INVASIVE ALIEN PLANT RESEARCH PROGRAMME PROPOSAL:

ASSESSING THE BIOLOGY AND ECOLOGY OF INVADING ALIEN PLANTS FOR OPTIMISING CONTROL STRATEGIES IN THE KNP

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FOREWORD

Alien invasive plants pose one of the biggest and most problematic threats to the long-term integrity of the Kruger National Park. Not only may their effects be latent and sometimes difficult to detect and assess in extent, but they may just as easily be explosive and overwhelming. A case in point have been the recent flood events in February 2000, which have resulted in a huge influx of both seeds and new species not previously recorded in the KNP. Similarly new areas have been invaded that were previously considered "clean" and safe from immediate threat.

Within the KNP we are therefore currently at a tough and challenging pivot point. Alien species are arriving and reproducing at an alarming and increased rate, driven by a combination of natural and man-made factors (such as floods and inappropriate landuse practices). At the same time critical decisions with far-reaching and long-lasting effects are needed at short timing about which species to target first, the most appropriate and effective way to remove or contain them and how to share resources between target species and local regions. Fact is, the ever-increasing threats by invading aliens to South Africa's natural biodiversity are relentless and expanding in terms of geographical extent and density.

In order to deal with these threats and challenges effectively, a sound knowledge base and understanding is essential. Limited funding must be applied in an efficient and focussed manner to those target areas and plants of greatest potential threat in a sustainable and balanced manner. A concerted and united effort must be made to work together through partnerships and collaborative initiatives, with united visions and a prioritisation of focus areas. The contribution of this report lies in the prioritisation of research and understanding needs and knowledge gaps for addressing present and future problems of alien plant control in the Kruger National Park, and also more widely in the region. As the alien threats become more severe, increased and enhanced levels of collaboration and focus are needed to enhance the appropriate reaction time and effectivity of integrated control actions.

Dr Stefanie Freitag-Ronaldson

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1. SUMMARY

With the increase in alien plant species and densities of species in the KNP and the severe threat posed by surrounding areas, research and knowledge is required to assist in the development of better and more effective control strategies. The over-arching objective of the alien biota section is: To anticipate, prevent entry, eradicate or minimise the influence of non-indigenous organisms so as to maintain the integrity of native biodiversity. The six sub-objectives, which include a strategic, preventative, eradication, prohibitive/discourage, awareness and research, are aimed at a multi-scale and multi-pronged approach to alien species control. The research objective aims to develop an understanding of the practically relevant aspects of specific alien biota and their control, often in the following areas:

- Autecology of aliens, especially reproduction and dispersal
- Their effect on biodiversity
- Efficacy of control measures, including cost effectiveness and environmental acceptability
- Environmental impact of control operations and make practical recommendations to improve the basis of control.

2. MOTIVATION FOR PROPOSED RESEARCH PROGRAMME

Invasive alien plants represent a recurrent and ubiquitous threat to both agricultural and natural ecosystems (Buhler 1996; Buhler *et al.* 2000). The impacts are often immense, insidious and frequently irreversible. Although both indigenous and alien (exotic) species are capable of attaining weedy status, the latter types are more likely to become problems because they often are released from their natural enemies, and also have not co-evolved with the indigenous species. Thus, alien species can interfere strongly with indigenous types and as a result they tend to dominate or even displace the desirable species. It is widely accepted that alien invader plants constitute a major threat to biodiversity, directly by displacement of flora and fauna, or indirectly through placing natural resources under strain. The discipline of weed science has experienced a recent paradigm shift from dominance by chemicals (=herbicides) and evaluating methods of clearing Invasive Alien species (IAS), to approaches that reflect growing concern for human safety and environmental issues such as biodiversity and pollution. At present, research efforts are arguably lagging behind in terms of testing new ideas and theories for implementation in future alien plant management strategies. Fact is that knowledge on the biology and ecology of weed species, and their interaction with indigenous species, are considered to be vital components of this fresh approach (Reinhardt, 2000). The present proposal is aimed at stimulating research and contributing to the embryonic knowledge base that exists for this new approach to alien plant management.

The conflict between weeds and human aspirations cannot be measured only in monetary terms, e.g., weeds causing yield and quality losses in crops. Losses that are difficult to quantify include aesthetic losses (e.g. the transformation of natural landscapes by invasive weeds) and the loss of

biodiversity (e.g. the abundance of plant species may be reduced, or species may be lost together with associated herbivores and other host-dependent organisms). The increase in global trade witnessed in the past years has and will continue to increase the opportunity to transfer organisms, with both beneficial and deleterious impacts. The scope of species invading areas is global, the cost enormous, both in economic and ecological terms. The direct economic costs of alien plants and alien plant control in the United States amount to more than $15 billion annually (Bridges 1994). The relative costs in developing countries are even greater (Akobundu 1991). In the latter countries, an estimated 25% of food production is lost due to the interference of weeds with crops (Koch 1992). In under-developed and developing countries, the costs of alien plants are not measured only in food and feed losses, but also in terms of social issues, such as the ramifications of the drudgery of hand-weeding, which is often assigned to women and children. Also, in South Africa and many other parts of Africa, alien plants impact negatively on natural resources, and particularly on water (Akobundu 1991; Koch 1992; Versveld *et al.* 1998). The recognition in South Africa of the threat that alien plant invasions pose to the water resource is reflected in a high-profile national programme 'Working for Water', under the auspices of the Department of Water Affairs and Forestry, which is aimed at bringing the problem of plant invasions under control (Versveld *et al.* 1998). This programme involves biological, chemical and mechanical weed control practices, with a significant part of the budget being spent on herbicides.

Ecological rules of invasion, according to Williamson (1998) indicate that of those species introduced, about 10% become established. Of those that become established about 10% become invasive. So as a rule of thumb, about 1% of introductions are likely to become invasive. Richardson *et al*. (2000) developed a conceptualisation model for the invasion process. Following this scheme, invasion is a process requiring a taxon to overcome various biotic and abiotic barriers. Phases in the process can be described on the basis of a species' ability to overcome (or its inability to overcome) these barriers. Introduction implies that a species (or its propagule) has overcome, through human intervention, a previously major geographic barrier that prevented further distribution. Many species may survive introduction, but never reach levels that can maintain their populations over a long time period, relying on repeated introductions to persist. Establishment and subsequently invasion only starts when the environmental barriers are overcome, until a plant is dominant in an area. At this stage, the plants may be regarded as transformer weeds, which are plants that alter the character, condition, form or nature of the ecosystem over a substantial area (Richardson *et al*. 2000).

In the Kruger National Park (KNP), alien plants violate the basic objective of this conservation area, namely to maintain the natural ecosystems (Lotter, 1996). Invasive biota are regarded as the greatest threat to the biodiversity of the KNP (Biodiversity Assessment Workshop, Skukuza 1997). The ability of alien plants to form monospecific stands, to the exclusion of indigenous plant species, results in the loss of structural diversity and species richness (Lotter, 1996). Permanent loss of ecological diversity leads to reduced stability and resilience within ecosystems. Every alien species that becomes established

alters the composition of native diversity and communities in any manner of ways. Ecological impact of IAS depends largely on the link between native species and their place in ecosystem functioning, such as pollination, seed dispersal, hydrological cycles, provision of habitat to specific species with low tolerance of variability etc. Whether the loss of any particular species or combination thereof affects a specific ecological function depends on the ability and number of alternative species to support the functioning of the ecosystem invaded. This may be more severe and pronounced where species or communities have specific functions or a narrow range of niches which have evolved over long periods of time.

The establishment of more that 200 alien plant species in the KNP, is unnatural and poses a very serious threat to the maintenance of the ecosystems of the KNP. Some invasive alien plant species have already invaded thousands of hectares of land, forming dense impenetrable thickets in some areas, (e.g. *Opuntia stricta*, which covers and area of over 35 000ha in the Skukuza region).

The KNP acknowledges and accepts the problems and risks involved in invasion by alien species, however resources do not allow for in depth study and research of all aspects mentioned herein. It is also acknowledged that cross-boundary co-operative efforts are needed to be successful in “on the ground” clearing operations, and the same is required to advance science on the process and relevant aspects in invasion ecology. This document serves to record the outcomes of the Post flood research workshop as well as to document the possibilities and important aspects that require attention and research in the KNP alien biota programme. It further invites interested persons and institutions to consider the opportunity of developing research co-operation on these aspects in a co-ordinated and structured manner.

3. PRIORITIES FOR KNOWLEDGE ENHANCEMENT AND ALIEN INVASION UNDERSTANDINGS

According to the Global Invasive Species Programme (GISP) a number of important aspects should be considered in developing knowledge to enhance the control and management of invasive species. Many of these aspects are important to understanding and better managing the invasion process in the KNP. Priorities such as the following should be included:

a) Developing and improving techniques to prevent IAS introductions;
b) Developing and improving techniques to detect and monitor incipient populations of IAS;
c) Developing and improving techniques to eradicate and control IAS;
d) Expanding research in systematics (including taxonomy), thereby building the capacity to identify, record and monitor invasions and up-to date lists;
e) Building a better understanding of the relationships between climate change, enhanced carbon dioxide, soil moisture availability, photosynthetic pathways and plant population dynamics;
f) Developing a better understanding of the geographical limitation of species distributions;

g) Finding ways of making assessments that include an approximate measure of likely second order impacts without having to fully understand the full web of interactions;
h) Improving the basis on which biological control strategies are evaluated, and the basis for valuing the potential impacts of species introductions;
i) Investigating the role of biological factors vs. stochastic events that mediate long-distance dispersal;
j) Improving the knowledge of how and why species establish and change into invasive species;
k) Assessing ways to predict the impact of a given invasive taxon in a given locality so that the importance of such an impact can be compared objectively with that of another taxon at a different locality;
l) Developing predictive indicators of invasive alien species impacts;
m) Developing effective, target specific, socially acceptable methods for eradication and control of IAS as well as efficacy of the techniques currently used;
n) Improving identification and management of pathways leading to unintentional introductions. Identifying high-risk entry points (such as areas adjacent to the KNP on the main rivers);
o) Developing a risk analysis model for biological introductions;
p) Economic costs of IAS invasion and control to the KNP; and
q) Impacts on biodiversity on the KNP.

4. KNP POST FLOOD RESEARCH WORKSHOP PRIORITIES

On the 7 February 2000, the Sabie River experienced a massive flood event, which dramatically changed the character of many riparian habitats, and presented unique opportunities for research. Plant communities, particularly those in riparian habitats, have undergone dramatic changes, and will take a long time to recover to their former composition. Flooding and stochastic events are accepted to be an integral part of the natural system, however, in the past the system was allowed to recover naturally after a flood event, a new and irreversible change is made to the system with the influx of greater number of Invasive alien species. These species threaten to disrupt natural succession processes in plant communities, altering the direction and composition of re-colonisation of the river, with potentially serious consequences.

During a workshop held in Skukuza from the 29-31 July 2000, efforts were made to determine the direction and implications for research after this flood event. Invasive alien plants were felt to be a major ecosystem driver and have the potential to create deleterious impacts on natural succession rates and processes after natural disturbance events. The meeting was also to decide on the Thresholds of Potential concern (TPC's) and the impact that the floods may have had thereto.

TPC's indicate measurable goals in the system, defined according to spatial and temporal scales of limits. Appendix 1 indicates the current Alien Biota TPC's. Through monitoring these TPC's indicate a level at which

management concerns become evident and management actions need to be instituted (Rogers & Bestbier, 1997; Foxcroft & Richardson, In prep).

The following is a result of the discussions held during the workshop pertaining to IAS.

4.1. Implications for current alien plant TPC (Threshold's of Potential Concern) listings:

It was determined that the flood event did not change any Alien Biota TPC's, but highlighted monitoring to determine whether any of the TPC's have been exceeded. It is also acknowledged that there are real logistical constraints about where monitoring could be done. Working with other organisations was determined to be important in order to achieve these tasks. New opportunities for research were determined as follows:

4.2. New Opportunities (short and long-term, with hypotheses):

1. Compile list of alien plant species in KNP.
   Risk assessment of various species to assist in determining priorities for management actions.
2. Autecological studies on highest priority alien species in KNP (or threatening from upstream)
   - What affects growth rates?
   - Identify biotic and abiotic factors (e.g. biological traits, preferred habitat, associated vegetation types) conducive to high growth rates, move towards predictive capabilities.

   Hypothesis 1: The stage of development of alien plants determines efficacy of control and method of control (identify the Achilles' heel).

   Hypothesis 2: The stage of development of alien plants determines the efficacy of control and method of control for biological control agents. Also, refuges for biocontrol agents during stochastic events such as floods.

3. Quantification and evaluation of incoming seed and propagule threats:
   - Quantify seed and propagule influx into KNP (waterborne and other, e.g. birds).
   - Evaluate the newly deposited (post-flood) seedbank (what, how much, when, etc.)
   - How do different seeds/propagules move within rivers – should give an idea of which geomorphological features they will be associated with after deposition. Needs to link into sediment transport work being done in other areas of the post flood work.
   - Evaluation of seeds being brought into KNP by tourist vehicles (e.g. Skukuza carwash)

4. The effects of aliens on natural succession patterns (retarding indigenous recruitment, etc.)

Hypothesis 1: Establishment and density of aliens is greatly increased after the floods.

Hypothesis 2: This increase will decrease establishment of indigenous species.

Hypothesis 3: The above impacts are linked to sediment deposition regimes at the scales of channel type and sequence of channel types, latitudinally up the banks, longitudinally downstream. Needs to link into vegetation theme research projects.
It must be extrapolated up to coarse (KNP-wide) scales for management/control implications.

Hypothesis 4: River morphology determines where suspended propagules are deposited (e.g. consolidated sediments more likely to have aliens)

- test the effects of levels of alien infestation/interference interactions (density, allelopathy, competition) on recruitment of indigenous species in different morphological reaches
- at finer scale, identify specific mechanisms by which this takes place
- evaluate successional status of various alien species at these different reaches.

5. The effects of stochastic events (e.g. recent floods) on biocontrol populations and long-term biocontrol strategies.

   Hypothesis 1: The efficacy of biocontrol is dependent on the release strategy and timing.
   - quantify how stochastic events affect/change dynamics between host plants and agents (including time-lags).

6. Study post-clearing succession and effectiveness of clearing operations (different types)
   - What is stimulated to germinate straight after clearing?
   - In situ longevity of seeds in the soil?
   - How to prevent/reduce seed production?

7. Does extensive alien clearing have negative (significant) impacts (e.g. increased risk of sedimentation, erosion, water quality reduction)? Do the benefits outweigh the costs/risks?
   - How important is time of clearing?
   - Rates of alien regrowth vs indigenous growth
   - Importance of rehabilitation (maybe not important in KNP context?).
   - Rehabilitation decreases regrowth?

8. The use of remote sensing methods for the monitoring of invasive alien plant species:

   Management procedures have to be designed and instituted on the basis of available knowledge, however inadequate it might be. It is essential that continual environmental monitoring forms part of a management programme which, in turn, must be sufficiently flexible to enable incorporation of viable alternatives if unforeseen developments occur. The monitoring of alien plants are particularly difficult in such vast areas as the KNP. Therefore, an improved technique for the monitoring of invasive alien species would enhance the success of monitoring and control programmes. Remote sensing techniques have been used successfully for a variety of rangeland management purposes. Plant canopy reflectance measurements have been used to distinguish noxious weed species from other rangeland plant species and arial photography and videography have been used to remotely detect weeds over large and inaccessible rangeland areas. Arial remote sensing offers rapid acquisition of data with generally short turnover time and is less costly than ground surveys.

5. EXPECTED RESEARCH OUTCOMES

- Knowledge enhancement of the invasion and re-colonisation of a river system by alien weeds, after stochastic disturbance events such as flooding.
- An evaluation of the potential use of remote sensing methods, in detecting alien plant infestations and monitoring distribution, dispersal and density.
- A series of research publications in accredited journals.
- Management recommendations.

6. RESEARCH OBJECTIVES

6.1 To identify the mechanisms by which alien plants are able to establish, become naturalised, invasive or transformer weeds (Richardson et al. 2000) by dominating or displacing indigenous plant species

Specific aims are the following:

- Finding 'biological reasons' how alien plant species assert themselves in indigenous plant communities, even to the extent of totally displacing desirable species.
- Identifying the interference mechanisms (competition, allelopathy and others) between alien and indigenous plant species, which would explain much of the dynamics of alien plant invasions.
- Identification of environmental factors which may determine the success of certain alien plant species in a community, and which could explain why they are able to attain ascendancy over others.

- Incorporation of knowledge about plant-to-plant interaction mechanisms and the biology/ecology of invader species in weed management programmes, with the view to increase effectiveness and to reduce adverse environmental impacts.
- Development of models based on biological dynamics in order to predict rates at which invasions spread and determine areas most likely to be invaded.
- Although not the focus of the present proposal, the knowledge gained should benefit: (1) assessments of the impacts of alien plant invasions in game parks, rangelands, and on other agricultural activities and (2) rehabilitation measures that could be employed at damaged or transformed localities.

6.2 To assess the re-colonisation of the Sabie River, KNP, by alien invasive weeds, after an extreme flood event.

The following more specific objectives will be pursued:

- To assess the rate of re-infestation of alien plants along fixed transects. (In terms of species composition, rate of spread over time, distance along and up the flood plain).
- Correlation of distance with geology, elevation above channels, geomorphology, hydrology, river topography and landscape. (Are some areas more prone to invasion?)
- Determine spatial distribution patterns of alien plants.
- Attempt to correlate invasions in KNP with upstream sources (inc. Skukuza).
- To determine the rate at which different species re-infest the riverine areas, and the succession thereof.
- To determine the survival of the various species, also in relation to the position on the flood line.
- To monitor the transect over a period of at least two to three years, to assess which species invade and establish themselves, and to what extent.
- Evaluation of seedbanks (Germination experiments?)
- Simultaneous evaluation of biocontrol recovery / re-infestation.

7. APPROPRIATE INVESTIGATIVE METHODOLOGY

7.1 Basic Principles

The investigations should involve biology/ecology studies in the field and under controlled conditions, followed by an evaluation of the efficacy of practices for the control of alien species.

The research approach that is considered appropriate for biology/ecology studies is 'individual-based', which in the ecology discipline represents the line of thought that primarily considers the fates of individuals in ecological systems by analyses of the properties of individuals and interactions among them. This information is then used as a basis for explaining changes in sizes of populations in ecosystems. This view of ecology is embraced by many ecologists' concept of biodiversity, and the research approach that is needed in the conservation of biodiversity (Slingsby & Barker 1999). The methodology is based on the theorem that interactions between alien and native plant species typically have a negative outcome, and that dominance of one over the other is the result of asymmetric interference phenomena. The term 'interference' is preferred above the more commonly used term 'competition', because it acknowledges the fact that two phenomena, competition and allelopathy, should be considered in plant-to-plant interactions. Competition between individuals means partitioning, typically unequal, of growth resources (water, light, nutrients). It can only occur once one or more of the resources has reached depletion levels to the extent that the level of supply does not meet the combined requirements of interacting individuals. Allelopathy refers to the release into the environment by plants of secondary metabolites (allelochemicals) that have the potential to influence the growth of other plants. The effect that is of interest in this case is a negative influence on indigenous plant growth, although stimulation of growth by low concentrations of allelochemicals have been reported. The phenomenon of allelopathy is a relatively new scientific discipline with a distinct multi-disciplinary character (biology, ecology, chemistry), and is increasingly acknowledged as an integral component of the natural processes that govern the composition of plant communities, and consequently, the fate of organisms that use plants for food and shelter.

Information obtained as described above should then be used in the design of management strategies aimed at controlling weeds with the least impact on desirable species and the environment in general. Field trials to assess the effectiveness of different control practices, evaluated separately and in combination, should be done in the same areas where biology/ecology studies were conducted. The techniques used for weed management are well described (Zimdahl 1993; DiTomaso 2000), but the performance of different practices should still be assessed under local conditions.

Manipulative experiments are instructive because the immense potential number of confounding factors can be minimized with this approach. Field situations are manipulated to investigate the circumstances that permit the establishment and spread of alien invaders.

7.2. Anticipated data to be generated from field experiments

- Species composition of study areas (frequency and abundance data)
- Assessments of the soil seed bank for alien plant species
- Periodic emergence counts
- Phenological observations – vegetative development, flowering and seed production
- Biological parameters: density, height, growth, leaf number and leaf area per plant, canopy expansion – i.e. indicators of competitive ability. (High allocation of biomass to leaves and rapid growth response when resources become available give an important "ecophysiological" advantage to invaders, and is consistent with the Empty Niche Hypothesis, i.e. that invaders possess one or more features that facilitate aggressiveness and persistence).
- Seedling establishment and growth rates in different vegetation mixes (Likely to involve manipulation of vegetation).
- Effectiveness of practices for the control of alien species. Chemical (=herbicides), biological (=natural enemies) and mechanical control techniques will be evaluated separately and in combination (integrated). Performance levels will be measured in terms of activity (=rate of control of alien infestations), selectivity (=risk posed to desirable organisms), persistence (=sustainability of the control measure, and environmental risks), and the cost.

7.3. Anticipated data to be generated from Glasshouse and laboratory experiments

- Seed germination and seed dormancy information. The influence of climatic (temperature, soil moisture, light, etc.) and soil factors (pH, salts, texture, etc.) will be tested.
- Influence of stratification (temperature/day length) on germination.
- Influence of seed ageing on germination/dormancy.
- Influence of depth of seed placement on emergence.
- Effects of water on seed survival (e.g. time in water).
- Seedling establishment and growth rates on different soils.
- Comparisons of the relative competitiveness and the allelopathic potential of interacting species. Techniques with which the effects of the two phenomena can be separated will be used. In the case of allelopathic effects, both live plants and their residual matter will be tested. Isolation and characterisation of allelochemicals from live plants or plant material where significant allelopathic activity was found should be done.

8. POTENTIAL APPLICATION OF PRODUCTS

Providing information regarding the invasiveness of alien plants, as well as the effects of a natural event (flooding) on the distribution and infestation of a natural area. This may be useful to conservation agencies and other industries concerned with the invasion of natural resources by alien invasive plants. The research opportunities and questions posed here could provide knowledge and insight into how alien infestations invade certain areas, and their role in interference of natural succession and competition. Further, information may be provided as to the sensitivity of areas to invasion and possible applications for prioritisation when determining control strategies.

9. PARTICIPATION AND RESEARCH OPPORTUNITIES

Should any person or institution be interested in a research or collaboration on projects, the SANParks web site, http://www.parks-sa.co.za/ under the:

Kruger National Park - Scientific Services Section **-** Research Opportunities. At this site the following options are shown and should provide the basic information needed for background to research in the KNP:


List of Prioritized Project Opportunities


Project Application Procedure


Project Application Form


Working as a Scientist in the Kruger National Park

Alternatively you could contact the KNP Alien Biota Section at: LlewellynF@parks-sa.co.za or telephone 013 735 4114.

9. LITERATURE

AKOBUNDU, I.O. 1991. Weeds in human affairs in sub-Saharan Africa: Implications for sustainable food production. *Weed Technology* 5: 680-690.

ANON. 1997. Management review on Biodiversity Conservation in the KNP. Scientific Service Department, Skukuza. Unpublished reports, South African National Parks.

BRIDGES, D.C.1994. Impacts of weeds on human endeavours. *Weed Technology* 8:392-395.

BUHLER, D.D. 1996. Development of alternative weed management strategies. *Journal of Production Agriculture* 9: 501-505.

BUHLER, D.D., M. LIEBMAN & J.J. OBRYCKI. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Weed Science* 48: 274-280.

DiTOMASO, J.M. 2000. Invasive weeds in rangeland: Species, impacts and management. *Weed Science* 48: 255-265.

FOXCROFT, L.C. & RICHARDSON, D.M. In prep. Alien plant invasions and management systems in the Kruger National Park, South Africa. 6th International Conference on the Ecology and Management of Alien Plant Invasions, 12-15 September 2001. Loughborough University, UK.

WITTENBERG, R & M. COCK. (eds.) 2000. A Toolkit For Best Prevention And Management Practices For Alien Invasive Species. Global Invasive Species Programme. CAB International. Unpublished document.

HURLE, K. 1998. Present and future developments in weed control — A view from weed science. *Pflanzenschutz-Nachrichten Bayer* 51: 109-128.

KLEM, K. & M. VÁNOVÁ. 2000. Asymmetric competition between wheat and weeds – a step to improve crop–weed interaction models. *Journal of Plant Diseases and Protection* 17, 113-120.

LOTTER, W.D. 1996. Strategic Management plan for the control of *Opuntia stricta* in the Kruger National Park. Scientific Report 17/96. South African National Parks.

KOCH, W. 1992. Impact of weeds on developing countries. *Proc. First Internat. Weed Control Congress*. Monash University, Melbourne, Australia. Vol. 1, pp. 127-133.

REINHARDT, C.F., S. KHALIL & S. BEZUIDENHOUT. 1999. Bioassay techniques in assessing the allelopathic effects of weeds on crop and plantation species. In: F.A. Macias *et al.* (Eds.). Recent advances in allelopathy. Vol. 1. Servicio de Publicaciones, University of Cadiz, Spain. pp. 29-46.

REINHARDT, C.F. 2000. Weed management in natural ecosystems: A critical overview. *Koedoe* 43: 67-74.

REINHARDT, C.F. 2000. Biology/ecology of alien invasive plant species and the mechanisms involved in their interference with indigenous species. Humboldt / South African Research Awards, Nomination for 2000. Unpublished document.

RICHARDSON, D.M., N. ALLSOPP, C.M. D'ANTONIO, MILTON, S.J., M.

REJMANEK, M. 2000. Plant invasions – the role of mutualisms. Biological Reviews, 75, 6-93.
RICHARDSON, D.M., P. PYSEK, M. REJMANEK, M. BARBOUR, D. PANETTA & C. WEST. 2000. Naturalization invasion of alien plants: concepts and definitions. Diversity and Distributions **6**, 93-107.
ROGERS, K.H. & BESTBIER, R. 1997. Development of a protocol for the definition of the desired state of riverine systems in South Africa. Department of Environmental Affairs and Tourism, Pretoria.
SLINGSBY, B. & S. BARKER 1999. The British Ecological Society educational symposium. *In*: A Farina (ed.). Perspectives in Ecology – A glance from the VII International Congress of Ecology. Backhuys Publishers, Leiden NL. pp. 419-429.
SPECIES SURVIVAL COMMISSION, INVASIVE SPECIES SPECIALIST GROUP. 2000. IUCN Guidelines for the prevention of biodiversity loss caused by alien invasive species.
VERSVELD, D.B., D.C. LE MAITRE & R.A. CHAPMAN. 1998. Alien invading plants and water resources in South Africa: A preliminary assessment. CSIR Environmentek Report No. ENV/S-C 97154; WRC Report No. TT 99/98.
WILLIAMSON, M. 1998. Measuring the impact of plant invaders in Britain, in Starfinger, S., K Edwards, I. Kowarik and M. Williamson (eds.). Plant invasions. Ecological Mechanisms and Human Responses, Leiden, Backhuys: 57-70.
ZIMDAHL, R.L. 1993. Fundamentals of weed science. Academic Press, New York.

Appendix 1: TPC's currently defined for IAS

TPC's for Distribution:

- Any new occurrence in KNP
- Imminent external threat by an alien species to the KNP
- Extension of range (first ever report from a new block, or on block not contiguous with the next block)
- Expansion of blocks, which represents more than a 5% increase in distribution over the number of blocks infected the previous year.

TPC's for Increase in density: (all areas infested –blocks- are measured in modified canopy cover estimates to measure plant density. These densities are arranged into a number of classes)

- An increase of density two classes upwards in any block.
- Overall increase in density

TPC's of Rate of spread vs. rate of clearing:

- Number of new blocks infested greater than number blocks cleared.

A TPC which is marked for future development is that of impact of aliens on biodiversity.