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Winderlich S (ed)

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Kakadu National Park Landscape Symposia Series 2007–2009

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27–28 November 2007, Jabiru Field Station, Supervising Scientist Division, Kakadu National Park

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1 Introduction

The Weeds Management Workshop is the second in the series of symposia and workshops held by Kakadu National Park focusing on agents of landscape change.

The aim of workshop is to serve as a forum for knowledge exchange between stakeholders in the Kakadu region, including identifying management issues, emerging threats, knowledge gaps and research needs pertaining to weed management on a local, regional and national scale. The aim was to achieve this through an effective two-way transfer of knowledge between Kakadu National Park staff, researchers, the Kakadu Research Advisory Committee (KRAC) members, stakeholders and Traditional Owners.

The objective was to place this knowledge in a management context and pose questions to Park Managers and Traditional Owners regarding future management frameworks and research directions. The topics of remaining forums in this series are Fire, Climate Change and Feral Animal Management.

The symposium was held at the ***eriss*** Jabiru Field Station, Jabiru East, Kakadu National Park, on 27 and 28 of November 2007.

Over fifty participants from a wide range of stakeholders including government agencies, academic institutions, landholders, Traditional Owners and Indigenous Associations attended. There is a list of the participants on page iv.

The forum included an optional field trip on the afternoon of Monday 26 November followed by two days of presentations and workshops.

The field trip looked at:

- Grassy weeds at Mudginberri paddocks
- Salvinia at billabong on Magela floodplain
- Para grass on Nardab floodplain (from Ubirr)

Topics presented at the symposium included:

- National and Northern Territory perspectives on weed management
- The West Arnhem Land perspective on weed managment
- Threat to Western Arnhem Land: Weedy Time Bomb Project overview
- Kakadu region perspective on weed managment
- Incorporating dispersal ecology and simulation modelling into the management of plant invasions
- Risk assessment and prioritising effort in weed management

Workshops were held on the following topics:

- Weed management in woodlands (grassy weeds including gamba grass, mission grass, grader grass)
- Floodplain/wetlands weed management (mimosa, salvinia, para grass, olive hymenachne, others)
- Escarpment and riparian weed management

The intention is to feed as much of the outcomes of the forum into on-ground management and research as possible and this has already been occurring.

One of the clearest messages was the need for greater regional and across jurisdiction cooperation in training, sharing technology and on ground management and significant steps have already been taken to progress this.

Steve Winderlich
Natural and Cultural Programs Manager
Kakadu National Park

2 Strategic weed management: linking national and local perspectives

S Wingrave[1]

2.1 Introduction

Weeds are among a range of issues presenting a serious threat to Australia's productive capacity, natural environment and in some cases human health. This threat is realised through negative impacts on production levels, increases in production costs, displacement of native plant and animal species and the contribution to general land degradation. In addition to this, weeds causing severe allergic reactions are contributing significantly to Australia's health care costs.

It has recently been estimated that the cost of weeds to agriculture in Australia is in the order of $4 billion annually while the cost to nature conservation and landscape amenity is of a similar magnitude.

It is widely recognised that significant resources have previously been and are currently being used to address various weed issues and that regardless of this, weeds continue to remain one of the major land degradation problems across Australia.

It also recognised that in order to effectively manage the threats and subsequent impacts of weeds a well planned and coordinated approach is required. In some cases this will be the result of effective planning and implementation of these plans at a range of levels – from the local level through to the national level.

2.2 The National Weeds Strategy

Given the challenges posed by weeds, in 1991 the Commonwealth, State and Territory ministers' for agriculture, forestry and the environment agreed to develop a National Weeds Strategy aiming to reduce the impact of weeds on the nation's productive capacity and natural systems.

The National Weeds Strategy, initially released in 1997, was a document describing a series of goals, objectives and strategies for the purpose of increasing the level of consistent, efficient coordinated action against identified high priority weed species and potential species at all management levels across Australia.

The original Strategy made significant progress in weed management, however, the target issues remain a significant challenge. In addition to this, threats from factors including climate change, limitations on chemical use and increasing international trade and travel have added to the complexity and challenges of management.

The current Australian Weeds Strategy provides a framework that guides a consistent approach toward the management of priority weed issues across Australia. The Strategy highlights the need to prevent new weed incursions and establish consistent approaches to

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providing a response to incursions should they occur. The Strategy is also an integral part of Australia's biosecurity programs and complements existing response strategies addressing a number of issues.

The Australian Weeds Strategy is based on the recognition and acceptance of 7 key principles:

1 Weed management is an essential and integral part of the sustainable management of natural resources for the benefit of the economy, the environment, human health and amenity.

2 Combating weed problems is a shared responsibility that requires all parties to have a clear understanding of their roles.

3 Good science underpins the effective development, monitoring and review of weed management strategies.

4 Prioritisation of, and investment in, weed management must be informed by a risk management approach.

5 Prevention and early intervention are the most cost effective techniques for managing weeds.

6 Weed management requires coordination among all levels of government in partnership with industry, land and water managers and the community, regardless of tenure.

7 Building capacity across government, industry, land and water managers and the community is fundamental to effective weed management.

The Strategy contains three goals and provides an outline of the objectives necessary for the achievement of these goals.

Goal 1 Prevent new weed problems

Objective 1.1: Prevent the introduction into Australia of new plant species with weed potential

Objective 1.2: Ensure early detection of, and rapid action against, new weeds

Objective 1.3: Reduce the spread of weeds into new areas within Australia

Objective 1.4: Implement weed risk management practices to respond to climate change

Goal 2 Reduce the impact of existing priority weeds problems

Objective 2.1: Identify and prioritise weeds and weed management problems and determine their causes

Objective 2.2: Implement coordinated and cost effective solutions for priority weeds and weed problems

Objective 2.3: Develop approaches to managing weeds based on the protection of values and assets

Goal 3 Enhance Australia's capacity and commitment to solve weed problems

Objective 3.1: Raise awareness and motivation among Australians to strengthen their commitment to act on weed problems

Objective 3.2: Build Australia's capacity to address weed problems and improve weed management

Objective 3.3: Manage weeds within consistent policy, legislative and planning frameworks

Objective 3.4: Monitor and evaluate the progress of Australia's weed management effort

Since its adoption in 1997 a number of key achievements have been made implementing the Australian Weeds Strategy including:

- National agreement on cost sharing arrangements for priority national eradication programs.
- The development of a list of agreed national priority species, the Weeds of National Significance (WoNS) and subsequent development of agreed national strategies to address these species.
- The establishment of guidelines and principles that promote consistent legislation and policy across jurisdictional boundaries.
- The development and implementation of a pre-border Weed Risk Assessment system screening proposed imports.
- An overall increase in the level of skills, understanding and coordination of weed management activities across government at all levels, industry groups and the community.

2.3 The Weeds of National Significance

One of the key outcomes of the Strategy has been the formal recognition that weeds can be managed at several different levels. Some species can be effectively managed on an individual basis, whilst others require coordinated action at the community, catchment, state or national level. Nationally significant species are those that:

- threaten the profitability or sustainability of Australia's principal primary industries
- threaten conservation areas or environmental resources of national significance
- require remedial action across several States and Territories.

Considering the *current* and *potential* economic, environmental and cultural impacts of the worst weed species in Australia, 20 species were formally recognised and listed as Weeds of National Significance (WoNS) on June 1 1999 by the Minister for Forestry and Conservation, the Minister for Agriculture, Fisheries and Forestry, and the Minster for the Environment (see Table 1).

Linked to each of these species is a national management strategy that has been developed and approved by an appointed committee of relevant land managers, land owners and industry representatives. These strategies aim to protect Australia from the adverse impacts of the particular species, restore infested natural habitats and productive lands through integrated and cost effective research, planning and implementation of on-ground control works. All States and Territories support the implementation of these strategies, and where appropriate, host their appointed coordinators. The NT for example hosts the National Coordinator for the Mimosa and Athel pine management strategies.

Table 1 The Weeds of National Significance

Alligator weed	*Alternanthera philoxeriodes*
Athel pine	*Tamarisk aphylla*
Bitou bush/Boneseed	*Chrysanthemoides monilifera* (sub sp)
Blackberry	*Rubus fruticosus aggregate*
Bridal creeper	*Asparagus asparagoides*
Cabomba	*Cabomba caroliniana*
Chilean needle grass	*Nassella neesiana*
Gorse	*Ulex europaeus*
Hymenachne	*Hymenache amplexicaulis*
Lantana	*Lantana camara*
Mesquite	*Prosopis* spp
Mimosa	*Mimosa pigra*
Parkinsonia	*Parkinsonia aculeata*
Parthenium	*Parthenium hysterophorus*
Pond apple	*Anona glabra*
Prickly acacia	*Acacia nilotica*
Rubber vine	*Cryptostegia grandiflora*
Salvinia	*Salvinia molesta*
Serrated tussock	*Nassella trichotoma*
Willow	*Salix* spp

Taking the example of the WoNS listed species mimosa (*Mimosa pigra*), (an NT priority species and also a regional priority species), we see that the national management strategy has 4 key components/programs.

Program 1 Information and education

Objectives/activities

- foster effective communication with stakeholders
- develop community support and understanding of issues
- develop and distribute appropriate information
- support other programs

Program 2 Prevention of spread

Objectives/activities

- prevent propagation, cultivation and sale nationally
- establish protocols to prevent spread
- conduct surveillance and eradication of outlying infestations
- reduce transport and dispersal into new areas
- decrease susceptibility of land to invasion
- recognise mimosa under all noxious weed legislation

Program 3 Research and development

Objectives/activities

- increase knowledge of mimosa biology and ecology and 'at risk' habitat ecology
- develop and implement biocontrol programs
- develop and implement integrated control programs
- develop and implement sustainable land management programs

Program 4 Impact reduction

Objectives/activities

- reduce incidence and adverse impacts in established areas through coordinated catchment management approach using most up to date methodologies and tools

2.4 WoNS species and strategic weed management in the Northern Territory

The Weed Management Branch is part of the Natural Resources Division of the NT Department of Natural Resources, Environment, the Arts and Sport. The Branch performs a number of roles in relation to the management of weeds across the Northern Territory, including:

- identification of weed management issues
- assessment and prioritisation of weed management issues
- development of cooperative action/management plans
- implementation of coordinated action/management plans
- encouragement of participation in action/management plans
- development of weed management legislation and policy
- enforcement of weed management legislation
- provision of training, education and awareness in relation to weed species and management requirements

- conducting of research and development in relation to weed impacts and management
- development and maintenance of partnerships
- provision of resources or assistance in accessing resources required for management
- reporting progress against programs aims and objectives to funding providers.

The first three roles and responsibilities are of key relevance in relation to this discussion paper. These points result in the fact that the Weed Management Branch may identify a weed species as a priority issue in addition to the agreed national priorities, provide a declaration level under legislation and then develop appropriate and specific management plans to address the species.

Looking at the example of mimosa we see that the species is declared a Class A (to be eradicated) or Class B (growth and spread to be controlled) weed in specific areas of the NT according to the plants current and potential distribution. (Mimosa is also classified a Class C weed (not to be introduced) in all of the NT).

Weed management plans developed by the Branch provide detail specific aims, objectives and management requirements in relation to the particular weed species and to where these requirements apply.

The NT Draft Mimosa Management Plan for example indicates that in areas classified as Class A/C the aims and objectives are based around the principle of eradication and preventing further introduction. In areas where the plant is classified as Class B/C the aims and objectives are based on preventing spread and reducing the impact of well established infestations.

In more detail, the NT Draft Mimosa Management Plan aims to limit the impact of mimosa on the natural environment, the NT economy and social and cultural land uses by:

- defining the management obligations which apply to all land managers and land users in the NT, which will form an integral part of the strategic management of mimosa across the Territory
- providing information on actions required to meet defined management obligations.

The NT Draft Mimosa Management Plan also details three key objectives:

Eradicate existing infestations and prevent further establishment of mimosa in the A/C zone by:

- eradicating isolated plants and outbreaks
- implementing early detection and eradication programs
- designing and implementing a seed spread prevention program

Control the growth and spread of mimosa in the B/C zone by:

- eradicating isolated plants and outbreaks
- implementing early detection and eradication programs to find newly established plants and outbreaks, for eradication purposes outside core infestations
- active containment of major infestations (eg though the implementation of grazing land management principles and buffer establishment and maintenance)
- minimising further seed production
- designing and implementing a seed spread prevention program.

Apply an adaptive approach to weed management by:

- developing and maintaining an ongoing monitoring program;
- maintaining an accurate record of control methods applied and results achieved for possible collation at a Territory level
- evaluating the efficiency of control and containment programs over time.

As we can see, that this is clearly consistent with the National Mimosa Management Strategy.

We also have the situations where weed species identified as priorities across the regions of the NT vary due to the range of environments encountered and as such a species identified as a priority in Darwin region (eg mimosa) will not necessarily be a priority in Alice Springs. This assessment is made through the use of the NT Weed Risk Management System.

Accordingly priority species and their associated aims, objectives and management responses to various weed management issues vary across the NT. The principles of the National Strategy, however still apply.

2.5 Regional weed management: Darwin region

Considering the aforementioned principles in the context of Darwin region, and using the NT Weed Risk Management System, weed species such as gamba grass (*Andropogon gayanus*) and bellyache bush (*Jatropha gossypiifolia*) amongst others, are identified as regional priorities in addition to a number of WoNS listed species.

Looking closer at the regional situation, in particular the distribution and risk posed to the various catchments, we may now also find that the current situation varies in regard to the particular weed species being considered. The weed species may be well established in the catchment, the species may be present at a very low level in the catchment or the species may represent a clear threat to the catchment. Accordingly our aims, objectives, responses and ultimately our level of resource allocation will vary.

Again taking the example of mimosa this is clearly the case considering the current and potential level of infestation. Currently there is approximately 140 000 hectares of mimosa in Darwin region, an area comprising 18 catchments and containing over 1.2 million hectares of vulnerable wetlands. Of these 18 catchments, four are completely free of mimosa, seven have a very low level of infestation and the remaining seven have varying degrees of infestation. As expected, the aims, objectives, responses and ultimately our level of resource allocation vary accordingly.

Figure 1 illustrates Darwin region mimosa management activities, aims and objectives in relation to the current distribution of the species (shown on the underlying catchment map of the Top End).

2.6 Local weed management: Kakadu National Park

In comparison with other national parks and reserves across Australia, Kakadu has surprisingly few weeds (less than 6% of the total number of plant species known from the Park are weed species). Despite this, there are some major weed issues facing the Park, including the continued spread of a number of WoNS species and introduced grasses. Some of the regional priority weed species identified by the Weeds Management Branch are currently found within Kakadu National Park or represent a significant threat. Accordingly these species are targeted for control or eradication or exclusion by both Kakadu staff and Weeds Branch programs.

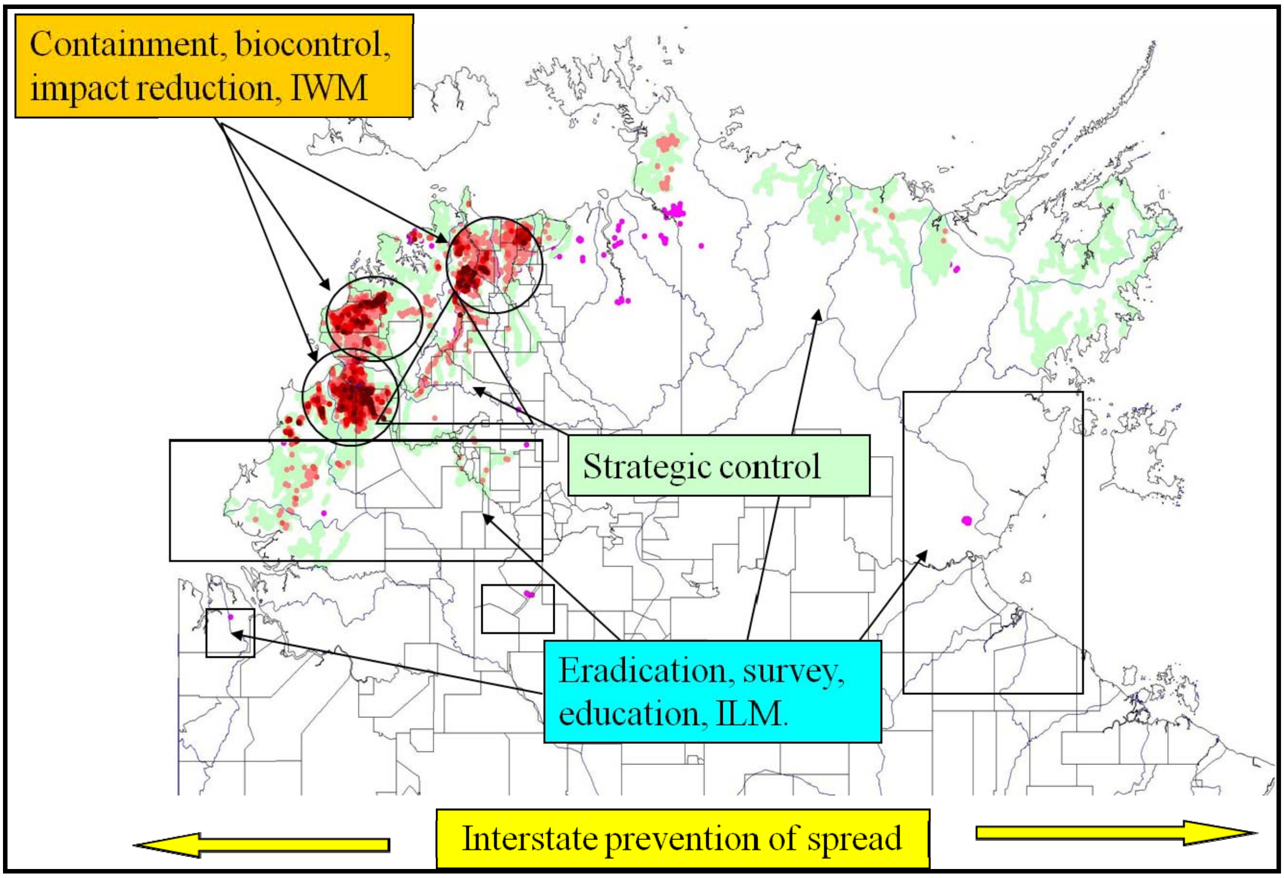

Figure 1 Mimosa distribution and management activities in the Top End

In the case of mimosa at Kakadu National Park where infestations are at a very low level management objectives and activities reflect this as the overall objectives are to increase awareness of the species, prevent further introduction and eradicate existing plants. A similar approach is also taken with other priority species such as olive hymenachne, gamba grass, salvinia and bellyache bush. The aims and objectives for all of these species individually reflect the current and potential situation, the regional management plans, and where relevant, the priority species management plans for the NT.

We can also see that the principles of the Australian Weed Strategy provide a logical and supporting framework for local management activities and their associated aims and objectives. More specifically we can clearly see that an informed risk management approach ensures the correct species are targeted as priorities in Kakadu.

We can see that prevention and early intervention through management of roadside infestations and implementation of quarantine policy on the Park help reduce new incursions. We can see the importance of coordination and effective partnerships between all levels of government and the community providing strategic benefits across the region. We can also see that the benefits of building capacity across the community is fundamental to providing additional protection to Kakadu through the development and implementation of complimentary weed management programs targeting the same species on adjoining lands.

Finally we can see how the Australian Weeds Strategy, national species management strategies, priorities species for the NT, their associated strategies and also regional weed management planning, provide a clear link between planning occurring at the national level and management activities implemented locally (see below).

National Weeds Strategy	Key national principles, aims and objectives
WoNS strategies	National level strategies to address the agreed 20 worst species in Australia
NT priority species list & management plans	Includes all relevant WoNS species + additional identified and assessed priority species for the NT. Provides NT level management plans and associated aims, objectives and management requirements.
Regional priorities	Includes a subset of the WoNS list where applicable + additional identified and assessed priority species for the region. Provides and reflects a regional perspective to NT and national level plans.
Local priorities and activities	Includes a subset of applicable regional priorities. Management activities reflect the local current situation

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3 Developing a WRM system in the Northern Territory, Australia

K Ferdinands[1], S Setterfield[2] & M Ibbett[3]

3.1 Focus summary

- Despite the threat invasive plants pose to the conservation of native flora and fauna and ecosystem processes, as well as threatening agricultural industries, infrastructure and human health, resources available to tackle risks posed by invasive plants in the Northern Territory will always be limited.
- Natural resource managers need a defensible and transparent system to prioritise species for action and to efficiently allocate the resources at their disposal.
- Weed risk management (WRM) systems are recognised internationally as useful to assist land managers with the task of prioritising and managing weed species.
- The NT WRM process has been developed through extensive consultation among key stakeholders and government agencies to address the issue of strategic weed management in the NT. It is consistent with nationally accepted protocols for post-border weed risk management.
- The NT WRM system consists of a two-stage risk-assessment process: (i) an assessment of the comparative risk a species poses (Weed Risk Assessment WRA) and (ii) an assessment of the likelihood of management intervention success (feasibility of control). Weed risk and feasibility of control are assessed using a list of questions about the species biology, invasiveness and negative impacts, current and potential future distribution and costs / complexity of control measure required for a given species. For 'conflict species' – species that offer economic benefits as well as potential environmental, social or cultural costs – a benefit cost analysis can also be undertaken before a final management recommendation is made.
- Using the NT WRM system 80 species have been assessed. The assessment results showed that a number of species that are currently declared in the NT may need their declaration status reviewed, and more importantly, some species that are currently not declared should be added to the declared list to ensure coordinated and strategic management of these high risk species.
- The outcomes of the NT WRM process are being used to (a) review the current list of declared species in the NT; (b) to provide advice to natural resource managers and policy makers on both priority species and the type of management response required and (c) provide an transparent and defensible approach, with active stakeholder engagement for responding to the risks posed by invasive plants in the NT and across northern Australia.

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The Paper

3.2 Introduction

In Australia, as elsewhere in the world, invasive plants pose a serious threat to the conservation of native flora and fauna and ecosystem processes, as well as threatening agricultural industries, infrastructure and in some instances human health. Even in the Northern Territory, which boasts large areas of intact native vegetation, declared weeds and invasive plants are identified, together with feral animals and altered fire regime as a major threat to biodiversity and rural primary industries. With increasing development in the Northern Territory, and the potential range expansion of many weeds as a result of predicted climate change, it is likely that the problems associated with invasive plant species will increase.

In 2008 there were 119 declared weeds in the Northern Territory, but the list of declared species is currently under review. This review has been prompted by concerns that some species that should be declared are currently not listed and others that are currently declared may not warrant listing. In addition, there are many weeds found elsewhere in Australia and overseas that have not been recorded in the Northern Territory but have the potential to become established here. Despite this large and increasing problem, there will always be limited resources to tackle invasive plants. An objective and defensible method of assessing weed risk is needed to identify and restrict the entry of new weeds into the Northern Territory, and to assist land managers to prioritise management actions for those weeds already present.

Weed risk management (WRM) systems are a set of decision support tools that allow an evidence-based and strategic approach to the management of invasive species. WRM systems are based on an objective assessment of the likelihood and magnitude of risks posed by a species, and the feasibility of control options should the species become established. At a national level, the development of value of a weed risk management systems has been progressed via the development of the National Post-Border Weed Risk Management Protocol (Virtue et al 2006). In developing a WRM system for the NT the national protocol was to guide the design, creation and implementation of the NT WRM system. and in the Northern Territory the need for such a system has been highlighted in the Natural Resource Management Strategy (Landcare Council of the Northern Territory 2005).

3.3 A WRM system for the Northern Territory

The Northern Territory WRM system has been developed through collaboration between Charles Darwin University, the Department of Natural Resources, Environment, The Arts and Sport, the Department of Regional Development, Primary Industries, Fisheries and Resources, the Australian Quarantine Inspection Service and other stakeholder groups. It has been developed to provide decision support tools that are consistent with recognised Australian standards for the management of invasive plants. Development of the NT WRM system has been guided by the National Post-Border Weed Risk Management Protocol (HB 294: 2006 Standards Australia/Standards New Zealand/CRC Australian Weed Management 2006) and the input of key stakeholders within the NT and weed risk experts from other jurisdictions.

The NT WRM system is a comprised of a series of linked steps which are described below and represented in Figure 1.

1 **Which weeds?** Determines candidate species for weed risk analysis. This involves collating existing weeds (declared and undeclared) lists and a review of potential weed

species. In addition we sought suggestions for candidate species from the key stakeholders involved in the construction of the NT WRM system.

2 **Risk posed?** Assesses the comparative risk of weed candidates using a WRA tool that scores and categorises weeds according to key risk indicators: Invasiveness, Impact and Potential Distribution.

3 **Feasibility of control?** The **feasibility** of control for each candidate species is evaluated using a system that scores and categorises three control related criteria: current distribution, control costs and duration of control (ie to eradication or maintenance).

4 **How to respond?** The consideration of weed risk versus feasibility of control is done using a management action matrix and provides an indication of the recommended management actions for a given species. These management actions might include: preventing entry, eradication, containment and improving targeted control techniques (Tables 1 & 2).

5 **Management response.** The management response represents the transition from the strategic planning stage of the WRM to the on-ground application of management responses. This stage may, for declared weeds, involve the drafting of a statutory weed management plan, which provides detailed information about the management actions required, the recommended timing and techniques for control and where in the landscape different types of control need to be pursued and supported by statute (the *Weeds Management Act*). This last stage is informed by, but is outside the WRM system.

During the development stage a continuous process of consultation with stakeholders and ongoing monitoring and review allowed the refinement of the assessment process and recommended responses to mitigate the weed risks identified. As with any decision support tool dependent on the quality of the data used, periodic review of the WRM system performance will be a standard procedure. It should also be noted that additional decision making or analysis eg benefit cost analyses or detailed survey may be required before a final management response can be made.

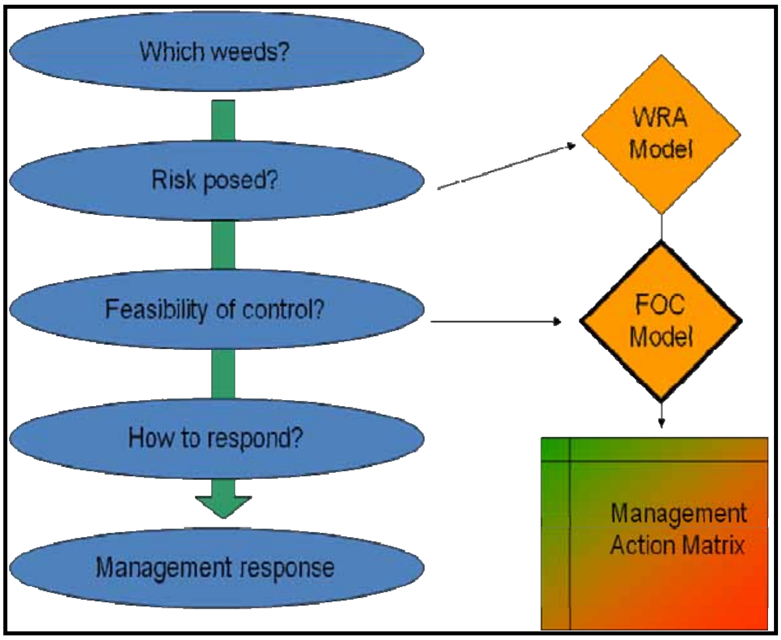

Figure 1 Overview of the NT weed risk management process showing the main elements of the WRM process

3.3.1 Development of the NT WRM system

The development of the NT WRM system involved a series of meetings of key stakeholder groups (pastoral producers, conservation, indigenous organisation representatives, Department of Defence and horticulture), during which attendees were invited to review and compare WRM systems from South Australia, Victoria, Queensland and from the Australian Quarantine Inspection Service and select the most appropriate (if any) for use in the NT. The workshop attendees considered the strengths and weaknesses of each system, based on information and resource requirements and major applications within its state of origin. A draft framework was established for the NT that included a number of guiding principles relating to ensuring transparency and accountability and ongoing stakeholder engagement. A WRM Technical Working Group was established to guide the development and testing of the NT WRM system.

The NT WRM system consists of a two-stage risk-assessment process: (i) an assessment of the comparative risk a species poses (weed risk assessment WRA) and (ii) an assessment of the likelihood of management intervention success (feasibility of control). Both weed risk and feasibility of control are assessed using a list of questions about the species biology, invasiveness and negative impacts, current and potential future distribution and costs / complexity of control measure required for a given species. For some species; that offer economic benefits as well as potential environmental, social or cultural costs, a benefit cost analysis can also be undertaken before a final management recommendation is made. A comparison of the weed risk versus the FOC enables a species to be categorised and prioritised for management actions using a weed risk management matrix (Figure 1).

One of the key steps in the development of the NT WRM system was modifying some elements of the WRA process from the South Australian model to a system that better suits the NT environment and land use systems. This involved changing the questions on the three criteria for assessing weed risk (invasiveness, impact and potential distribution), deleting questions where they were not appropriate and adding questions that were more appropriate for application in the NT. The primary reason for these changes was the difference in the extent of land modification and the types of land use in South Australia and the NT. Some of the key changes that were made included rewording of the questions to take into account the need to protect native vegetation, to take into consideration indigenous as well as western values and to give appropriate consideration to fire (and particularly the grass-fire cycle) as a key ecosystem driver in the NT. In addition, the South Australian model assesses candidate species differently for individual land use types but it was decided that the NT WRM system will assess candidate species in respect to one land use type, namely the broader landscape with its relatively intact native vegetation(Setterfield et al 2006). Questions that could not be reliably or consistently answered for candidate species in the NT were removed from the WRA model. The final scores for comparative weed risk and feasibility of control is derived by multiplying the scores for each of the component criteria (ie invasiveness, impact, potential distribution), as per the South Australian system (Virtue et al 2005).

After each candidate species is assessed using the WRA model and the FOC model, it is assigned to categories (eg low, medium, high, very high) and can then be placed within a cell in a management action matrix that is used to identify priority weed risks (Table 1) and make broad management recommendations. Those species that fall within the high and very high weed risk categories are identified as priority species. Based on a combination of weed risk and feasibility of control categories assigned suitable management actions can be recommended (Table 2).

Table 1 Categorisation of priority species based on risk and FOC (the weed risk management Matrix)

		Feasibility of control			
		Low	**Medium**	**High**	**Very high**
Weed risk	**Low**				
	Medium				
	High	Priority species	Priority species	Priority species	Priority species
	Very high	Priority species	Priority species	Priority species	Priority species

Table 2 Management action matrix showing comparison of weed risk and feasibility of control (Note: high feasibility of control = high likelihood of success)

		Feasibility of control			
		Low	**Medium**	**High**	**Very high**
Weed risk	**Low**	Assist interested parties	Assist interested parties	Assist interested parties	Monitor or assist interested parties
	Medium	Improve general weed management#	Improve general weed management	Targeted control Improve general weed management	Targeted control Monitor Protect priority sites
	High	Targeted control	Targeted control	Protect priority sites	Prevent entry Contain regional spread
	Very high	Targeted control (incl biocontrol) protect priority sites	Targeted control (incl biocontrol) Protect priority sites	Prevent entry Contain regional spread protect priority sites	Prevent entry Regional eradication protect priority sites

eg improve vehicle hygiene, reduce disturbance

3.3.2 Application of the NT WRM system

In November 2007, the WRM Technical Working Group with assistance from professional weed contractors, tested the WRA and FOC models on 80 candidate species, consisting of a variety of growth forms (grass, herb, shrub, tree), from variety of habitats (aquatic/terrestrial); with different status (declared /un-declared); plus species which identified as representing a range of potentially very high through to low risk. This testing was undertaken to assess the ability of the WRM system to assign these weeds to defensible categories of risk and FOC. The prediction of the WRM Technical Group was that most (but possibly not all) of the declared weed species would be assessed as a high/very high weed risk.

Somewhat unexpectedly, of the 80 species that were assessed using the WRA and FOC models, 40 were ranked in the high/very high risk category and 40 in the low/medium risk category (Table 3). Management recommendations are also being developed for these 80 species based on the results of this assessment. Of those species assigned to the high/very high risk category a large proportion were found to be grassy species and many were undeclared species in the NT. Of those species ranked in the low/medium risk categories, four were species that are currently declared in the NT.

Based on the WRM principles, used to guide the construction and application of the NT WRM system, species ranked as high/very high risk should be nominated for declaration in the NT. A total of 15 of the 80 assessed species are candidates for declaration. These are: *Acacia mangium; Andropogon gayanus* gamba grass; *Cenchrus ciliaris* buffel grass; *Leucaena leucocephala* coffee bush; *Sporobolus pyramidalis and S. natalensis* giant rats tail grass; *Megathyrsus maximus* guinea grass; *Pennisetum pedicellatum* annual mission grass; *Urochloa mutica* para grass; *Dichanthium annulatum* sheda grass; *Hyparennhia rufa* thatch grass; *Neptunia plena* and *N. oleracea* water mimosa; *Schinus terebinthifolius* Brazilian pepper; and *Azadirachta indica* neem tree).

A total of 13 species (*Barleria prionitis, Tribulus terrestris and T. cistoides* caltrop*; Senna alata* candle bush; *Dalbergia sissoo*; *Alternanthera pungens* khaki weed; *Datura ferox* longspine thornapple; *Leonurus leonotis* lion’s tail; *Hyptis capitata* knob weed; *Cenchrus echinatus* Mossman river grass; *Carthamus lanatus* saffron thistle; *Acanthospermum hispidum* starr burr; and *Argemone ochroleuca* Mexican poppy) are currently declared but should be reviewed given their scores for comparative weed risk. The distribution of these species needs to be further considered to determine if they are a problem sub-regionally and therefore should remain as declared species. This reflects the fact that the NT WRM system assesses feasibility of control being assesses at the regional scale.

Table 3 Comparative weed risk of 80 species assessed using the WRA and FOC models (as of November 2007) ***** NT Weed Declaration Categories: Class A – to be eradicated; Class B – growth and spread to be controlled; Class C – Not to be introduced into the NT; ‘-’ no weed declaration status in the NT; WONS (weed of national significance).

Common name	**Botanical name**	**Current NT declaration status***
Very high risk species		
Athel pine	*Tamarix aphylla*	B and C (WONS)
Bellyache bush	*Jatropha gossypifolia*	B and C
Brazilian pepper	*Schinus terebinthifolius*	-
Buffel grass	*Cenchrus ciliaris*	-
Cabomba	*Cabomba* spp	A and C (WONS)

Common name	Botanical name	Current NT declaration status*
Chinee apple	*Ziziphus mauritiana*	A and C
Coffee bush	*Leucaena leucocephala*	-
Gamba grass	*Andropogon gayanus*	A/C and B/C as of Nov 2008
Grader grass	*Themeda quadrivalvis*	B and C
Guinea grass	*Megathyrus maximus*	-
Lantana (common)	*Lantana camara*	B and C (WONS)
Limnocharis	*Limnocharis flava*	C
Mequite	*Prosopis* sp	A nd C
Mimosa	*Mimosa pigra*	B and C (WONS)
Mission grass – annual	*Pennisetum pedicellatum*	-
Mission grass – perennial	*Pennisetum polystachion*	B and C
Neem	*Azadirachta indica*	-
Olive hymenachne	*Hymenachne amplexicaulis*	B and C (WONS)
Para grass	*Urochloa mutica*	-
Parkinsonia	*Parkinsonia aculeata*	B and C (WONS)
Parthenium	*Parthenium hysterophorus*	A and C (WONS)
Pond apple	*Annona glabra*	A and C (WONS)
Prickly acacia	*Acacia niloltica*	A and C (WONS)
Rubber vine	*Cryptostegia* spp	A and C (WONS)
Salvinia	*Salvinia molesta*	B and C (WONS)
Sheda grass	*Dicanthium annulatum*	-
Siam weed	*Chromolaena odorata*	C
Sicklepod	*Senna obtusifolia*	B and C
High risk species		
Acacia mangium	*Acacia mangium*	-
Castor oil plant	*Ricinis communis*	B and C
Devils claw	*Martynia annua*	A and C
Giant rats tail grass	*Sporobolus pyramidalis* & *Sporobolus natalensis*	-
Hyptis	*Hyptis suaveloens*	B and C
Kosters curse	*Clidemia hirta*	C
Mikania	*Mikania microcantha*	C
Noogoora burr	*Xanthium occidentale*	B and C
Rubber bush	*Calotropis procera*	B and C
Sida	*Sida acuta*	B and C
Thatch grass	*Hyparennia rufa*	-
Water mimosa	*Neptunia plena & Neptunia oleracea*	-
Medium risk species		
African mahogany	*Khaya senegalensis*	-
Coral vine	*Antigon leptopus*	-
Knob weed	*Hyptis capitata*	B and C

Common name	Botanical name	Current NT declaration status*
Kudzu	*Pueraria Montana var lobata*	-
Lions tail	*Leonotis nepetifolia*	B and C
Longspine thornapple	*Datura ferox*	A and C
Mexican poppy	*Argemone ochroleuca*	B and C
Miconia	*Miconia calvescens*	-
Mossman River grass	*Cenchrus echinatus*	B and C
Mother of millions	*Bryophyllum* spp	-
Singapore daisy	*Sphagneticola trilobata*	-
Tully grass	*Urochloa humidicola*	-
Low risk species		
African tulip tree	*Spathodea campanulata*	-
Bahia grass	*Paspalum notatum*	-
Barleria	*Barleria prionitis*	A and C
Caltrop (*T cistoides*)	*Tribulus cistoides*	B and C
Caltrop (*T terrestris*)	*Tribulus terrestris*	B and C
Candle bush	*Senna alata*	B and C
Cavalcade	*Centrosema pascuorum*	-
Crotalaria/rattlepod	*Crotalaria gorensis*	-
Dalbergia	*Dalbergia sisso*	A and C
Finger grass	*Digitaria milanjiana*	-
Fishtail palm	*Caryota mitis*	-
Golden rain tree	*Cassia fistula*	-
Khaki weed	*Alternanthera pungens*	B and C
Lippia	*Phyla canescens*	_
Molasses grass	*Melinis minutiflora*	-
Mother-in-laws-tongue	*Sanseviera trifasciata*	-
Neurada	*Neurada procumbens*	-
Pannical joint vetch	*Aeschnomene paniculata*	-
Poinciana	*Delonix regia*	-
Ruby dock	*Acetosa vesicaria*	-
Sabi grass	*Urochloa mosambicensis*	-
Saffron thistle	*Carthamus lanatus*	B and C
Siamese cassia	*Cassia siamea*	-
Spider flower (fringed and prickly)	*Cleome rutidosperma & Cleome aculeata*	-
Starr burr	*Acanthospermum hispidum*	B and C
Tipuana	*Tipuana tipu*	-
Vetiver grass	*Vetiveria zizanioides*	-
Yellow oleander	*Cascabela peruviana*	-

Once the assessment of these 80 species was completed to the satisfaction of the WRM Technical Working Group, broad management recommendations were assigned to each of the 80 species based on their positioning in the weed risk management matrix (see Table 5 for preliminary Darwin Region risk management matrix).

Table 5 Preliminary Darwin region weed risk management matrix

		Feasibility of control		
		Low–Medium	**High**	**Very high**
Weed Risk	**Low**	1 Assist interested parties Cavalcade, Crotalaria, Finger grass, Sabi grass	2 Assist interested parties Bahia grass, Barleria, Caltrop (*T. cistoides*), Caltrop (*T. terrestris*), Candle bush, Khaki weed, Pannicle joint vetch, Poinciana	3 Monitor/assist interested parties African tulip tree, Dalbergia, Fishtail palm, Golden rain tree, Molasses grass, Mother-in-laws-tongu, Siamese cassia, Spider flower (fringed & prickly),Tipuana, Vetiver grass, Yellow oleander
	Medium	4 Improve general weed management African mahogany, Knob weed, Mossman River grass, Tully grass	5 Targeted control/ Improved general weed management Lions tail, Singapore daisy	6 Targeted control/Monitor/ Protect priority sites Mother of millions
	High	7 Targeted control Coral vine, Giant rat's tail grass, Hyptis, Noogoora burr, Rubber bush, Sida	8 Protect priority sites Castor oil plant, Devils claw, Water mimosa	9 Prevent entry/contain regional spread *Acacia mangium*, Thatch grass
	Very high	10 Targeted control/ protect priority sites Buffel grass,Cabomba, Coffee bush, Gamba grass, Grader grass, Guinea grass, Mimosa, Mission Grass (annual), Mission Grass (perennial), Olive hymenachne, para grass, Salvinia, Sicklepod	11 Prevent entry/ contain regional spread/ protect priority sites Bellyache bush, Lantana (common), Neem	12 Prevent entry/ Regional eradication/ protect priority sites Brazilian pepper, Chinee apple, Parkinsonia, Parthenium#, Pond Apple#

\# FOC scores for these species are under review at the time of writing

The information derived from the NT WRM system is being used to undertake a review of the NT declared weeds list and associated management plans, including nominating high/very high risk species for declaration. The development of management plans for priority species will be guided by the results of this assessment process. Recommendations will be provided to regional weed managers and to NRM managers to facilitate co-ordinated implementation of the WRM process. The results of these assessments will also allow the identification of opportunities for cross-jurisdictional co-operation where weed risk priorities are aligned.

3.4 Challenges and impediments to the strategic management of weeds in northern Australia

The development and implementation of the NT WRM system is a critical step in improving strategic weed management in the NT and across northern Australia in general. However, there are still a number of issues that pose challenges to the successful and strategic management of weeds in the region. Our current limited ability to predict where and when weeds may become established across the landscape is a major obstacle in the prioritisation and allocation of management resources and needs to be refined within the weed management process. Similarly, the explicit inclusion of cost benefit analysis in the WRM process is an important refinement to the national WRM approach and will allow a defensible appraisal of conflict species (those that have some economic value but pose a serious environmental/cultural/economic threat) such as exotic pasture grasses or biofuel species. Cost benefit analysis will also provide a useful method of deciding on the appropriate management response for a particular species (eg whether to aim for eradication or containment). Research projects aimed at addressing some of these fundamental issues, particularly in relation to grass weed species, are underway.

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4 Weed management in Kakadu National Park

F Hunter[1], M Ibbett[2] & B Salau[3]

4.1 Focus summary

- Invasive weeds have the capacity to cause dramatic changes across the landscapes of Kakadu National Park
- The Kakadu National Park Management Plan 2007–2014 identifies a number of priority actions in relation to weed management in the Park, including the development and implementation of management programs and strategies for high priority weeds, and the mapping of the distribution of weeds in the Park.
- Two teams of rangers are employed to combat weeds in the Park: the mimosa team which primarily targets *Mimosa pigra* but also assists with other weeds in the wet season, and the grassy weeds team which targets para grass, mission grass, olive hymenachne and gamba grass.
- Mimosa, salvinia and olive hymenachne are listed as Weeds of National Significance and are specifically targeted for action in the Park's Plan of Management.
- Grassy weeds, particularly mission grass, gamba grass and para grass have the capacity to fuel destructive fires which can cause significant impact to native vegetation and habitat for native wildlife. All weed species discussed in this paper have the capacity to restrict or prevent traditional hunting activities, limit or prevent access to traditional foods like yams, lilies and to make habitat unsuitable for traditionally significant species like magpie geese. These are important reasons for ongoing control of weeds in Kakadu National Park.

The Paper

4.2 Introduction

Invasive weeds have the capacity to cause dramatic changes across a variety of landscapes. In the Top End of the Northern Territory *Mimosa pigra* has converted thousands of hectares of floodplain habitat to sometimes impenetrable shrubland, simultaneously reducing biodiversity and rendering areas unsuitable for cultural, recreational and pastoral activities. Similarly, pasture grasses such as mission, gamba and para grass have the capacity to outcompete native species, in the process altering fire regimes and other essential ecosystem processes.

Kakadu National Park has a relatively impressive record of removing, controlling and preventing the invasion of weed species within the Park. Of the 700+ species of plants recorded in the Park, only 120 (approx 7.8%) are considered invasive in comparison with the average of 21% in other conservation reserves in Australia. Despite this, it is expected that the number of invasive species in the Park will continue to rise in the future, primarily as a

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consequence of increasing tourism and development. The impact of feral animals on the spread of weeds is also a matter of some concern. Weed control programs need to be undertaken with feral animal control programs for their effectiveness to be maximised.

The current Plan of Management for Kakadu (Director of National Parks, 2007) outlines a number of key actions in regards to the management of weed plants in the Park. Two of these, the development and implementation of management programs and strategies for high priority weeds, and the mapping of the distribution of weeds in the Park, are primarily the responsibility of two dedicated teams of rangers.

This paper describes the current progress against actions 5.11.11 and 5.11.13 of the Plan of Management, the development and implementation of management programs and strategies for priotiry weed species and the ongoing mapping of the distribution of weeds in KNP. The paper particularly focuses on the management of mimosa *Mimosa pigra*, salvinia *Salvinia molesta*, olive hymenachne *Hymenachne amplexicaulis* and para grass *Brachiaria mutica* but also briefly considers mission grass *Pennisetum polystachion* and gamba grass *Andropogon gayanus* which are also serios weed issues in Kakadu.

4.2.1 *Mimosa pigra*

Mimosa pigra (also known simply as Mimosa or the giant sensitive plant) is native to tropical America. It is thought to have entered Australia through Darwin, but the exact timing and mode of entry are not confirmed. Within its native distribution mimosa grows to a maximum of 1–2 m tall but in Australia, where there are no native predators of the plant, it can grow to up to 6 m. In its favoured floodplain habitat, mimosa forms dense stands that out-compete all other native vegetation. Mimosa is a major problem in the Northern Territory because it decreases the cultural and conservation value of wetlands and reduces pastoral productivity by replacing grass and sedges with an inedible, impenetrable wall of thorny vegetation. Mimosa is a prolific seeder and as such has the capacity to spread and become established rapidly. The seeds are readily dispersed by vehicles, livestock and other animals. However, the most important dispersal agent in floodplain habitats is water itself, as the seeds can be carried considerable distances downstream from the source plant.

Mimosa was first discovered in Kakadu in 1981, at the outflow end of Yellow Waters. Since then a dedicated team of four staff has worked to locate and record new outbreaks and then undertake control work at these sites. Hundreds of plots have been surveyed across Kakadu (Figure 1). The floodplains of Kakadu are largely free of mimosa.

The approach to controlling mimosa usually involves cutting tracks into the stand and the broad application of Velpar, a herbicide that sterilises the ground and reduces future germination from the seed bank. Some of the major outbreaks that have been targeted in Kakadu have been at Munmarlary, Bamboo Creek and Cattle Creek (Figure 2).

4.2.2 *Salvinia molesta*

Salvinia molesta, or salvinia as it is commonly known is a free-floating aquatic fern that can grow rapidly to form dense mats on the surface of still or slow-moving water bodies. It reproduces asexually, from pieces of leaf or stem material that are spread by floodwaters, animals, vehicles and boats. Salvinia was first recorded in Kakadu in 1983. It has been recorded in a number of waterways in Kakadu including Yellow Water.

Various methods have been used to control salvinia including herbicides, mechanical removal and biological control. Herbicides have limited success because the non-wettable upper parts of the plant prevent absorption of the chemicals. The ease with which plants break into fragments and spread also reduces the effectiveness of mechanical removal. In Kakadu the preferred method of control is the use of the biological control agent (the weevil *Crytobagous salviniae*). The weevils can be highly effective at removing salvinia (Figure 3) but because of the rapid nature of reproduction in this species, re-infestation and new infestations can develop quickly.

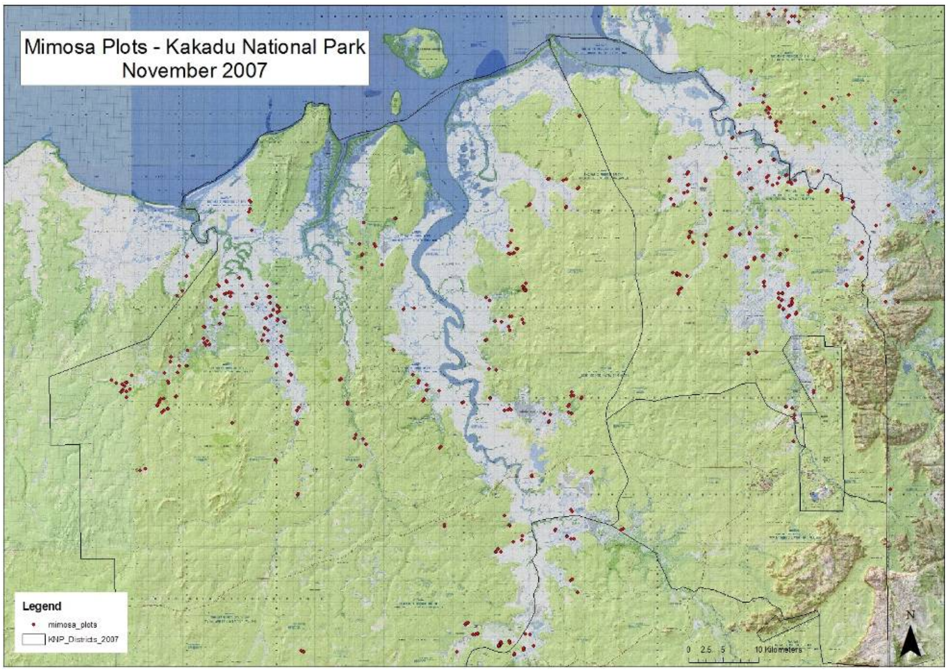

Figure 1 Location of Mimosa pigra plots in Kakadu National Park, November 2007

Figure 2 Mimosa outbreak at Cattle Creek before treatment (left) and after treatment (right)

4.2.3 Olive hymenachne

Olive hymenachne *Hymenachne amplexicaulis* is recognised as a weed of national significance that has the potential to smother native vegetation and form dense monospecific stands in riverbank and swampy, seasonally inundated areas. It is a native of tropical and central South America that was deliberately introduced and planted in Australia as a pasture grass. It produces an abundance of seed that can be spread by water flows and livestock, as well as some native wildlife like magpie geese. The root systems of the grass are also easily broken and can be spread to other areas by water and livestock. Olive hymenachne is very similar to the native hymenachne species *Hymenachne acutigluma* (Figure 4).

Olive hymenachne can cause major environmental impacts including reducing or preventing the flow of waterways, reducing plant diversity and habita availability for native wildlife and reducing the opportunity for traditional use of natural resources by indigenous people. Olive hymenachne has the potential to rapidly become a major weed issue in Kakadu as it has been recently found in a number of the remotest wetlands in the Park (Figure 5). Infestations of olive hymenachne are managed by physical removal and chemicals.

Figure 3 Salvinia infestation at Djabiluka Billabong (clockwise from top left): April 1992 (prior to release of weevils); September 1992 after weevil release; October 1992 other vegetation emerging through salvinia; and November 1992 billabong surface is clear of salvinia

Figure 4 Olive hymenachne (on the left of this photo) has much broader leaves than native hymenachne (right)

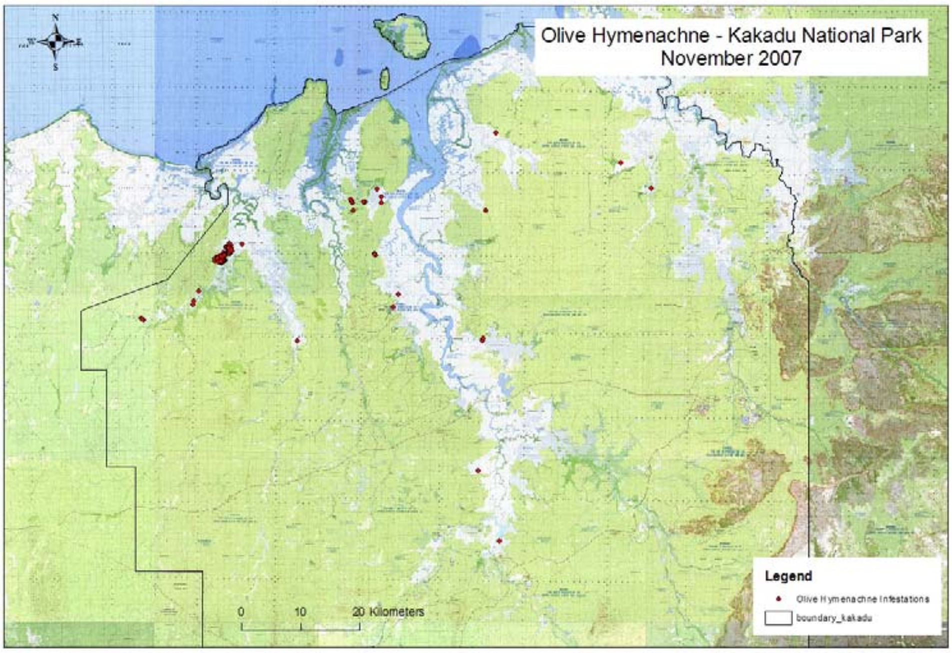

Figure 5 Olive hymenachne has been found in a number of remote wetlands in Kakadu

4.2.4 Para grass

Like many other grassy weeds para grass *Urochloa mutica* was introduced to Australia as an improved pasture grass. It has been present in Kakadu for many years, with infestations known to have become established in the Cannon Hill area as early as 1940. It grows in wet or seasonally flooded areas, drainage lines and creek banks where it can form dense floating mats 1–2 m thick. As a result it can choke out native species and prevent the establishment of more desirable native species. It can adversely affect wildlife and restrict traditional hunting. Dense infestations of para grass can provide a substantial fuel load for late season fires on the floodplains. These fires can be particularly intensive and destructive. Para grass has the capacity to re-establish after these fires but many other native species do not.

Infestations of para grass have the potential to rapidly spread by seed and through the dispersal of vegetative parts. Monitoring of an infestation on the Magela Floodplain has demonstrated the rapid spread and increase in density of the species. Predictive modelling suggests that the infestation will continue to develop if left unchecked (Figure 7). Para grass is a difficult weed to control. In Kakadu, control work is only undertaken in catchments where there is a reasonable likelihood of success.

4.2.5 Mission grass

Mission Grass *Pennisetum polystachion* (Figure 8) is a tall, tussocking perennial grass that was introduced to Australia from Africa as a pasture grass. It is listed as a noxious weed under Northern Territory legislation. It is common in disturbed areas such as roadsides, degraded pastures and waste sites. The seed is readily spread by water, wind, in the fur of animals and often in the radiators or other parts of vehicles. It is now common in many parts of Kakadu and in the town of Jabiru. Mission grass is the main species targeted by Kakadu's grassy weed team. Grid surveys are undertaken to locate and spray mission grass, preferably before it sets seed in April. Mission grass stays green until late in the dry season and it can provide substantial fuel loads for late season fires. These fires can be particularly destructive, and may result in the loss of native vegetation and important habitat for native wildlife.

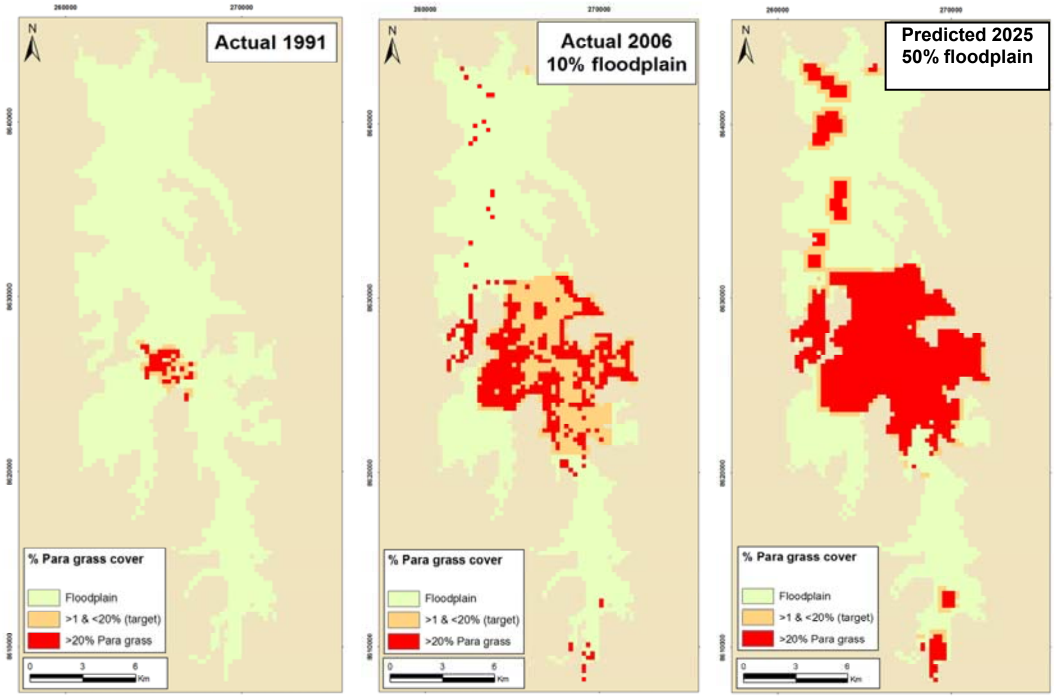

Figure 7 GIS-based modelling is being used to predict the likely development of para grass infestations in the Magela floodplain in Kakadu (Bayliss et al 2006)

4.2.6 Gamba grass

Like mission grass, gamba grass *Andropogon gayanus* (Figure 8) was introduced to Australia from Africa as a pasture grass. It is also a perennial tussock-forming grass that can grown up to 4 metres tall. It inhabits creek lines, flood plain fringes, *Eucalyptus* dominated savannas where rainfall is greater than 600 mm per year and degraded areas including roadsides. The seeds are easily spread short distances by wind as well as being carried by vehicles. It is a deep rooted grass that forms very dense stands. It cures later in the season than native grasses and like mission grass can fuel very hot, destructive fires that can often result in the death of native woody vegetation. Gamba grass is a priority species for the grassy weeds team and targeted spraying is regularly undertaken to control this species.

Figure 8 Mission grass (left) and gamba grass (right) form dense, highly combustible stands

4.3 Conclusion

Compared to other national parks and reserves in Australia, Kakadu has a relatively low number of weeds. However, the Park still faces major challenges in controlling or eradicating the weed species that are presently found in the Park and preventing invasion by new weeds. The continuation of rigorous surveillance and control programs by dedicated weeds teams and other Parks staff will assist in achieving this goal.

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5 The need for weed data

D Walden[1]

5.1 Data for decisions

The purpose of this paper and the preceding symposium presentation is to summarise the important role data/knowledge plays in terms of strategic planning, prioritising, and implementation of control. This paper does not detail the methods of weed data collection, nor does it present available data and other knowledge of the species of concern as this has been addressed in the literature. Thus, the information presented does not follow the original focus questions, and is not necessarily specific to Kakadu National Park (KNP). Some aspects of this topic and others related to KNP are discussed in Walden and Gardener (2008), which also includes an extensive bibliography that is largely specific to KNP weed issues. Comprehensive guidelines for weed data collection in the Northern Territory (Weeds Management Branch NRETA 2007), survey and mapping techniques (McNaught et al 2006) and guidelines for the development of local weed management plans (Cooperative Research Centre for Australian Weed Management 2008) are readily accessible.

Weeds are very social creatures and rarely come to a party in ones or twos. Thus the land manager is usually faced with a host of species, all with differing degrees of actual impact (often unquantified) and perceived impact (ie by various stakeholders). Other confounding parameters include (but are not limited to) differing environmental ranges, spread rates and spread pathways. The control methods vary between species as does the knowledge base of control mechanisms and biology of the individual species. The manager must carefully address the following questions, the latter of which is often overlooked when planning strategies and allocating resources.

'How much will it cost to reduce the impact of the infestation to a socially acceptable level?'

'How much will it cost to maintain the infestation at that level in perpetuity?'

Resources for weed control are always limiting, so species priority has to be determined in conjunction with realistic, achievable and sustainable targets. Determination of these priorities and targets relies on comprehensive and objective data on weed impacts, distribution and spread which also enables outcomes of weed research and control to be measured. Obtaining this data and the subsequent research is typically resource intensive and it may be many years before a 'profile' of the weed is established. McNaught et al (2006) summarise the need for weed data as follows:

'You can't manage what you can't measure'

There is often a perception that if weeds are being sprayed with herbicide, burnt or physically removed, then there will ultimately be an impact on the problem. However, if the extent of the problem is an estimation at best, or the spread rate is faster than the control rate, or the method lacks the efficacy to prevent regrowth the following season (ie from the soil seed bank), then the resources employed have been largely wasted. On the other hand, if the

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manager is armed with knowledge of the attributes listed in Table 1 for example, this information can influence how the control strategy is approached.

Table 1 Some attributes of weeds where data/knowledge can greatly influence control approach

Attribute	Comments
Flowering 'window', peak flowering times and time to maturation	Targeting control at these times can prevent seeding of the next generation
Seed germination period, germination factors, longevity of seeds in the soil	Relevant to the above. Some germination factors eg fire can be controlled. Longevity crucial to follow-up control
Invasion rates and key pathways	Important for modelling spread. Some pathways can often be removed or minimised
Hydroperiod and inundation levels	Good indicator of habitat preference. Can sometimes be used as a control tool eg drowning following spraying or cutting (timing is critical)
Local topography, soil type, soil moisture and pH, nutrient requirements	Often indicators of habitat preference. If the plant is particularly sensitive to change in these – maybe used as a control tool
Salinity tolerance	Indicator of habitat preference. Given the right circumstances, introduction of saline water could be used for control
Associated plant communities and competition and shade tolerances	Essential information when planting competition species. Can also be indicators of habitat preference
Response to fire	Fire can be a powerful control tool or a powerful facilitator of weed spread. Knowledge of this attribute is essential for determining which.
Allelopathic capabilities	Chemicals and other factors that weeds use to reduce competition. Knowing how these work can be particularly useful for post control rehabilitation using native species
Potential pathogens	Essential knowledge when considering biological control which for some species is the only long-term option

Mapping is perhaps the most important component when planning a weed management strategy. Monitoring the success of control by regularly updating maps and revisiting sites will provide the necessary feedback to assess the need for adapting the strategy if required. This is often referred to as 'adaptive management' (or systematic learning by doing), and can be achieved using experimental plot trials. Systematic records of weed infestations can help support the understanding of:

- What weed is found, where and when
- Changes in area and density over time
- The effect of land management practices and weed management programs

With the rapid progression of technologies such as Global Positioning Systems (GPS), Geographic Information System (GIS) and a wide variety of remote sensing techniques eg satellite imagery, maps are becoming more prolific, more accurate, more accessible and often less expensive than previously.

Accurate and regularly updated maps and databases enable the manager to:

- Assess the size/extent of the problem
- Detect satellite infestations (if possible given the method)
- Determine rates of spread

- Divide the problem into manageable portions
- Identify the threat to significant habitats
- Audit and monitor the success of control programs
- Communicate results in a spatially explicit, comprehensible way

To avoid duplicating information and discussion on the need and applications of weed mapping issues, see Boyden et al 2010 in this publication for details and examples for application to weeds of high resolution satellite imagery in Kakadu National Park.

The control cost figures presented at the symposium as derived for several species in KNP were presented at the KNP Landscape change symposium in April 2007 (see Internal Report 532 – http://www.environment.gov.au/ssd/publications/ir/532.html) and are not included in this paper.

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6 The role of remote sensing for the monitoring and control of wetland weeds in Kakadu National Park

J Boyden[1], R Bartolo[1], D Walden[1] & P Bayliss[2]

6.1 Introduction

Cost-effective and strategic weed management is achieved though timely detection of new incursions and monitoring and controlling the extent of known weed infestations. Management priorities are defined by the distribution of weeds in context to the native vegetation (assets) vulnerable to invasion in conservation areas, where native vegetation communities (or the habitats for biodiversity conservation) can be considered as the mapping units for landscape management. Implicit is the need for accurate current (and historical) maps of weeds in context to the distribution of these assets. However, in remote and inaccessible landscapes such as Kakadu National Park, vegetation maps have tended to be incomplete or out of date, resulting in uncertainty in setting management priorities in remote conservation areas (Harvey & Hill 2001). We contend that remotely sensed data have the potential to address these information gaps and to assist in developing an integrated, landscape-scale, weed monitoring and control policy.

A general framework for the spatial risk assessment of weeds and the role of remote sensing (RS) in monitoring weeds on wetlands is provided in Figure 1. Captured over appropriate spatial extents and spatio-temporal scales, RS allows repeated mapping of vegetation, and allows managers to monitor changes in the distribution of weeds in relation to the current and historical extent of native vegetation. Repeated mapping of weeds in relation to native vegetation is also useful for developing spatial models to predict the likely occurrence of future weed invasions. Predictive maps are among the decision support tools that may be used in operational planning to prioritise control of weeds in key areas. A monitoring program that incorporates remotely sensed data has potential also for assessing the effectiveness of weed control strategies in preserving the integrity of key habitats.

RS has been applied to map weeds and native vegetation condition on wetlands, ranging in scales from aerial photography to coarser scale satellite products such as Landsat (Menges et al 1996, Phinn 1996, Phinn et al 1999, Tuxen et al 2007). In general finer spatial scale (<2.5 m) imagery produce higher accuracy and are better able to detect small weed patches, while coarser scale (>25 m pixel resolution) products can resolve only large weed infestations reliably (Catt & Thirarongnarong 1992). This paper focuses on the application of Very High Resolution (VHR) satellite imagery such as Quickbird, which offer a more cost effective solution to traditional aerial photography techniques.

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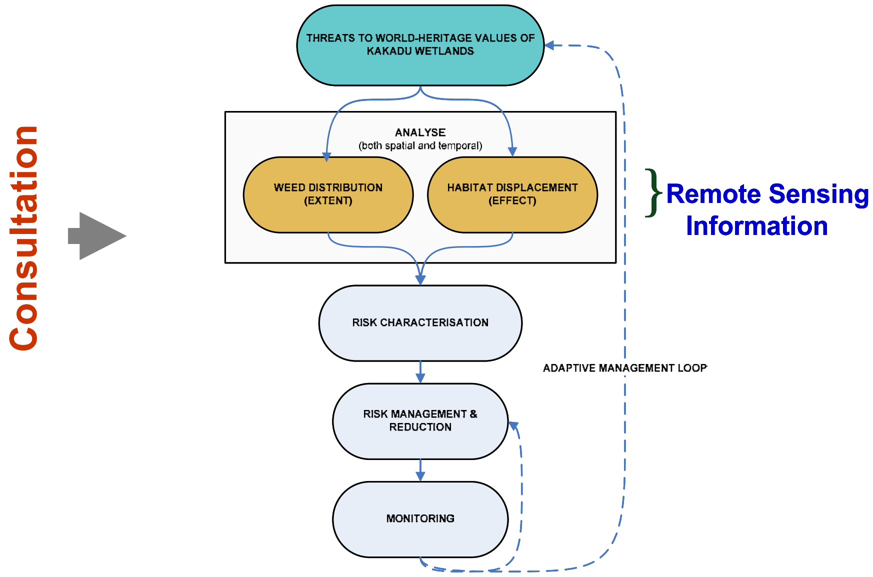

Figure 1 General framework for monitoring and weed risk assessment, indicating the role of RS in providing timely information on weed distribution and native habitat displacement (adapted from USEPA 1998)

6.2 Very high resolution (VHR) satellite imagery for mapping weeds

Satellite sensors are now capable of characterising vegetation distribution at comparatively very high spatial resolutions ranging from 0.6 m to 2.5 m pixels with several advantages over conventional aerial photography. These include: lower cost with increased spatial accuracy; a greater field of view, producing a image with reduced spectral noise[3] (Tuxen et al 2007); and greater spectral range (visible to near infrared). Revisit time for VHR QuickBird imagery is 10 days in the NT Top End region, allowing flexibility in capture time.[4]

Users of VHR maps can navigate to locations confidently using GPS technologies as spatial accuracy of VHR imagery is high (in the order of ±15m or ± 2.5m if surveyed ground control targets are also deployed). Importantly, VHR makes the link between ground validation information (including photos) and satellite imagery easier by allowing for clear recognition of small objects in the landscape, such as weed patches or individual trees (Phinn et al 1999, Tuxen et al 2007).

In general terms VHR can delineate fine-scale detail of habitat distribution in highly variable wetland ecosystems, and is complementary to field sampling by providing continuous coverage in expansive and often inaccessible wetland environments (Phinn et al 1999, Everitt et al 2004, Everitt et al 2007). Other authors have shown that VHR can also provide a good surrogate to ground-based measurements of native vegetation condition and is generally more cost-effective and a less invasive solution for assessing condition across extensive areas (Phinn et al 1999, Johansen et al 2007). VHR has advantages over systematic visual surveys of weeds by air or ground. Maps produced by aerial surveys are of coarse resolution and do not identify the specific locations of weed patches. Grounds surveys tend not to be practical

3 A single 'synoptic' image will have reduced spectral noise resulting from a reduction in variation of Bi-directional reflectance, compared to the same scene produced from a mosaic of multiple images (such as aerial photography) taken from various view angles.

4 QuickBird revisit time based on obtaining an image at 0–15º NADIR at 12ºLatitude

over extensive and often inaccessible areas and may in fact exacerbate the dispersal of weeds into more pristine areas.

In Kakadu National Park (KNP) pilot studies conducted on the Magela floodplain and at Boggy Plain (lower South Alligator Floodplain) demonstrated the utility of VHR to map para grass (*Urochloa mutica*) and key wetland habitats as illustrated in Figures 2a & b (Boyden et al 2007, Boyden & Bartolo 2008). Accuracy of para grass detection using computer based map classification was in the order of 95% on the Magela floodplain.

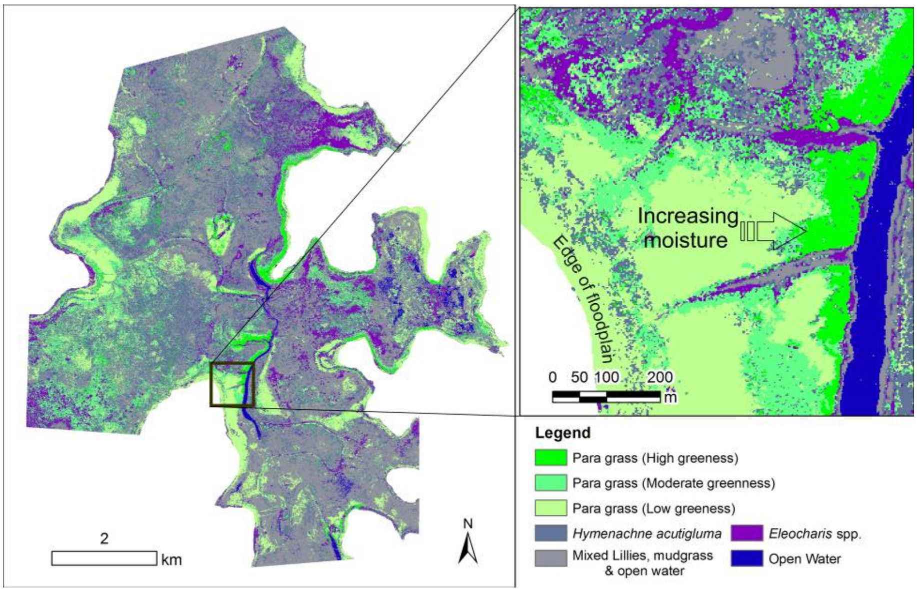

Figure 2a Map of para grass distribution for a selected region of the Magela Creek floodplain produced using QuickBird imagery captured in 2004 (Digital Globe® all rights reserved).

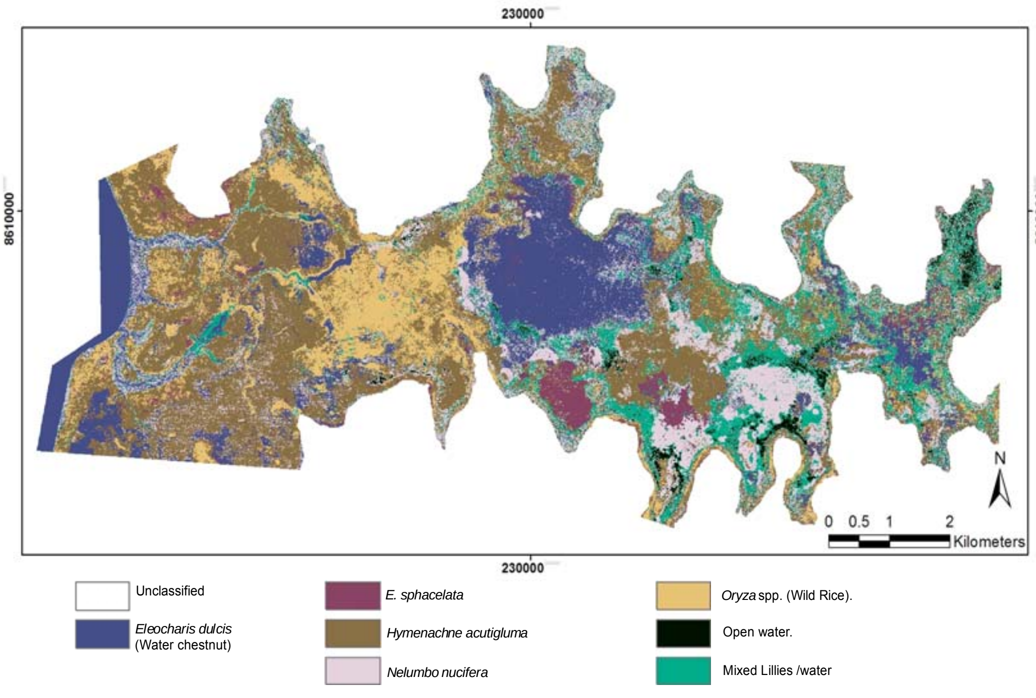

Figure 2b Major native habitats mapped in May 2003 at Boggy Plain, South Alligator River, Kakadu National Park (Digital Globe® all rights reserved). For best interpretation of Figures 2a&b, please see online version of this report on the SSD website.

The utility of VHR is improved through proactive use of imagery by KNP field staff. Weed managers trained in aerial and ground survey techniques are an important resource as they can also be adept at VHR image interpretation. In this context it is also worth noting that KNP rangers have successfully used VHR imagery sourced through Google Earth to locate new patches of para grass in the South Alligator region of KNP (Atkins pers comm 2008).

6.3 Optimising the quality of weed maps

With the aim to produce accurate vegetation maps, there are a number of factors that need to be considered in the design and implementation of any remotes sensing monitoring program. Key issues are vegetation phenology, inundation (water in the landscape), cloud cover , fire, smoke, and the spectral resolution of the sensor. The view angle of the satellite sensor can also influence image quality and should be kept as minimal as possible (eg 0–15º off NADIR[5]).

Seasonal variability must be accounted for in any mapping exercise, where changes in plant phenology, and the degree of inundation on floodplains influence the spectral response of plants and other surface features. Image captures should to be planned for times when target weeds and habitats are most clearly resolved (ie when the diagnostic optical differences between targets are optimal). In this regard, ***eriss*** has established a spectral database for major weeds and native vegetation in the region. However there remain information gaps with regard to acquiring quantitative spectral profiles of some key aquatic weed species (and native aquatic plants). More comprehensive hyperspectral profiles acquired from ground targets across ranges of seasonal variability in plants will assist in improving knowledge based mapping techniques.

For the above reasons remotely sensed mapping of vegetation should occur in conjunction with coincident field reference and validation surveys. Appropriately designed surveys allow the quality of map products to be assessed. Quality control of maps produced from RS is important for providing confidence in the reliability of maps of weed or native vegetation distribution.

Image quality and capture times are also influenced by atmospheric conditions and ground disturbance effects. For example, excessive cloud cover during the Wet season necessitates that capture times for optical imagery are limited to the Dry season period. Dry season smoke haze can also effect image quality and higher incidence of fire on wetlands is in the late dry season means that these times should be avoided when wetland weed mapping is the aim. In general it is recommended that capture times be limited to the early to mid-Dry season (April to June) period, when water levels have receded substantially, but remain high enough to allow some access by airboat for field surveys. If airboat access is not possible, a helicopter is a suitable alternative for field validation surveys.

It should be noted that those with field (and aerial survey) based experience in wetland environments and weed identification can also provide useful advice on the best times for image capture. Given the variability of wetlands between years, a reconnaissance field survey (undertaken in the late-wet/early-dry season) may be useful in anticipating optimal image capture times in any one year.

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5 NADIR is defined as the single point, or locus of points on the surface of the Earth directly below a sensor as it progresses along its line of flight.

6.4 Applications of mapping information

VHR is perhaps the most effective technology at detecting small ‘satellite’ weed colonies. Early detection and eradication of small ‘satellite’ weed incursions[6] is important to minimise costs of weed management. Early detection of Olive Hymenachne outbreaks, that have tended to occur in relatively isolated and unpredictable locations within KNP, would likely be facilitated by applying VHR.

In situations where large weed infestations occur, VHR also can provide information for rehabilitation of key habitats where the effectiveness of weed control strategies aimed at reducing the density or extent of weeds may be evaluated. Some of the potential applications of VHR and the status of these in terms of development towards operational monitoring in KNP are provided in Table 1.

Table 1 The authors’ assessment of potential applications of remote sensing for monitoring key wetland habitats (landscape management units), the impacts of weeds and other environmental pressures; and the current status in terms of development towards an operational monitoring framework.

	TARGET	POTENTIAL APPLICATIONS	CURRENT STATUS
WEEDS	Para grass	• Monitor extent & detect new incursions	• High potential • Some R & D • Not operational
	Olive Hymenachne	• Monitor both for new incursions & current control effort locations	• High Potential • No R & D, • Not operational
	Salvinia	• Monitor weevil/salvinia distribution?	• Some potential • No R & D, • Not operational
	Mimosa	• Probably not applicable in current context	• Low potential in current context; • Some R & D • Monitoring of large infestations using coarser imagery
	Aleman Grass	• Detect new outbreaks	• Some potential • No R & D, • Not operational
OTHER DISTURBANCE	Feral Animals	• Monitor ground disturbance extent	• Some potential • No R & D, • Not operational
	Salt Water Intrusion	• Monitor extent & effects	• High potential • Some R & D, • Not operational
	Fire	• Monitor effects & interaction	• Some potential • Some R & D • Not operational
NATIVE HABITAT	*Eleocharis dulcis* (Water Chestnut)	• Monitor extent in relation to disturbance effects	• High Potential • Some R & D, • Not operational
	Oryza spp. (Wild Rice)	• Monitor extent in relation to disturbance effects	• High Potential • Some R & D, • Not operational
	Native Hymenachne	• Monitor extent & fire interaction	• High Potential • Some R & D, • Not operational

Note: R & D = Research and Development

6 Four square metres (9 pixels) is a conservative estimate of the smallest weed patch size that can be detected using VHR. Smaller patch detection may be possible.

6.5 Weed risk assessment modelling

Multi-temporal information derived from remotely sensed data can be used to predict invasion rates of weeds in different habitats. A specific example from KNP is shown in Figure 3, in which the rate of increase in extent of para grass on the Magela floodplain was assessed to be 14% per annum or to be doubling in extent every 5 years. Distribution maps and other environmental information relating to habitat preferences of weeds (eg site specific water depth on wetlands) can be also integrated into spatially explicit models developed within Geographic information systems (Ferdinands et al 2001, Ferdinands et al 2005, Ferdinands 2007).

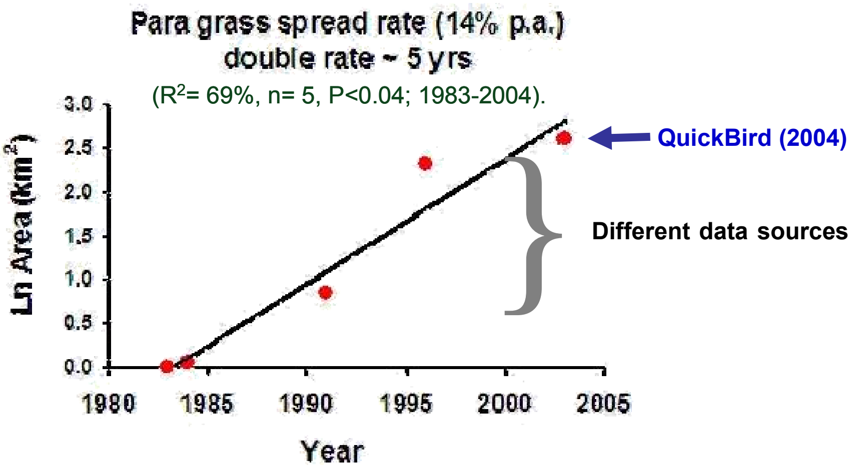

Figure 3 Estimate of increase in area for para grass on a selected region of the Magela Creek floodplain (as shown in Figure 2b) (from Bayliss et al 2006)

6.6 Conclusions and recommendations

Managers are better able to combat the spread of weeds through an understanding of the spatial and temporal context of weed invasions. VHR remotely sensed imagery can address the information gaps associated with managing weeds in remote and inaccessible landscapes by providing detailed and accurate maps of specific wetland weed species and native vegetation. In particular, if VHR imagery were to be applied for routine monitoring in high-value conservation areas, there would be a improved capacity to detect small ‘satellite’ weed colonies in a timely and cost-effective manner.

Remote sensing provides a tool to recognise, understand, and manage change in remote environments, by delivering reliable, defensible, and measurable criteria for mapping weeds and the condition of native habitats. Satellite RS is the most cost-effective source of information for acquiring continuous spatial coverage of vegetation condition over large areas. Such information also contributes to a broader understanding of ecological function of natural environments such as wetlands (Johnston & Barson 1993, Ozesmi & Bauer 2002, Baker et al 2006). RS, coupled with GIS based models, are a basis also for incorporating spatial and temporal knowledge of the landscape into risk assessment decision support tools for managers (Leuven & Poudevigne 2002).

While the utility of VHR imagery for mapping para grass has been demonstrated, utility for other target weed species of the region has not been fully investigated. However it is likely that any weed species which forms dense monospecific patches in the landscape, is a candidate for mapping using VHR imagery, provided there are sufficient visual differences (in spectral reflectance, texture, and shape) to distinguish colonies from surrounding features. In this context grassy weeds on wetlands (Olive Hymenachne) and terrestrial woodland (*Pennisetum* spp) are good candidates for mapping.

Management priorities within Kakadu are focused on conserving the unique natural and cultural heritage values (which are tightly coupled with respect to wetlands within the region). In this context maps of weeds and native vegetation (representing habitat management units) can be used as monitoring endpoints for risk assessment and decision support for managers. Such an approach is complementary to the KNP Plan of Management (2007–2014) and will facilitate adopting a 'habitat-unit' approach to managing natural resources within the Park at a landscape scale (Director of National Parks 2007).

Cost-effective delivery of RS products requires developing procedures, standards, and agreed measurement endpoints under a coordinated framework. In this respect there is a need to refine protocols and allocate resources to monitoring and assessment of change in variable wetland ecosystems (Shanmugam et al 2006). Adaptive weed control operations will also benefit from such a monitoring program, where remote sensing mapping and validation is integrated with spatial knowledge from weed control operations and surveys.

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7 Incorporating dispersal ecology and simulation modelling into the management of plant invasions

HT Murphy, DA Westcott & C Fletcher[1]

7.1 Introduction

Dispersal processes determine the proportion of seeds moved any given distance from the source plant and for invasive species the outcome of these processes may be the most important determinant of invasion success (Lockwood et al 2005). An understanding of dispersal processes is necessary for predicting the potential rate and pattern of invasive spread (Kot et al 1996); this information can be fundamental in the design and implementation of management programs (Trakhtenbrot et al 2005). For fleshy fruited plants, dispersal curves are in large part the product of the movement and foraging behaviour of the animals that feed upon their fruits. These dispersers determine the quantity, distance and direction seeds are dispersed as well as the quality of that dispersal (Wang & Smith 2002, Levin et al 2003).

In many contexts, search and eradication efforts are reliant on on-ground efforts being distributed in the right places and at the right time. Currently these decisions must often be made in the absence of complete information from the field. For example, in the rainforest habitats of eastern Australia search and eradication efforts are severely hampered by dense vegetation, high species diversity, difficult terrain, trying climatic conditions and the remoteness of much of the area from vehicle access. These factors can conspire to make operational decisions about the investment of effort more akin to guesswork than considered and information based. Very similar issues confront the weed managers and control crews in Kakadu National Park. Use of predictive weed spread models incorporating realistic dispersal curves will greatly increase search efficiency through better prediction of the extent and likely location of weed infestations.

We describe here how we have developed dispersal curves for fleshy-fruited weed species occurring in rainforest habitats in North Queensland and how these have been incorporated, along with life-history parameters, into models of weed spread in order to improve management efficiency.

7.2 Generating dispersal curves for weeds

An important descriptor of dispersal processes is the dispersal kernel, which is the frequency distribution of dispersed seeds relative to distance from a parent plant (Levin et al 2003). Relatively little is known about the dispersal of weed species and, in particular, the proportion of seeds being dispersed over long distances is poorly understood and is probably often under-estimated. Seeds dispersed short distances tend to contribute to increased density or abundance in current infestations while those dispersed long distances contribute to spread. Because containment is a primary goal of most weed programs, understanding long-distance

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dispersal is critical for effective management. For most weed species, the frugivores actually removing and dispersing seeds are unknown. Furthermore, for highly invasive species, when mature individuals are identified they are quickly eradicated, and observing seed removal by fruigivores is not an option. Although new to a particular area, invasive species rarely rely on novel dispersal processes; instead co-opting dispersal processes already existing in the new environment (Westcott & Dennis 2006). Therefore a surrogate or analogue native species with fruit characteristics similar to the weed species can be used to generate the dispersal kernel because it can be assumed that the dispersers will ultimately be very similar.

There are several steps involved in generating dispersal curves for fleshy-fruited species:

1 Identifying potential dispersers based on fruit characteristics and characteristics of the dispersers themselves (eg gape size).

2 Determining relative contributions to dispersal by different dispersers (ie per cent of fruit crop removed by different dispersers). This is achieved by a variety of methods including observations of disperser behaviour at fruiting trees, measuring removal rates of fruits and seeds placed on the forest floor, and measuring fruit production in the canopy and fruit fallen to the ground.

3 Determining seed retention times ('beak to bum' times) for dispersers. Seed retention times are measured by recording time from ingestion to defecation during observation of captive animals (Fig 1a).

4 Measuring disperser movement patterns (Fig 1b & 1c). Disperser movement in space as a function of time is measured through the use of continuous radio-telemetry. A radio-tagged disperser's location at any given point in time, a 'fix', is determined by triangulating bearings from GPS-mapped stations.

7.3 Dispersal ecology and weed management

Dispersal estimates resulting from the methods described above, while not being direct or exact measures of actual dispersal, provide managers with an immediate indication of the nature of dispersal the new invasive is likely to receive, and consequently an indication of the kind of response that is appropriate (Westcott & Dennis 2006). For example, the most immediate and effective use of a well-described dispersal kernel for a weed species is in determining how far on-ground teams should be searching for individuals from any source individual or population. Based on the example dispersal kernel below (Fig 2), searching out to a radius of 250 m from a source will likely account for about 90% of dispersed seed. However, the remaining 10% of seed will be dispersed up to 1400 m from the source. These relatively rare long-distance seed dispersal events which subsequently develop into outlying, or satellite populations, may be critical in contributing to weed range expansion and spread. In addition, an understanding of dispersal agents or vectors that contribute to the long-distance tail of the dispersal kernel may allow targeted management strategies for those vectors – for example focusing searches at known roost sites or frequented habitats.

While both a plant's demography and dispersal play important roles in determining the rate of invasion, modellers have shown that the speed and pattern of spread of invasive species is extremely sensitive to the shape of the dispersal kernel (Kot et al 1996, Buckley et al 2006). The use of well-parameterised dispersal kernels in models of weed spread is in its very early stages. In the following section we describe a model of spread for a fleshy-fruited woody weed, *Miconia calvescens* (Melastomataceae) which incorporates both a realistic dispersal kernel and estimates of reproduction and mortality (see also Murphy et al 2008).

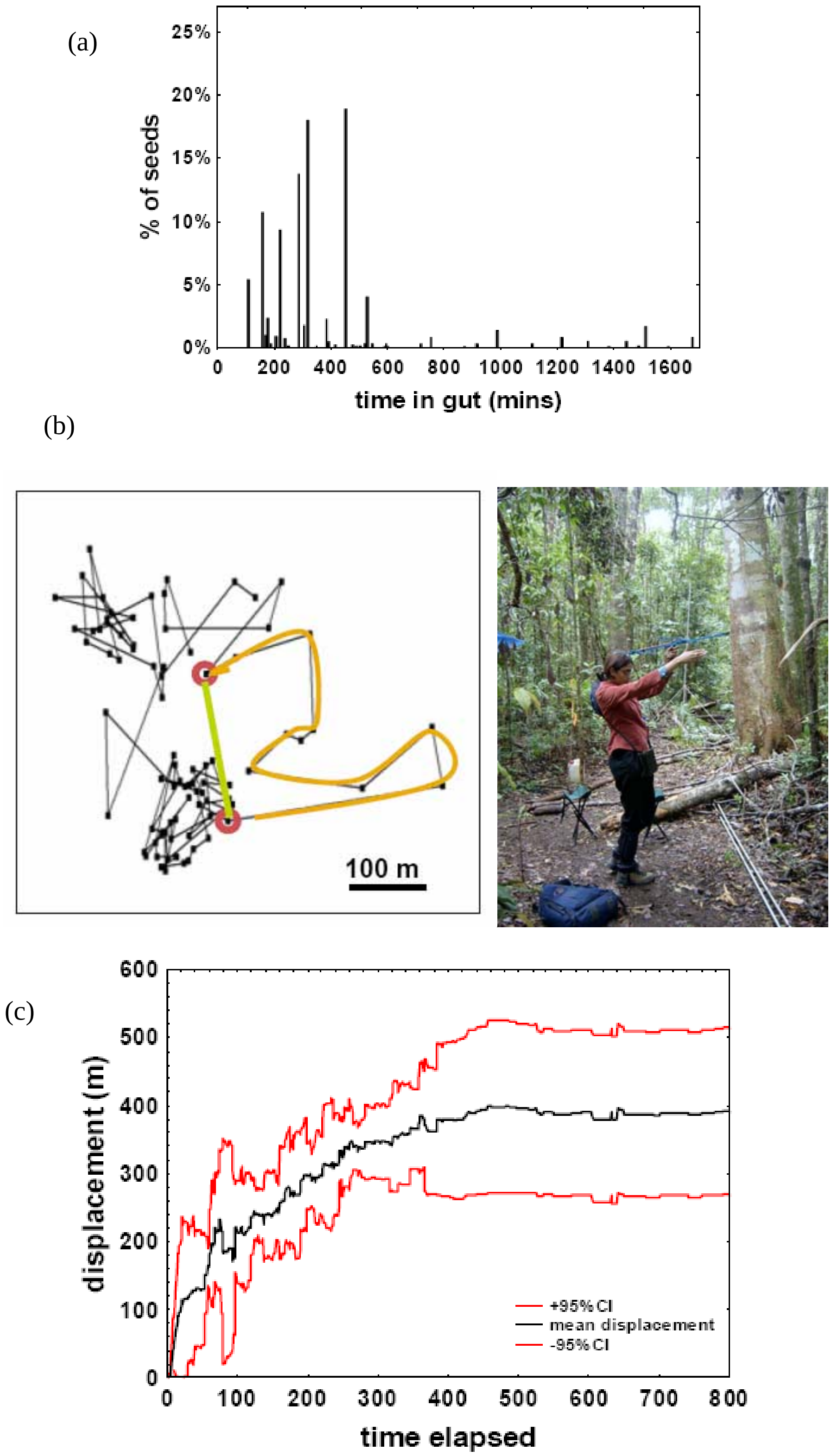

Figure 1 Example of data used in generating weed dispersal kernels. (a) Percentage of ingested seeds versus time in gut (b) using radio telemetry to record disperser movement and (c) disperser movement distances (or displacement) over time.

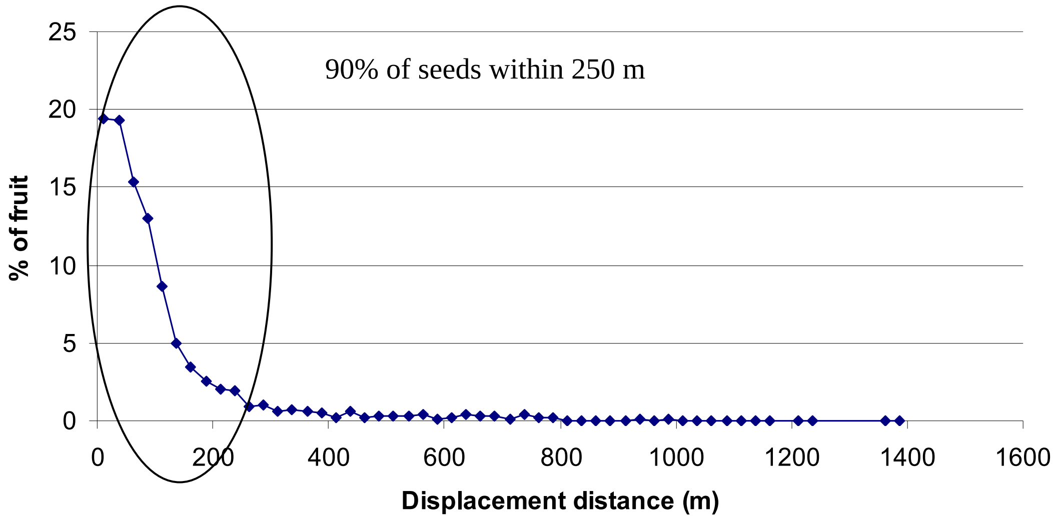

Figure 2 A dispersal curve for a fleshy-fruited rainforest species

7.3.1 Example of a model of spread for *Miconia calvescens*

Miconia is a declared Class 1 weed (the highest priority category) in Queensland (Land Protection [Pest and Stock Route Management] Act 2002) and is currently the target of a national eradication program. *Miconia* embodies many of the traits which make for a successful invader; the species can persist in both high and low light environments (Csurches 1998). The small (ca. 6–7 mm), spherical fleshy fruits contain large numbers of tiny seeds (ca. 0.65 mm) (Meyer 1998a) and the small fruit size means they can be consumed by nearly the entire range of frugivores present in tropical forests.

For *Miconia* in Australia, the eradication program aims to control all individuals in known infestations before they reach maturity. Therefore we used dispersal curves assembled for *Miconia* based upon two integral components: plant species with similar fruit characteristics for which we have already developed dispersal curves and frugivore movement patterns adapted from functional groups of those animals likely occurring within the range of present *Miconia* infestation areas (Westcott & Dennis 2006, Metcalfe et al 2006). The model we employed used a dispersal curve based on parameters derived from foraging patterns, seed retention times in the gut, and displacement distances of each species of seed disperser (Westcott et al 2005, Westcott & Dennis 2006, 2007) as described above. These values were generated from hundreds of hours of telemetry data from radio-tracking of avian frugivores in the Wet Tropics region of Australia. The dispersal kernel also included the proportion of fruit estimated to fall directly below the fruiting individual.

We developed a single-species, individual-based model of weed spread in a homogenous landscape, that included the dispersal kernel as well as life-history parameters related to reproduction, mortality and seedling establishment. All the life-history parameters were estimated from a combination of field experience and experimental data. Within the model, up to one million seeds are produced by a mature adult plant per reproductive season. Several types of mortality occur once a seed has been dispersed, including mortality associated with limited seed viability, density dependence, and generally high seedling mortality in the first year. Once a seedling has become established it may die in any year depending on an age-dependant mortality curve, where the probability of dying decreases with age. When an individual in the model reaches maturity it begins to produce seeds, which are themselves dispersed across the landscape. For this particular case study, we began the model with 4 reproductive individuals and let the model run for 30 years; we then compared the number and spatial extent of individuals predicted by the model with an actual infestation occurring in North Queensland that was approximately 30 years old (Fig 3).

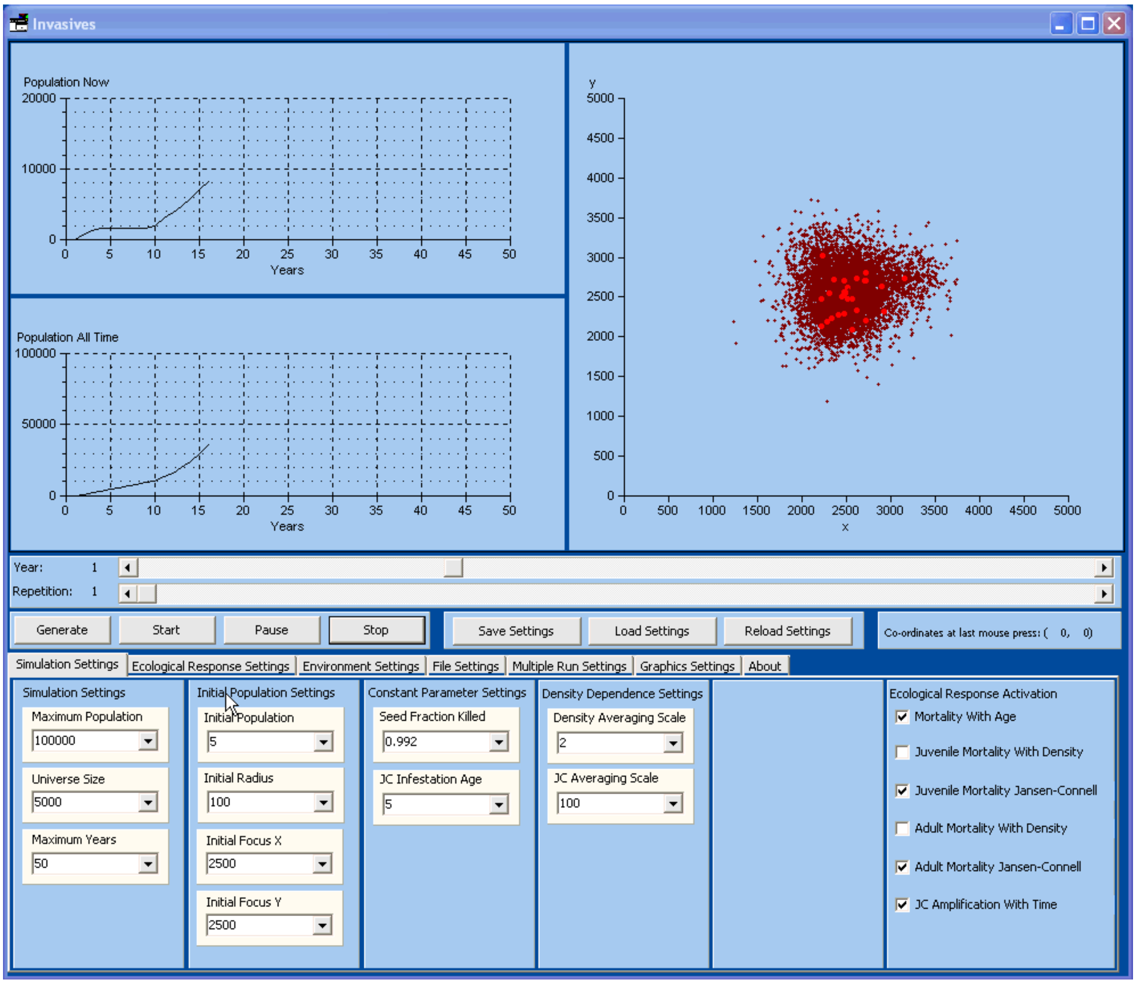

Figure 3 Example of the dispersal model. The figure at top right indicates the number of individuals in the infestation. Large dots indicate mature individuals.

We found that the model generally over-predicted the spatial extent and size of the real infestation after 30 years of simulations. There are several possible reasons for this, most notably that the effect of management effort is not included in the model. For example, whereas in the model individuals were allowed to grow and reproduce yearly until they suffered natural mortality, in reality, recent control activities mean that all individuals in the infestation are removed as soon as they are encountered and it is very rare that an individual remains undetected long enough to reproduce for many years. Therefore, in real infestations, mature trees do not provide a regular source of seeds into the population. During the last 20 years local landholders may also have suppressed the population growth by occasionally controlling established individuals. The model also does not include a stored seed bank, however, we know that *Miconia* seeds may be viable for up to 14 years in the seed bank.

Another factor having a significant impact on the accuracy of the model is that landscape features are not accounted for. The model currently assumes that seeds are dispersed 360°

around the source and have an approximately equal probability of survival in all directions (an isotropic distribution) (Fig 4). In reality this is clearly not the case; far from being a homogenous landscape, the area where the infestation occurs is topographically complex and diverse, including various native and human-modified habitats. Landscape features influence both the movement pathways of dispersers as well as the probability of establishment of a dispersed seed. Future work on the model will incorporate data on frugivore habitat use and movement patterns resulting in an anisotropic model (Fig 4). The effect of different spatial and temporal patterns of management investment on population spatial structure and spread will also be incorporated to determine whether it is possible to identify more effective strategies for distributing management effort whilst ensuring a high probability of detecting stray individuals.

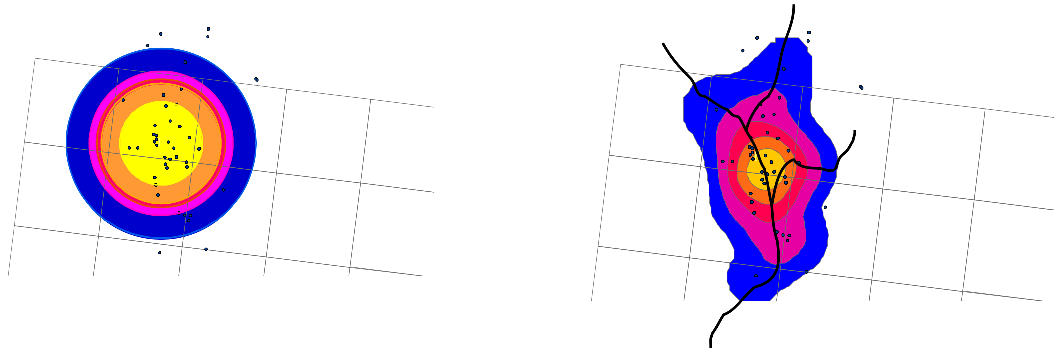

Figure 4 Example of an isotropic model (left) and anisotropic model (right) which incorporates the effect of landscape structure on disperser movements and establishment probabilities

7.4 Conclusions

When combined with field data, modelling approaches such as the one described here allow an understanding of the net effect across the landscape of alternate dispersal curves which reflect plant and/or frugivore attributes. For example, for a species occurring in a different habitat, a different suite of dispersers could be considered and dispersal curves could be altered to reflect the frugivore community, if that information is at hand.

The approach described here requires a detailed understanding of dispersal of native species which may seem like a daunting task. However, the fact that this can be achieved for tropical rainforest habitats which are perhaps the most complex ecosystems in terms of plant-disperser interactions suggests that it could be readily achieved for other systems as well.

Finally, the process described here focuses on animal dispersed weeds, but the concept is equally applicable to predicting and modelling the spread of species that are dispersed by other vectors, eg wind or water. Naturally, the methods utilised to describe dispersal kernels will differ in some respects. As is the case for vertebrate dispersed weeds, the method introduces an explicit consideration of how weeds move through a landscape, forcing consideration of the processes that drive weed spread and consequently encouraging a more strategic approach to management.

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8 The weedy time bomb project

G Kyle[1], M Gardener[2] & M Ibbett[3]

8.1 Focus summary

Jabiru is a small town located in the centre of Kakadu Natioal Park in Western Arnhem Land. This area is recognised as a biodiversity hotspot. Invasion by exotic weeds poses a major threat to the biodiversity assets of this area.

- There are currently 55 introduced species in Jabiru including known invasives like Salvinia, Rubber Vine, Lantana and Ivy Gourd. Many of these species have the capacity to escape into the surrounding landscape.
- Major stakeholders in the town of Jabiru have collaborated to design a project and obtain Envirofund support to tackle the weed problem in Jabiru.
- The Weedy Time Bomb Project aims to completely eradicate 10 of these species with distributions limited to houses in Jabiru, before they escape to the surrounding landscape.

The project partners identified seven distinct stages of the project. These are:

- Community consultation
- Mapping of introduced species
- Prioritisation of target species
- Target species control
- Monitoring and evaluation
- Education
- Supply of alternate garden plants

At the completion of the Envirofund component of the project, partners have committed to 3 years of ongoing monitoring and control to ensure the goal of complete eradication is achieved.

The Paper

8.1 Introduction

The management and control of exotic weeds is a difficult and resource-hungry process. However it can be cost effective and feasible to completely eradicate potentially invasive species whilst their distributions are still limited to less than one hectare (Rejmánek & Pitcairn 2001). There are currently 55 introduced species known to occur in the township of

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Jabiru, in the World Heritage listed Kakadu National Park. Amongst these 55 species are a number of known invasive species including lantana, rubber vine, blue thunbergia, salvinia and ivy gourd that have the potential to escape and become established outside of the township (NB Salvinia is already established in some wetlands within Kakadu National Park, but not in waterways in the immediate vicinity of Jabiru).

The land tenure in Jabiru, and hence who is responsible for the strategic management of weeds in the town is complicated. The Mirrar people are the recognised Aboriginal traditional owners of the area. The Commonwealth, through the Director of National Parks currently holds the title for the land and has leased it to the Northern Territory through the Jabiru Town Development Authority (JTDA). The current lease is due to expire in 2026.

There is no free-hold title in Jabiru and all housing, commercial and recreation facilities are sub-let to various organisations (including Telstra, Northern Territory Government (NTG) departments, Jabiru Town Council (JTC), Energy Resources of Australia (ERA) and Parks Australia North (PAN)). ERA, the largest sub-lease holder, has made a commitment to rehabilitate the land at the cessation of it’s mining operations in the area, but the future of the town of Jabiru is still not clear. In the meantime, plants are escaping from household gardens to open spaces in the town and into the surrounding landscape. It has been difficult to determine which organisation should fund a pro-active project aimed at controlling some of these supposedly innocuous garden plants before they become a larger problem. This is despite the fact that the cost-savings and environmental benefits of achieving such control are obvious and substantial.

The Weedy Time Bomb Project was established in 2007 and was endorsed by the major stakeholders in the town including ERA, JTC, JTDA, PAN, NTG, the Environmental Research Institute of the Supervising Scientist (***eriss***), and Gundjeihmi Aboriginal Corporation (GAC). Funding was sought from Envirofund and a grant of nearly $50 000 was subsequently received to support the project, which actively commenced in the 2008–09 financial year.

8.2 The Weedy Time Bomb Project: background and project design

The aim of the Weedy Time Bomb Project is to completely eradicate at least 10 known invasive plant species whose current regional distribution is limited to houses within the township of Jabiru before they escape and become established in the surrounding landscape. The project has the potential to contribute to the prevention of serious and irreversible environmental and/or economic harm in the surrounding landscapes of Kakadu National Park.

The project partners identified seven distinct stages of the project:

1 Community consultation

The 1200 residents of Jabiru will be informed about the importance of these potentially invasive species and requested to participate in the project.

2 Mapping of introduced species

A residential survey of gardens in Jabiru was undertaken in the early 1990s. This will be updated and expanded by experts to include all of the Jabiru Lease (1333 ha). All species locations will be spatially mapped using GIS.

3 Prioritisation of target species

The 10 target species will be determined with the help of the NT Government Weeds Branch using their Weed Risk Assessment tool, the extent of species distributions and local expert opinion.

4 Target species control

Target species will be controlled using the most appropriate methods, including registered herbicide and hand pulling. Repeat weed control will be undertaken when initial kill is not 100%. Since all sub-leases are under institutional control it was considered that that any disputes arising about plant removal in the town would be far easier to negotiate.

5 Monitoring and evaluation

The Envirofund project will go for 18 months in which time the bulk of the on-ground work will be carried out. Monitoring of eradicated success will be undertaken 2 and 12 months respectively after control work. A final report will be given to Envirofund, partners and the community. However, no species can be declared eradicated until there has been zero observed recruitment from the seed bank in three years. The project partners will commit to undertake this post-project monitoring.

6 Education

Education to prevent reintroduction and communication of success: a crucial component to the long-term success of the program is to prevent reintroduction of target species. This will be done by developing community education/quarantine programs, an updated permitted species list, and increasing the availability of local native plant species for gardening. The current and future works will be incorporated into the Jabiru Weed Management Plan (a separate project).

7 Supply of alternative garden plants

A nursery supplying indigenous plants has been recently established in Jabiru and this has provided a valuable source of suitable alternative plant species for gardens in the town. The nursery is entirely operated and staffed by indigenous people.

The bulk of the on-ground work and initial monitoring of eradication success will be undertaken within the 18 month Envirofund project but project partners are currently committed to undertake monitoring and control activities of target species for a further three years and to develop and implement strategies to prevent the re-establishment of these species. In addition all key regional stakeholders have existing weed management programs which have the capacity to detect target species outside of the project area.

8.3 Implementation of the project

8.3.1 Selection of target species

Through a consultative process between staff from the partner organisations and from the Weeds Branch of the Northern Territory Government, a list of potential target plants was identified. Although present in the Jabiru area, the species listed in Table 1 were considered unsuitable for targeting due to their size and difficulty of removal, the extent of their spread, and/or their having already escaped into the wider environment. Table 2 shows a shortlist of potential target species, identified on the basis that successful eradication was considered possible within the scope and budget of the project, and that these species were presently restricted to the township of Jabiru.

Table 1 Species considered unsuitable as targets for the Weedy Time Bomb Project

Scientific name	Common name
Khaya senegalensis	African mahogany
Pennesetum polystachion	Mission grass
Senna spp	Sennas
Eucalyptus camaldulensis	River red gum
Ficus virens	Strangling fig
Wedelia trilobata	Singapore daisy
Synedrella nodiflora	Cinderella weed

Table 2 Shortlist of potential target species for the Weedy Time Bomb Project

Scientific name	Common name
Leucaena leucocephala	Coffee bush
Stachytarpheta jamaicensis	Snake weed
Cryptostegia madagascariensis	Rubber vine
Jatropha gossypifolia	Bellyache bush
Thevetia peruviana	Yellow oleander
Sansevieria trifasciata	Mother in law tongue
Coccinea grandis	Ivy gourd
Lantana camara	Lantana
Arundo donax	Lucky bamboo
Senna alata	Candle bush
Ipomoea aquatica	Kang kong
Thunbergia grandiflora	Blue thunbergia
Cyperus involucratus	Cypress
Tecoma stans	Golden bell
Azadirachta indica	Neem
Spathodea campanulata	African tulip
Caryotis mitis	Fish tail palm

8.3.2 Community consultation

There is a long history of communication and consultation between the partners in this project and other stakeholders in the Western Arnhem Land region. A number of methods will be used to inform the community of Jabiru about the Weedy Time Bomb Project. Local news publications (notably '*The Jabiru Rag*') and a letterbox drop to all lessees and individuals will be the primary methods of communication. Face-to-face consultation will be undertaken with residents who have target species on their property. It is also anticipated that a presentation will be conducted at the local area school to provide further information to the community about the project. In addition, weed inspections of properties will be introduced as part of the inventory process for people taking up new residence in the town, for long-term employees and for individuals leaving residences.

8.3.3 The next steps

The next phase of the project will see the implementation of the community consultation and awareness raising strategies. Following this process, the distribution of the target species within Jabiru will be mapped and the list of target species will be finalised. A control program will be initiated for each of these species and this will be accompanied by a monitoring program that will assess the success of eradication efforts two and twelve months after treatment. Ongoing community education will be undertaken to maintain community awareness and support for the project.

The Envirofund supported component of the Weedy Time Bomb Project will be completed in 18 months, after which time the project partners are committed to undertake ongoing monitoring and control of the target species in the Jabiru area for a further three years with a commitment from some of the partners (notably GAC and ERA/EWLS to continue the project beyond this time.

8.4 Acknowledgments

The Gundjeihmi Aboriginal Corporation would like to thank all partners and contributors that have supported this project.

8.5 Postscript

At the time of writing, the Weedy Time Bomb Project is essentially complete. All targeted results outlined in the NHT Envirofund project were achieved and future monitoring is planned. The Kakadu Native Plant Supply has distributed replacement plants to residents from whose gardens weeds were removed or eradicated. There is general agreement amongst the partners in this project that it was a success.

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9 Workshop summaries: priority issues for management, knowledge gaps and ways forward

M Ibbett[1]

9.1 Focus summary

Participants at the Kakadu Weeds symposium identified a number of priority weed management issues, knowledge gaps associated with these issues and actions necessary to address them.

The priority issues identified by workshop participants were:

- The need to identify the geographic distribution of existing and emergent weed species in the region, with a focus on using distributional mapping and modelling to identify avenues and barriers to dispersal;
- The need to acquire and allocate adequate resources, including funding, personnel and equipment, to tackle weed management issues across the region;
- The need to develop consistent and effective methods of data acquisition and management across the region, and to improve the manner in which weed management agencies share and utilise this information;
- The need to improve community awareness of weed issues across the region to better enable communities and agencies to manage problem weeds;
- The need to better integrate the management of weed issues with other major management activities such as fire and feral animal control; and
- The need to improve our understanding of the impacts of major weed species, particularly grassy weeds on biodiversity, traditional hunting and gathering activities and on local economies, including carbon trading opportunities for remote communities.

Knowledge gaps and some potential ways to progress these issues were also discussed.

9.2 Introduction

Following a series of presentations and discussions, participants at the Kakadu Weeds Symposium undertook workshop activities to identify priority weed issues for the West Arnhem region and the steps required to address these major weed issues. This paper briefly summarises the outcomes of those workshops.

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9.3 Identifying and managing priority weed species

9.3.1 Management issues

- Require clarification of who is responsible for managing weed issues across the region
- Need a robust and strategic approach to prioritising weed management issues/areas based on criteria such as cultural significance, biodiversity value, size and location of infestation.
- The priority weed species identified by workshop participants were: Gamba grass, annual and perennial mission grass, hyptis, stylom, mimosa, guinea grass, calopo, snakeweed, rattlepod, rubber bush and olive hymenachne.
- Need to identify distribution of existing and emergent weed species and avenues for dispersal into Arnhem Land. Some species are not present yet or are present in only small infestations so may still be controllable.
- Identify new areas of disturbance eg gravelpits, irrigation clearing, roads, unofficial tracks, walking tracks etc and look to control any emerging infestations.
- Target areas and issues outside of Kakadu:
  - Marlkawo: Mann River & Bulman (grader and mission grass)
  - Barwananga – Maningrida – mission grass – outstations and roadsides – hunting/ fishing camps (but distribution not exactly known and needs work).
  - Adjamarrl – can't access in wet. No gamba grass found, some grader (2 infestations on tracks) green panic, passion fruit, some mission grass (Marlwon)
  - High Plateau – mission grass need more information.
- Identify new areas of disturbance eg gravelpits, irrigation clearing, roads, unofficial tracks, walking tracks etc and look to control any emerging infestations.

9.3.2 Knowledge gaps

- Need to improve knowledge of current and potential distribution of weeds across the region, and identify avenues/barriers for dispersal and control
- Need to improve understanding of general biology and ecology of priority weed species, including seed bank viability and dispersal, pathways of infestation.
- Investigate and identify optimum methods of control/treatment through experimental trials (including optimal time and conditions for spraying, use of other methods of control including fire/mechanical removal etc, biological control including sterilants and methods to manage seed banks)
- Investigate regeneration of native species after treatment of infestations, including active planting of native species

9.3.3 Moving forward

- Investigate avenues for collaboration between agencies and neighbours for weed management, and formalise these agreements with MOUs or similar documentation
- Continue to compile comprehensive distribution information for all species, including investigating the use of high resolution satellite imagery and on-ground surveys.

- Develop a consistent approach to data acquisition and management and distribution mapping across the region, perhaps using KNP model.

9.4 Resource acquisition and allocation

9.4.1 Management issues

- Resources: obtaining and efficiently allocating the limited resources that are available (including acquiring and managing adequate staff). Need to explore new ways of increasing the resources (staff but also other resources) available: eg partnerships with CDEP, community organisations, other Park users.
- Is the current level of staffing adequate to cope with the existing and potential weed threat. Consider the KNP situation where there are dedicated crews for dealing with grass weeds and mimosa (is this approach working?).

9.4.2 Knowledge gaps

- What level of resourcing is required to effectively tackle weed issues: eg. Is it adequate to have four dedicated rangers fighting grassy weeds in Kakadu? Can this model be used elsewhere?
- Do onground staff, communities etc have access to the resources they require to effectively undertake weed management? No, but what additional resources do they require and how can they get them? Need to identify funding and resourcing opportunities.

9.4.3 Moving forward

- Investigate how different ranger groups can work together and share resources such as helicopter flights along common boundaries, to make management activities more effective.

9.5 Data management and knowledge sharing

9.5.1 Management issues

- Data acquisition and management: need to develop consistent and efficient methods of collecting, storing and accessing data that will overcome issues associated with knowledge and skills loss resulting from staff turnover, institutional reforms etc.
- Regional communication and knowledge sharing: need to develop and maintain relationships between neighbouring land managers to more effectively manage weeds across the landscape and to share skills and information.
- Data acquisition and management: need to develop consistent and efficient methods of collecting, storing and accessing data that will overcome issues associated with knowledge and skills loss resulting from staff turnover, institutional reforms etc.

9.5.2 Knowledge gaps

- Outside of organisations like Kakadu and Weeds Branch the capacity of staff and institutions to manage and utilise data needs to be enhanced (ie improve staff development and access to computing, GPS and other date management equipment).

9.5.3 Moving forward

- Develop a consistent approach to data acquisition and management and distribution mapping across the region, perhaps using KNP model.
- Explore avenues for staff development through exchange between agencies
- Develop comprehensive training for staff and other community groups including species identification, data collection and management, operation of equipment etc

9.6 Community education

9.6.1 Management issues

- Community education: need to provide information to communities and outstations about existing and emerging weed issues and their management.
- Education and management: need to improve hygiene practices of contractors, staff and visitors to Parks, mining leases and other areas.

9.6.2 Knowledge gaps

- Best methods for improving community awareness about weed issues and for changing community behaviours need to be investigated.

9.6.3 Moving forward

- Develop community education strategies suitable for all groups across the west Arnhem region.

9.7 Integrated management of weeds and other issues

9.7.1 Management issues

- Require a more integrated approach to weed management and other landscape scale issues like feral animal control and fire

9.7.2 Knowledge gaps

- Role of feral pigs, horses, buffalo and cattle in dispersal of some priority weeds needs to be better understood.
- How can fire be better utilised in the strategic management of weed species, and how can burning activities be better managed to prevent (or at least not promote) the spread of priority weeds.

9.7.3 Moving forward

- Consider developing comprehensive weed management strategies that take into account fire and feral animal management components (need to consider these factors as potential weed vectors and management tools).
- Investigate avenues for collaboration between agencies and neighbours for weed management, and formalise these agreements with MOUs or similar documentation

9.8 Understanding the impacts and costs of weeds

9.8.1 Management issues

- Changing fire regimes as a result of weed infestations pose a threat to biodiversity and local economy including potential impact on carbon trading funding
- Impact of weeds on biodiversity, bush tucker and traditional hunting activities not known.

9.8.2 Knowledge gaps

- Impact of weeds on traditional hunting and bush tucker not well understood at present
- Need to investigate how weeds impact on the economic and ecological sustainability of communities and their industries, including opportunities like carbon trading, pastoral and tourism ventures.

9.8.3 Moving forward

- Work with Indigenous communities, outstations, ranger groups to improve our understanding of the impacts of weeds on bush tucker and hunting, and also to consider how bush hunting practices may affect weed distribution etc.
- ILC cattle project: hold discussions regarding management and monitoring of movement of stock and associated weed risks in and out of KNP and Arnhem Land. Investigate partnerships between ILC, landholders, ranger groups, NT Weeds Branch and KNP.