 267	2 173	116 584	24 912	410	197	8 908	2 754	0	0	414	10	0	0	1 938	1 059	174 462	54 916
Acanthospermum hispidum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	17	0
Agave species	11 575	497	0	0	0	0	0	0	0	0	187	5	298	0	573 341	14 333	17 025	426	1 202	1	603 628	15 262
Ageratum conyzoides	0	0	0	0	0	0	0	0	0	0	4 598	358	0	0	135	47	0	0	0	0	4 733	405
Alnus viridis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	389	0	389	0
Aristolochia elegans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	161	6	0	0	0	0	161	6
Anthemis species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	290	7	0	0	0	0	290	7
Argemone mexicana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8 737	1 203	0	0	0	0	8 737	1 203
Argemone ochroleuca	0	0	0	0	0	0	0	0	0	0	112	19	0	0	11 297	2 403	0	0	0	0	11 409	2 422
Argemone species	0	0	0	0	0	0	0	0	0	0	4 598	300	0	0	2 545	1 195	0	0	1 988	298	9 131	1 793
Arundo donax	15 078	155	695	17	0	0	112 307	1 372	0	0	0	0	456	2	392	10	47 948	1 303	11 072	288	187 948	3 147
Atriplex lindleyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	171 434	12 929	171 434	12 929
Atriplex nummularia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 688	42	1 688	42
Atriplex semibaccata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 688	42	1 688	42
Azolla filiculoides	21	1	695	17	0	0	0	0	0	0	0	0	0	0	0	0	5 148	1 225	0	0	5 864	1 243
Bidens pilosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	17	0
Bromus species	0	0	0	0	0	0	0	0	0	0	0	0	1 890	1 654	0	0	0	0	24 435	5 214	26 325	6 868
Caesalpinia decapetala	727	20	0	0	0	0	161 982	6 674	0	0	720 070	3 842	0	0	434 464	13 412	0	0	0	0	1 317 243	23 948
Callitris glauca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160	1	160	1

Species	EC		FS		GA		KZ		LE		MP		NC		NP		NW		WC		RSA	
	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond
Canna indica	663	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	663	0
Cardiospermum grandiflor	0	0	0	0	0	0	0	0	0	0	300	8	0	0	48	1	0	0	0	0	348	9
Cardiospermum halicabum	0	0	0	0	0	0	0	0	0	0	2 712	49	0	0	7 455	211	0	0	0	0	10 167	260
Carica papaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104	3	0	0	0	0	104	3
Cassia species	7 366	55	0	0	0	0	1 414	272	0	0	75	2	0	0	7 562	727	0	0	0	0	16 417	1 056
Castanea dentata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	261	8	261	8
Casuarina cunninghamiana	8 685	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8 685	79
Catharanthus roseus	0	0	0	0	0	0	0	0	0	0	4 139	137	0	0	588	56	0	0	0	0	4 727	193
Cedrela toona	0	0	0	0	0	0	0	0	0	0	541	14	0	0	17 635	1 955	0	0	0	0	18 176	1 969
Cedrus deodara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Cereus species	58	0	0	0	43	1	0	0	0	0	33 716	843	0	0	623 399	15 585	85 238	5 440	3 234	81	745 688	21 950
Cestrum laevigatum	1 192	76	0	0	0	0	0	0	0	0	0	0	0	0	72	5	0	0	0	0	1 264	81
Chamaesyce prostata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 133	37	0	0	0	0	2 133	37
Chenopodium carinatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	1	0	0	0	0	17	1
Chromolaena odorata	203	5	0	0	0	0	326 139	43 178	0	0	343	9	0	0	206 278	35	1 692	0	0	0	534 655	43 227
Cinnamomum camphoratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Cirsium species	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0
Conyza bonariensis	0	0	0	0	0	0	0	0	0	0	112	1	0	0	2 382	39	0	0	0	0	2 494	40
Cortaderia sp	826	27	0	0	0	0	0	0	0	0	42	1	0	0	0	0	0	0	2 863	69	3 731	97
Cupressus glabra	0	0	0	0	48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	1
Cupressus species	0	0	0	0	0	0	0	0	0	0	10 192	1	0	0	1 172	0	0	0	0	0	11 364	1
Datura species	0	0	0	0	0	0	0	0	0	0	4 139	260	0	0	2 847	330	0	0	1 688	42	8 674	632
Delonix regia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 597	15	0	0	0	0	1 597	15
Echinopsis spachiana	670	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	670	7
Eichhornia crassipes	76	67	695	17	455	11	35	9	0	0	33 759	914	0	0	622 342	15 569	2 442	143	16 714	472	676 518	17 202
Eucalyptus species	164 943	9 747	13 561	2 775	9 046	3 189	167 418	5 052	636	16	521 988	7 910	1 967	24	865 547	18 108	75 247	3 601	608 976	12 527	2 429 329	62 949
Ficus species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	66	0
Flaveria bidentis	0	0	0	0	0	0	0	0	0	0	3 588	155	0	0	1 273	145	0	0	0	0	4 861	300
Gleditsia triacanthos	4 975	41	0	0	48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5 023	42
Grevillea robusta	642	0	0	0	0	0	0	0	0	0	4 842	171	0	0	680	37	0	0	0	0	6 164	208
Hakea species	14 760	1 927	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	708 689	62 162	723 449	64 089
Homalanthus populifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	261	8	261	8
Hypericum perforatum	0	0	0	0	0	0	259	26	0	0	0	0	0	0	0	0	0	0	0	0	259	26
Ipomoea sp	663	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	663	0
Jacaranda mimosifolia	17 628	56	0	0	43	1	86 980	658	0	0	668 785	2 320	0	0	972 201	18 970	73 321	1 833	50	0	1 819 008	23 838
Jatropha species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 154	54	2 154	54

Species	EC		FS		GA		KZ		LE		MP		NC		NP		NW		WC		RSA	
	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond
Lantana camara	2 297	1 156	0	0	498	12	235 849	10 518	0	0	1 071 171	31 825	0	0	872 569	24 039	53 893	1 684	684	34	2 236 961	69 268
Leptospermum laevigatum	81	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	118 900	3 817	118 981	3 854
Leucaena leucocephala	7	1	0	0	0	0	22 599	2	0	0	454	11	0	0	0	0	0	0	0	0	23 060	14
Ligustrum japonicum	221	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221	1
Ligustrum lucidum	0	0	0	0	0	0	0	0	0	0	18 859	267	0	0	8 324	171	0	0	0	0	27 183	438
Ligustrum ovalifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	66	0
Litsea sebifera	0	0	0	0	0	0	15 755	788	0	0	0	0	0	0	0	0	0	0	0	0	15 755	788
Macfadyena unguiscati	0	0	0	0	0	0	0	0	0	0	449	67	0	0	435	84	0	0	0	0	884	151
Mangifera indica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104	3	0	0	0	0	104	3
Melia azedarach	37 462	91	0	0	93	17	220 764	12 592	0	0	1 061 933	13 129	0	0	1 637 283	43 009	81 401	3 787	66	0	3 039 002	72 625
Metrosideros excelsus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0	78	0
Mimosa pigra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	981	21	0	0	0	0	981	21
Morus alba	0	0	0	0	0	0	16 931	169	0	0	963 824	215	0	0	17 141	36	64	2	0	0	997 960	422
Myoporum serratum	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0
Myriophyllum aquaticum	0	0	0	0	0	0	0	0	0	0	440	69	0	0	0	0	150	23	372	39	962	131
Nerium oleander	3 131	76	0	0	0	0	0	0	0	0	0	0	376	147	0	0	51 413	1 285	56 522	2 308	111 442	3 816
Nicotiana glauca	12 135	33	0	0	0	0	0	0	636	16	71 945	1 804	2 700	1 224	182 595	4 630	0	0	4 324	583	274 335	8 290
Nicotiana tabacum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	17	0
Opuntia species	47 375	1 885	0	0	43	1	133 344	33 178	341	9	147 633	3 661	642	227	1 378 756	34 595	64 722	1 618	43 858	182	1 816 714	75 356
Other alien species	1 042	156	0	0	0	0	0	0	0	0	0	0	475	6	0	0	0	0	0	0	1 517	162
Paraserianthes lophantha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14 225	576	14 225	576
Passiflora edulis	0	0	0	0	0	0	2 366	0	0	0	1 871	43	0	0	687	25	0	0	0	0	4 924	68
Passiflora sp	0	0	0	0	0	0	0	0	0	0	163	4	0	0	0	0	0	0	0	0	163	4
Passiflora subpeltata	0	0	0	0	0	0	0	0	0	0	1 780	18	0	0	0	0	0	0	0	0	1 780	18
Pereskia aculeata	0	0	0	0	0	0	295	44	0	0	0	0	0	0	0	0	0	0	0	0	295	44
Pereskia sp	0	0	0	0	0	0	13 505	2 026	0	0	0	0	0	0	0	0	0	0	151	4	13 656	2 030
Phoenix sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phragmites sp?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3 151	1 537	3 151	1 537
Phytolacca octandra	11	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	10
Pinus species	311 015	8 917	9 973	1 758	1 190	93	114 926	5 184	636	16	489 334	3 194	92	0	246 687	2 846	0	0	1 778 420	55 085	2 952 273	77 093
Pistia stratiotes	0	0	0	0	0	0	0	0	0	0	536	101	0	0	4	2	0	0	0	0	540	103
Pittosporum undulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	343	11	343	11
Populus species	58 206	722	9 233	2 001	4 745	1 299	72 310	1 818	1 996	50	985 637	1 849	3 317	476	18 476	48	51 285	2 622	99 814	4 350	1 305 019	15 235
Prosopis species	16 596	205	116 606	4 834	0	0	0	0	0	0	0	0	1 047 135	134 495	0	0	210 968	27 370	417 924	6 245	1 809 229	173 149
Prunus serotina	0	0	0	0	0	0	80	8	0	0	0	0	0	0	0	0	0	0	0	0	80	8
Psidium guajava	814	147	0	0	0	0	104 250	4 550	0	0	618 542	16 153	0	0	36 159	2 773	79	2	0	0	759 844	23 625

Species	EC		FS		GA		KZ		LE		MP		NC		NP		NW		WC		RSA	
	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond	Tot	Cond
Pyracantha	106	1	16	4	0	0	259	26	0	0	0	0	22	0	0	0	0	0	0	0	403	31
Quercus species	11 152	334	169	31	0	0	0	0	0	0	6 699	167	16	0	24 527	2 142	0	0	4 663	129	47 226	2 803
Ricinus communis	12 064	2	0	0	0	0	57	0	0	0	590 052	437	0	0	591 512	15 280	71	2	389	2	1 194 142	15 723
Robinia pseudoacacia	455	4	0	0	0	0	1 936	48	0	0	0	0	95	0	0	0	554	83	35	0	3 075	135
Rubus species	0	0	0	0	0	0	163 475	11 845	0	0	457 481	13 548	16	0	20 922	888	0	0	5 453	180	647 347	26 461
Salix species	15 714	435	23 541	4 716	6 012	1 780	39 429	2 113	2434	154	15 125	1 774	935	91	0	0	14 795	1 277	3 849	68	121 834	12 408
Salvinia molesta	0	0	0	0	455	11	0	0	0	0	2 304	132	0	0	0	0	0	0	0	0	2 759	143
Schinus molle	82 799	2 061	0	0	0	0	0	0	0	0	0	0	1 346	5	0	0	0	0	683	4	84 828	2 070
Schinus sp	0	0	0	0	0	0	0	0	0	0	0	0	116	3	0	0	3 877	97	0	0	3 993	100
Sesbania punicea	900	117	0	0	498	12	103 999	1 940	0	0	622 663	1 205	361	9	635 274	15 651	8 315	1 091	32 495	4 122	1 404 505	24 147
Solanum mauritianum	43 380	4 262	0	0	0	0	404 998	44 265	0	0	1 053 094	36 143	0	0	258 940	4 766	1 692	42	160	1	1 762 264	89 479
Solanum seaforthianum	0	0	0	0	0	0	0	0	0	0	2 272	5	0	0	290	7	0	0	0	0	2 562	12
Sonchus oleraceus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	66	0
Sorghum halepense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 257	43	0	0	0	0	1 257	43
Stenocarpus sinuatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Syncarpia glomulifera	0	0	0	0	0	0	0	0	0	0	5 341	1	0	0	24	1	0	0	0	0	5 365	2
Tamarix sp	0	0	0	0	0	0	0	0	0	0	0	0	265	7	0	0	0	0	3 135	597	3 400	604
Tecoma stans	0	0	0	0	0	0	0	0	0	0	4 888	415	0	0	1 827	176	0	0	0	0	6715	591
Thevetia peruviana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 257	7	0	0	0	0	1 257	7
Tithonia diversifolia	0	0	0	0	0	0	0	0	0	0	152	39	0	0	0	0	0	0	0	0	152	39
Ulmus species	0	0	0	0	0	0	0	0	0	0	6 699	167	0	0	6 836	171	0	0	0	0	13 535	338
Uncertain	69	23	2 194	174	0	0	0	0	0	0	0	0	0	0	497	231	0	0	0	0	2760	428
Verbena bonariensis	0	0	0	0	0	0	0	0	0	0	112	1	0	0	2 382	223	0	0	0	0	2 494	224
Xanthium species	0	0	0	0	0	0	0	0	0	0	2 931	125	0	0	8 972	3 381	0	0	989	495	12 892	4 001
Zinnia peruviana	0	0	0	0	0	0	0	0	0	0	1 780	110	0	0	0	0	0	0	0	0	1 780	110

EC	-	Eastern Cape	MP	-	Mpumalanga
FS	-	Free State	NC	-	Northern Cape
GA	-	Gauteng	NP	-	Northern Province
KZ	-	KwaZulu-Natal	NW	-	North west Province
LE	-	Lesotho	WC	-	Western Cape

Summary of the extent of invasion of tertiary catchments by alien plant species (in hectares and as a percentage of the catchment area)

Table 2.1 : Eastern Cape

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
D12	Middle Orange (Aliwal North)	143 605	0	0.00	0	0.00
D13	Kraai	935 265	68	0.01	24	0.00
D14	Stormberg & Middle Orange	545 340	0	0.00	0	0.00
D17	Sinqua & Sinqunyane	708	0	0.00	0	0.00
D18	Upper Orange	80 535	0	0.00	0	0.00
D32	Seacow	72 030	245	0.34	159	0.22
D34	Orange (below Gariep Dam)	13 018	0	0.00	0	0.00
D35	Orange (Gariep Dam)	398 975	251	0.06	83	0.02
J31	Upper Olifants	23 725	271	1.14	7	0.03
J32	Traka	151 164	1 478	0.98	37	0.02
J33	Middle Olifants	3 289	0	0.00	0	0.00
K60	Plettenberg Bay & Keurbooms	870	379	43.57	181	20.80
K70	Groot & Bloukrans	5 646	2 079	36.82	363	6.42
K80	Lottering R to Cape St Francis	119 167	12 500	10.49	7 440	6.24
K90	Bietou	155 338	10 104	6.50	7 475	4.81
L11	Salt (Nuweveld Mntns, endoreic)	967	0	0.00	0	0.00
L12	Salt	142 045	0	0.00	0	0.00
L21	Upper Buffalo	275	0	0.00	0	0.00
L22	Lower Buffalo	64 735	3	0.01	0	0.00
L23	Kariega	287 214	94	0.03	0	0.00
L30	Upper Groot	152 766	0	0.00	0	0.00
L40	Hops	135 645	0	0.00	0	0.00
L50	Sandpoort	102 325	1 233	1.21	31	0.03
L60	Heuningklip	134 819	0	0.00	0	0.00
L70	Lower Groot & Gamtoos	369 749	52 952	14.32	3 408	0.92
L81	Baviaanskloof	122 049	104 476	85.60	9 459	7.75
L82	Kouga	232 986	57 555	24.70	10 213	4.38
L90	Lower Gamtoos	120 040	23 368	19.47	984	0.82
M10	Swartkops	139 349	54 423	39.06	4 905	3.52
M20	Maitland to Bakens (P.E.)	65 976	4 651	7.05	4 147	6.29
M30	Coega	55 831	11 302	20.24	2 306	4.13
N11	Van Ryneveld	147 392	1 613	1.09	157	0.11

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
N12	Upper Sundays	204 286	751	0.37	198	0.10
N13	Kamdeboo	148 542	5 198	3.50	1 749	1.18
N14	De Hoop	185 523	1 043	0.56	13	0.01
N21	Upper Middle Sundays	215 594	1 510	0.70	348	0.16
N22	Lower Middle Sundays	233 432	220	0.09	1	0.00
N23	Skoenmakers	78 239	0	0.00	0	0.00
N24	Traka & Middle Sundays	251 279	1 404	0.56	42	0.02
N30	Vogel	193 176	311	0.16	50	0.03
N40	Lower Sundays	439 797	13 142	2.99	1 406	0.32
P10	Bushmans	275 704	13 970	5.07	2 244	0.81
P20	Alexandria coast	74 876	13 235	17.68	10 829	14.46
P30	Kariega	64 603	23 706	36.70	2 799	4.33
P40	Cowie & Riet	115 623	23 263	20.12	7 022	6.07
Q11	Great Brak	157 660	39	0.02	3	0.00
Q12	Teebus	169 209	71	0.04	15	0.01
Q13	Upper Great Fish	172 539	12	0.01	2	0.00
Q14	Klein Brak	277 543	1 207	0.43	404	0.15
Q21	Upper Great Fish (source)	98 062	521	0.53	150	0.15
Q22	Willem Burgers	73 771	1 502	2.04	11	0.01
Q30	Upper Middle Gt Fish	193 336	4 752	2.46	948	0.49
Q41	Upper Tarka	129 178	0	0.00	0	0.00
Q42	Elands	82 116	0	0.00	0	0.00
Q43	Vlekpoort	150 813	0	0.00	0	0.00
Q44	Tarka	112 848	68	0.06	14	0.01
Q50	Middle Gt Fish	124 033	1 791	1.44	348	0.28
Q60	Baviaans	81 646	5	0.01	4	0.01
Q70	Lower Middle Gt Fish	95 839	1 643	1.71	346	0.36
Q80	Little Fish	283 671	724	0.26	157	0.06
Q91	Lower Gt Fish	147 710	1 704	1.15	690	0.47
Q92	Koonap	333 446	142	0.04	124	0.04
Q93	Lower Gt Fish (to mouth)	163 294	9 981	6.11	1 590	0.97
Q94	Kat	171 539	3 038	1.77	2 172	1.27
R10	Keiskamma	269 759	6 755	2.50	4 605	1.71
R20	Buffalo	128 699	3 243	2.52	1 461	1.14
R30	Nahoon R to Morgans Bay	228 587	3 681	1.61	835	0.37
R40	Border Coast	84 738	6 777	8.00	2 841	3.35

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
R50	Mgwaluma & Bira (Peddie)	80 046	4 324	5.40	2 741	3.42
S10	White Kei	292 529	0	0.00	0	0.00
S20	Indwe	160 665	0	0.00	0	0.00
S31	Klaas Smits	265 189	0	0.00	0	0.00
S32	Black Kei	425 245	1 186	0.28	547	0.13
S40	Thomas & Middle Kei	217 028	21 441	9.88	15 058	6.94
S50	Tsomo	343 222	0	0.00	0	0.00
S60	Kubusi	128 748	30 999	24.08	14 824	11.51
S70	Gcuwa & Lower Kei	215 681	3 571	1.66	264	0.12
T11	Xuca	248 742	4 178	1.68	496	0.20
T12	Upper Bashee	214 708	0	0.00	0	0.00
T13	Lower Bashee	141 584	96	0.07	67	0.05
T20	Mtata	259 860	20 283	7.81	3 181	1.22
T31	Upper Mzimvubu	122 435	21 416	17.49	3 275	2.67
T32	Mzimtlava	156 994	14 155	9.02	3 430	2.18
T33	Kaneka	435 871	18 003	4.13	4 819	1.11
T34	Tina	318 988	17 732	5.56	2 733	0.86
T35	Tsitsa & Inxu	492 667	3 150	0.64	624	0.13
T36	Lower Umzimvubu	72 633	324	0.45	154	0.21
T40	Mtamvuna	86 589	2 621	3.03	782	0.90
T60	Wildcoast	372 613	15 274	4.10	1 062	0.29
T70	Coast S of Port St Johns	188 094	6 370	3.39	1 378	0.73
T80	Coast: Xhora to Mnwasa	104 073	597	0.57	227	0.22
T90	Coast: Qolora to Nqabara	262 062	1 785	0.68	795	0.30
Eastern Cape	16739817	671 958	4.01	151258	0.90	
T80	Coast: Xhora to Mnwasa	104 073	463	0.44	149	0.14
T90	Coast: Qolora to Nqabara	262 062	1 121	0.43	603	0.23
Eastern Province		16 986 983	438 387	2.58	94 276	0.55

Table 2.2 : Free State

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
C12	Upper Middle Vaal & Waterval	208 782	662	0.32	249	0.12
C13	Klip	344 746	3 146	0.91	1 142	0.33
C21	Suikerbos	178	179	100.13	156	87.62
C22	Klip (JHB) & Vaal Barrage	132 001	7 619	5.77	3 815	2.89
C23	Mooi & Upper Middle Vaal	188 721	920	0.49	129	0.07
C24	Skoonspruit & Middle Vaal	137 117	923	0.67	46	0.03
C25	Lower Middle Vaal	393 614	7 338	1.86	183	0.05
C41	Upper Vet	699 307	0	0.00	0	0.00
C42	Sand	755 374	0	0.00	0	0.00
C43	Lower Vet	460 192	6 152	1.34	154	0.03
C51	Riet & Kaffir	1 349 201	7 517	0.56	431	0.03
C52	Modder	1 709 733	38 311	2.24	2 876	0.17
C60	Vals	786 865	6 477	0.82	162	0.02
C70	Rhenoster	665 389	1	0.00	0	0.00
C81	Upper Wilge	613 503	21 240	3.46	8 025	1.31
C82	Middle Wilge	446 682	3 878	0.87	1 915	0.43
C83	Liebenbergsvlei & Lower Wilge	752 149	9 384	1.25	3 747	0.50
C91	Lower Vaal (Vaalharts)	778 527	28 702	3.69	718	0.09
D11	Madimabatso (Lesotho)	30	0	0.00	0	0.00
D12	Middle Orange (Aliwal North)	153 103	425	0.28	11	0.01
D14	Stormberg & Middle Orange	69 174	0	0.00	0	0.00
D15	Kornet	38 676	0	0.00	0	0.00
D16	Upper Orange (Source)	59	0	0.00	0	0.00
D21	Upper Caledon	151 299	0	0.00	0	0.00
D22	Upper Middle Caledon	302 407	0	0.00	0	0.00
D23	Middle Caledon	367 482	0	0.00	0	0.00
D24	Lower Caledon	659 818	0	0.00	0	0.00
D31	Orange Vanderkloof Dam	277 923	0	0.00	0	0.00
D32	Seacow	64	0	0.00	0	0.00
D33	Middle Orange	205 229	234 33	11.42	586	0.29
D34	Orange (below Gariep Dam)	185 742	0	0.00	0	0.00
D35	Orange (Gariep Dam)	154 628	0	0.00	0	0.00
V11	Upper Tugela	1 993	0	0.00	0	0.00
V12	Klip	1 995	0	0.00	0	0.00
V31	Upper Buffalo (Newcastle)	1 904	0	0.00	0	0.00
V60	Sundays & Middle Tugela	142	0	0.00	0	0.00
Free State		12 993 751	166 307	1.28	243 46	0.19

Table 2.3 : Gauteng

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
A21	Crocodile (Witwatersrand)	357 102	3 357	0.94	2 880	0.81
A23	Sand & Pienaars (Pretoria)	247 694	1 058	0.43	933	0.38
B20	Wilge	152 840	4 324	2.83	1 766	1.16
B31	Elands	76 126	1 805	2.37	397	0.52
B32	Moes & Upper Middle Olifants	194	194	99.99	29	15.00
C12	Upper Middle Vaal & Waterval	24 031	105	0.44	47	0.20
C21	Suikerbos	267 856	2 292	0.86	1 022	0.38
C22	Klip (JHB) & Vaal Barrage	372 618	9 113	2.45	5 952	1.60
C23	Mooi & Upper Middle Vaal	153 103	3	0.00	2	0.00
C83	Liebenbergsvlei & Lower Wilge	339	3	0.94	1	0.42
Gauteng		1 651 903	22 254	1.35	13 031	0.79

Table 2.4 : KwaZulu-Natal

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
C13	Klip R	222	31	14.18	16	7.09
C81	Upper Wilge R	1 496	179	11.95	57	3.78
D16	Upper Orange R (Source)	1 075	0	0.04	0	0.00
D17	Sinqua & Sinqunyane R	345	0	0.06	0	0.00
T31	Upper Mzimvubu R	236 309	11 270	4.77	3 274	1.39
T32	Mzimtlava R	137 535	15 524	11.29	3 999	2.91
T33	Kaneka R	8 444	640	7.58	282	3.33
T40	Mtamvuna R	134 048	42 431	31.65	12 572	9.38
T51	Upper Mzimkulu R	273 790	7 907	2.89	2 376	0.87
T52	Lower Mzimkulu R	392 411	98 376	25.07	22 968	5.85
U10	Mkomazi R	438 557	10 987	2.51	4 376	1.00
U20	Mgeni R	443 866	30 002	6.76	8 133	1.83
U30	Mdloti to Mhlali R	130 484	19 734	15.12	7 652	5.86
U40	Mvoti R	273 659	53 423	19.52	15 327	5.60
U50	Nomoti R	29 586	575	1.94	306	1.03
U60	Mbokodweni, Mlazi, Mhlatuzana & Umbilo R	152 135	25 157	16.54	4 057	2.67
U70	Lovu R	108 949	4 046	3.71	2 225	2.04
U80	KZN South Coast	251 921	7 822	3.11	4 366	1.73
V11	Upper Tugela	260 299	24 563	9.44	3 778	1.45
V12	Klip R	213 381	5 925	2.78	2 176	1.02
V13	Little Tugela R	134 316	8 029	5.98	2 114	1.57
V14	Upper Middle Tugela R	150 755	59 517	39.48	9 884	6.56
V20	Mooi R	286 797	26 425	9.21	5 526	1.93
V31	Upper Buffalo R (Newcastle)	358 472	10 341	2.88	4 101	1.14
V32	Middle Buffalo R	401 795	5 310	1.32	608	0.15
V33	Lower Buffalo R	183 675	2 625	1.43	609	0.33
V40	Middle Tugela R	175 359	3 897	2.22	1 368	0.78
V50	Lower Tugela R	134 811	13 939	10.34	2 268	1.68
V60	Sundays & Middle Tugela R	370 906	15 907	4.29	4 064	1.10
V70	Boesmans R	191 446	80 846	42.23	24 847	12.98
W11	Matigulu R	95 225	40 338	42.36	7 761	8.15
W12	Mhlatuze R	419 889	164 572	39.19	53 245	12.68
W13	Mlalazi R	49 557	15 314	30.90	2 385	4.81
W21	White Mfolozi R	527 348	16 155	3.06	3 352	0.64

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
W22	Black Mfolozi R	356614	5 128	1.44	1 907	0.53
W23	Mfolozi R	116 659	18 434	15.80	3 310	2.84
W31	Upper & Middle Mkuze R	462 920	28 513	6.16	6 118	1.32
W32	Hluluwe & Lower Mkuze R (Lake St Lucia)	490 034	4 680	0.95	2 207	0.45
W41	Manzana & Bivana R	169 094	2 656	1.57	755	0.45
W42	Upper Pongola R	245 026	23 721	9.68	13 001	5.31
W43	Ngwavuma R	63 694	679	1.07	238	0.37
W44	Middle Pongola R (Pongolapoort Dam)	125 148	1 015	0.81	436	0.35
W45	Lower Pongola R	179 728	1 425	0.79	499	0.28
W51	Mkonda R	249	0	0.00	0	0.00
W57	Great Usutu R	23 334	333	1.43	252	1.08
W70	Maputaland	258 226	13 621	5.27	2 070	0.80
KwaZulu/Natal		9 459 590	922 012	9.75	250 862	2.65

Table 2.5 : Lesotho

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
C81	Upper Wilge	1 030	0	0.00	0	0.00
D11	Madimabatso (Lesotho)	335 800	270	0.08	54	0.02
D12	Middle Orange (Aliwal North)	46	0	0.00	0	0.00
D13	Kraai	56	0	0.00	0	0.00
D15	Kornet	297 282	0	0.00	0	0.00
D16	Upper Orange (Source)	450 322	265	0.06	26	0.01
D17	Sinqua & Sinqunyane	716 608	1 200	0.17	261	0.04
D18	Upper Orange	545 178	722	0.13	161	0.03
D21	Upper Caledon	204 929	0	0.00	0	0.00
D22	Upper Middle Caledon	317 431	0	0.00	0	0.00
D23	Middle Caledon	183 114	0	0.00	0	0.00
D24	Lower Caledon	1 585	0	0.00	0	0.00
T31	Upper Mzimvubu	529	0	0.00	0	0.00
T33	Kaneka	680	0	0.00	0	0.00
T34	Tina	427	0	0.00	0	0.00
T51	Upper Mzimkulu	294	0	0.00	0	0.00
U10	Mkomazi	181	0	0.00	0	0.00
V11	Upper Tugela	1 154	0	0.00	0	0.00
V13	Little Tugela	221	0	0.00	0	0.00
V70	Boesmans	111	0	0.00	0	0.00
Lesotho		3 056 978	2 457	0.08	502	0.02

Table 2.6 : Mpumalanga

Tertiary	River system	Area (ha)	Total invaded area		Condensed invaded area	
			(ha)	(%)	(ha)	(%)
A23	Sand & Pienaars (Pretoria)	1 573	0	0.00	0	0.00
B11	Upper Olifants	471 537	458	0.10	94	0.02
B12	Klein Olifants	239 086	318	0.13	87	0.04
B20	Wilge	282 792	3 405	1.20	552	0.20
B31	Elands	326 625	21 154	6.48	3 708	1.14
B32	Moes & Upper Middle Olifants	477 585	28 014	5.87	1 165	0.24
B41	Steelpoort	399 822	60 489	15.13	6 422	1.61
B42	Spekboom	209 153	105 009	50.21	15 298	7.31
B51	Middle Olifants	19 178	11 008	57.40	1 924	10.03
B60	Blyde	192 855	181 412	94.07	26 741	13.87
B73	Klaserie, Timbavati & Lower Olifants	178 972	8 281	4.63	607	0.34
C11	Upper Vaal	877 559	16 721	1.91	5 075	0.58
C12	Upper Middle Vaal & Waterval	416 459	1 730	0.42	912	0.22
C13	Klip	172 465	1 451	0.84	627	0.36
C21	Suikerbos	85 945	22	0.03	3	0.00
V31	Upper Buffalo (Newcastle)	34 354	937	2.73	808	2.35
W42	Upper Pongola	137 070	662	0.48	660	0.48
W51	Mkonda	265 895	1 221	0.46	997	0.38
W52	Ohlelo	87 630	536	0.61	355	0.41
W53	Ngwempisi	158 489	843	0.53	586	0.37
W54	Upper Usutu	79 636	741	0.93	162	0.20
W55	Mpuluzi	165 917	672	0.40	263	0.16
W56	Klein Usutu	27 345	105	0.38	16	0.06
W60	Mbuluzi	2 732	0	0.00	0	0.00
X11	Upper Komati	352 727	46 821	13.27	5 394	1.53
X12	Middle Komati	249 819	26 559	10.63	2 649	1.06
X13	Lower Komati	167 045	617	0.37	36	0.02
X14	Lomati	92 232	20 998	22.77	2 121	2.30
X21	Upper Crocodile & Elands	309 112	297 529	96.25	36 698	11.87
X22	Middle Crocodile	236 645	179 550	75.87	18 497	7.82
X23	Kaap	164 002	116 410	70.98	12 275	7.48
X24	Lower Crocodile	334 782	8 233	2.46	2 794	0.83
X31	Upper Sabie	223 868	110 023	49.15	33 683	15.05
X32	Sand	73 565	9 687	13.17	2 324	3.16
X33	Lower Sabie (KNP)	143 184	15 678	10.95	1 475	1.03
X40	Nwaswitsintso & Nwanedzi (KNP)	299 399	521	0.17	139	0.05
Mpumalanga		7 957 056	1 277 814	16.06	185 149	2.33

Table 2.7 : Northern Cape

Tertiary catchment	*River system*	*Area (ha)*	*Total invaded area*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
C33	Lower Harts	692 075	0	0.00	0	0.00
C51	Riet & Kaffir	394 269	0	0.00	0	0.00
C52	Modder	26 318	4 081	15.51	2 040	7.75
C91	Lower Vaal (Vaalharts)	299 540	989	0.33	25	0.01
C92	Lower Vaal to Orange	784 225	2 013	0.26	263	0.03
D31	Orange Vanderkloof Dam	212 629	175	0.08	23	0.01
D32	Seacow	842 134	266	0.03	68	0.01
D33	Middle Orange	752 890	5 961	0.79	186	0.02
D34	Orange (below Gariep Dam)	302 891	81	0.03	36	0.01
D35	Orange (Gariep Dam)	10 180	0	0.00	0	0.00
D41	Kuruman/Molopo area	1 447 729	1 230	0.08	56	0.00
D42	Nossob, Auob & Molopo area	5 152 802	416 430	8.08	25 813	0.50
D51	Rhenoster (Orange system)	219 207	906	0.41	23	0.01
D52	Upper Fish (Orange system)	389 531	2 701	0.69	405	0.10
D53	Grootvloer & Sout area	2 304 486	4 836	0.21	2 105	0.09
D54	Van Wyks Vlei area	2 361 762	227 891	9.65	44 089	1.87
D55	Upper Sak	1 751 324	22 347	1.28	691	0.04
D56	Riet	630 315	0	0.00	0	0.00
D57	Lower Sak	1 016 484	107 316	10.56	16 097	1.58
D58	Lower Fish (Orange system)	441 462	33 676	7.63	3 951	0.89
D61	Groen & Ongers	1 339 001	1 115	0.08	52	0.00
D62	Brak (De Aar)	2 029 870	11 651	0.57	7 577	0.37
D71	Middle Orange	738 113	20 652	2.80	9 457	1.28
D72	Middle Orange (Prieska area)	673 877	12 796	1.90	6 426	0.95
D73	Lower Orange (Upington area)	2 595 867	50 254	1.94	7 308	0.28
D81	Lower Orange (Pofadder area)	1 278 206	14 208	1.11	2 321	0.18
D82	Lower Orange to mouth	2 012 608	5 131	0.25	2 823	0.14
E21	Leeu	8 223	60	0.73	21	0.25
E22	Upper Doring	36 148	111	0.31	78	0.22
E23	Tanqua	359 784	303	0.08	85	0.02
E24	Middle Doring	486 182	44 030	9.06	1 126	0.23
E31	Kromme	951 132	42 977	4.52	1 075	0.11
E32	Hantams	419 965	331	0.08	45	0.01
E33	Sout & Lower Olifants	24 874	831	3.34	23	0.09
E40	Oorlogskloof	243 686	9 487	3.89	2 692	1.10
F10	Holgat	270 497	0	0.00	0	0.00

Tertiary catchment	*River system*	*Area (ha)*	*Total invaded area*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
F20	Kamma (Port Nolloth)	311 707	499	0.16	249	0.08
F30	Buffels (Springbok)	973 443	4 157	0.43	518	0.05
F40	Swartlintjies to Spoeg	531 457	54 335	10.22	8 150	1.53
F50	Groot & Swartdoorn	357 882	34 351	9.60	6 259	1.75
F60	Sout	46 228	34 778	75.23	13 512	29.23
J11	Buffels	54 509	0	0.00	0	0.00
J22	Leeuw	71 689	691	0.96	346	0.48
J24	Dwyka	14 201	0	0.00	0	0.00
L11	Salt Nuweveld Mntns (endoreic)	181 728	1 691	0.93	73	0.04
L21	Upper Buffalo	143 549	3 033	2.11	8	0.01
L22	Lower Buffalo	5 223	0	0.00	0	0.00
N12	Upper Sundaysiver	1 598	0	0.00	0	0.00
Q11	Great Brak	2 377	0	0.00	0	0.00
Q14	Klein Brak	2 181	0	0.00	0	0.00
Northern Cape		36 198 060	1 178 373	3.26	166 097	0.46

Table 2.8 : Northern Province

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
A23	Sand & Pienaars (Pretoria)	189 859	1 816	0.96	319	0.17
A24	Lower Crocodile, Bier & Sand	678 626	586	0.09	25	0.00
A32	Lower Groot Marico area	256 273	4 794	1.87	719	0.28
A41	Matlabas	537 859	0	0.00	0	0.00
A42	Mokolo	835 540	0	0.00	0	0.00
A50	Lephalala	667 613	0	0.00	0	0.00
A61	Nyl & Sterk	545 194	291 236	53.42	44 100	8.09
A62	Upper Mogolakwena	579 361	36 181	6.25	4 533	0.78
A63	Lower Mogolakwena	804 405	0	0.00	0	0.00
A71	Sand & Hout	1 229 695	220 629	17.94	27 907	2.27
A72	Brak	346 210	0	0.00	0	0.00
A80	Nzhelele	418 394	2 113	0.51	1 211	0.29
A91	Luvuvhu	377 063	18 688	4.96	18 253	4.84
A92	Mutale	213 895	703	0.33	478	0.22
B31	Elands	211 995	127 033	59.92	21 466	10.13
B32	Moes & Upper Middle Olifants	31 614	9 570	30.27	241	0.76
B41	Steelpoort	104 490	63 854	61.11	7 659	7.33
B51	Middle Olifants	597 822	384 962	64.39	61 695	10.32
B52	Lower Olifants	355 842	181 858	51.11	23 572	6.62
B60	Blyde	91 192	32 386	35.51	4 176	4.58
B71	Lower Middle Olifants	303 733	176 161	58.00	18 356	6.04
B72	Selati & Lower Olifants	446 082	3 833	0.86	570	0.13
B73	Klaserie, Timbavati & Lower Olifants	285 192	8 554	3.00	2 341	0.82
B81	Upper Great Letaba	494 919	94 987	19.19	8 121	1.64
B82	Klien Letaba	544 986	9 703	1.78	1 556	0.29
B83	Lower Letaba	325 957	13 244	4.06	9 045	2.78
B90	Shingwidzi	529 718	587	0.11	268	0.05
X31	Upper Sabie	72 406	6 592	9.10	2 720	3.76
X32	Sand	117 992	12 745	10.80	3 688	3.13
X40	Nwaswitsintso & Nwanedzi (KNP)	20 378	0	0.00	0	0.00
Northern Province		12 214 306.8	1 702 816	13.94	263 017	2.15

Table 2.9 : North West Province

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
A10	Lehurutshe	183 474	2 185	1.19	755	0.41
A21	Crocodile (Witwatersrand)	276 126	5 372	1.95	2039	0.74
A22	Elands & Hex	621 465	89 147	14.34	11 006	1.77
A23	Sand & Pienaars (Pretoria)	319 561	507	0.16	73	0.02
A24	Lower Crocodile, Bier & Sand	241 166	25 301	10.49	3 927	1.63
A31	Groot Marico	667 166	19 310	2.89	2 846	0.43
A32	Lower Groot Marico area	277 971	3 102	1.12	452	0.16
C22	Klip (JHB) & Vaal Barrage	6 334	154	2.43	135	2.13
C23	Mooi & Upper Middle Vaal	485 463	20 814	4.29	2 044	0.42
C24	Skoonspruit & Middle Vaal	859 099	4 169	0.49	1 769	0.21
C25	Lower Middle Vaal	498 125	55 158	11.07	4 758	0.96
C31	Upper Harts	1 101 856	4 930	0.45	1 249	0.11
C32	Dry Harts	1 019 133	82 572	8.10	12 995	1.28
C33	Lower Harts	290 577	155	0.05	31	0.01
C70	Rhenoster	1	0	0.00	0	0.00
C91	Lower Vaal (Vaalharts)	377 397	13 394	3.55	2 016	0.53
D41	Kuruman/Molopo area	4 376 095	78 890	1.80	10 137	0.23
Total		11 601 010	405 161	3.49	56 232	0.48

Table 2.10 : Western Cape

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
D55	Upper Sak	188 177	1	0.00	1	0.00
D56	Riet	10	0	0.00	0	0.00
E10	Olifants	288 879	135 376	46.86	4 831	1.67
E21	Leeu	298 965	108 123	36.17	2 245	0.75
E22	Upper Doring	379 231	28 828	7.60	741	0.20
E23	Tanqua	284 751	71 880	25.24	1 846	0.65
E24	Middle Doring	278 437	19 384	6.96	424	0.15
E31	Kromme	20 805	0	0.00	0	0.00
E32	Hantams	132	0	0.00	0	0.00
E33	Sout & Lower Olifants	796 503	67 248	8.44	22 391	2.81
E40	Oorlogskloof	28 556	3	0.01	0	0.00
F50	Groot & Swartdoorn	128 193	0	0.00	0	0.00
F60	Sout	231 213	109 124	47.20	17 930	7.75
G10	Berg	889 021	707 335	79.56	101 882	11.46
G21	Swartland	232 556	122 278	52.58	29 679	12.76
G22	Cape Flats & Peninsula	171 287	25 228	14.73	5 948	3.47
G30	Sandveld	514 735	398 748	77.47	75 072	14.58
G40	Steenbras to Uilkraals	305 237	161 456	52.90	63 239	20.72
G50	Pearly Beach to Salt	411 537	181 991	44.22	108 815	26.44
H10	Upper Breede	204 641	112 227	54.84	9 828	4.80
H20	Hex	83 198	47 733	57.37	1 034	1.24
H30	Koo	120 723	34 541	28.61	242	0.20
H40	Upper Middle Breede	260 814	74 569	28.59	3 391	1.30
H50	Lower Middle Breede	69 508	13 953	20.07	794	1.14
H60	Sonderend	224 160	98 234	43.82	18 099	8.07
H70	Lower Breede	292 093	167 497	57.34	7 793	2.67
H80	Duiwenhoks	135 793	82 214	60.54	14 483	10.67
H90	Kafferkuils	160 941	110 440	68.62	28 733	17.85
J11	Buffels	510 174	25 671	5.03	167	0.03
J12	Touws	631 065	68 042	10.78	1 797	0.28
J13	Groot	135 488	103 097	76.09	13 792	10.18
J21	Upper Gamka	306 473	3 360	1.10	1 330	0.43
J22	Leeuw	444 612	1 340	0.30	593	0.13
J23	Lower Gamka	420 243	44 215	10.52	2 377	0.57
J24	Dwyka	448 356	2 447	0.55	573	0.13

Tertiary Catchment	*River system*	*Area (ha)*	*Total area invaded*		*Condensed invaded area*	
			(ha)	*(%)*	*(ha)*	*(%)*
J25	Gouritz	142 799	67 412	47.21	2 813	1.97
J31	Upper Olifants	88 154	34 696	39.36	1 636	1.86
J32	Traka	155 347	2 763	1.78	77	0.05
J33	Middle Olifants	238 888	108 845	45.56	3 655	1.53
J34	Kammanassie	184 502	125 141	67.83	13 256	7.18
J35	Lower Olifants	256 650	79 846	31.11	7 427	2.89
J40	Lower Gouritz	232 106	42 119	18.15	9 515	4.10
K10	Mossel Bay & Klein Brak	90 426	7 422	8.21	1 209	1.34
K20	Groot Brak	16 653	144	0.86	55	0.33
K30	Witels to Touws	70 033	14 403	20.57	2 799	4.00
K40	Sedgefield & Goukamma	69 579	14 074	20.23	6 379	9.17
K50	Knysna	41 802	7 917	18.94	3 044	7.28
K60	Plettenberg Bay & Keurbooms	125 334	51 608	41.18	20 584	16.42
K70	Groot & Bloukrans	21 951	11 399	51.93	3 464	15.78
K80	Lottering to Cape St Francis	16	0	0.00	0	0.00
L11	Salt Nuweveld Mntns (endoreic)	505 783	45	0.01	7	0.00
L12	Salt	194 127	744	0.38	104	0.05
L21	Upper Buffalo	311 383	724	0.23	41	0.01
L22	Lower Buffalo	213 746	0	0.00	0	0.00
L23	Kariega	1 722	0	0.00	0	0.00
L81	Baviaanskloof	1 255	0	0.00	0	0.00
L82	Kouga	48 975	31 508	64.34	9 962	20.34
N12	Upper Sundays	13 481	0	0.00	0	0.00
N13	Kamdeboo	4 173	0	0.00	0	0.00
N14	De Hoop	6 021	0	0.00	0	0.00
W Cape		12 931 413	3 727 392	28.82	626 100	4.84

APPENDIX 6:

Table 1 : Impacts of alien plant species on the MAR of tertiary catchments in South Africa. The catchments have been arranged in alphabetic order. The province is listed for convenient reference. Where a catchment is shared between provinces the province with the largest portion of that catchment is the one listed in this table.

Province	Tertiary catchment	Mean annual runoff (millions of m^3)	Reduction in mean annual runoff (millions of m^3)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
NW	A10	15.03	1.61	10.71	755
NW	A21	267.63	16.88	6.31	4 919
NW	A22	112.86	25.67	22.74	11 008
NW	A23	163.28	4.58	2.80	1 325
NW	A24	137.28	4.72	3.44	3 953
NW	A31	94.41	0.45	0.48	2 846
NW	A32	43.53	1.08	2.48	1 170
NP	A41	62.47	0.00	0.00	0
NP	A42	315.27	0.00	0.00	0
NP	A50	149.14	0.00	0.00	0
NP	A61	198.39	64.56	32.54	44 100
NP	A62	69.96	3.02	4.32	4 533
NP	A63	46.79	0.00	0.00	0
NP	A71	53.54	17.78	33.21	27 907
NP	A72	18.34	0.00	0.00	0
NP	A80	113.99	3.16	2.77	1 212
NP	A91	362.93	46.34	12.77	18 253
NP	A92	156.98	0.52	0.33	478
MP	B11	175.84	0.31	0.18	94
MP	B12	81.6	0.29	0.36	88
MP	B20	166.98	9.56	5.73	2 319
NP	B31	83.46	22.84	27.37	25 574
NP	B32	165.31	5.84	3.53	1 435
NP	B41	232.82	15.36	6.60	14 081
MP	B42	164.75	39.25	23.82	15 298
NP	B51	61.96	52.75	85.14	63 618
NP	B52	59.56	19.00	31.90	23 572
NP	B60	531.71	79.82	15.01	30 917
NP	B71	202.22	23.30	11.52	18 357
NP	B72	204.62	0.75	0.37	570
NP	B73	78.43	2.35	3.00	2 948
NP	B81	411.19	16.72	4.07	8 120

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
NP	B82	151.84	2.30	1.51	1 556
NP	B83	42.33	0.01	0.02	9 045
NP	B90	89.48	0.01	0.01	268
MP	C11	547.14	20.66	3.78	5 076
MP	C12	296.46	4.95	1.67	1 208
MP	C13	291.12	7.21	2.48	1 785
MP	C21	141.57	4.41	3.12	1 026
NW	C22	131.59	38.11	28.96	9 902
NW	C23	252.19	8.64	3.43	2 175
NW	C24	203.17	3.33	1.64	1 815
NW	C25	43.39	6.41	14.77	4 942
NW	C31	86.53	1.45	1.68	1 249
NW	C32	78.7	23.53	29.90	12 995
NW	C33	71.18	0.08	0.11	31
FS	C41	317.06	0.00	0.00	0
FS	C42	225.72	0.00	0.00	0
FS	C43	17.5	0.22	1.26	154
NC	C51	232.73	0.73	0.31	431
NC	C52	217.59	7.04	3.24	4 916
FS	C60	169.68	0.46	0.27	162
FS	C70	205.99	0.00	0.00	0
LE	C81	450.07	34.77	7.73	8 082
FS	C82	197.8	8.03	4.06	1 915
GA	C83	283.7	16.18	5.70	3 746
NW	C91	54.74	3.93	7.18	2 757
NC	C92	51.75	0.40	0.77	263
LE	D11	765.38	0.16	0.02	54
LE	D12	163.17	0.04	0.02	11
LE	D13	667.95	0.08	0.01	24
FS	D14	123.1	0.00	0.00	0
LE	D15	520.8	0.00	0.00	0
LE	D16	827.77	0.10	0.01	26
LE	D17	1 105.2	1.04	0.09	261
LE	D18	781.36	0.58	0.07	160
LE	D21	518.43	0.00	0.00	0
LE	D22	467.19	0.00	0.00	0
LE	D23	257.48	0.00	0.00	0
LE	D24	158.96	0.00	0.00	0
NC	D31	37.31	0.03	0.08	24

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
NC	D32	41.27	0.46	1.11	226
NC	D33	20.5	1.08	5.27	770
NC	D34	40.28	0.06	0.15	36
NC	D35	53.14	0.16	0.30	84
NW	D41	83.31	12.00	14.40	10 194
NC	D42	14.87	4.89	32.89	25 813
NC	D51	13.83	0.03	0.22	23
NC	D52	14.53	0.45	3.10	405
NC	D53	28.75	2.00	6.96	2 106
NC	D54	60.25	56.19	93.26	44 090
WC	D55	42.09	0.71	1.69	694
WC	D56	18.84	0.00	0.00	0
NC	D57	14.7	16.21	110.27	16 097
NC	D58	2.92	4.30	147.26	3 951
NC	D61	31.62	0.07	0.22	52
NC	D62	52.91	8.58	16.22	7 578
NC	D71	35.51	10.80	30.41	9 458
NC	D72	26.47	6.47	24.44	6 426
NC	D73	141.8	12.17	8.58	7 309
NC	D81	10.26	1.66	16.18	2 321
NC	D82	5.81	1.06	18.24	2 823
WC	E10	472.32	11.86	2.51	4 832
WC	E21	278.62	5.39	1.93	2 265
WC	E22	40.87	0.10	0.24	820
WC	E23	35.77	0.10	0.28	1 932
WC	E24	124.84	2.75	2.20	1 551
WC	E31	5.67	1.10	19.40	1 076
WC	E32	12.39	0.07	0.56	45
WC	E33	10.63	12.52	117.78	22 414
WC	E40	27.24	1.66	6.09	2 691
NC	F10	0.23	0.00	0.00	0
NC	F20	1.07	0.00	0.00	250
NC	F30	10.55	0.18	1.71	517
NC	F40	4.78	5.62	117.57	8 151
WC	F50	7.38	2.88	39.02	6 260
WC	F60	1	14.08	1408.00	31 442
WC	G10	930.31	180.33	19.38	101 882
WC	G21	114.23	44.16	38.66	29 679
WC	G22	327.58	11.97	3.65	5 948

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
WC	G30	62.36	95.02	152.37	75 073
WC	G40	513.15	115.78	22.56	63 239
WC	G50	109.12	199.24	182.59	108 813
WC	H10	860.5	19.74	2.29	9 828
WC	H20	99.19	2.00	2.02	1 034
WC	H30	64.33	0.48	0.75	242
WC	H40	159.06	5.13	3.23	3 391
WC	H50	23.54	1.46	6.20	794
WC	H60	459.04	50.35	10.97	18 099
WC	H70	210.46	15.54	7.38	7 794
WC	H80	105.48	27.42	26.00	14 483
WC	H90	106.75	59.51	55.75	28 733
WC	J11	37.76	0.18	0.48	167
WC	J12	54.3	1.88	3.46	1 797
WC	J13	13	19.44	149.54	13 792
WC	J21	32.05	2.27	7.08	1 330
WC	J22	71.51	1.71	2.39	939
WC	J23	31.22	1.65	5.29	2 379
WC	J24	33.42	0.26	0.78	572
WC	J25	34.02	0.91	2.67	2 813
WC	J31	15.92	2.18	13.69	1 643
WC	J32	7.99	0.09	1.13	114
WC	J33	65.65	2.96	4.51	3 656
WC	J34	56.52	21.84	38.64	13 257
WC	J35	82.78	1.08	1.30	7 427
WC	J40	134.49	18.33	13.63	9 515
WC	K10	64.77	1.95	3.01	1 209
WC	K20	39.85	0.12	0.30	55
WC	K30	185.43	6.15	3.32	2 799
WC	K40	165.17	14.93	9.04	6 378
WC	K50	97.51	9.47	9.71	3 044
WC	K60	148.24	35.86	24.19	20 765
WC	K70	66.3	10.71	16.15	3 826
WC	K80	395.81	27.37	6.91	7 441
EC	K90	134.22	27.90	20.79	7 474
WC	L11	37.69	0.16	0.42	80
WC	L12	10.25	0.09	0.88	104
WC	L21	52.73	0.10	0.19	49
WC	L22	22.06	0.00	0.00	0

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
WC	L23	19.5	0.00	0.00	0
EC	L30	11.37	0.00	0.00	0
EC	L40	7.43	0.00	0.00	0
EC	L50	8.17	0.08	0.98	31
EC	L60	7.22	0.00	0.00	0
EC	L70	32.74	11.33	34.61	3 408
WC	L81	45.68	27.46	60.11	9 459
WC	L82	148.02	53.02	35.82	20 174
EC	L90	91.85	4.29	4.67	984
EC	M10	78.63	19.86	25.26	4 904
EC	M20	61.16	17.11	27.98	4 147
EC	M30	10.25	3.21	31.32	2 306
EC	N11	17.21	0.13	0.76	157
WC	N12	26.51	0.62	2.34	197
WC	N13	19.75	4.11	20.81	1 749
WC	N14	33	0.01	0.03	13
EC	N21	30.02	0.91	3.03	348
EC	N22	23.35	0.00	0.00	1
EC	N23	11.46	0.00	0.00	0
EC	N24	21.26	0.07	0.33	43
EC	N30	35	0.03	0.09	50
EC	N40	62.33	2.46	3.95	1 406
EC	P10	58.32	7.31	12.53	2 243
EC	P20	45.39	31.44	69.27	10 829
EC	P30	20.3	10.33	50.89	2 799
EC	P40	48.91	24.00	49.07	7 022
NC	Q11	22.29	0.01	0.04	3
EC	Q12	27.56	0.04	0.15	15
EC	Q13	16.24	0.00	0.00	2
NC	Q14	31.56	1.30	4.12	404
EC	Q21	10.82	0.35	3.23	150
EC	Q22	8.63	0.04	0.46	11
EC	Q30	22.46	1.03	4.59	948
EC	Q41	24.67	0.00	0.00	0
EC	Q42	16.08	0.00	0.00	0
EC	Q43	16.82	0.00	0.00	0
EC	Q44	10.86	0.01	0.09	14

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
EC	Q50	17.25	0.45	2.61	349
EC	Q60	20.26	0.02	0.10	4
EC	Q70	13.07	1.08	8.26	345
EC	Q80	51.43	0.52	1.01	158
EC	Q91	27.18	1.64	6.03	690
EC	Q92	76.44	0.56	0.73	124
EC	Q93	34.87	4.28	12.27	1 590
EC	Q94	72.23	9.80	13.57	2 173
EC	R10	141.25	20.75	14.69	4 605
EC	R20	108.62	6.58	6.06	1 462
EC	R30	210.73	3.44	1.63	835
EC	R40	76.44	12.65	16.55	2 840
EC	R50	41.87	12.16	29.04	2 741
EC	S10	95.64	0.00	0.00	0
EC	S20	65.74	0.00	0.00	0
EC	S31	52.36	0.00	0.00	0
EC	S32	144.88	2.47	1.70	547
EC	S40	99.89	67.88	67.95	15 058
EC	S50	284.26	0.00	0.00	0
EC	S60	124.11	66.90	53.90	14 824
EC	S70	175.47	0.97	0.55	264
EC	T11	374.72	1.22	0.33	497
EC	T12	237.17	0.00	0.00	0
EC	T13	193.23	0.11	0.06	67
EC	T20	392.03	6.07	1.55	3 181
LE	T31	385.07	28.54	7.41	6 549
KZ	T32	346.36	30.77	8.88	7 427
LE	T33	467.43	22.87	4.89	5 101
LE	T34	536.28	11.25	2.10	2 735
EC	T35	967.41	1.61	0.17	624
EC	T36	126	0.24	0.19	154
KZ	T40	417.14	26.26	6.30	13 354
LE	T51	789.6	9.06	1.15	2 375
KZ	T52	588.91	67.50	11.46	22 968
EC	T60	792.6	4.23	0.53	1 062
EC	T70	283.64	4.16	1.47	1 377
EC	T80	163.17	0.31	0.19	227

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
EC	T90	323	3.18	0.98	795
LE	U10	1088.05	15.90	1.46	4 376
KZ	U20	739.55	22.46	3.04	8 133
KZ	U30	239.24	17.52	7.32	7 651
KZ	U40	352.61	40.71	11.55	15 327
KZ	U50	59.05	0.69	1.17	306
KZ	U60	172.52	12.30	7.13	4 058
KZ	U70	138.43	7.29	5.27	2 225
KZ	U80	331.75	9.50	2.86	4 367
LE	V11	915.44	15.67	1.71	3 778
KZ	V12	266.69	9.13	3.42	2 178
LE	V13	318.58	7.41	2.33	2 115
KZ	V14	120.96	0.92	0.76	9 883
KZ	V20	401.97	15.35	3.82	5 525
MP	V31	535.51	20.78	3.88	4 908
KZ	V32	344.12	2.25	0.65	607
KZ	V33	136.87	1.90	1.39	609
KZ	V40	170.63	3.87	2.27	1 369
KZ	V50	156.54	4.86	3.10	2 268
KZ	V60	311.58	5.37	1.72	4 063
LE	V70	311.99	17.16	5.50	24 847
KZ	W11	205.7	12.68	6.16	7 761
KZ	W12	574.64	89.73	15.61	53 245
KZ	W13	146.85	3.90	2.66	2 385
KZ	W21	464.42	8.95	1.93	3 349
KZ	W22	356.96	5.52	1.55	1 905
KZ	W23	150.39	5.78	3.84	3 310
KZ	W31	206.43	23.02	11.15	6 118
KZ	W32	330.72	5.51	1.67	2 207
KZ	W41	326.96	2.57	0.79	755
MP	W42	713.52	59.68	8.36	13 659
KZ	W43	22.75	0.40	1.76	238
KZ	W44	36.21	1.19	3.29	435
KZ	W45	51.91	0.84	1.62	499
MP	W51	360.27	3.78	1.05	997
MP	W52	97.25	1.33	1.37	356
MP	W53	191.33	2.23	1.17	587

Province	Tertiary catchment	Mean annual runoff (millions of m³)	Reduction in mean annual runoff (millions of m³)	Reduction in mean annual runoff (%)	Condensed invaded area (ha)
MP	W54	92.85	0.74	0.80	161
MP	W55	218.5	1.18	0.54	263
MP	W56	74.22	0.07	0.09	16
KZ	W57	7.03	0.68	9.67	253
MP	W60	2.05	0.00	0.00	0
KZ	W70	110.78	0.08	0.07	2 070
MP	X11	359.42	13.53	3.76	5 395
MP	X12	308.72	6.25	2.02	2 649
MP	X13	42.44	0.07	0.16	37
MP	X14	165.11	4.91	2.97	2 121
MP	X21	507.86	94.00	18.51	36 699
MP	X22	418.15	42.89	10.26	18 496
MP	X23	206.04	28.53	13.85	12 276
MP	X24	104.34	2.07	1.98	2 794
NP	X31	584.65	78.29	13.39	36 405
NP	X32	136.42	12.36	9.06	6 010
MP	X33	11.31	0.36	3.18	1 475
NP	X40	26.94	0.00	0.00	139

Table 2: **Water use by invading alien species in each province (millions of m^3).** A key to the province abbreviations is provided at the end of the table.

Species	EC	FS	GA	KZ	LE	MP	NC	NP	NW	WC	Total
Acacia baileyana	0.075	0.011	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.138
Acacia cyclops	21.006	0.000	0.000	0.000	0.000	0.000	15.135	0.000	0.000	451.486	487.627
Acacia dealbata	85.177	16.377	1.490	99.795	0.153	44.433	0.000	0.868	0.000	0.021	248.315
Acacia decurrens	0.000	0.000	2.719	4.214	0.000	0.191	0.000	0.013	0.000	2.690	9.827
Acacia elata	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006
Acacia longifolia	17.038	0.000	0.000	1.675	0.000	0.000	0.000	0.000	0.000	20.012	38.725
Acacia mearnsii	210.628	4.203	13.386	58.196	0.052	125.856	0.001	4.298	5.738	154.221	576.579
Acacia melanoxylon	4.344	0.000	0.000	2.452	0.000	2.422	0.000	9.015	0.000	13.967	32.201
Acacia pycnantha	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.732	0.761
Acacia saligna	35.026	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	136.100	171.130
Acacia species	86.331	15.494	9.807	112.419	0.888	12.390	0.000	0.047	0.000	5.253	242.630
Arundo donax	0.214	0.028	0.000	2.168	0.000	0.000	0.002	0.009	1.758	0.170	4.348
Caesalpinia decapetala	0.031	0.000	0.000	10.542	0.000	5.068	0.000	18.179	0.000	0.000	33.820
Cestrum laevigatum	0.008	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.013
Chromolaena odorata	0.000	0.000	0.000	68.199	0.000	0.000	0.000	0.051	0.000	0.000	68.250
Cupressus glabra	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Eucalyptus species	39.183	12.521	14.390	22.797	0.072	33.942	0.053	55.544	13.054	22.424	213.981
Gleditsia triacanthos	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.092
Hakea species	3.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	63.295	66.302
Jacaranda mimosifolia	0.123	0.000	0.003	1.852	0.000	5.056	0.000	0.000	4.296	0.000	11.331
Lantana camara	1.826	0.000	0.020	16.613	0.000	49.214	0.000	37.068	2.358	0.035	107.133
Leptospermum laevigatum	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.596	3.654
Ligustrum lucidum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	27.074	0.000	0.000	27.074

Species	EC	FS	GA	KZ	LE	MP	NC	NP	NW	WC	Total
Melia azedarach	0.000	0.000	0.048	35.445	0.000	34.324	0.000	0.000	9.641	0.000	79.458
Metrosideros excelsus	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
Mimosa pigra	0.000	0.000	0.000	0.000	0.000	0.000	0.000	85.198	0.000	0.000	85.198
Morus alba	0.000	0.000	0.000	0.477	0.000	0.605	0.000	0.000	0.004	0.000	1.086
Myoporum serratum	0.252	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.252
Nerium oleander	0.000	0.000	0.000	0.000	0.000	0.000	0.164	0.000	3.190	3.399	6.754
Nicotiana glauca	0.201	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.000	0.000	0.287
Other alien species	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.011
Paraserianthes lophantha	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.586	0.586
Phytolacca octandra	0.541	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.541
Pinus species	0.000	7.934	0.421	23.393	0.072	13.965	0.001	0.000	0.000	134.891	180.677
Pistia stratiotes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.692	0.000	0.000	12.692
Pittosporum undulatum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011
Populus species	38.158	9.027	5.862	8.203	0.225	8.322	1.222	0.000	9.257	8.987	89.262
Prosopis species	2.529	7.364	0.000	0.000	0.000	0.000	134.088	0.000	41.155	8.885	194.022
Psidium guajava	0.446	0.000	0.000	7.187	0.000	25.514	0.000	0.194	0.003	0.000	33.345
Pyracantha species	0.232	0.006	0.000	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.280
Quercus species	0.001	0.088	0.000	0.000	0.000	0.192	0.000	4.371	0.000	0.231	4.883
Ricinus communis	0.732	0.000	0.000	0.000	0.000	0.000	0.000	5.994	0.000	0.000	6.726
Robinia pseudoacacia	0.000	0.000	0.000	0.136	0.000	0.000	0.001	0.000	0.234	0.000	0.371
Rubus species	0.000	0.000	0.000	18.710	0.000	21.242	0.000	0.000	0.000	0.174	40.127
Salix species	0.010	13.017	5.011	5.949	0.433	4.993	0.145	0.000	2.519	0.123	32.200
Schinus molle	1.017	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.003	1.024
Sesbania punicea	2.616	0.000	0.035	5.462	0.000	2.270	0.012	1.208	2.126	4.597	18.325
Solanum mauritianum	0.329	0.000	0.000	69.917	0.000	56.007	0.000	27.741	0.067	0.001	154.062

Species	**EC**	**FS**	**GA**	**KZ**	**LE**	**MP**	**NC**	**NP**	**NW**	**WC**	**Total**
Solanum seaforthianum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	7.270	0.000	0.000	7.270
Tamarix species	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.793	0.800
Uncertain species	6.713	0.787	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	7.500
Verbena bonariensis	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.744	0.000	0.000	0.848

EC - Eastern Cape
FS - Free State
GA - Gauteng
KZ - KwaZulu-Natal
LE - Lesotho
MP - Mpumalanga
NC - Northern Cape
NP - Northern Province
NW - North west Province
WC - Western Cape

Appendix 7: An analysis of invasion processes and risks and a strategy for modelling invasions by alien plant species at a national and regional scale

1. Introduction

The aims of this project include providing information and developing models to address the following questions:

- What area of the country could be invaded if nothing is done to limit the spread of woody alien plant species?
- How rapidly will this area be invaded?

In order to address these questions we need to understand (a) what species invade, how they invade, what factors facilitate and limit such invasions, and (b) how rapidly different species are able to invade and increase in density. This chapter reviews what is known about invasion processes, with particular emphasis on quantitative model, suggests an approach to modelling invasions and reviews what is known about which species have invaded South Africa and what factors influence their invasion patterns. The first section summarises the constraints that the nature of this study imposed on the modelling approach. The next section introduces the model and modelling procedures which were found to be suitable. The final section contains the detailed literature review that provided the background for the proposed modelling approach.

A large body of information on invasions by plant species and their impacts on natural systems has been assembled (see the reviews by MacDonald *et al.* 1986; Drake *et al.* 1988; Hengeveld 1989). These studies have shown that there are some general patterns in invasions. In general, the process of invasion of a landscape in both space and time can be divided into two phases:

- *expansion* - dispersal from the existing patches as an expanding front and by establishing satellite colonies (which later become patches); and
- *densification* - increases in the density of populations within the colonised patches.

Dispersal can be modelled mathematically in various ways using functions that calculate the density of seeds at a given distance from the source (see Higgins & Richardson 1996 for a recent review). The most convenient way to model increasing density, when the data are in the form of density classes, is to use a transition model based on the probability that an area will go from one density to another in a given period of time.

In this review the term *seeds* is used as shorthand for all propagules - parts of the plant that can grow and become new individuals.

2. Constraints

This section discusses the constraints that the nature of the project and the available information placed on the kinds of models that could be used.

2.1 The nature of the project

The aims of the project include providing an assessment of the extent and potential impacts of alien plant invasions in the RSA to help in determining priorities for funding for alien plant control. This work had to be completed in a period of about 15 months. These requirements introduced some constraints:

- The information has to be suitable for use by national and provincial decision makers in determining overall priorities for the allocation of funds for alien plant control.
- The base maps for mapping aliens had to use a standard map scale which was readily available, provided a consistent level of detail and facilitated rapid mapping either in the field or from expert knowledge. The scale adopted was 1:250 000 as this is compatible with the level of detail required (national-provincial). This also limited the number of maps to a reasonable quantity compared with the more detailed 1:50 000 maps.
- An explicitly spatial approach (e.g Auld and Coote 1980, 1990; Le Maitre *et al.* 1996) has the advantage of modelling the key processes (e.g. dispersal, recruitment) directly. However, a spatially explicit model would have resulted in complex and time consuming calculations involving hundreds of individual polygons. This was not possible within the time and logistical constraints on the project. Thus the data were aggregated and modelled in smaller units which are then summed to provide information at the scale required by decision makers.

2.2 The limited amount of information available on invasion rates

There have been remarkably few studies which have quantified the physical invasion process of plants in space and time in detail compared with animals and diseases (see for example Drake *et al.* 1988; Hengeveld 1989). This is in marked contrast to the numerous theoretical and empirical studies of seed dispersal and of the factors which may prevent, limit or facilitate invasions. Although there have been a few South African studies which have analysed changes over time (Boucher 1984; Smit & de Kock 1984; Taylor *et al.* 1985; Moll & Trinder-Smith 1992), only four South African studies could be found which provided sufficient data for parameterising a model of spread over time: Brownlie (1982) for various species (mainly *Acacia*), Richardson & Brown (1986) for *Pinus radiata*, Harding & Bate (1991) for *Prosopis* species and for *Acacia cyclops* (Macdonald *et al.* 1989). The study of the invasion of

Western Cape lowland fynbos site by Brownlie (1982) could not be included because it will require more detailed analysis than was possible for in this study.

One additional study of *Mimosa pigra* in Northern Australia was also found (Lonsdale 1993). This study is relevant because there are similar habitats for *Mimosa pigra* to invade in southern Africa.

2.3 *The role of disturbance*

Rapid colonisation and increases in density of invasive plants are often tightly linked to disturbances. For example, fires, floods and overgrazing create areas of open soil, or reduce competition from other plants, providing open space which is ideal for colonisation by invasive plants (see Hobbs 1988; Noble 1988; Richardson & Cowling 1992). Colonisation continues between disturbances for most species, but at a much slower rate than shortly after disturbances. Fires typically initiate expansions and increases in density of invasive alien plants in fynbos (Richardson & Cowling 1992), but the same may not be true of grasslands. The frequent fires which occur in grasslands in good condition may actually prevent regeneration, and factors which reduce fire frequencies, or exclude fires (e.g. overgrazing), may be needed to initiate invasion. Floods or good rainfall years may stimulate recruitment in many invasive aliens. For example, there is some evidence that recruitment in *Prosopis* depends on good rainfall years (Harding & Bate 1991) and floods increase invasions by *Sesbania* (Hoffman & Moran 1988). The modelling scale in this study does not allow for modelling of disturbances or disturbance regimes, even if hard data were available. The lack of spatial realism also makes it impractical to attempt model the patchiness of disturbance. Given the size of the units (secondary catchments, Provinces) it is reasonable to assume that the distribution of disturbances within these units, in both space and time, is such that the overall changes can be modelled using an annual "mean" disturbance rate. This assumption has been used in the models developed here.

2.4 *Mapping of the density or cover of the invaded areas*

A wide variety of approaches and classifications have been employed in mapping invasions by alien plants. In order to provide some consistency the mapping technique developed for catchment management in the Cape mountains (Le Maitre & Versfeld 1994; Le Maitre *et al.* 1996) was adapted for this study. The technique involves estimating relative density classes but the densities can also be expressed as percentage canopy cover. The technique was originally developed for mapping extensive areas at a scale of 1:50 000, but can also be used at other scales. The number of density classes was reduced from seven to four while keeping the class boundaries consistent. The primary reason for this was to reduce the size of the data sets that have to be processed and to simplify mapping. The final classes were as follows (for canopy cover): <5%, 5-25%, 25-75% and 75-100%. Field experience has shown that there are extensive areas which have occasional plants (<5% cover). These should be distinguished from the next class to avoid overestimating the extent of invasion. Studies of experimental catchments show that there is a rapid increase in water use from medium to dense canopies, with little increase in water use once the area has become dense. Therefore it is useful to distinguish between medium (25-75%) and dense (>75%) cover classes.

3. Developing a model

As discussed in the introduction, invasions can be split into two phases: expansion into new areas followed by increases in density (densification) within these areas. Attempts were made to obtain additional data on rates of expansion and increases in density during the data gathering process but these were largely fruitless.

3.1 Expansion

Numerous studies of the expansion of invading species, both plants and animals, have shown that it typically goes through the following stages (see Harper 1977; Mack 1985; Birks 1989):

- a lag or delay during which the plant reaches maturity or builds up to a level at which new colonisation begins;
- a stage of rapid, frequently exponential, increase in invaded area; and
- a gradual slowing down of the expansion rate as the potentially invadable area becomes fully occupied.

The first step is to identify a suitable, simple model that accommodates an exponential rate of increase and reduces the expansion rate as the available space becomes saturated, showing the typical sigmoidal form . A basic and well understood function which meets these criteria is the 'logistic' model. As the overall model for assessing the impacts of aliens operates in discrete annual time steps it is used in its discrete form:

$$N_t = N_{t-1} + r(1 - N_{t-1}/K)N_{t-1}$$

> where N = the number of individuals which in this case is the number of habitat units occupied; t = the current time step, t-1 = the previous time step; r = the intrinsic (maximum) rate of increase which in this case is the exponent derived from fitting an exponential regression through the expansion data; K = the carrying capacity, the number of habitat units that can be occupied.

The 'logistic' model requires an initial number of habitat units to begin with (N_{t-1}), it cannot begin with zero; the default assumed here is 0.1ha. The number of invaded units in the next time step depends on the previous number. As N_{t-1} approaches K the rate of growth declines asymptotically, reaching zero when N_{t-1} = K.

The most promising models of expansion use information on seed dispersal to predict expansion (see Higgins & Richardson 1996). They require spatially explicit models and are, therefore, not suitable for this study, which means that data on the rate of expansion in area has to be used. There have been very few studies of this at the regional scale that is required (see Appendix 1) so the available data are sparse, from disparate situations and data for invasions in grassland or savanna are lacking. This makes it very difficult to give a single value for the expansion rate (r). The exponents of fitted exponential models range from 0.01-0.65 and values in the range of about 0.10-

0.30 are probably reasonable for the most important and aggressive species with short generation times (see Table 1). The rates for *Mimosa pigra* of about 0.65 (Lonsdale 1993) are very high but may be close to the rate for species such as *Chromolaena* which have spread extremely rapidly since introduction (J. Goodall pers. comm. 1996). The review found little evidence that invasions of riparian areas are more rapid than those in landscapes but observations do suggest that they are more rapid for species such as *Acacia mearnsii* (D. Versfeld pers. comm. 1996).

To keep the model as simple as possible and with the minimum of assumptions we opted for the following approach:

(a) The expansion rate of patches decreases as they get larger because the proportion of the plant population's seed being dispersed outside a patch decreases (McClanahan 1986; Moody and Mack 1988).

(b) The information in Table 1 and the likely range in the size of invadable areas, show that it is not possible to have a single value for the expansion rate (r). For example, data from Richardson & Brown (1986) give the expansion rate of *Pinus radiata* as about 0.20 which is equivalent to the invasion of about 750 ha in 50 years. At the same rate it would invade about 95% of 100 000 ha in 90 years. This is probably unreasonably high because it assumes *inter-alia* that the invaded expands equally in all directions; in practice the invadable area is non-circular and often very elongated which would reduce the invasion rate.

Table 1 : The expansion coefficient (r) required for an invasive plant to invade ≈95% of the potentially invadable area in the given period of time. This is based on the logistic model outlined above and an initial invaded area of 0.1ha.

Time period (years)	Size of potential area (ha)					
	100	1 000	5 000	10 000	50 000	100 000
20	0.58	0.67	0.89	0.95	1.10	1.17
30	0.36	0.47	0.54	0.58	0.66	0.70
40	0.27	0.34	0.39	0.42	0.47	0.50
50	0.21	0.27	0.31	0.33	0.36	0.38
60	0.17	0.22	0.25	0.27	0.30	0.31
70	0.15	0.19	0.21	0.23	0.25	0.26
80	0.13	0.16	0.18	0.20	0.22	0.23
90	0.11	0.14	0.16	0.17	0.19	0.20
100	0.10	0.13	0.14	0.15	0.17	0.18
110	0.09	0.12	0.13	0.14	0.16	0.16
120	0.09	0.11	0.12	0.13	0.14	0.15
130	0.08	0.10	0.11	0.12	0.13	0.14
140	0.08	0.09	0.10	0.11	0.12	0.13
150	0.07	0.08	0.10	0.10	0.11	0.12

Therefore reasonable time periods were chosen for the invasion of areas of different sizes based on Table 1. The time period to invade 95% of 100 ha was estimated at 50 years and for 95% of 100 000 ha was 120 years (Table 2). These two points were drawn on a semi-log graph and the periods required to invade areas in between these sizes were estimated to the nearest year by interpolation[1]. These estimated time periods were used to derive the following relationship between the expansion coefficient and the potentially invadable area:

Expansion rate (r) = EXP(-1.3512-0.05185*LN(Area)), r = 0.92, n = 6

where EXP = e to the power of and LN = the Naperian logarithm ($\log_e$)

This relationship is used to estimate the expansion rate to use in each case based on the size of the total potentially invadable area (currently invaded + uninvaded potential area).

Table 2 : Estimated time periods required for the invasion of 95% of areas of different sizes based on the literature review and expert judgement. For more information see the text.

Area (ha)	Time period (years)	Predicted expansion rate (r)
100	50	0.202
1 000	74	0.179
5 000	90	0.165
10 000	97	0.160
50 000	113	0.146
100 000	120	0.141

3.2 Densification

The information available from the literature suggests that increases in density are initially slow and then accelerate rapidly. There is little hard evidence that the rate of increase in density slows down as the cover reaches 100%, so an exponential rate of increase to a maximum of 100% was used. The mapped data were in the form of cover classes so the initial idea was to model changes using density transitions. The only study that could be used to estimate density class transitions was the one by Richardson & Brown (1986). This study was of a particular species in a small area and therefore not suitable for broad generalisations. In addition, transition probabilities will also be

1 An exponential growth curve becomes linear when drawn on a semi-log graph with time (x) against the log of the area.

affected by the dependence of species on disturbance to facilitate invasion and the rates of disturbance in particular habitats. The best solution was, therefore, to use a model which simply increased the percentage cover over time, with the initial cover value being the midpoint of the density/cover class given on the maps. As described above, the model is a discrete one using an annual time step, so a discrete form of a model for an exponential increase in cover was used:

$$P_t = P_{t-1} + rP_{t-1}$$

where P = percentage cover; t = the current time step; t-1 = the previous time step; and r = the rate of increase in cover.

Studies by Boucher (1984), Richardson & Brown (1986) and others (see Appendix 1) suggest that transitions from initial invasion to complete cover take of the order of 40-160 years over a wide range of situations. This is equivalent to a rate of increase coefficient ranging from 0.045-0.194 per year. Some guidelines on the relationship between the expansion coefficient and the time required to reach specified percentage cover values are given in Table 3.

Table 3 : The approximate densification coefficient (r) required for an invasive plant to achieve a cover of the ≥99.5% in the given period of time. This is based on the exponential model outlined earlier and an initial cover of 0.1%.

Time period (years)	Densification coefficient
20	0.435
30	0.267
40	0.193
50	0.151
60	0.124
70	0.105
80	0.091
90	0.081
100	0.072

For this analysis a mean cover increase (densification) rate of 0.105, or 70 years from first invasion to 100% cover in landscape areas and 0.151 (50 years) in riparian situations, has been used.

3.3 *Available space or habitat*

The next requirement is to define the available space and/or the preferred habitat. The constraints suggested below are first approximations and will need to be re-examined and refined using the mapped data. The areas invaded by aliens can be broadly grouped into two major categories: landscapes where plants invade the entire area and riparian where species primarily, or only, invade riparian areas. Some broad generalisations are given below:

Landscapes: In South Africa a key constraint is rainfall, particularly the frequency and intensity of dry seasons and droughts. The only species which invades landscapes in the semi-arid and arid interior is *Prosopis* and even it is largely confined to alluvial plains where ground water stores are easily accessed and reliable, for example the valleys of the major rivers. Otherwise landscape invasions appear to be restricted to areas with at least 500-600 mm/year. Exceptions are the southern Cape coastal lowlands and the west coast lowlands where the cut-off is about 300 mm/year except for a strip near the coast (extending as far north as Hondeklip Bay) where regular fogs are an important source of moisture. Only a few species appear to be successful as landscape invaders on a large scale. These include: *Pinus pinaster* and *P. radiata* in the winter and all year rainfall regions and *P. patula* and *P. halepensis* in the summer rainfall regions; *Hakea* species in the western and southern Cape mountains; *Acacia cyclops*, *A. saligna* and *A. pycnantha* on the coastal plans and dune fields on the Western and Eastern Cape coasts; and *Acacia mearnsii* in KwaZulu-Natal, especially in the midlands. In many areas landscape invasions are restricted by regular burning (e.g. *Acacia* species in grasslands used as pastures) or by agricultural practices such as intensive cultivation. If the land cover mapping of South Africa was complete these and similar land-use classes could be used to define limits to invasion. The Water Resources 1990 data sets (Midgley *et al.* 1994) do have land-use categories but they only include forestry (pine, eucalypt, wattle, indigenous), sugar-cane and urban areas and are too limited to use in this study.

Riparian zones: Extensive invasions and the formation of dense stands in riparian zones is largely limited to perennial rivers. The exceptions are species such as *Nicotniana glauca*, which survives as seeds even in ephemeral river systems, and *Prosopis*. *Prosopis* appears to be limited largely to major river systems (e.g. those with regular seasonal flow) and their alluvial plains except for areas with >300 mm per year (SJ Milton pers. comm. 1996). Most of the invasive alien plants in the summer rainfall region are found in riparian areas, especially in grassland and savanna. Prominent invaders of riparian zones include *Acacia mearnsii*, *A. dealbata* and *A. decurrens* which are primarily confined to river systems except in the moist grasslands (e.g. mist-belt grasslands *sensu* Acocks); and species such as *Lantana*, *Melia azederacha*, *Caesalpinia decapetala*, *Salix*, *Populus* and *Rubus*. For riparian species dispersal is primarily unidirectional and downriver, especially during floods, although most are dispersed upriver as well by some means or other. Thus areal expansion should be lower than species which invade omnidirectionally across landscapes. This may be compensated for by the relatively long-range dispersal during floods and high flows. Although the evidence from the available studies is inconclusive, the limited anecdotal information does suggest that it is reasonable to assume that expansion and densification rates are more rapid than those of landscape invaders. The potentially invadable area for riparian species was calculated by buffering the rivers to the typical widths recorded during the mapping exercise.

5. Model algorithm

This section sets out the steps that were followed in to apply the models to calculate the rates of expansion and densification of alien plant species. The data from the GIS contained the following information: records for polygons that have single species and sets of records for those polygons invaded by various mixtures of species. No species is represented more than once in a given polygon.

The adoption of a non-spatial model has some important consequences for modelling spread. For example, where there are mixtures it is no longer possible to model how the proportion of mixtures changes. The difficulties can be illustrated using the following example with two species (Figure 1). Initially the two species each occupy an area (as indicated by line shading) and there is an area of overlap (cross-hatched). After one time step they have expanded to the new boundaries. The area of the mixture has also changed (to area ABCD in Figure 1) and this is where the problem lies. There seems to be no general way to derive what the expansion of the mixture is because it depends on the spatial arrangement and relative sizes of the areas occupied by each species. Additional complications are that the areas are irregular and that and there may be several species which overlap in different ways.

The data for the model includes the following information: the polygon number, the species in that polygon and its percentage cover class in that polygon. As each species is represented individually in the data set it is possible to calculate:

(1) The total invaded area = $\sum$ (areas of invaded polygons counting each polygon only once regardless of the number of species).

(2) The total cover (%) for that polygon = $\sum$(percentage cover for each species). Four density (cover) classes are used. The cover codes are converted to the mean cover values. In cases where the sum of the cover values is > 100%, the individual species values will be adjusted back to 100% cover by scaling each one (multiplying by a factor = maximum total cover (100%) ÷ actual total % cover).

(3) The mean percentage cover for the whole area

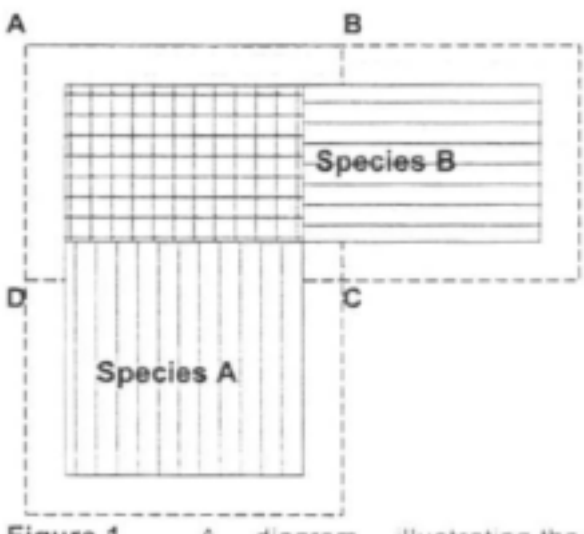

Figure 1 A diagram illustrating the expansion of two alien plant species. The initial boundaries are indicated by the solid lines and the new boundaries by the broken lines. For more information see the text.

i.e. the polygon area weighted percentage cover = ∑(polygon area* total polygon cover) ÷ ∑(total invaded area (see (1) above).

The calculations proceed as follows:

(a) The expansion of the invaded area each time step (one year) is modelled using the logistic function. The area calculated in (1) gives the starting area (N_0 or N_{t-1} [when t=1]).

(b) The increasing canopy cover in the initially invaded area is modelled using the exponential function. The initial starting value is given by the value calculated in step (3) above.

(c) Each new area added (N_t-N_{t-1}) begins with 0.1% cover and its densification is modelled using the exponential relationship described above.

(d) Once the model has been iterated the desired number of times there will be the initial area with a new percentage cover and a series of annual increments with their percentage cover.

(e) The data are now summarised before calculating the water-use as described in chapter ##.

6. Literature review

The aim of this literature review was to determine the basic principles of the invasion process, to summarise the available quantitative information on invasion rates in different areas and to identify appropriate models for simulating this process. The emphasis was placed on studies of actual invasions rather than model based analyses which incorporate assumptions based on the structure and approach of the models concerned.

Plant dispersal and invasions by exotic plants have been the focus of many scientific studies. Harper (1977) provides a brief review of the history of these studies and recent reviews are given by Drake *et al.* (1988), Hengeveld (1989), Bunce & Howard (1990), Hobbs & Huenneke (1992), Kot *et al.* (1996) and Higgins *et al.* (1996). The first section reviews studies of dispersal, the next the information increases in density (densification) and the final section summarises information on the habitat relationships of important invasive species.

6.1 Dispersal

Seed dispersal is a function of several variables (after Harper 1977): (a) the height and distance of the seed source; (b) the amount (concentration) of seeds at the source; (c) the dispersibility of the seed as determined by its size, weight and form (e.g. winged, plumed, smooth, round, flat); and (d) the type and activity of the dispersal vectors (agents) such as wind (speed, direction, turbulence), birds (size, mobility) and water (surface flow, floods).

6.1.1 *Dispersal vectors*

There are essentially two kinds of dispersal of seeds (Harper 1977; Hengeveld 1989; Le Maitre *et al.* 1996). Broadcast dispersal by agents such as wind which spreads seeds over a wide area with some bias depending, for example, on prevailing winds at times when seeds are released (Lamont 1985; Manders 1986; Richardson *et al.* 1987; Bond 1988). In contrast, directed dispersal concentrates the seeds within particular environments, with the dispersal agent providing the focus; for example water moves seeds down river, birds disperse seeds in the vicinity of perches (Glyphis *et al.* 1981; Brownlie 1982; Gill 1985; Hoffman & Moran 1988; Hoppes 1988, Pysek & Prach 1993, 1995). For example, *Prosopis* seeds are readily dispersed by water because they float; they are also carried in livestock away from water courses (up to 300 m in altitude, Glendenning & Paulsen 1955).

6.1.2 *Seed dispersal ranges*

Numerous studies have shown that (seed) dispersal typically follows a leptokurtic (right-skewed) distribution, with a rapid decline in seed density with increasing distance from the source (point or patch boundary) (Howe & Westley 1986; Wilson & Lee 1989). When the numbers are expressed as the frequency of seed deposition at different distances from a *point source* they typically show an initial increase in frequency followed by a decline with increasing distance (see Harper 1977; Lamont 1985; Greene and Johnson 1989; Marshall and Hopkins 1990; Portnoy & Willson 1993). When expressed as frequencies with increasing distance from an *area source*, or as densities, the decline is typically monotonic from the source or source boundary (Harper 1977; Greene and Johnson 1989). The decline is most simply modelled as a negative exponential relationship or a geometric progression (Hengeveld 1989; Le Maitre *et al.* 1996; Greene & Johnson 1996). Other commonly used forms are an inverse square or cube which would give a slope (using a log-log or power regression) of <-2.0 for a point, -1.0 for a line and -1.0-0.0 for an area source where most seeds disperse from the perimeter (Gregory 1973 in Legg *et al.* 1993; Harper 1977; Watkinson 1978). Alternatively slopes ≤ -2.0 are associated with a clear advancing front and from -1.0-0.0 with a 'broken' front with colonisation by isolated individuals from long-distance dispersal followed by short-distance, second generation dispersal (Van der Plank 1960 in Legg *et al.* 1993). In the case of wind dispersal the typical decline with distance is actually the result of complex interactions between wind speed, wind turbulence, seed release requirements and height, and seed fall rates which require sophisticated models (Okubo & Levin 1989; Greene & Johnson 1989; Andersen 1991; Shigesada *et al.* 1995; Kot *et al.* 1996).

The curves reported in the literature are usually based on studies of seed fall in still air or analyses of the densities or numbers of seeds or seedlings at different distances from the source or both. Both observations and models of dispersal using these functions typically show that most seeds, even well-dispersed ones, reach only 10s of metres, at most a few 100s of metres from the source with a very small percentage travelling further (see Harper 1977).

6.1.2.1 Birds as vectors

There have been a wide variety of studies of bird dispersal of seeds, most of which have focussed aspects such as why birds select particular seeds. Few studies have attempted to quantify seed dispersal distances and to model them. There seems to have been only one South African study of the dispersal of an alien plant species - that of *Acacia cyclops* by Glyphis *et al.* (1981). The derived the following equation:

$$\text{Seedling density } (n/m^2) = 8.49e^{(-0.04 * \text{distance in metres})} \quad (r=0.88,\ n=16).$$

This relationship implies that virtually all seedlings are found within 200 m of the source and beyond 400 m densities are less than one seedling per km². In contrast, Slingsby (1978) mapped data which gives a rate of spread of *Acacia* up the Witels River as about 420 m per year. Taylor *et al.* (1985) noted that the available records that *Acacia longifolia* seeds may have been carried a distance of six kilometres.

Birks (1989) found that British species dispersed by birds were carried further, 4-10km per generation, than wind dispersed species. This is in line with observed distances of about 4km and the range of 1-8 km per generation for similar species in North America (Johnson & Webb 1989). The maximum observed distances were 22 km for Clark's nutcracker (Vander Wall & Balda 1977) and, by inference, from palynological studies 90-130 km (Webb 1986, 1987).

6.1.2.2 Water as a vector

Hoffman & Moran (1988) suggest that long-range dispersal in flooding rivers is the primary dispersal mode of *Sesbania*. *Fraxinus ornus* was found to spread down river via autumn floods up to 61 km from the source (about 970m/year), much faster than it was spread by wind upstream, about 2 km in the 63 years since it was introduced (Thebaud & Debussche 1991). Expansion of the annual plant *Impatiens glandulifera* in Great Britain occurred at rates of 1.9 to 5 km per year, or from 290-750 km² from 1920-40 and 750-7040 km² from 1940 to 1960 (Usher 1986) and up to of 13-38 km/yr (Perrins *et al.* 1993). These rates were increased by the establishment of multiple colonies (foci, see below) and very long range expansions, probably anthropogenic, and so are indicative only.

6.1.2.3 Wind

Van Wilgen & Siegfried (1986) give data on the density of *Pinus pinaster* versus the distance from the parent stand. This gives the following regression model:

$$\text{Density (plants/m}^2) = 0.05990 * \text{distance in metres}^{-0.67866} \quad (r^2 = 0.63,\ n = 9).$$

This relationship predicts a far longer tail than the one for *Acacia cyclops* and accords with observations that dispersal distances of more than a kilometre are common and up to 3.2 km was reported by Richardson and Brown (1986) for *P. radiata*. In practice when a finite number of seeds is allocated in a spatial model, dispersal was limited to about 400m from the source (Le Maitre *et al.* 1996) so a different approach is needed for predicting long-range dispersal. The spread of wind and animal dispersed *Chromolaena* along the lower eastern escarpment and the coastal belt has averaged about 15km/year northwards to Louis Trichardt and 5km/year southwards to Port St

Johns (based on J. Goodall pers. comm. 1996).

Analyses of post-glacial migrations in the Northern hemisphere using palynological studies have found that pines disperse at about 1500 m/yr, with typical distances for wind dispersed species ranging from 50-2000 m/yr and bird or vertebrate dispersed species 25-500 m/yr (Hengeveld 1989). Many of these tree species require 15-60 years to flowers and set fruit so these mean rates include long pauses and the individual dispersal events cover significantly greater distances. Birks (1989) calculated dispersal ranges of 1-10 km per generation, regardless of dispersal vector and derived diffusion coefficients of 1.0-9.1 km^2 per year for the different species. These rates may well be slower that the actual rate of movement of the population front because a minimum density of trees is needed to produce sufficient pollen to be detected (Bennet 1986). Studies of the (wind) dispersal of minute *Calluna* seeds into severely burnt areas gave the following relationship: Nseeds/(100x100x30 mm soil sample) = 2.10*Distance(m)$^{-0.93}$ and for flowers (which can roll along the surface): Nflowers/(0.2x0.3m trap)=2.18D$^{-0.68}$ (Legg *et al.* 1993).

6.1.2.4 Long-range dispersal

Several studies also have shown, or found evidence which implies that seeds travel considerably further, albeit relatively rarely, and that this is important (Harper 1977; Mollison 1986). This process has been called stratified dispersal (Hengeveld 1989). For example, most seeds of wind-dispersed *Asclepias*, released at a height of 1m, travelled ≤ 10m, but some 2% travelled more than 150 m (Morse & Schmitt 1985). Mollison (1986) and Greene & Johnson (1995; 1996) have developed models for long-range dispersal by wind. These are based on the fact that winds are turbulent and the vertical air currents can lift and hold seeds for substantial distances (see also McCartney 1990). Greene & Johnson (1995) argue that the typical negative exponential relationship between seed density and distance is due to seeds dropping relatively rapidly in the wind-sheltered lee of the source stand. Their model, and comparison with measurements, suggests that the long-range dispersal involves only a small fraction of the seeds (≪10%). Beyond the initial leptokurtic decline there was an almost constant seed deposition to at least 1600 m. Whichever model is used, the tail of the distribution is very important but difficult to measure and model reliably (Birks 1989; Portnoy and Willson 1993; Greene and Johnson 1995; Kot *et al.* 1996).

These long distance dispersal events, although comparatively rare, are important because they can significantly increase the rate at which an area is invaded (Auld *et al.* 1978/9; Moody and Mack 1988; Goldwasser *et al.* 1994). This happens in the following way: as a patch expands more and more of the seeds from plants in the middle of the patch fall within the patch (McClanahan 1986; Moody and Mack 1988). Thus as a patch increases in size its relative rate of expansion decreases. New colonies add new area and expand relatively rapidly. Once they become a seed source they can establish new colonies, producing a 'leap-frog' effect. Thus the rate at which a given area is occupied increases in direct proportion to both the rate of patch expansion and the rate of new patch formation. Mack (1985) developed a model for the relationship between the number of foci and the expansion rate (from a constant total initial area):

$$A = \pi[r^2+2\sqrt{n}(rat)+na^2t^2]$$

where A = area, n= number of foci, a = growth rate, r = focus radius (maximum initial value of 1 for the single focus) and t = time.

6.1.3 Expansion of the invaded area

A number of studies have attempted to model the expansion of the area invaded by species based on the intrinsic rate of increase and the dispersal ability of species (see Higgins & Richardson 1986). Many of these analyses have used diffusion models where population expansion is a function of the diffusion coefficient and the rate of population growth with a measure of success (Andow *et al.* 1990). Skellam's (1951) pioneering study used the typical negative exponential function for seed density versus distance in a diffusion model to characterise the rate of spread as a linear function of the square root of the invaded area. In this form of model the expansion rate is related to the product of the intrinsic population growth rate (*r*; seedlings per parent) and the diffusivity (*k*) of the dispersal distribution (Williamson & Brown 1986). This diffusion model assumes a 'normal' distribution of dispersal distances, a constraint which has been relaxed in a new approach which merits further exploration (see Kot *et al.* 1996).

Auld & Coote (1980) developed a simple model on these lines using four parameters: (i) the population growth rate at a site (c); (ii) the proportion of the annual population increase dispersed beyond the boundaries of the infection site (s); (iii) the area over which the fraction (s) is dispersed; and (iv) the susceptibility of the area to colonisation. The basic model is as follows:

$$P_n = P_1*(1+c/K)^{n}*(1-s/K)^{n}$$

where P_n = the population in year n; K = the saturation population (100).

The available studies clearly show the typical exponential increase in the area invaded over time (Hengeveld 1989). Theoretically the exponential increase can continue indefinitely but in reality this is not so. No alien plant species can invade everywhere, various factors restrict them largely or entirely to particular habitats or to areas where land-use practices prevent invasion. In addition, the rate of expansion slows down as the remaining uninvaded area of a suitable habitat decreases, as shown by various studies (see Bennett 1986; Birks 1989; Richardson & Brown 1986; Perrins *et al.* 1993). Thus expansion within a bounded area tends to follow a sigmoid curve over time.

Estimates of the post-glacial areal expansion rates give values, for the movement of the invasion front, in the range 0.05 to 0.35 km per year with little evidence of consistent differences between wind, water and animal dispersed species (Birks 1989). Studies of the number of localities (±10 x 12 km latitude-longitude quadrants) occupied by invasive herbaceous species, including *Impatiens*, in Western Europe during the last 100 years show that, after an initial lag, the increase is exponential with time (Pysek & Prach 1993, 1995). *Impatiens glandulifera*, which spreads primarily along rivers, had annual spread rate exponents ranging from 0.05-0.131. Other analyses of the spread of annual *Impatiens* species in Britain have given expansion rates (r) ranging from 0.031 to 0.056, equivalent to maximum linear invasion front spread rates of 13-38 km/yr, probably assisted by humans (Perrins *et al.* 1993). The exponent of the annual rate of increase ranged from 0.04 to 0.107 in all habitats, including riparian zones. Auld *et al.* (1982/3) provide information on the areal expansion of *Parthenium* (annual, wind, water and animal dispersed) and *Opuntia* (prickly pear, vegetative propagation, vectors animals, humans and water) which gives coefficients (km^2 per year) of 0.44 and 0.10 respectively. Data from Anneke & Moran (1978) and Moran & Anneke (1979) for *Opuntia* species give expansion (1000s of ha per year) coefficients of about 0.09. *Leptospermum laevigatum* shrubland and scrub on Wilson's Promontory (an area where it is invasive - Burrell 1981) expanded from 2179 ha in 1941 to 3436 ha in 1972 and 4156 ha in 1987 (Bennett 1994) and annual expansion coefficient (r) of about 0.016.

Lonsdale (1992, 1993) reports values for the exponent of the rate of areal expansion (r) of 0.64-68 for *Mimosa pigra* in riparian and wetland situations in Northern Australia. In mountain fynbos *Pinus radiata* spread more slowly but still relatively rapidly, occupying 98% of 237 ha in 40 years (Richardson & Brown 1986), equivalent to an areal expansion exponent (ha per year) of 0.203 (r^2=0.90, n=5). Similar analyses give an exponent 0.084 (r^2=0.98, n=3) for *Acacia cyclops* at Cape Point (based on data from Macdonald *et al.* 1989), for *Prosopis* species 0.180 (r^2=0.92, n=5; based on maps in Harding & Bate 1991) and for *Mimosa pigra* 0.26 (Lonsdale 1993) (Figure 2). Beukes (1958 in Walsh 1968) reported that *Acacia cyclops* was introduced to the Albertinia, Still Bay, Riversdale and Heidelberg districts in 1928. By 1958 it had invaded some 41 000 ha. At the rate of spread estimated for the Cape Peninsula this would have taken about 126 and not 30 years; the latter period requires a rate of spread exponent of the order of 0.36. The spread rate was undoubtedly accelerated because it was actively planted in driftsand areas by farmers, but this does give an idea of the potential rates of spread of this species.

6.2 Increases in density

The only South African study that had sufficient data to permit calculations of the transitions between density classes was Richardson & Brown (1986; Table 4). During the 39 (1938-77) year period of the study the area of 237 ha went from uninvaded to 14% having scattered (1-20 trees/ha) and 83% medium to dense (21-1000 trees/ha) stands. McLachlan *et al.* (1980) estimated that the density of *Pinus pinaster* could increase from 1.7 to 250 trees per ha over 35-40 years. Assuming this to be mature trees, this would roughly equate to a change from an occasional (<5% cover) to a medium to dense stand (> 50% cover).

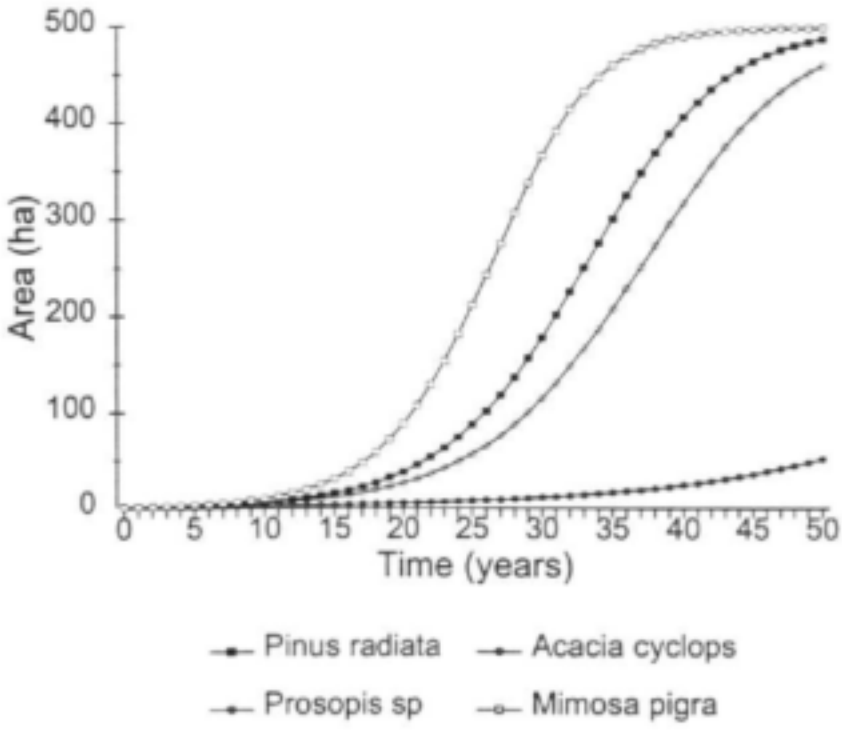

Figure 2 Expansion curves for different alien plant species based on the logistic model and the expansion rates derived from data in Richardson & Brown (1986) - *Pinus radiata;* Macdonald *et al.* (1989) - *Acacia cyclops*; Harding & Bate (1991) - *Prosopis* species; and Lonsdale (1992) - *Mimosa pigra*. For more information see the text.

Table 4 : Mean density class transitions derived from data in Richardson and Brown (1986) for *Pinus radiata* invading mountain fynbos. Density classes were: scattered = 1-20 , medium = 21-1000 and dense > 1000 trees per hectare, roughly equivalent to <5% canopy cover (occasional), 5-50% cover and >50% cover for trees with ±4 m diameter canopies.

Class	Proportion per year
Nothing -> Scattered	0.0279
Nothing -> Medium	0.00769
Scattered -> Medium	0.0325
Scattered -> Dense	0.000141
Medium -> Dense	no data

Seed banks of 14-18 year old serotinous pines range from 200--8600 seeds (Richardson & Cowling 1994). Studies have shown that serotinous Proteaceae typically produce one seedling for every ten seeds (Le Maitre 1992). If this holds for pines as well, then very high population growth rates are possible and no more than two to three generations are needed to go from occasional colonists to dense stands. Assuming that fires occur at 15 years of age, net recruitment rates of 10% of the seeds and that all trees are killed in each fire, the intrinsic rates of increase (r) would range from 0.204-0.460, which is very high.

Boucher (1984) reported on studies of the spread of aliens (acacias, pines, eucalypts) on the Western Cape lowlands. From these he estimated that regularly burnt renosterveld would have a 100% cover of aliens in 140 years (50% in 110 years) using an exponential growth model. For undisturbed sand plain fynbos 50% cover would take 125 years and 100% cover 170 years. In strandveld (thicket) it would take 165 years to reach 100% cover. This is equivalent to an cover increase exponent ranging from 0.028 (fynbos) to 0.034 (renosterveld). *Sesbania* was first noted as a weed in the mid-1960s (Hoffman & Moran 1988). In 1983 a survey of 532 km of the major rivers (Breërivier to Olifants River) in the Western Cape showed that 31% of the river courses had dense, 25% medium, 8% light invasions and the remainder had isolated plants or was uninvaded (Bruwer 1983). The high proportion of dense invasions illustrates the invasive potential of *Sesbania* in this short period.

In large rivers (minimum flow rates >5m^3/second) the increase rates of *Impatiens* were equivalent to a period of 75 years from initial colonisation to 100% occupation (Pysek & Prach 1993). *Nasella* grass can reach saturation in 15 years, with light infestations becoming medium (2.5-10% of saturation) in 7 years and medium becoming heavy (>10%) in 3 years (Auld and Coote 1981; Auld *et al.* 1982). This is equivalent to:

$$P_n = 1.67^n * 0.95^n \text{ where } K = 100$$

and a saturation (percentage) expansion coefficient of about 0.33.

Glendenning & Paulsen (1955) report that densities *of Prosopis* species in permanent sample plot in the southwest USA increased at 5-10% per year (5-27 seedlings/ha/year) depending largely on the amount of rainfall. Bennett (1986) summarised the results of a number of studies of actual tree populations, and palynological analyses. Population doubling times ranged widely from 8 - 408 years with the typical period being of the order of 10^2 years. Many of these studies were of long lived species, with long juvenile periods unlike the typical invasives in South Africa which have short generation times (Table 5).

It is possible that density transitions are not constant with time and that they follow the same pattern as the occupation of available space: an initial exponential increase followed by a decrease in the transition rate as the space is saturated. There is little evidence for this in the literature so it is reasonable to assume a constant and exponential increase to the point of saturation.

6.3 Habitats

This section reviews what is known about the areas currently invaded by the major weed species in South Africa as a first step in defining habitat preferences. In the descriptions that follow the old province names are used for convenience rather than using 'the former...' each time. Terminology for Fynbos Biome veld types follows Richardson *et al.* (1992). Species groups will have to be used to aggregate species with similar invasive tendencies. Some groupings are given below based on their attributes as derived from the available literature (see also Chapter 5, Table 5.2).

Habitat constraints are not necessarily easy to define because the limits can be determined by a number of factors including: climatic or edaphic constraints on the plant, facilitation or inhibition by disturbance, competitive interactions with native plants, the kind of seed dispersal and land-uses which limit or prevent invasion (Hengeveld 1989; Richardson & Cowling 1992). Two examples provide clear illustrations. On the coastal plains of the western and southern Cape the soils can be divided according to their fertility. On the more fertile shale-derived soils the dominant land-use is intensive agriculture (wheat, oats, vines) and invasions are largely restricted to river courses, fence lines, road and rail reserves. On the less fertile sandstone-derived soils and deep sands the dominant land uses are flower harvesting and grazing. Here invasions occur in any situation, especially where there has been degradation of the natural vegetation. The dominant invasives are the same, bird-dispersed *Acacia* species and to a lesser extent pines. Historically, the invasion of sandy soils was facilitated by 'reclamation' of aeolian dune sands using *Acacia* species, but the cause of the divergence in invasion patterns is the differences in land-use brought about by variation in soil fertility. The other example is in grasslands where invasions are largely restricted to river courses. This appears to be largely due to two main factors: fires and disturbance. Frequent fires, grazing and competition from vigorous grass plants limit the invasion of grasslands by woody plants, which are naturally confined to topographically sheltered sites, rocky areas with sparse grass cover, and river courses where fires are less frequent or rare. *Acacia* species, jacaranda, syringa and other woody invasives are able to establish themselves in these riverine environments, outcompeting and replacing to native woody plants. Landscape invasions are confined to situations where grass cover (and thus competition) has been reduced, resulting in lower fire frequencies. For example where the trees were planted, protected from fire and subsequently abandoned, or the land was ploughed or overgrazed. *Pinus patula* may be an exception to this rule as it is able to invade seemingly healthy grasslands, particularly at high altitudes (e.g. Dullstroom area).

One of the key limiting factors in much of South Africa is low rainfall. In most of the semi-arid and arid interior, north and north-west, woody plants are confined to water courses, including invasive species (cf. Henderson 1991a,b, 1992).

Acacia cyclops, saligna, pycnantha, longifolia: These species are most found on the coastal plains in the Cape, from about Vanrhynsdorp to about the Fish River. *Acacia longifolia* is the only one in this group which has penetrated mountain fynbos areas (but not dry fynbos), primarily along the rivers, streams and forest margins and around agricultural lands; it has not invaded other vegetation types or lowland areas much (Richardson *et al.* 1992). *Acacia cyclops* has mainly invaded lowland vegetation (fynbos & thicket) but is apparently less successful in renosterveld and grassy fynbos but has the potential to invade mountain fynbos; *A. saligna* invades agricultural and transformed lands but not thicket. *A longifolia* also occurs with *A. cyclops* and *A saligna* in coastal forest (Acocks 1,2,7) in the Eastern Cape (Henderson 1992) where drift sands were controlled. *Acacia cyclops*, *A longifolia* and *A saligna* were also common in mountain fynbos in the eastern Cape. As noted earlier, the main factor limiting spread in the western and southern Cape is intensive land-uses on shale-derived soils. In the north-west rainfall becomes the limiting factor, restricting spread inland from the coast and north of Hondeklipbaai.

Acacia mearnsii, A. dealbata, A. melanoxylon: *A. dealbata* was found in riparian zones in moist subtropical and transitional grasslands (Acocks 44, 54 & 56) in the OFS; it was also frequent in roadsides and fields in these grasslands and other temperate grasslands (Acocks 48-51, 53, 58; Henderson 1991a). In the Transvaal *A dealbata* & *A mearnsii* were both important in moist forested escarpment (Acocks 8, 9) and grassland (Acocks 61-64, 67) in streamlines, roadsides and veld areas (e.g Gauteng); they have the potential to spread into the moister bushveld (Acocks 10-16, 18-20) areas along water-courses (Henderson & Musil 1984). In KZN these two species have similar distributions: *A mearnsii* is most common in the mist-belt grasslands (Acocks 5, 45), rare in high-altitude grasslands (Acocks 48, 53, 54, 56, 57, 58), bushveld and savanna (Acocks 10, 11, 23) and is invading the coastal strip in southern KZN; *A. dealbata* occurred in all veld types being restricted largely to riparian zones in bushveld and savanna. In the Eastern Cape *Acacia mearnsii* is found on streamlines in all veld types, but is most abundant in mountain fynbos followed by moist grassland (Acocks 44), thicket (Acocks 21, 36, 37), coastal forest (Acocks 1, 2, 7) and temperate grassland (Acocks 22, 48, 50, 58-60) (Henderson 1992). It has the potential to invade all the river systems except the karoo in the Eastern Cape, especially the cool, moist montane areas. *Acacia dealbata* was recorded in the Eastern Cape only in moist grassland (as very common) and in temperate grassland where it could invade all watercourses. *Acacia melanoxylon* is largely confined to riparian and forest habitats with relatively high rainfall in the Cape (e.g southern Cape forests, Amatola and Hogsback), KwaZulu-Natal and Drakensberg escarpment in the Transvaal. *Acacia decurrens* is most common in Transvaal and KZN mistbelt grasslands (Acocks 61-64, 67). In the Western Cape *Acacia mearnsii* is found primarily in the montane areas but has spread extensively along rivers in the lowlands (Richardson *et al.* 1992).

Chromolaena odorata: Although herbaceous, this species forms dense, tall thickets. The prime habitat is riparian strips and to a lesser extent forest and other woody vegetation (Macdonald 1983) in moist, frost-free areas (Henderson 1989). It is currently found throughout Acocks veld type 9 & 10 in areas below 1000 m and from Port St Johns through Swaziland (lowveld to Piggs Peak) to Louis Trichardt (J Goodall pers. comm. 1996). It is unlikely to spread southwards of East London because of the increasing aridity along the coast (Henderson 1989).

Eucalyptus species: in the OFS gums were most abundant in grasslands but also occurred in the karoo and thornveld (Henderson 1991a). In the Northern Cape eucalypts have invaded riparian habitats and savanna (Henderson 1991b). *Eucalyptus camaldulensis* is classed as highly invasive in both natural vegetation and anthropogenically disturbed areas while *E. microtheca* is highly and moderately invasive respectively (Brown & Gubb 1986). Both invade episodic river banks, marshes, springs and river islands in the upper karoo, Kalahari savanna and Northern Cape savanna. In the Transvaal eucalypts are most important on the escarpment grasslands and less common in moist bushveld areas (Henderson & Musil 1984). In the Eastern Cape eucalypts were most prominent in fynbos.

Gleditsia triacanthos: This appears to be a widespread but not very important species in the dry interior. In the OFS its distribution was most similar to gums (Henderson 1991a) and in the Eastern Cape it was found in 'false' karoo (Acocks 36-38, 42) (Henderson 1992). It is ranked as only lightly invasive by Brown & Gubb (1986).

Jacaranda mimosaefolia, Caesalpinia decapetala: *Caesalpinia* is widespread but apparently confined to forest and riparian scrub in the summer rainfall regions (Macdonald 1983). *Jacaranda* was largely confined to riparian forest/scrub and forest margins in the bushveld and on the escarpment in the Transvaal (Henderson & Musil 1984). Undisturbed forest and grassland and woodland with frequent fires were able to resist invasion by both species.

Lantana camara is found from the Western Cape to the Northern Province along the eastern coastal belt (between the escarpment and the coast) and also on the central and western highveld (Henderson 1995). It is most common on forest and plantation margins, in watercourses and in savannah and occurs also on roadsides and degraded lands. It is light demanding, accumulates large fuel loads and colonises areas burnt in fires and where the overstorey is removed (Fensham *et al.* 1994). Seeds were found in soil in savannah up to 1300 m from the boundary of the invaded area.

Leptospermum laevigatum is a weed found mainly in the south-western Cape but it occurs as far east as Port Elizabeth and invades coastal fynbos on acid sands and is also found in forest clearings (Henderson 1995). It is weakly serotinous and has small seeds with a limited potential for dispersal by wind and water (Richardson *et al.* 1992). Research in Australia, where it invades coastal heath and thicket, suggests that the main factors favouring invasion are fire and disturbance but fire is the most important (Burrell 1981; Bennett 1994). It appears to require mycorrhizae to grow well and the mycorrhizae require somewhat elevated levels of phosphorus to develop properly.

Melia azederach: this species invades forest and riparian vegetation primarily in the summer rainfall regions (Macdonald 1983). Undisturbed forest and grassland and woodland with frequent fires were able to resist invasion. *Melia* was found in the OFS in riparian habitats in temperate grassland (Acocks 48-51, 53, 58) and savanna (Acocks 16, 17, 19, 32, 40) but rarely in the karoo biome (Acocks 16, 17, 23, 32, 36; Henderson 1991a,b). In OFS savanna *Melia* was also prominent in roadside habitats but confined to the Orange River in karoo areas. It is classed as highly invasive in disturbed and natural areas in the upper Karoo, Thornbush savanna, Kalahari & Northern Cape savanna where it invades virtually all habitats except rocky areas, marshes and pans (Brown & Gubb 1986). In the Transvaal *Melia* was ubiquitous in streamlines but most abundant in the bushveld and in grasslands (Henderson & Musil 1984). In KZN *Melia* is widespread in tropical bush and savanna and will probably invade all river systems in the savanna biome (Henderson 1989). In the Eastern Cape *Melia* was recorded in coastal forest (Acocks 1, 2, 7) and thicket (Acocks 21, 36, 37) in the savanna biome and in mountain fynbos (Henderson 1992).

Nerium oleander: Widespread but uncommon to occasional in the Eastern Cape in grasslands and savanna river systems (esp. the Baviaanskloof river) (Henderson 1992). In the Western Cape it occurs mainly in the dryer river systems inland of the coastal mountains.

Nicotiniana glauca: This species is currently widespread in the river systems of the arid interior where it is highly invasive in disturbed and natural areas except irrigated lands, perennial river banks (where it is outcompeted by other vegetation), marshes and pans (Brown & Grubb 1986). Its seeds are small and apparently wind and water dispersed. During drought period the plants die but as soon as the rains come they regenerate from seed. The species does not appear to be able to compete with other riverine vegetation in moist areas, but it can potentially invade all the river systems of the arid interior (SJ Milton pers. comm. 1996; J Kritzinger pers. comm. 1996). In the Northern Cape and Eastern Cape it was more common in savanna (riparian and non-riparian) than karoo veld types (Henderson 1991b; Henderson 1992).

Paraserianthes lophantha: this species occurs in fynbos in the Western Cape and is rarely found in non-fynbos vegetation types in the Eastern Cape (Henderson 1992).

Pines and hakeas: Pine invasions are found primarily in the mountain catchments coastal ranges of the Cape and the temperate grasslands of the Eastern Cape, KwaZulu-Natal and Mpumalanga. One constraint is rainfall, pines seem to be unable to invade vigorously where rainfall is lower than about 500-600 mm in the winter and all-year rainfall regions. Although scattered pines are found at altitudes >750m in the Cape mountains, indications are that invasion is slow. The summer rainfall pines, especially *Pinus patula* actively invade grassland at much higher altitudes (see Henderson 1991a), but are probably also limited by rainfall in dryer areas. *Pinus patula* is an aggressive invader of the Drakensberg escarpment grasslands, forest edges and scrub (Henderson & Musil 1984). In KZN this species is most invasive in the grasslands (Acocks 44, 63-66) in the south. In the Eastern Cape *Pinus halepensis* was widespread in all veld types and particularly abundant in fynbos and grasslands; *P. patula* was confined to moist grassland (Acocks 44); *P pinaster* was largely confined to fynbos, excluding dry fynbos; and *P radiata* and *P. pinea* to moist grassland or fynbos (Henderson 1992). In the Western Cape *P. pinaster* colonises both montane and lowland fynbos but not strandveld (thicket) (Richardson *et al.* 1992). *Hakea* species are essentially confined to fynbos and appear to have rainfall and altitude limits similar to pines, being largely absent from dry and lowland fynbos and on non-sandstone substrata.

Pittosporum undulatum is currently confined to the extreme south-west Cape where it invades forest and, to a limited extent, moist fynbos. It appears to establish and grow very well in indigenous forest on screes and in riparian zones and also spreads under plantations (Henderson 1995). It is bird dispersed and thus has the ability to spread very widely in forests in South Africa as it has done in Australia (Gleadow and Ashton 1981; Gleadow 1982; Gleadow and Rowan 1982; Gleadow *et al.* 1983). The seedlings appear to require shade to establish properly

(Gleadow & Rowan 1982; Gleadow *et al.* 1983).

Populus species, *Salix babylonica:* these species are found primarily in the highveld and adjacent regions of the eastern Free State, Gauteng and Mpumalanga in riparian habitats. *Salix* and poplars were most abundant in grassland (Acocks 44, 54 & 56) but also occurred in the karoo and thornveld (Acocks 16, 35, 36, 41; Henderson 1991a). In the Transvaal the dominant invasive riparian strips in 'false' grasslands (Acocks 48, 50, 52-55, 57) was *Salix*, followed by poplars, while in grasslands (Acocks 61-64, 67) they were both frequent (Henderson & Musil 1984). In the bushveld poplars were more common than *Salix*. *Salix* is prominent in grasslands in KZN (Henderson 1989). *Salix* and poplars are found in the karoo (Acocks 24-26, 30, 31) but are more prominent in the 'false' karoo (Acocks 36-38, 42), and in grasslands (Acocks 48, 50, 58-60) in the Eastern Cape (Henderson 1992). In the Northern Cape poplars and *Salix* are confined to perennial river banks and river islands where they are moderately invasive (Brown & Gubb 1986).

Prosopis species: Harding & Bate (1991) described the potential habitat of *Prosopis* as areas with relatively deep soil with ground water close to the surface, river banks, pans and depressions. Areas north of the Orange River and west of the Sakrivier were considered less vulnerable to invasion although the Kuruman and Molopo river systems are heavily invaded (Henderson 1991b). Alluvial plains are also extensively invaded in the Northern Cape (W Lloyd pers. comm. 1995). In the southern and Little Karoo they appear to be restricted to the larger river systems which, perennial or non-perennial, flow relatively regularly, being absent from rivers which flow episodically (Brown & Gubb 1986; SJ Milton pers. comm. 1996). They are not as drought tolerant as *Acacia karoo*. In the OFS *Prosopis* were occasionally recorded in riparian and non-riparian areas in grasslands, but were far more abundant in karoo and thornveld habitats outside the actual streamsides (Henderson 1991a). In the Northern Cape *Prosopis* was frequent in karoo and less abundant in savanna in riparian and near riparian habitats (Henderson 1991b). In the Eastern Cape *Prosopis* was only recorded in the karoo (Acocks 24-26, 30, 31) (Henderson 1992).

Pyracantha species: these were most abundant in moist subtropical grasslands (Acocks 44, 54 & 56) and less so in temperate grasslands (Acocks 48-51, 53, 58) on rocky hillslopes (Henderson 1991a).

Robinia pseudacacia: In the OFS it is only found in grasslands (Henderson 1991a) and similarly in the Transvaal (Henderson and Musil 1984). Although it is not very abundant yet it, is very difficult to eradicate and thus can be a serious problem.

Schinus molle: Most abundant in karoo in the OFS in riparian and non-riparian habitats (Henderson 1991a) and in riparian habitats in the upper Karoo, Kalahari savanna and Northern Cape savanna (Brown & Gubb 1986; Henderson 1991b), occasionally invading disturbed non-riparian habitats. In the Eastern Cape it was more common in 'false' karoo (Acocks 36-38, 42) than in karoo (Acocks 24-26, 30, 31) (Henderson 1992).

Sesbania punicea: Hoffmann & Moran (1991) describe *Sesbania punicea* as invasive mainly in riparian zones and wetland areas. In the winter rainfall region it can only survive where there is enough moisture for seedlings to survive summer. In the moist summer rainfall regions it can spread into agricultural, range and forested land. In OFS it was found only in riparian habitats in grasslands (Henderson 1991a). In KZN it was most common in bushveld and savanna and the coastal belt along river systems (Henderson 1989). In the Eastern Cape it was fairly abundant only in the savanna biome and occasional in the moist grassland (Acocks 44) (Henderson 1992). In the Northern Cape it invades outskirts of towns, and islands and riverbanks of perennial rivers in the thornveld, highland and northern Cape savanna (Brown & Gubb 1986).

Tamarix: in the Eastern Cape this species was found in streamlines in the 'false' karoo (Acocks 36-38, 42) and more prominently in the karoo (Acocks 24-26, 30, 31) (Henderson 1992). In the Northern Cape it occurs primarily in seasonal pans and around dams on exposed mudflats in the savanna areas (Brown & Gubb 1986).

6.4 Summary

The key facts arising from this review are:

1. There is only a very limited data set for parameterising the models so it may be better to work with a range of values for expansion and 'densification'.

2. Disturbances usually act as a cue for expansion and densification but the model's resolution necessitates working with mean rates. The available data are equivocal about whether riparian invasions expand or densify at different rates to landscape invasions but anecdotal observations suggest that they may be more rapid.

3. Colonisation events, though relatively rare, can have a significant impact on the rate of expansion and should be included in some way.

4. While the expansion is initially exponential, constraints on available space and/or suitable habitat ultimately limit the rate of expansion. The extent of the invadable habitat, of necessity, will have to be defined in a highly simplified fashion.

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Appendix 8:
Literature on Alien Plants and Invasion Process

Useful handbooks with descriptions and information on distributions and control

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More than 400 species, colour photographs, descriptions, information on control

Campbell P 1993. Wattle Control. Plant Protection Research Institute Handbook No 3, Agricultural Research Council, Private Bag X9059, Pietermaritzburg.

Information on wattle and guidelines for control; the principles could be applied to many other species.

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Descriptions, line drawings, distribution maps, legal status

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Line drawings, descriptions

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Colour photographs, line drawings, many of the species are common in other provinces

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Appendix 9: Summary of the cost data obtained from project managers in the Working for Water Programme

Table 9.1: The costs of clearing alien invasives averaged for South African conditions. All costs are in Rands/hectare. % refers to the percentage of total cost of this stage of the operation (e.g. clearing as a percentage of total cost including follow-up)

Acacia mearnsii (black wattle)

	Dense	**%**	**Medium**	**%**	**Light**	**%**
clearing	2 063 (788-4 517)	40	1 505 (1 300-1 905)	38	486 (188-880)	50
burning	950 (400-1 500)	19	1 300	33	-	
1st Follow-up	1 403 (600-3 000)	27	746 (90-1 500)	19	310 (100-500)	32
2nd Follow-up	694 (300-750)	14	428 (330-504)	10	169 (126-220)	18
Total	5 110		3 979		965	

Eucalyptus spp clearfelled or killed standing

	Dense	**%**	**Medium**	**%**	**Light**	**%**
clear felling	6 934	85	6 879	90	-	
kill standing	1 318 (1 137-1 500)	52	1 078 (956-1 200)	59	525 (250-800)	56
clearing average (for both methods)	4 786 (1 137-6 934)	80	4 518 (956-6 879)	86	525 (250-800)	56
1st Follow-up	802 (800-803)	13	429 (213-574)	8	275 (150-400)	29
2nd Follow-up	441 (400-482)	7	323 (300-345)	6	145 (90-200)	15
Total clear felling	8 177		7 631			
Total kill standing	2 561		1 830		945	
Total average	6 029		5 270		945	

Pinus sp

	Dense	%	**Medium**	%	**Light**	%
clearing	3 844 (1 400-9 464)	63	1 112 (800-1 336)	38	585 (113-1 018)	57
1st Follow-up	818 (400-1253)	13	512 (300-737)	17	249 (150-400)	24
2nd Follow-up	400	7	300	10	200	19
burning	1 019	17	1 019	35	-	
Total	6 081		2 943		1 034	

Hakea sericea

	Dense	**Medium**	**Light**
clearing	4 187	1 477	238.2
1st Follow-up			
2nd Follow-up			
Total	6 280*	2 215*	357*

* figures assume follow-up is above half of original clearing costs - similar to pine

Caesalpinia decapatela (Mauritius thorn)

	Dense	%	**Medium**	%	**Light**	%
clearing	500	44	400	45	300	43
1st Follow-up	400	35	300	33	250	36
2nd Follow-up	250	21	200	22	150	21
Total	1 150		900		700	

Rubus cuneifolius (bramble)

	Dense	%	Medium	%	Light	%
clearing	550	46	450	48	300	43
1st Follow-up	400	33	300	31	250	36
2nd Follow-up	250	21	200	21	150	21
Total	1 200		950		700	

Solanum mauritanum (bugweed)

	Dense	%	Medium	%	Light	%
clearing	500	44	400	45	300	43
1st Follow-up	400	35	300	33	250	36
2nd Follow-up	250	21	200	22	150	21
Total	1 150		900		700	

Chromolena

	Dense	Medium	Light
clearing	900	600	250
1st Follow-up			
2nd Follow-up			
Total			

Lantana camara

	Dense	%	Medium	%	Light	%
clearing	500	44	400	45	300	43
1st Follow-up	400	35	295 (290-300)	33	250	36
2nd Follow-up	250	21	200	22	150	21
Total	1 150		895		700	

Average costs

Type	Dense	Medium	Light
Large trees	5 875	3 601	825
Small	1 163	911	700

Table 10.1: Rating of the biocontrol potential of a list of the most important invading plant species identified in this study. For an explanation of the scoring see section 6.7. The four criteria are: con = conflict, ava = availability, eff = effectiveness and time = time factor. The final factor is the final score (weighted) divided by twice the maximum final score for any species for that form of biocontrol.

Species	Seed attacking biocontrol agents				Final score (weighted)	Factor	Vegetative feeding biocontrol agents				Final score (weighted)	Factor
	con	ava	eff	time			con	ava	eff	time		
A. cyclops	5	4	5	3	20	0.91	2	2	3	2	10.5	0.47
A. dealbata	5	5	5	3	21.5	0.98	1	4	4	2	14	0.62
A. decurrens	5	5	5	3	21.5	0.98	2	4	4	2	15	0.67
A. longifolia	5	5	5	3	21.5	0.98	3	4	4	2	16	0.71
A. mearnsii	3	5	5	2	19	0.86	0	4	3	1	11	0.49
A. melanoxylon	5	5	5	3	21.5	0.98	0	3	3	1	9.5	0.42
A. pycnantha	5	5	5	3	21.5	0.98	4	4	4	2	17	0.76
A. saligna	5	4	4	3	18.5	0.84	2	4	5	2	16.5	0.73
Agave americana	5	3	4	4	17.5	0.80	1	3	4	3	13	0.58
Ageratum conyzoides					0	0.00					0	0.00
Argemone spp	5	4	4	5	19.5	0.89	5	4	4	5	19.5	0.87
Arundo donax	0	0	0	0	0	0.00	3	1	2	2	8.5	0.38
Atriplex lindleyi	5	4	3	3	17	0.77	2	4	4	4	16	0.71
Azolla filiculoides	0	0	0	0	0	0.00	3	5	5	5	20.5	0.91
Bromus spp	3	1	1	2	7	0.32	1	2	2	1	7.5	0.33
Caesalpinia decapetala	5	5	5	3	21.5	0.98	4	4	4	3	17.5	0.78
Cardiospermum grandiflorum	5	5	5	4	22	1.00	5	4	4	4	19	0.84
Cassia spp	5	5	5	3	21.5	0.98	3	4	4	3	16.5	0.73
Catharanthus roseus	4	3	3	4	15	0.68	2	4	4	4	16	0.71
Cereus jamacarus	4	1	2	3	10	0.45	4	4	4	4	18	0.80
Cestrum laevigatum	5	3	3	2	15	0.68	4	4	3	2	15.5	0.69

APPENDIX 10 : RATING OF THE BIOCONTROL POTENTIAL OF A LIST OF THE MOST IMPORTANT INVADING PLANT SPECIES

Species	Seed attacking biocontrol agents				Final score (weighted)	Factor	Vegetative feeding biocontrol agents				Final score (weighted)	Factor
	con	ava	eff	time			con	ava	eff	time		
Chromoleana odorata	5	5	5	4	22	1.00	3	5	5	4	20	0.89
Cortaderia spp	5	2	2	3	12.5	0.57	4	2	2	2	11	0.49
Cylindra opuntia					0	0.00					0	0.00
Datura spp	5	4	4	5	19.5	0.89	5	5	3	4	19	0.84
Eichornia crassipes	5	1	2	4	11.5	0.52	5	5	4	5	21	0.93
Eucalyptus camaldulensis	4	4	4	2	17	0.77	1	4	4	1	13.5	0.60
Eucalyptus lemannii	5	5	4	3	20	0.91	2	4	4	2	15	0.67
Flaveria bidentis	5	3	3	3	15.5	0.70	4	5	5	4	21	0.93
Gleditsia triacanthos	2	4	4	2	15	0.68	1	3	3	2	11	0.49
Hakea sericia	5	4	4	2	18	0.82	5	3	3	2	15	0.67
Hakea gibosa	5	2	4	2	15	0.68	5	3	3	2	15	0.67
Jacaranda mimosifolia	4	4	5	2	18.5	0.84	2	4	4	2	15	0.67
Lantana camara	5	5	4	4	20.5	0.93	5	5	2	1	16	0.71
Leptospermum laevigatum	5	4	4	3	18.5	0.84	3	4	4	2	16	0.71
Leucaena leucocephala	4	4	4	3	17.5	0.80	0	3	3	1	9.5	0.42
Ligustrum lucidum	5	3	4	3	17	0.77	3	3	3	2	13	0.58
Macfadeyana	5	4	4	4	19	0.86	4	5	5	4	21	0.93
Melia azederach	5	3	4	3	17	0.77	2	4	3	2	13.5	0.60
Mimosa pigra	5	5	5	4	22	1.00	5	5	3	2	18	0.80
Morus alba	1	2	2	3	8.5	0.39	1	3	3	3	11.5	0.51
Myrophyllum aquaticum					0	0.00	5	4	4	4	19	0.84
Nerium oleander	5	4	4	4	19	0.86	3	4	3	4	15.5	0.69
Nicotinia glauca	5	3	3	3	15.5	0.70	5	4	4	3	18.5	0.82
Opuntia stricta	4	1	4	3	13	0.59	4	4	5	3	19	0.84
Paraserianthus lophantha	5	4	5	3	20	0.91	5	4	3	3	17	0.76

Species	Seed attacking biocontrol agents				Final score (weighted)	Factor	Vegetative feeding biocontrol agents				Final score (weighted)	Factor
	con	ava	eff	time			con	ava	eff	time		
Passiflora edulis	0	3	4	3	12	0.55	0	4	4	3	13.5	0.60
Pereskia	5	3	2	3	14	0.64	5	3	3	3	15.5	0.69
Pinus spp. (American)	3	4	4	2	16	0.73	0	4	4	2	13	0.58
Pinus pinaster	4	4	4	3	17.5	0.80	3	4	4	2	16	0.71
Pistia stratiotes	5	3	2	4	14.5	0.66	5	5	4	3	20	0.89
Pittosporum undulatum	5	4	4	3	18.5	0.84	3	3	3	3	13.5	0.60
Populus alba/canescens					0	0.00	3	2	2	3	10.5	0.47
Prosopis spp	4	5	4	3	19	0.86	2	4	4	2	15	0.67
Pisidium guajava	0	3	3	3	10.5	0.48	0	3	3	3	10.5	0.47
Pyracantha spp	3	4	4	2	16	0.73	3	3	3	2	13	0.58
Quercus spp	4	5	5	2	20	0.91	2	4	4	2	15	0.67
Ricinus communis	3	3	3	3	13.5	0.61	3	4	4	3	16.5	0.73
Robinia pseudoacia	4	5	4	3	19	0.86	2	3	3	2	12	0.53
Rubus cunifolius	4	2	2	2	11	0.50	4	2	3	2	12.5	0.56
Salix spp	0	0	0	0	0	0.00	2	4	4	3	15.5	0.69
Salvinia molesta					0	0.00	5	5	5	5	22.5	1.00
Schinus terebinthifolius	5	4	4	3	18.5	0.84	3	4	4	3	16.5	0.73
Sesbania punicea	5	5	5	3	21.5	0.98	4	4	5	3	19	0.84
Solanum mauritianum	5	4	4	3	18.5	0.84	5	5	5	2	21	0.93
Solanum seaforthianum	5	4	4	3	18.5	0.84	5	4	4	3	18.5	0.82
Sorghum halepense	4	3	2	1	12	0.55	4	1	3	2	11	0.49
Tecoma stans	5	4	4	3	18.5	0.84	4	4	4	3	17.5	0.78
Toona sp.	5	4	4	3	18.5	0.84	4	4	4	2	17	0.76
Verbena spp (invaders)	5	4	4	4	19	0.86	5	4	4	4	19	0.84
Xanthium spp.	5	4	4	4	19	0.86	5	3	3	4	16	0.71

Appendix 11: Using the Web

Modern information technology is transforming the way in which science is done and how it is applied. Modern technology has resolved most of the difficulties faced by earlier users of the network - the World Wide Web (WWW) or simply the web - by providing reliable and easy-to-use software and efficient ways of finding the information that is needed. A significant proportion of the world's information resources can be accessed by anyone with a computer, a modem and a telephone connection. The WWW and associated technologies constitute the ideal medium for:

- searching for relevant information at various levels for different purposes,
- information exchange, debate and reaching consensus on scientific matters,
- managing and ensuring the integrity of distributed data sets,
- multi-media presentations to educate the public and decision makers,
- direct planning, management decision support and scenario testing.

The results of this study show clearly that there is a crying need for more comprehensive information for better decision making on the control of alien plant invaders in South Africa. Information requirements range from facts and figures to address broad-scale national issues (e.g. prioritising catchments) to answering specific on-site questions (e.g. what species are present and what steps need to be taken to prioritise, plan and implement control operations?).

A well structured web site, suitably indexed and maintained could store (or provide links to) all the relevant information and provide multiple threads (routes) to guide users through particular types of decision processes. In addition, discussion groups and surveys could be set up at the various levels to focus on accuracy of the data sets (resident on-site validation), contentious issues and research needs. Ultimately, the web site(s) may capture more than just static information and provide more dynamic, interactive knowledge: on-line modelling, access to spatial data and expert systems. The content of this report, contact names and address lists for data, and information collated through this project could also be included on the Web.

Kim Tucker (CSIR Stellenbosch) will be addressing these aspects through 1997/98 in the following WRC-supported project "Multi-level decision support for a strategic, cooperative approach to the control of alien invasive plants with the aim of conserving water resources in South Africa".

The project will include the following:

(i) Prioritising catchments on a National scale;
(ii) Screening alien plants prior to introduction (focus: fynbos canopy dominant species);
(iii) One detailed environmental management plan (catchment level) as an example for the other catchments to follow/adapt;
(iv) Characteristics of alien invasive plants in South African Fynbos - prototype database for the other biomes in the country;
(v) Generic alien plant treatment advisor.

Some established international web sites:

- The Federal Interagency Committee for the Management of Noxious and Exotic Weeds:
  http://refuges.fws.gov/FICMNEWFiles/FICMNEWHomePage.html

- Hawaiian Ecosystems at Risk (HEAR) Project:
  http://www.hear.org/

- Fire and weeds:
  http://www.blm.gov/education/fire_and_weeds.html

- Biocontrol Cornell:
  http://www.dnr.cornell.edu./bcontrol/weeds.htm

- Additional internet resources on weeds are listed at the Consortium for International Crop Protection (CICP) web site:
  http://www.ippc.orst.edu/cicp/gateway/weed.htm

- Colorado Weed Management Association:
  http://www.fortnet.org/CWMA/

- CRC Weed Management Systems Australia:
  http://www.waite.adelaide.edu.au/CRCWMS/

  Plant Pest Control (Hawaii):
  http://www.mic.hawaii.edu/hawaiiag/512.htm

- America's National Wildlife Refuges ...
  http://bluegoose.arw.r9.fws.gov/NWRSFiles/InternetResources/Weeds.html

- AMERICA'S LEAST WANTED: Alien Species Invasions of U.S. Ecosystems
  http://www.consci.tnc.org/library/pubs/dd/toc.html
- WSSA-Weed Science Society of America
  http://piked2.agn.uiuc.edu/wssa/
- Weeds of the World Project
  http://ifs.plants.ox.ac.uk/wwd/wwd.htm

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