Australian Government
Department of Sustainability, Environment, Water, Population and Communities
Supervising Scientist

internal report 568

Kakadu National Park Landscape Symposia Series 2007–2009 Symposium 5: Feral animal management, 3–4 December 2008

Edited by M Jambrecina

October 2010

(Release status – unrestricted)

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Kakadu National Park Landscape Symposia Series 2007–2009

Symposium 5: Feral animal management, 3–4 December 2008

Jabiru Youth Centre, Kakadu National Park

Edited by M Jambrecina

Kakadu National Park, Parks Operations and Tourism Branch, Parks Australia

Supervising Scientist Division

GPO Box 461, Darwin NT 0801

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Registry File SG2009/0283

(Release status – unrestricted)

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How to cite this report:

Jambrecina M (ed) 2010. Kakadu National Park Landscape Symposia Series 2007–2009. Symposium 5: Feral animal management, 3–4 December 2008, Jabiru Community Centre, Kakadu National Park. Internal Report 568, October, Supervising Scientist, Darwin.

Location of final PDF file in SSDX Sharepoint:

Supervising Scientist Division > PublicationWork > Publications and Productions > Internal Reports (IRs) > Nos 500 to 599 > IR568_Kakadu Landscape Symposium – Feral Animal Management.pdf

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The Supervising Scientist is part of the Australian Government Department of Sustainability, Environment, Water, Population and Communities.

Supervising Scientist
Department of Sustainability, Environment, Water, Population and Communities
GPO Box 461, Darwin NT 0801 Australia

Printed and bound in Darwin NT by Supervising Scientist Division

Contents

Acknowledgments

The Feral Animal Management Symposium was made possible due to the efforts of the Natural and Cultural Programs Section of Kakadu National Park including Mim Jambrecina, Steve Winderlich, Trish Flores, Sally-Anne Atkins, Terry Mahney, Meredith Billington and Mary Blyth. Thank you to all the presenters who gave generously of their time and knowledge, and to Ann Webb (Supervising Scientist Division) who prepared the final copy for publication. A very special thank you to Buck Salau (Kakadu National Park), who this year celebrated 24 years managing feral animals and weeds in Kakadu. Buck presented a fantastic after dinner talk on his personal recollections of buffalo management in Kakadu over the years. Finally, thank you to all who attended.

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1 Introduction and overview of the Kakadu Feral Animal Management Symposium and workshops

M Jambrecina[1]

1 Introduction

The Feral Animal Management Symposium is the fifth and final in the series of symposia and workshops held by Kakadu National Park focused on agents of landscape change. Previous symposia have included an overview of landscape change, weed and fire management, and climate change.

The Feral Animal Management Symposium was held at the Jabiru Youth Centre in Kakadu on 3–4 December 2008. The symposium was successful in bringing together researchers, practitioners, managers, planners and land owners involved in making decisions about feral animal management and implementing control programs. Over 80 participants attended from a wide range of stakeholders including government, commercial enterprises, academia, traditional owners, indigenous associations and indigenous ranger groups.

The aims of the symposium were to: share knowledge between all stakeholders; discuss the management implications from research outcomes; identify knowledge gaps in order to better direct research; and investigate opportunities for regional collaboration. Presentations brought participants up to date on the status of pest animals in the region, current control, monitoring and research activities, and future directions.

A workshop was held at the end of each day. The first workshop was an exercise to identify priority areas in Kakadu for the control of feral animals. Using local knowledge, participants mapped areas of high value. The second workshop was an opportunity for participants to reflect on the two days of presentations and discussions, and to identify key points for further discussion, action and research.

Key recommendations from the symposium and outcomes from the workshops are presented below.

1.2 Recommendations from the symposium

1.2.1 Traditional owner perspectives

- Continue discussion, consultation and participatory planning with traditional owners to develop control plans for buffalo, cattle, horses and donkeys. There is broad agreement on the need to control pigs, however, the opinions of traditional owners vary enormously with regard to the management of the species listed above.

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- Demonstrate to traditional owners the impact of feral animals on natural, cultural, social and economic values.
- Monitor the efficacy of control programs to reduce damage and evaluate against agreed performance criteria that have been developed with traditional owners.

1.2.2 Focal resource approach v direct population approach

- Consider the focal-resource approach as an alternative or complimentary method to the direct population approach. The focal-resource approach considers population data to be of secondary importance and gives landscape more direct importance than the pest animal population. The condition and health of landscape resources is the focus.
- Ask how to best utilise available resources for pest animal control to achieve a specified conservation goal, and whether or not it is even necessary to expend resources monitoring and measuring pest animal populations.
- Consider direct population control as a means to temporarily lower feral animal numbers in relatively closed populations, and use the focal resource approach to influence the density-dependant aspects of the animals' ecology, thus reducing the capacity of the populations to grow again. Where populations are not closed direct population control will be limited in use. Use direct population control for eradication programs.
- Accept that control has no end-point. Realistically assess the resources that are likely to be available year after year, decade after decade. Based on the assumption that human and financial resources are finite, what are going to be the priority areas?
- Focus feral animal control activities in areas that are key a resource for the species. This approach can result in long-term reductions in individual animal fitness and reduce the ability of populations to sustain the same numbers across the whole landscape. That is, control activities can have impacts beyond the target area.
- Decide what level of impact is biologically, culturally or aesthetically acceptable and explicitly state what level is considered acceptable. Accept that some level of impact will always be present unless total eradication is possible. Not all landscape elements can be conserved, and even the ones that can will suffer a degree of impact.
- Set highly specific targets for conservation of habitats and/or native species and select appropriate indices of impact and success. Work towards achieving those targets, and not towards feral animal carcass counts.
- Ensure that control sites are chosen where the same indices can be measured. This allows you to infer that your cull effort, rather than some other factor, is leading to improvement.
- Projects and funding should be directed to record improvements in habitat condition as a measure of success, not the numbers of feral animals culled.

Pigs

- Test the hypothesis, using sound experimental design, that wild pigs are predation-sensitive foragers. It may be possible to reduce the damage caused by pigs to localised environmental assets by changing their foraging behaviour through sustained and targeted control activities. Anecdotally, at a range of scales, it appears wild pigs may alter their distribution according to the perceived risks of predation.

- Use the Judas technique to collect significant ecological data on pigs within a management area. This can be achieved by recording observations such as numbers seen, age class (by size) and locations when undertaking tracking, or by taking more detailed age measurements, samples or sex ratios from culled animals. This information can greatly improve the knowledge on the ecology of local pig populations and how they use their environment.
- Consider future co-operative control measures with the Department of Defence. The use of Judas pigs on Defence estate at the Mount Bundy Training Area (ABS Scrofa unpublished data) indicates distinct seasonal movements of pigs along drainage lines between Kakadu and Mount Bundy. .

Ants

- Ensure efficient quarantine processes and reduce the level of disturbance to pristine locations. Invasive ant species are best managed through prevention since other control methods are either not completely effective and/or damaging to the natural environment.
- Eradication of ants should be given priority in conservation areas, especially while species are in the early stages of invasion. The campaign implemented by Kakadu in 2001 to eradicate the African Big-headed ant demonstrates that large-scale eradication is possible from point locations, particularly where there are large distances between settlements.

Cats and black rats

- Establish an integrated research and management program targeting cats and black rats.
- Establish one or more moderately large enclosures that can serve to demonstrate unequivocally the impact of cats in this region, and provide ongoing conservation benefit.
- Undertake an intensive study of some additional native mammal species likely to be affected by cat predation, such as northern brush-tailed phascogale, and an intensive study of cats themselves including their disease status.
- Establish a broad-scale assessment and monitoring program based on sand plots to provide indication of trends in cat numbers and identify key areas that could be specific foci for targeted control.
- Conduct experimental trials to identify the most effective control mechanisms for cats such as the feral cat bait.
- Minimise extensive areas of hot fire.
- Implement a communication program to dissuade people keeping cats in Kakadu.
- Established a study at one site to determine the ecology of black rats in native vegetation.
- Examine the disease status of all known populations of black rats.
- Exterminate known populations of black rats in Kakadu.

Cane toads

- Keep Field and Barron islands toad free. Monitor these island regularly for toads, and eradicate if detected.
- Consider developing a fenced toad-free section of Kakadu that could act as a mainland refuge for quolls as well as several impacted goanna and snake species. Refuges can be

Climate change

The research needed to anticipate changes and devise responses falls into four areas:

- Determine limits to adaptation – the physiological responses of feral animals to changed climates, particularly increased temperature - in order to understand at what point pest animal control is no longer necessary.
- Model the impacts of feral animals under different climate change scenarios. Use these models to help understand where and what impacts control strategies are likely to have on environmental values. Kakadu has some excellent studies of the interaction of feral animals and vegetation structure.
- Sustain on-going monitoring with sufficient sampling and statistical strength to detect change in both vertebrate and invertebrate dynamics, particularly to detect new insects but also to detect changes in local insect dynamics. Management can rarely respond directly to such events, but targeted protection of key species and other values may be possible if detection is sufficiently early.
- Model the impacts of feral animal control on methane production within Kakadu, taking into account reproductive rates and density dependence. This would be essential to develop feral animal reduction as a product on the voluntary carbon market. There also needs to be more detailed analysis of methane production by buffalo which is likely to vary according to forage type and a number of other factors for which data are currently lacking.

Commercial harvesting

- Where appropriate, commercial use may be useful as an initial control method to reduce populations from high density but is unlikely to be an effective long term method.
- Given that any decision regarding the potential effectiveness of commercial harvesting relies on determining the density-damage relationship, a priority topic for future research should be determining the relationship between these pest species and their impacts.

Genetic studies

Consider using genetic studies in conjunction with demographic and life history information to determine the dynamics, population structure, biology and colonization dynamics of invasive plants and animals. These types of studies can (1) establish the rate and most probable history of spread of feral species and (2) quantify the genetic distance and mixing rates between populations. In other words, it can help define populations and sub-populations, and how much movement there is between sub-populations and over what time-frame. This information can help determine if sub-populations of animals can be managed without the need for expensive broad-scale control efforts.

Disease

Train field staff to look out for and report signs and unusual occurrences amongst animals that could indicate a disease. The North Australian Quarantine Strategy (NAQS) is dependent on assistance from rangers and communities. Land management groups are the front line in disease detection.

Collect incidental information on feral animal populations while assisting NAQS with surveillance activities, such as the condition of populations and what they are eating. For example, autopsy of feral pigs can provide information on the types and quantities of native species that feral pigs are consuming. Incidental information like this can show how destructive feral animals such as pigs are to native fauna and flora.

1.3 Workshop outcomes

Workshop 1: Mapping values for values based management

Kakadu recognises the importance of values based management. With limited funds for feral animal control, areas need to be prioritised for management. Mapping areas by their values is one way to do this.

During this exercise participants were asked to circle areas on a 1:100 000 km topographic map using different colours that corresponded to particular values – recreation, tourism, cultural heritage, prime hunting and gathering areas, weed management areas, and sites with high environmental values (threatened species, high biodiversity, unique landscape). They were also asked to write short descriptions of the values for the areas they circled.

This exercise was valuable in demonstrating that certain high value areas of Kakadu are also highly impacted by feral animals. Some of these areas also tend to be where there are conflicting perspectives on how feral animals are managed and whether certain species should be controlled at all. Negotiating over what are acceptable levels of damage, and which values are given priority, presents a major challenge to traditional owners and park management.

Mapping socio-economic, cultural and environmental values helps to identify and describe priority areas. It also provides a process through which participants think about and discuss conflicting values and views on feral animal management.

Figures 1 Workshop participants mapped areas of Kakadu based on their values, to identify priority sites for feral animal control, and to discuss the often conflicting values for areas (photo DEWHA)

Figure 2 Example of a map produced during the workshop (photo DEWHA)

Workshop 2: Reflecting on key messages

The audience were asked to reflect on the main messages that they received during the symposium. The key messages identified by participants were:

Planning

- Need to consider the following types of questions when planning for feral animal control:
  - What is the original purpose of the park?
  - What are the values we want to protect?
  - What do we want the park to look like in 5 years, 10 years and 20 years?
  - What does Kakadu want to do about feral animals? How do we make this happen?
  - What do we need to know more about – small mammal decline?
  - How are we going to address the decline of small mammals?
- Most feral species cannot be eradicated.
- Feral animals have already changed the landscape. The focus of feral animal control should be on maintaining native species.
- Get cat impacts on the radar.
- Integrate pest management.

- Monitor cane toads on islands such as Field Island in the late dry season and focus eradication efforts in these areas. Look at Field Island as a feral animal exclusion zone and develop a contingency plan.
- Use models to encourage a change in thinking and to explore other options.
- Identify specific conservation targets.
- Focus control on specific high value areas.
- Set achievable goals against which to measure progress.
- Continue to identify knowledge gaps and research needs.

Damage

- Identify where the damage is and what it is.
- Get traditional owners back on country to look at the damage. Set up demonstration sites to help show the benefit of control.
- Governments are interested in how much conservation outcome is achieved by a program. Demonstrate changes to the quality of the landscape as a result of feral animal control.
- Measure damage and manage for that rather than the numbers of feral animals.
- Measure damage but relate to population numbers as well.

Funding

- Sustained funding for control is essential.
- Investigate other avenues of funding.

Research and monitoring

- Through research, improve understanding of cascading effects of feral animal control.
- Notify researchers about feral animal control activities. Good information can be gathered from dead animals.
- Capture data during ongoing/everyday management.
- Use data from the BTEC program and from feral animal programs in the 1980s to determine what effort is needed to reduce pest animals in Kakadu to achieve a desired level of impact reduction.

Working together

- Extend knowledge out to other areas, for example, indigenous ranger groups.
- Maintain good communication between neighbours so that control programs can be coordinated where possible.
- Think regionally and create regional partnerships.
- Share information. Establish a group email list with key regional neighbours, including indigenous ranger groups.

2 Kakadu traditional owner and stakeholder views on feral animal management in Kakadu National Park

S Winderlich[1]

2.1 Introduction

The purpose of this paper is to focus symposium participants on what a selection of Kakadu National Park traditional owners think and feel about the management of feral animals. It is hoped that participants will use the information to ensure their responses address the issues raised by traditional owners.

All management actions in Kakadu must be consistent with the relevant legislation and the Kakadu Plan of Management (2007–2014). Hence this paper also summarises the precriptions in the plan relevant to feral animal management. Extensive consultation with traditional owners was undertaken in the development of this plan, hence it reflects the views of a wide cross section of the Park's traditional owners.

This paper also summarises the views of a broad range of stakeholders as expressed at the Landscape Change Symposium (Walden & Nou 2008, IR532) – the first in this series of symposia. These views were not published as part of the proceedings.

2.2 What do the traditional owners say?

2.2.1 Methods

Questionnaires were used as the basis for 'one-on-one' interviews with traditional owners, who were asked to respond to several key questions relating to feral animal management. Fifteen interviews were carried out with traditional owners and other indigenous residents of Kakadu. The interviews were conducted by park staff in November and December 2009. This included the making of a video that was presented at this symposium. The views of traditional owners that participated in the Landscape Change Symposium (the first in this series of symposia) have also been incorporated.

This paper does not attempt to analyse survey responses or to cross reference with other literature or surveys undertaken elsewhere. The results are consistent, however, with the work done by Robinson et al (2006) on feral animal management in a joint management context. There is also no attempt to present any of the results as being truly representative of the broader population of the Kakadu area since the sample size is too small. However, results do outline some key issues and concerns held by traditional owners that are relevant to any discussion on feral animal management in Kakadu. When these views are considered in combination with the information obtained from the Landscape Change Symposium and prescriptions from the plan of management – which involved extensive consultation – a

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representative position can be determined. It should be noted that participants focussed on vertebrate rather than invertebrate feral species.

2.2.2 What do you think about feral animals?

Respondents viewed feral animals as:

- Pests that spread weeds, cause soil erosion, carry disease and cause problems for the country;
- An important food for Bininj, especially pig and buffalo;
- Dangerous to people;
- An economic resource that can be harvested for sale as pet meat;
- Bush pets to some people.

Examples of responses to the questionnaire:

> KNP is a world heritage area and national park and feral animals are feral animals to me.
>
> They carry disease, spread weeds and muck up the country. Buffalo, donkey, pig destroy the country.
>
> Some of the traditional owners grew up before the Park and on station and grew up with these animals so they are like pets to them.
>
> Feral animals are damaging country. Good food. Buffalo are good food, pigs too. Bininj eat feral cattle. Means we don’t have to go to the shop all the time.
>
> If all the pigs are removed what food is there for crocs? Perhaps they would eat all the fish turtles and more dangerous for people.
>
> Get rid of them, destroying country. Cane toad – taking animals that we eat.
>
> Clean out of Kakadu.

2.2.3 Are you worried about the effect feral animals are having on the country?

Almost all participants said they were worried about the impact of feral animals on country. In particular, they were concerned that feral animals: spread weeds; dig up country; eat bush tucker, especially turtle; carry disease; are a danger to road users; and are dangerous to people when wounded (60% of the respondents).

Some respondents were worried about certain animals more than others. Generally, respondents were worried about the damage that feral animals are doing to the country but at the same time they like to have feral animals in the landscape as a food resource.

Examples of responses to the questionnaire:

> Pigs horse dig up country, make it difficult to drive on country – they eat and dig up our bush tucker. Horse leave some kill some. Buffalo and cattle OK because we eat them.
>
> Yes I worry about the damage. No native cats anymore due to cane toads.
>
> Mostly pigs. Not much damage from buffalo.
>
> Yes because they carry disease, spread weeds and muck up the country.
>
> Buffalo, donkey, pig destroy the country.

2.2.4 Have you noticed any changes in the country that are due to feral animals?

All respondents, except one, have noticed changes to country due to feral animals. The main changes mentioned include:

- Floodplain areas dug up, making it hard to drive on.
- Pigs spreading mission grass, eating turtle and yams.
- Goannas gone since the cane toad arrived.
- Saltwater coming into areas more.
- Pigs damaging swamps, billabongs and floodplains.
- Damage to rock art.

Example of responses to the questionnaire:

> Still heaps of ferals. What happens to dead animals – make the country stink, dig hole to dispose of carcass.
>
> I have seen places like Djuwarr coming back after they have been removed. Before buffalo were there for a long time and it was demolished and now is coming back to life.
>
> Goanna have dropped to nothing since cane toad have arrived. Pigs have taken over from where buffalos left off. Pigs digging, eating turtle and yams, rooting up the country.
>
> Saltwater coming up the channel at Red Lily and Horseshoe. It’s always been there but now comes up more.
>
> Not many emus now. Wondering what effect feral animals might have. Maybe pigs eat eggs?
>
> It’s changed a lot especially from pigs. Cats affect birds. Pigs eat turtles.

2.2.5 Which changes (impacts of feral animals) are you most worried about?

- Make it hard to drive on country & get to places for hunting and fishing.
- Make it hard to find bush tucker.
- Salt water intrusion.
- Spread of weeds.
- Loss of native animals, bush tucker animals especially.

A sample of responses to the questionnaire:

> Cattle, horses and buffalo trample country and step on turtles and ground nesting birds (plovers).
>
> Salt water intrusion – no goose or turtles.
>
> Worry about all those changes and impacts. Changes come and go. Might look okay sometimes but other times looks bad. Need to get rid of all the feral animals
>
> Pigs and buffalos. Buffalo make big swim channels and cause erosion. Can be said for horses and cattle as well. They also carry around a lot of weeds.
>
> Cats are also a problem, kill birds and small animals. People used to have a lot of cats but no one has them anymore. I don’t see many cats.
>
> Cane toads now hardly see any snakes, goannas, pythons, freshwater crocodiles.

2.2.6 What areas of the park are you most worried about?

Responses included:

- Wetlands, especially Yellow Water, Mamukala, Kapalga and Magela.
- Hunting and fishing areas.
- Rock art and burial sites.
- Walking tracks and tourist areas. Some visitors have been chased on walking tracks and in tourist areas.
- The whole Park.

2.2.7 What feral animals (which species) are you most worried about?

Respondents were most worried about pigs. Most respondents also listed buffalo and cane toads. Some respondents were worried about cats, donkeys and horses and some were worried about all feral animals.

Example of responses to the questionnaire:

> Buffalo and pig are the ones I worry about most because they can do the most damage because they like the water rivers and billabongs and make a mess of these places.
>
> Pigs are the worst ones. Cane toad no good. Buffalo are OK. They have been here for many years. Cats are no trouble. Only look for food for themselves. Donkeys are alright

2.2.8 What do you think should be done about feral animals?

Responses included:

- Numbers need to be controlled but through proper consultation that is not rushed.
- Get rid of feral animals from the park but keep some in a fenced area for food supply.
- Shoot, trap and muster feral animals to sell.
- Keep some for pets.
- Get rid of as many feral animals as possible.

Example of responses to the questionnaire:

> Need to keep numbers down. Need to do full consultation right from the start. Clear consultation needs to be followed. Need to let people know early. Not rushed consultation.
>
> Need to sort out things before any action happens. Make sure talking to the right people so people don’t get blamed.
>
> Should get rid of them. Some can be fenced in for meat for community but they shouldn’t be roaming all over the country.
>
> Shoot some of the pigs and buffalo’s but leave enough for meat for Bininj. The Buffalo Farm is a good idea. Keep those ones to eat and shoot ones outside but leave some for hunting. Need to be able to get fresh meat when out camping and walking around.
>
> Shoot pigs – market sell, mustering cattle, create futures.
>
> More shooting mainly pig. Should have got rid of (feral) animals a long time ago.

2.2.9 Is there anything you think we need to find out that might help look after the country from the effects of feral animals eg, any research gaps?

Responses included:

- Parks needs to implement a feral program.
- Find ways to stop cane toads and pigs breeding.
- Need to provide more information to traditional owners on the impact of feral animals on country.
- Need to know if they've got a disease. Need to keep a check on them for TB (tuberculosis). Show Bininj how to check for disease in pigs and buffalo. Is there TB in the pigs?
- Test water to make sure it is healthy. See if ferals are contaminating the water.
- What is the effect of climate change on shelter and food for ferals and how this will affect numbers and distribution.
- Get out on the country with the people who live there.
- More staff to help.

2.2.10 Any other comments?

Additional comments that were made include:

> What is the relationship between Ngalyod and these introduced animals? Maybe she protects them? Maybe she gets upset if they rub off rock art. If they dig up the floodplain it comes under her. If animals come under one creator (Ngalyod) then can't call them pests but introduced is okay.
>
> Bullock are important to Bininj for meat. Buffalo as well. These animals provide cheap meat so we don't have to go to the shop all the time.
>
> Give buffalo meat to the community. .
>
> I would like to see every pig shot out. The feral animal control should be ongoing. Rangers should be looking out for feral animals and should shoot them when they see them.

2.3 What do our colleagues, neighbours, stakeholders say?[2]

2.3.1 Current knowledge/priorities

- Key restriction: district basis to feral animal management-need for more centralised, strategic approach according to traditional owners.
- Need to know more about disease (more of a potential problem).
- Density reduction/maintaining cultural resource. What is the target for density reduction and what are the methods that can be used to measure biodiversity impacts? (eg exclosures).
- Scale of damage on park-wide basis (seasonal influence-eg pigs after wet season).

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[2] Taken from the Landscape Change Symposium, April 2007 – IR532

2.3.2 Knowledge gaps

- Knowledge gaps on diet, fecundity, survival rates, movement, fundamental biology. Need to address these gaps in order to manage feral animals.
- What level of control needs to be achieved to keep damage to acceptable levels?
- What are environmentally, socially or culturally acceptable levels of feral damage?
- Need for ongoing surveys/long term data sets-(rationale needed for funding).

2.3.3 Biodiversity indicators of damage

- *Eleocharis* bulbs (water chestnut sedge), invertebrates in soil, rate of bioaccumulation of leaf litter, rate of turnover in soil, soil disturbance.
- Loss of bush tucker eg yams, turtles (predated on by pigs)-index measures but differ according to habitat.
- What is the role of adaptive measurement?
- Need appropriate reference points.
- Should value add and make use of existing monitoring work (eg use fire plots).

2.3.4 Bininj perspective

- Ongoing funding is an issue.
- Feral animals bringing in disease a big concern.
- Need to balance between cultural values of animals and environmental impact.
- Feral animals are an important food resource.
- Pigs-impact on other bush tucker resources (eg yams).
- Employment opportunities for Bininj in addressing knowledge gaps and density reduction measures. People on country managing populations that have been reduced to a manageable level.

2.3.5 Key threatening species and processes and future threats

- Disease –may override cultural considerations if the threat poses a significant danger to national interests.
- Weeds-feral animals as vectors.
- Pig damage.
- Threats to World Heritage and Ramsar wetland values.

2.3.6 Comments on specific species

Buffalo

- Big game valued as a food resource. Disease is a concern. AQIS randomly checks for disease in KNP and Arnhem Land.
- Need different management strategies for different areas?

Cane toads

- Do we make this a priority?
- Island Ark program (Bininj raised concern about competition with other fauna in the unique island ecosystems).
- Impact of toads on stone country aquatic endemics.
- Need better PR- publicise research findings, increase community awareness.

Cats-knowledge gaps and issues

- Australia-wide problem, can we start trapping programs in KNP?
- They are sneaky, smart, elusive.
- Some Bininj have an affinity for cats.
- Cat population trends.
- Document predation rates in sensitive areas.
- No single factor responsible for small mammal decline-several factors responsible. A few cats are all that is needed to tip the balance on threatened species.
- Need to record any incidental sightings or trapping of cats?

2.3.7 Climate change

- Feral species interactions as a result of climate change
- Is there potential improvement in pig habitat due to climate change? Focus on tidal interface.
- Additive effects/synergies.

2.8 Wish list

- Need to find out more about the relationship between density and damage.
- Promote a regional approach (KNP-West Arnhem) to feral management.

2.4 What does the Kakadu National Park Management Plan say about feral animal management?

Management actions in Kakadu need to be consistent with the *EPBC Act 99* and the Plan of Management (Director of Parks 2007). Discussion and actions relating to Feral Animals are found in section 5.12 of the current plan. The contents of this section are summarised below. Some of the sections of the plan considered less relevant to discussions at this symposium have been omitted.

Section 5.12 Feral and domestic animals

Our aim

> Through control programs developed and implemented in consultation with Bininj, the adverse effects of domestic and feral animals on the natural and cultural values of the Park, and on human safety, are minimised.

Background

Feral animals can damage the cultural and natural values of country. They may impact on access, aesthetics and available food resources, and cause erosion, salt water intrusion, and the spread of weeds. Asian water buffalo, cattle, pigs, horses, donkeys, dogs, cats, European bees, cane toads and introduced ants are present in Kakadu. There are also risks that new species, such as crazy ants, will invade.

Issues

- To ensure that effective control programs are in place, there is a need for a strategic integrated regional approach. Control programs need to consider:
  - **how the priority of protecting the parks natural and cultural values can be achieved while respecting the range of values that Bininj place on some introduced animals.**
  - **the range of habitats, differing sensitivities to disturbance, susceptibility to weed invasion, and feral animal populations within adjoining country.**
  - what levels of damage to country caused by feral animals are seen as unacceptable to Bininj and Park staff.
  - analysis and implementation of each control operation in close consultation with Bininj from the different clan estates.
- Some Bininj seek active involvement in conducting control programs and pursuing potential commercial and employment opportunities either jointly with the Park or independently through contracts between the Park and local Aboriginal associations.
- Preventing introductions of species that have the potential to establish unmanaged populations is the most important option available for reducing risk of additional damage caused by feral animals. At the time of writing this Plan, species that have the potential to enter the Park include banteng, sambar deer and crazy ants.
- Rules regarding restrictions on what animals may be brought into the Park are not always followed, either intentionally or accidentally through lack of knowledge. Some introduced fish and bird species could become pests or transmit disease to wild populations.
- The risks of some captive animals being released may increase when the population of Jabiru declines.
- Control programs must be conducted safely, effectively and with regard to animal welfare. There is a need to ensure that individuals undertaking control operations are appropriately trained and licensed.
- It is important to provide residents with good information prior to their arrival in the Park about the potential impacts of introduced animals on Park values.
- Programs for individual species need to be well designed to ensure that important values are protected and damage caused by individual species is reduced. Program effectiveness needs to be measured by the protection of values, not numbers of feral animals controlled.
- Pigs, buffalo, horses, cane toads and big-headed ants are regarded as the greatest threats to Park values by both Bininj and Park managers.
- Presently absent from the Park but important potential threats already established or present in the Top End include yellow crazy ants, mosquito fish and other aquarium fish. Invertebrates and smaller vertebrates, including fish, probably present the greatest mid-term threats that the Park needs to be prepared to control.

Issues for individual species

- ***Buffalo and cattle*****:** Buffalo and cattle are abundant in neighbouring Arnhem Land and pastoral properties, and their numbers are increasing within the Park. Given the costs of culling, the Director may need to investigate cost recovery mechanisms through commercial activities. The future management of the Buffalo Farm needs to be considered. Some Bininj

- ***Pigs:*** Pigs cause noticeable widespread impacts around springs, floodplains and small rainforest patches. Bininj are concerned about the decline in the numbers of turtles and yams that may be related to the presence of pigs. The spread of weeds such as mimosa and olive hymenachne by pigs through foraging activities is of major concern. Pigs breed rapidly, so populations can quickly re-establish following control.
- ***Horses and donkeys:*** Horses and donkeys cause erosion around water bodies, carry disease, and aid the spread of weeds such as mission grass, gamba grass and rattlepod. Horses near roads are a public safety issue. Information is required on seasonal distribution and survey techniques to help develop more effective targeted control programs.
- ***Cane toads:*** Cane toads arrived in the southern regions of Kakadu in 2001 and populations are now well established throughout the Park. Cane toads have serious impacts on some wildlife populations. Toads eat a variety of invertebrate and vertebrate native animals (which not only impact on prey species but also reduces food resources for other native animals), and they have toxic defences that can result in the deaths of animals that eat toads. These impacts also affect the availability of some bush foods for Bininj. Following the arrival of toads in the Park, there has been a notable decline in the numbers of quolls and goannas. Large dragons, elapid snakes and other species are also likely to be affected.
- ***Introduced ants***: Introduced ants are capable of displacing other invertebrates such as green ants, therefore altering food availability for native animals. Introduced ants currently found in the Park include the ginger ant, pharaohs ant, Singapore ant, ghost ant and big-headed ant. Major costs have been associated with the control of big-headed ants in Kakadu since 2001. The possible introduction of the crazy ant is of major concern. Staff and residents need to be well equipped to quickly and reliably recognise introduced ant species.
- ***Cats and dogs:*** There is a lack of information about the impacts and population of cats. However, cats are believed to prey on animals within all habitat types. Cats are also vectors of human and animal disease. To date, no effective cat control program has been developed. Feral dogs interbreed with dingoes, and in some locations hybrid dingoes may come to dominate dingo populations and place increased pressure on native wildlife within the Park. Dogs that are not looked after may pose health risks in Jabiru and in Aboriginal living areas.
- ***Exotic aquatic animals:*** The introduction of exotic aquatic animals and aquarium plants into waterways within the Park would pose significant ecological risks. In addition exotic marine animals, such as the Black Stripped Mussel could pose significant threats to the coastal and estuary areas of the Park.
- ***Exotic birds:*** Residents and visitors are not allowed to bring in pet birds, as they may introduce diseases and some species may become pests. Eradication of exotic birds is difficult if large populations become established over significant areas. Species accidentally introduced into Darwin, such as tree sparrows and spice finches, could become a problem in Kakadu if they become established on the Territory mainland.
- ***European bees***: European bees may adversely affect native insects and compete with native animals for nectar, pollen and tree hollows. Research is required to determine the abundance and level of impacts of European bees on wildlife within the Park. Control by Park staff does not presently extend beyond Park infrastructure and tourist areas.
- ***Biological control agents***: The Cyrtobagous weevil was introduced into the Park in 1983 to aid with salvinia control. The side leaf-feeding beetle (*Calligrapha pantherina)* is also present in the Park. No adverse ecological impacts of these agents have been reported. Research is currently under way into the development of a biological control agent for cane toads. Some

What we are going to do?

Policies

5.12.1 Recommendations from the Feral Animal Management Strategy for the Park will be implemented after public comments have been sought and following Board approval. Decision support tools will be used to help Park staff and Bininj to make joint decisions using current information about costs, reducing damage, generating income, monitoring populations over time and acknowledging the interest of some individuals in small populations being maintained.

5.12.2 Protocols for ensuring that animal welfare standards are met will be rigorously observed.

5.12.3 The Director will implement controls for the entry and movement within the Park of soils, pot plants, logs and other materials with a high potential for spreading feral animals and diseases.

5.12.4 The entry of dogs to the Park with visitors will be restricted to guide dogs for the vision and hearing impaired, or an assistance animal used by a person with a disability. Permits to bring dogs in for other purposes will only be considered in exceptional circumstances.

5.12.5 Park staff, and residents within lease areas may keep no more than two dogs per household without a permit issued by the Director. Cats or pet birds are not permitted to be kept, but exceptions may be made with the Director's approval for local, native birds that cannot be rehabilitated to the wild.

5.12.6 Park staff, Jabiru residents and residents within lease areas will only be permitted to keep fish native to the Magela Creek system in aquariums and permits may be issued to collect specimens for this purpose.

5.12.7 The Director may provide training in control techniques to enable Bininj not employed by the Park to obtain required licences.

5.12.8 Park staff will work with neighbours and cooperate with relevant Northern Territory authorities to develop regional approaches for feral animal management.

5.12.9 Opportunistic control will be undertaken for cats and dogs. Feral dogs and European bees will be actively controlled where they present particular health and safety risks to people or otherwise cause a significant nuisance.

5.12.10 Future proposals regarding the introduction of biological control agents will only be approved subject to rigorous research. This will help to ensure that the chance of any potential negative impacts on Park values caused by their introduction is minimised.

5.12.11 Non-native animals may be brought into or taken through the Park in accordance with a permit issued by the Director and where it is consistent with policies and actions in this Plan.

5.12.12 Managed herds may only be kept at the existing Buffalo Farm.

Actions

5.12.13 Develop and implement feral animal plans for districts which include identification by Park staff and Bininj of:

- the values to be protected
- sites suffering damage and hence requiring control programs
- methods to be adopted
- processes to measure and report on effectiveness of actions.

5.12.14 Develop decision support tools to assist in implementation of feral animal plans.

5.12.15 Develop contingency plans for managing introductions of particularly high risk feral animal species.

5.12.16 Cooperate with relevant agencies in pursuing a collaborative approach to the management and control of cane toads.

5.12.17 Provide regular reports to the Board that include information on Bininj participation, assessment of outcomes achieved and lessons learnt.

5.12.18 Park staff will work with Bininj to investigate the ecological, operational and safety issues associated with business and tourism proposals that involve the harvest of feral animals.

5.12.19 Review the future of the Buffalo Farm and prepare a rehabilitation strategy.

5.12.20 Work with landowners in Arnhem Land and on the western boundary and cooperate with relevant Northern Territory authorities to develop regional approaches for feral animal management and to help minimise cross border movement.

5.12.21 Liaise with the Jabiru Health Clinic to develop appropriate management programs for dogs kept in Jabiru and Aboriginal living areas.

5.12.22 Maintain awareness about national research into the development of biological and other control methods, and seek involvement with relevant decision-making committees regarding the introduction and keeping of exotic species in the Top End. Develop contingency plans as needed for particularly high-risk species.

5.12.23 Continue to monitor populations of Cyrtobagous weevil within Salvinia infested localities.

5.12.24 Work with relevant regional authorities to prepare public education programs. Prepare and distribute information about the recognition of feral animals, their known impacts and preferred management actions. Review the information annually.

5.12.25 Prepare and distribute an information kit to all Park residents, businesses, relevant tourism associations, freight companies and contractors to inform them of relevant EPBC Regulations and Management Plan requirements regarding the entry of plant, animal and soil material into the Park.

2.5 Conclusion

This paper illustrates that there is universal concern among traditional owners and other stakeholders about the impact of feral animals on Kakadu, especially on bush tucker. Traditional owners want feral animals controlled to acceptable densities, however, there are also competing values placed on feral animals. While some respondents argued for total eradication, others valued feral animals as a food resource or as a potential source of income.

While the need to control feral animals is generally agreed, the target species, method and extent of control is keenly debated. Most people agree on the need to control pigs. In contrast, the views on other species such as buffalo, cattle, horses and donkeys are diverse.

A clear message from traditional owners in particular, is that there needs to be proper consultation prior to a control operation and this should not be rushed. It is clear that there is no ‘one size fits all’ approach to this complex issue. The approach to this issue must be dynamic and flexible in order to address the compounding landscape-scale challenges. These include the risks from weeds, fire, climate change, and their influence on feral animal management in Kakadu.

The park needs to continue its emphasis on working with neighbours and conducting targeted research and monitoring. In particular, Kakadu must be able to demonstrate to traditional owners and other stakeholders the impact feral animals are having on country. In addition, the effectiveness of control programs in reducing damage must be monitored and evaluated against agreed performance criteria or benchmarks.

The current management plan recognises the need to develop and implement feral control programs in consultation with Bininj, to ensure that the adverse effects of domestic and feral animals on the natural and cultural values of the Park, and on human safety, are minimised. The plan of management incorporates many of the concerns expressed by the traditional owners and sets out a framework to work closely with them in planning and implementing feral animal management programs.

2.6 Acknowledgments

Thank you to Kakadu staff especially Sally-Anne Atkins, Terry Mahney and Mary Blythe for conducting interviews with traditional owners. I thank Dr Peter Bayliss for reviewing this paper. Thanks also to the traditional owners of Kakadu for participating in the surveys.

2.7 References

Director of National Parks 2007. Kakadu National Park Plan of Management Plan 2007–2014. Australian Government.

Robinson CJ, Smyth D & Whitehead P 2006. *Managing for country. Decision-making guidelines for joint management of feral animals in Kakadu National Park. Report to the Board of Management for Kakadu National Park*, Department of Environment and Heritage, Jabiru, NT.

Walden D & Nou S (eds) 2008. Kakadu National Park Landscape Symposia Series 2007–2009. Symposium 1: Landscape Change Overview, 17–18 April 2007, South Alligator Inn, Kakadu National Park. Internal Report 532, April, Supervising Scientist, Darwin. Unpublished paper.

3 Feral animals in the Northern Territory: impacts, current programs and future management

A Walters[1]

3.1 Introduction

Feral animal populations are regarded, together with fire and weeds, as one of the main threats to biodiversity within the Northern Territory. In order to preserve the integrity of ecosystems and ecological processes, it is necessary to control the number of feral animals wherever possible.

Throughout Australia, many large vertebrate pest animals have had significant negative impacts on social, economic and environmental values. Impacts may include, but are not limited to, the following:

- Declines in the abundance and diversity of native plant communities due to trampling and ingestion of seedlings.
- Increased soil erosion and sedimentation of natural waterways and water bodies as a result of trampling.
- Competition with native species for feed and habitat.
- Consumption of seedlings and plant materials, reducing the capacity for the ecosystem to regenerate.
- Increased spread and establishment of weeds.
- Decreased abundances and diversity of aquatic and terrestrial invertebrates.
- Decreased agricultural productivity by reducing the availability of feed for stock.
- Damage to fences and other infrastructure, including sacred sites or sites with significant cultural value.

3.2 Impacts and management

3.2.1 Camels

Within the Northern Territory, feral camels occur over an area of approximately 55,0000 km^2 or around 40% of the land area. Although commonly associated with sandy country, camels can be found in any of the habitat types in the southern half of the Northern Territory.

Camels are generally classed as a browsing animal because it has an upper lip which is designed to grip and strip leaves and a long tongue to assist. Camels also graze, which means that they are capable of eating most of the plant species available.

Feral camels are known to foul waterholes and damage stock fences and infrastructure at cattle watering points.

[1] NT Department of Natural Resources, Environment, The Arts and Sport, PO Box 496, Palmerston NT 0831

Currently, camel management in the Northern Territory is limited to the live muster and aerial culling of wild populations. While this off-take is not enough to curtail population growth, it may reduce some of the pressure on the environment caused by wild camels. In remote areas, where it is not economically feasible to harvest camels, the only option available for reducing camel numbers and impacts is aerial culling.

3.2.2 Buffalo

Buffalo occur in floodplain, woodland and sandstone escarpment habitats in areas where surface water is available (Tulloch 1969 & 1970). Although the range of buffaloes in the NT is restricted mainly to areas that receive greater than 1000 mm of rainfall annually (Corbett 1998), their population distribution appears to be increasing.

The most obvious signs of buffalo damage are disturbance of soils and vegetation owing to overgrazing and wallowing in mud. Buffaloes have also been implicated in the spread of weeds, particularly *Mimosa pigra* on floodplain habitats. Buffalo activity may also affect the quality of water (Fogarty 1982, Skeat et al 1996).

Management is primarily undertaken through aerial and on-ground culling.

3.2.3 Donkeys and horses

It is estimated that there are hundreds of thousands of feral horses in the arid zones of central Australia, Western Australia and the Top End (Olsen 1998). This is largely due to their capacity to tolerate a wide range of environmental conditions. Donkeys are able to produce a foal every year, enabling the population to increase rapidly under favourable conditions.

Feral donkeys and horses pose a significant threat to the natural environment. They have been associated with increased erosion of soil, spread of weeds, trampling of native vegetation, consumption of native seedlings, sedimentation of waterways and waterbodies, destruction of infrastructure, and competition with native species and domestic cattle for resources (Dobbie et al 1993, Olsen 1998).

Two of the most common and effective management techniques are aerial and on-ground culling (Dobbie et al 2003, Olsen 1998).

The NT Government is working with local Landcare groups, indigenous groups, pastoralists and industry to conduct feral horse and donkey management in the Victoria River District. This program seeks to reduce feral animal densities by 60% and has currently removed 15,000 animals on five properties. This program has also focused on improving community awareness of the impacts of large feral animals.

3.2.4 Pigs

Today it is estimated that there are between 13 and 23 million feral pigs spread across approximately half of the continent (Victoria, New South Wales, Queensland and northern Australia) (Hampton et al 2006).

The rooting behaviour of pigs seriously disrupts the seed bank, disturbs surface vegetation, alters soil composition, increases the growth of weeds, disperses the seeds of exotic plants, and destroys habitat utilised by native species (Choquenot et al 1996). In addition, pigs are omnivorous, meaning that they eat a wide and varied diet including small animals and invertebrates (Choquenot et al 1996). Pigs also foul waterways (Choquenot et al 1996).

There are a number of management strategies that may be implemented to control feral pigs, including baited trapping, aerial culling and poisoning.

3.2.5 Wild dogs

Populations of feral domestic dogs and dingo/domestic dog hybrids are common throughout the Northern Territory. They are known predators of livestock and they can cause significant economic losses to pastoral production (Fleming et al 2001). Wild dogs may also be a menace to tourists and staff at remote tourist resorts and national parks. Of particular concern is the loss of the genetic integrity of dingo populations as a result of hybridisation with wild and domestic dogs (Fleming et al 2001).

Current baiting procedure includes using non-refined fresh meat baits injected with 1080 poison, trapping, exclusion fencing and shooting.

3.2.6 Cats

Feral cats live independently of humans and are found in all habitats ranging from rainforest to desert throughout the Northern Territory (Dickman 1996). Expansion of their distribution in arid regions has been facilitated by their ability to obtain most of their moisture requirements from the live prey they consume (Dickman 1996). Feral cats feed on a wide variety of native animals, including invertebrates, reptiles, birds and mammals, and they may consume animals up to their own body mass in size (Dickman 1996).

Feral cats are secretive, cryptic, largely nocturnal and hard to catch which makes management difficult. Although they are susceptible to 1080 poison, feral cats do not readily accept baits unless they are nutritionally stressed. This makes broad-scale control difficult to achieve under most circumstances (Dickman 1996).

The NT Government is undertaking research into the impacts of cats on islands in the Gulf District, with specific emphasis on educating and training the local Indigenous Ranger group to ensure on-going management of cats on these islands in the future.

3.2.7 Cane toads

Cane toads can exist in many different habitats but must have water available to breed. During the dry season, toads remain inactive in shallow burrows under the ground or in clusters under logs, rocks or sheets of iron, etc.

Cane toads have a suite of characteristics that increase their invasion success, including: nocturnal activity; an ability to survive in sea water; and prolific reproduction rates. They can breed twice a year and lay 10 000 to 20 000 eggs each cycle. The main threat to native animals is through poisoning, and even the tadpoles are poisonous.

The NT Government currently provides financial support to Frogwatch to undertake community activities and education relating to cane toads.

3.2.8 Black rats

The black rat is native to Asia, but has become common in many areas throughout Australia (Caughley et al 1998), including many locations in the Northern Territory. This species prefers warmer habitats. It has been a highly successful invader because of its very wide diet and rapid reproduction (Caughley et al 1998). Female rats will give birth to between 5 to 10 young and may have up to six litters per year. Rats are omnivorous, meaning that they will eat many different types of foods, including fresh and dry fruits, seeds, leaves, bark, insects, slugs and snails, bird's eggs, young birds, and lizards (Clelland 2002, Garcia et al 2002, Morris 2002). In urban areas, black rats will also scavenge on scraps of foods, commercial and pet foods and any other bits and pieces that may be left lying around (Caughley et al 1998).

Of particular concern is that Black rats have moved into areas of high biodiversity value, where they will prey on the eggs of birds and reptiles as well as consuming large numbers of invertebrates (Major 1991).

Currently, the NT Government is undertaking research to identify the impacts of Black Rats on specific threatened species.

3.2.9 Exotic ants

Exotic ants are a major problem worldwide because they compete with native ants for food and habitat, and prey on other native invertebrates and vertebrates (Holway et al 2002). In addition, exotic ants may affect the plant community because they do not disperse the seeds of native plants (Christian 2001).

A number of exotic ants have become established in the Northern Territory, including the yellow crazy ant (*Anoplolepis longipes*), big-headed ant (*Pheidole megacephala*), and ginger ants (*Soleopsis geminata*) – (Hoffmann & O'Connor 2004, Andersen et al 2004).

3.3 Future management programs

Feral animals are a common problem, and for this reason it is important that we work together to achieve our biodiversity and conservation goals. It is necessary that future feral animal management programs are large-scale, long-term programs that include consultation and involvement with a wide-range of stakeholders. Successful feral animal management programs in the future must aim to manage feral across a range of tenures, rather than focusing at the property level as has occurred in the past. Moreover, since the scale of this issue is so extensive and the financial requirements so great, the NT Government intends to promote the identification significant sites for management, rather than aiming to manage all feral animals across the entire NT.

3.4 References

Andersen AN, Woinarski JCZ & Hoffmann BD 2004. Biogeography of the ant fauna of the Tiwi Islands, in northern Australia's monsoonal tropics. *Australian Journal of Zoology* 52, 97–110.

Caughley J, Bomford M, Parker B, Sinclair R, Griffiths J & Kelly D 1998. *Managing vertebrate pests: Rodents*, Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Choquenot D, McIlroy J & Korn T 1996. *Managing vertebrate pests: Feral pigs*. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Christian CE 2001. Consequences of a biological invasion reveal the importance of mutualism for plant communities. *Nature* 413, 635–639.

Clelland P 2002. Eradication of pacific rats (*Rattus exulans*) from Whenou Hou Nature Reserve (Codfish Island), Putauhinu and Rarotoka Islands, New Zealand. In *Turning the tide: The eradication of invasive species.* Proceedings of the International Conference on

Eradication of Island Invasives, eds Veitch C & Clout M, Occasional Paper of the IUCN Species Survival Commission 27, 173–181.

Corbett L 1998. Fauna responses to feral swamp buffalo and fire in Kakadu National Park: implications for environmental management at the Ranger Mine. In *Fauna habitat reconstruction after mining: Workshop proceedings*, eds Asher CJ & Bell LC, 10–11 October 1997, Adelaide, Australian Centre for Mining Environmental Research, Kenmore Qld, 65–72.

Dobbie WR, Berman DMcK & Braysher ML 1993. *Managing vertebrate pests: Feral horses*. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Fogarty PJ 1982. *A preliminary survey of environmental damage associated with the activity of feral buffalo*. Technical Report 88. Darwin Feral Animals Committee, Conservation Commission of the Northern Territory, Darwin NT.

Fleming P, Corbett L, Harden R & Thomson P 2001. *Managing the impacts of dingoes and other wild dogs*. Bureau of Rural Sciences, Canberra.

Garcia M, Diez C & Alvarez A 2002. The eradication of *Rattus rattus* from Monito Island, West Indies. In *Turning the tide: the eradication of invasive species.* Proceedings of the International Conference on Eradication of Island Invasives. eds Veitch C & Clout M, Occasional Paper of the IUCN Species Survival Commission 27, 116–119.

Holway DA, Lach L, Suarez AV, Tsutsui ND & Case T 2002. The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics* 33,181–233.

Hampton J, Spencer PBS, Elliot AD & Thompson RCA 2006. Prevalence of zoonotic pathogens from feral pigs in major public drinking water catchments in Western Australia. *EcoHealth* 3, 103–108.

Hoffmann BD & O'Connor S 2004. Eradication of two exotic ants from Kakadu National Park. *Ecological Management and Restoration* 5, 98–105.

Major RE 1991. Identification of nest predators by photography, dummy eggs and adhesive tape. *Auk* 108, 190–196.

Morris K 2002. The eradication of the black rat (*Rattus rattus*) on Barrow and adjacent islands off the north-west coast of Western Australia., In *Turning the tide: the eradication of invasive species.* Proceedings of the International Conference on Eradication of Island Invasives. eds Veitch C & Clout M, Occasional Paper of the IUCN Species Survival Commission 27, 219–25.

Olsen P 1998. *Australia's pest animals: New solutions to old problems*. Bureau of Resource Sciences. Kangaroo Press, Hong Kong.

Skeat A, East TJ & Corbett L 1996. Impact of feral water buffalo. In *Landscape and vegetation ecology of the Kakadu Region Northern Australia. eds* Finlayson CM & von Oertzen I, Kluwer, Dordrecht, 155–178.

Tulloch DG 1969. Home range in feral water buffalo, *Bubalus bubalis* Lydekker. *Australian Journal of Zoology* 17, 143–152.

Tulloch DG 1970. Seasonal movements and distribution of the sexes in the water buffalo, *Bubalus bubalis*, in the Northern Territory. *Australian Journal of Zoology* 18, 399–414.

4 Feral animal management in Kakadu: current and future directions

M Jambrecina[5]

4.1 Background

Kakadu is enormous at 20 000 km², and managing feral animals is a costly and continuing task. To help provide direction on the most effective programs for control of ferals in the park a new feral animal management strategy has been developed. To help staff implement feral animal control, the strategy is accompanied by a cross-cultural decision making guideline called 'Managing for Country' and a management strategy evaluation modelling tool called the spatio-temporal reduction model (STAR). As a first step to implement the strategy, a one-off allocation of funds has been made by the Director of National Parks in 2008/09. These funds are to be used to commence large scale feral animal control and surveys to update our understanding of feral animal numbers and distribution, and then to plan and seek subsequent investments to sustain a multi-year control program.

It is expected that a comprehensive feral animal program will be developed over several years. In 2008/09, the focus is on achieving the following outcomes:

- Environmental benefits through reduced feral animal density and associated impacts on park values, and an environment more resilient to climate change.
- Demonstration that the program can be successfully implemented and achieve positive results, leading to a stronger case for ongoing funding.
- Spacio-temporal animal reduction (STAR) model calibrated with local estimates of habitat densities and used to more accurately model optimum control operations, predict outcomes and better estimate the budget required over successive years.
- Improved staff capacity to implement an ongoing survey and culling program.
- Improved regional stakeholder relationships and a cooperative approach to feral animal management leading to more sustainable reductions in feral animal density and impacts.

This paper describes the activities, tools and strategies that comprise the Kakadu Feral Animal Program.

4.2 Kakadu Feral Animal Strategy

The control of feral animal populations is a high priority for Kakadu, however, implementing a feral animal management program in Kakadu is challenging. There are a wide range of views amongst key stakeholders, particularly traditional owners, regarding feral animals. Different groups attribute different values to feral animals, their threats and impacts. Populations are also spread over a large area, in a remote and rugged landscape with many refugia. The key feral species can travel over long distances, are long lived, able to utilise a

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range of habitats, and some such as pigs reproduce rapidly. Furthermore, there are large reservoir populations in the surrounding region. Broad-scale and highly coordinated approaches are needed to reduce density. The cost of control is high and will need to be maintained over a long period of time, and requires long term funding.

The priority species for control in Kakadu are those of greatest concern for which control measures are available. These include pigs (*Sus scrofa*), swamp buffalo (*Bubalus bubalis*), horses (*Equus caballus*), cattle (*Bos taurus*) and donkeys (*Equus asinus*). Of these, pigs are to be controlled as the utmost priority. An action plan will be developed for each target species. The key method for control of the priority species is aerial shooting combined with ground shooting and trapping where possible. Cats, rats, and cane toads are also present in Kakadu, however these are invasive species for which broad scale control measures are currently unavailable. Attention will need to be directed to species not yet detected in Kakadu, but which could pose a threat. Contingency plans will be developed to guide Kakadu's response should an emergency that requires management of feral animals arise.

A successful program in Kakadu requires a regional approach to ensure animals do not recolonise from unmanaged surrounding areas, particularly southern Arnhem Land, the most likely source for invasion of large feral animals. A significant focus on liaison with neighbours is essential. Monitoring and research will focus on describing and measuring the impact feral animals have on a range of park values and quantifying the relationship between animal density and level of impact. This information would enable Kakadu to set more accurate target goals to achieve a desired level of impact reduction.

Further information can be found in 'Feral Animals in Kakadu National Park: A Management Strategy for the Future' (Field et al 2006).

4.3 'Managing for Country' decision making guidelines

The Kakadu Feral Animal Strategy is based on an adaptive management approach using a seven step community-based decision-making model (Figures 1 & 2). The model is used to make decisions jointly with full knowledge of all participants. The model is designed to be used most when there is likely to be disagreement over the level of reduction, areas to be controlled or methods used. It must not be over-used. Where there is agreement about a particular species, consultation is not repeated unless there are changes to the ongoing routine such as an increase off-take. Where there is a failure to resolve a conflict after this process has been fully implemented, the Director negotiates between relevant parties. The criteria for which Kakadu was established as a World Heritage Area are used to assist in making a final decision.

Further information can be found in 'Managing for Country: Decision-making Guidelines for Joint Management of Feral Animals in Kakadu National Park' (Robinson et al 2006).

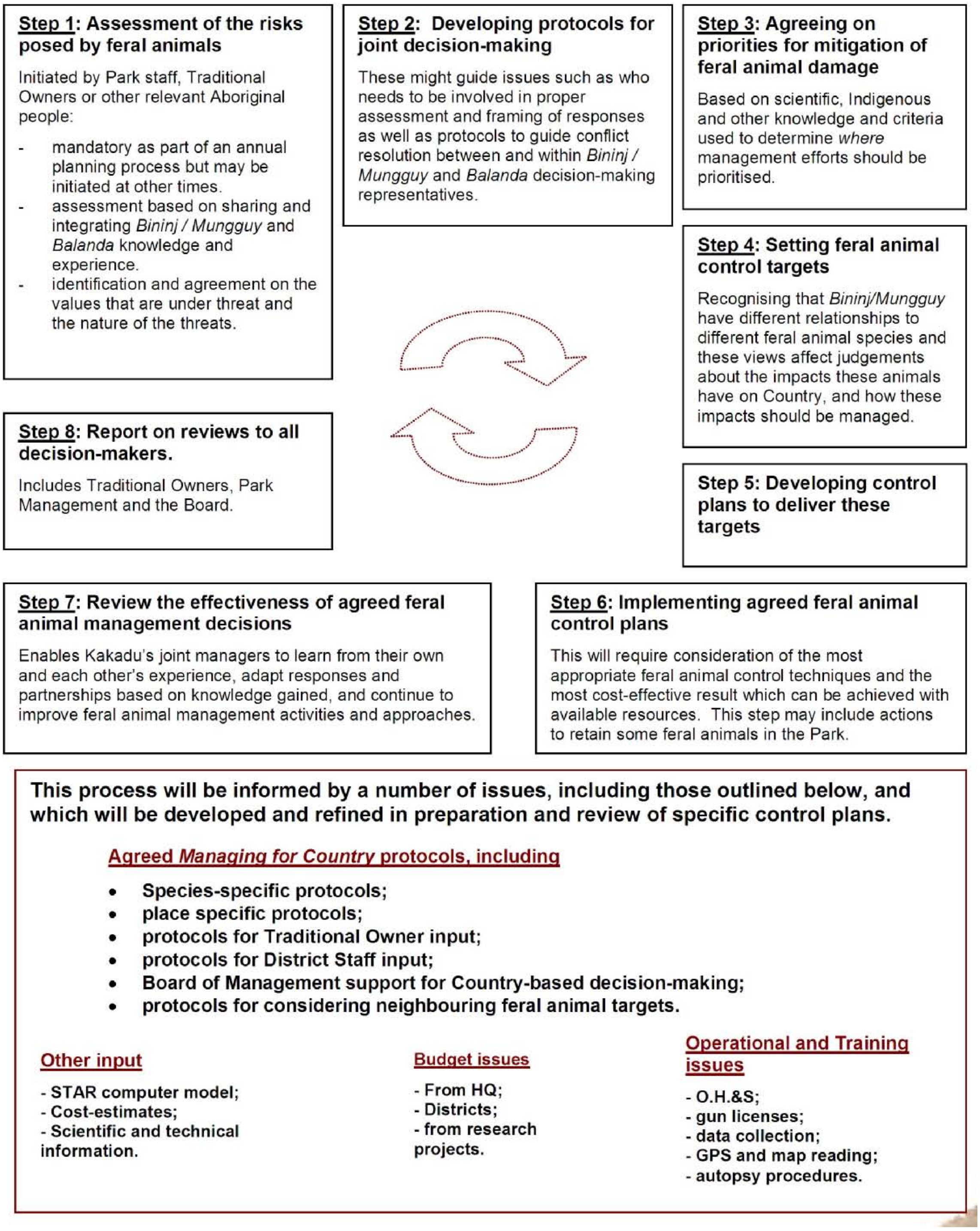

Figure 1 Overview of Country-based feral animal planning and management. Taken from 'Managing for Country: Decision-making guidelines for Joint Management of Feral Animals in Kakadu National Park' (Robinson et al 2006).

Agreed control target for damage mitigation

Checklist
☺ *Target is explicit about where and when they control efforts will be achieved*
☺ *Target is based on joint assessment* of social, economic and environmental impacts feral animals have on target area that utilises the decision-support systems available (including the STAR model)/
☺ *Target has been identified as a priority for the conservation of values recognised by joint managers/*

Who is involved in achieving targets, what are their responsibilities

Checklist
☺ *Representatives have been chosen to guide input into decision-making.*
☺ *A schedule and processes for input (meetings, visits to country, involvement of HQ, etc) has been negotiated/*
☺ *Protocols have been agreed to guide engagement between decision-makers (including conflict resolution).*

Control method(s) chosen

Checklist
☺ *Cost-benefit analysis into the range of control options available has been considered (including commercial use options of feral animals). Numerous methods available ranging in scale and complexity might be considered. All need to be based on appropriate data using decision-support systems available.*
☺ *Training and employment* opportunities for *Traditional Owners and other relevant Aboriginal people have been considered.*
☺ *Control methods meet high standards in animal welfare and minimise direct or indirect impacts on other Park values.*

Resources required

Checklist
☺ *Budget outlining costs (including time and $) involved for preparing control plan, delivering control operation, training / information sharing required, and reviewing performance of control operation.*
☺ *Inputs into planning process* – *e.g. scientific or technical information, workshop facilitator, equipment needed, etc.*

Monitoring and evaluation of targets

Checklist
☺ *Indicators developed to monitor changes to target area and performance of joint management responses.*
☺ *Schedule and process to review progress and / or appropriateness of control target.*
Questions to consider might include: How well were targets achieved? How well were operational issues managed? Were the targets the right ones? Were the methods chosen the best ones? Should this assessment be done by external party and / or a process of self-assessment?

Figure 2 A checklist to guide the development of control plans under the Managing for Country process. Taken from 'Managing for Country: Decision-making guidelines for Joint Management of Feral Animals in Kakadu National Park' (Robinson et al 2006).

4.4 Spatio-Temporal Animal Reduction model

The Spatio-Temporal Animal Reduction (STAR) model can assist managers to plan feral animal culling strategies. STAR is a density dependent model for horses, pigs and water buffalo. It enables staff to forecast the effects and costs of proposed control plans, to compare management scenarios and optimise management plans. STAR is an MS Excel™ based program that represents Kakadu by a 10 x 10 km cell grid as an approximation of the real world, including a 10 km buffer outside the Park. Each cell is interdependent on its neighbours. STAR takes into account:

- carrying capacity of four main habitats (Floodplain, Paperbark, Woodland, Savannah Woodland and Forest);
- density dependent population dynamics (recruitment, dispersal, human-induced mortality, habitat configuration, availability and change);
- damage and management vexation (areas where certain species will not be controlled for socio-political reasons);
- biological priorities;
- economics (the cost of control, whether commercial benefits can be derived to offset the cost of control eg pet meat production);
- spatial regions for control (target areas set by the user or the entire landscape);
- time-frame for control (single treatment, sustained or sporadic).

STAR will calculate the total number of animals present at the start of a control program, the number remaining after control has occurred, and the final spatial configuration of the population in the Park.

STAR is heuristic. It does not predict exact population outcomes and control costs, but does:

- provide the minimum proportion of the population the needs to be culled for effective control,
- identify which habitats in which configuration provide the most optimal culling regime,
- provide comparisons of the cost of control across different areas (by size and location) and over different time periods.

Using the model, staff can explore and compare different management scenarios in a virtual landscape. The user can create a management scenario by modifying certain parameters in the model or they can choose to run pre-defined management scenarios (Figures 3 to 6). Thirty-two pre-defined scenarios for pigs, buffalo and horses are available. These examine a range of different goals from zero culling rate to eradication. Management plans can be optimised for:

- Non-spatial versus spatial optimisation for a constrained budget in a single park district
- Non-spatial versus spatial optimisation for a constrained budget park wide
- Optimised culling rates for a density goal

More specific information on the STAR model can be found in the ‘Spatio Temporal- Animal Reduction (STAR) Model User’s Manual’ (Brook & Bradshaw 2006).

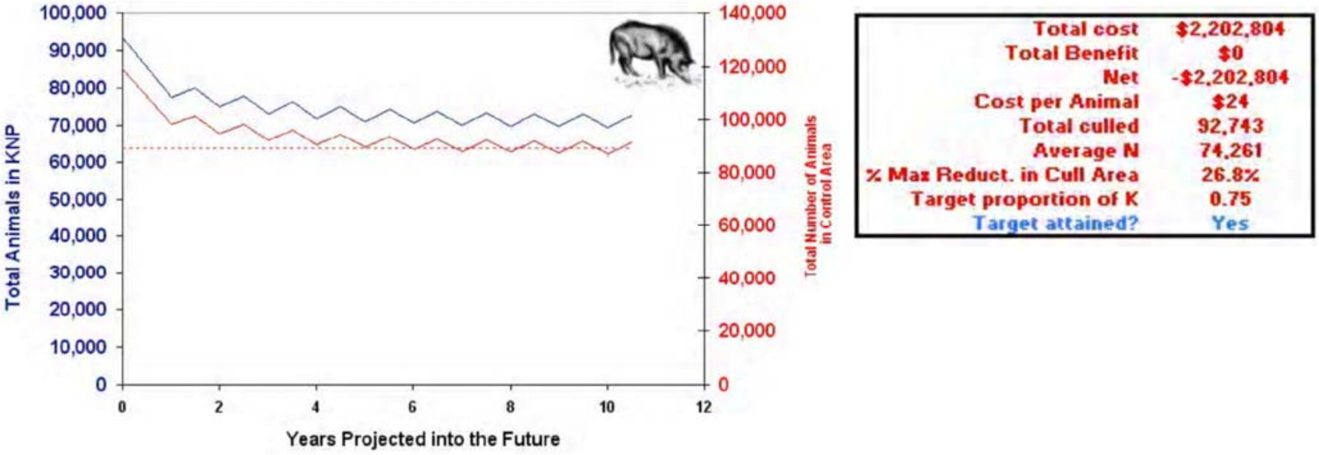

Figure 3 This graph shows the results of a culling scenario (number 2) that has been pre-loaded into STAR. The scenario sets the initial cull rate of 17% during the first year of a ten year program, followed by a maintenance cull of 9% to achieve a 25% population reduction. This cull includes the whole park and a 10 km buffer outside the park. The population trajectory graph shows that the population was reduced to 27% at a cost of $2.2 million to cull approximately 90,000 pigs. This result can be compared with other scenarios. The red line includes the whole park and a 10 km buffer. The blue line includes only the park as the control area. Taken from 'Spatial Modelling of Feral Animal Density Reduction' (Bradshaw et al 2006).

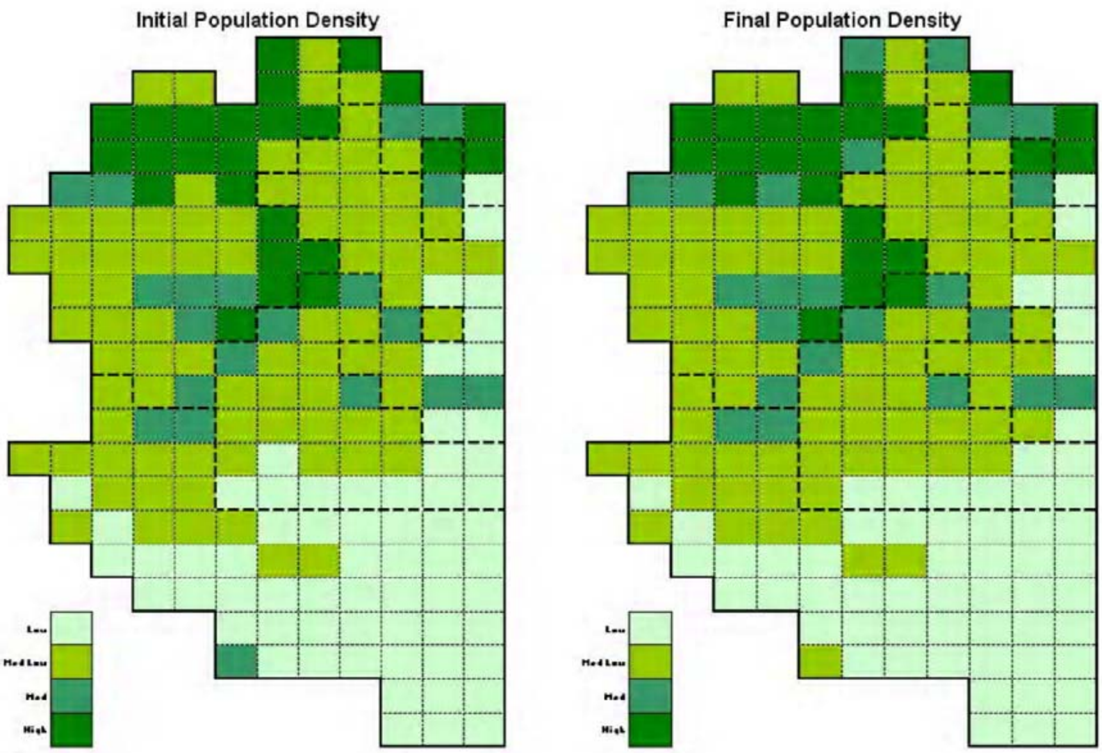

Figure 4 Examination of output maps produced for scenario 2, shows that population density did not change much over the ten years of the control program when a target of 25% population reduction was chosen for pigs. A much higher target is required. The user can choose to compare this result with a other reduction targets, for example a 75% population reduction target. Taken from 'Spatial Modelling of Feral Animal Density Reduction' (Bradshaw et al 2006).

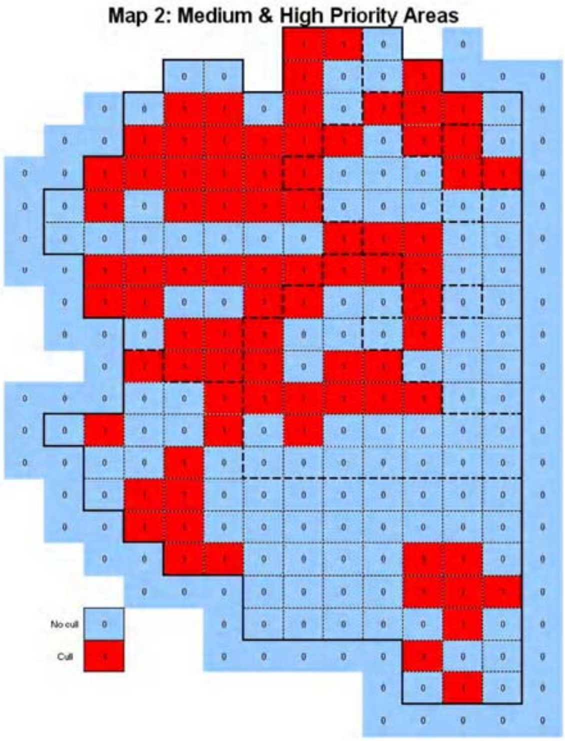

Figure 5 STAR enables users to choose target areas based on their priority (high, medium, low) and compare the output with an ad hoc culling configuration. Priority is assigned to a cell based on damage and / or management vexation. Taken from 'Spatial Modelling of Feral Animal Density Reduction' (Bradshaw et al 2006).

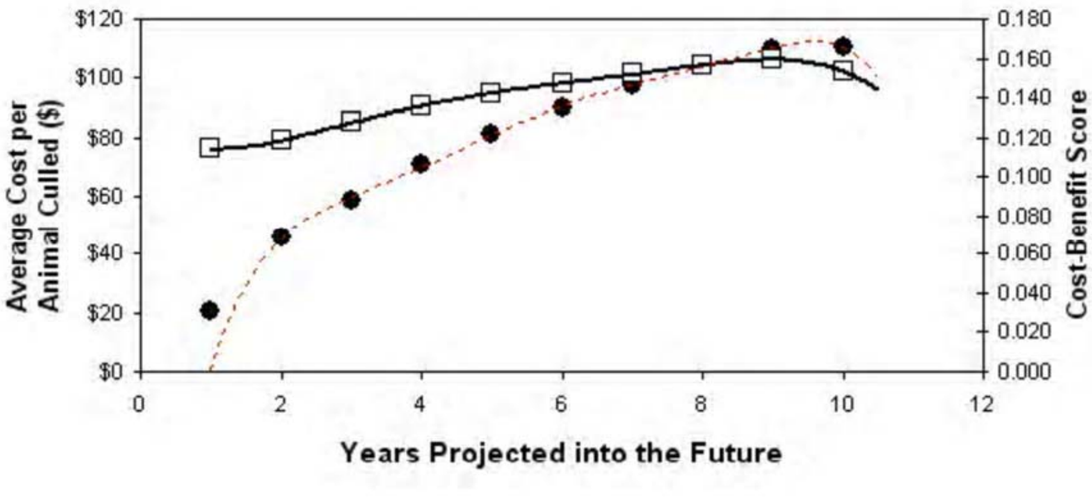

Figure 6 Strategies can be visualised as cost-benefit plots. This allows users to compare the efficiency of different culling scenarios. Taken from 'Spatial Modelling of Feral Animal Density Reduction' (Bradshaw et al 2006).

4.5 Feral animal control program 2008–09

4.5.1 Introduction

In 2008/09, the start to implementing the new strategy, the feral animal program will include a number of activities. A high intensity aerial survey of Kakadu has already been completed. This will be followed by a fixed–wing and helicopter survey in May 2009 and a final helicopter survey in June 2009. The later surveys will be used to both verify data from the October survey as well as provide a pre-control density index against which to measure the success of the control operation in May 2009 (index-manipulate-index). A park-wide aerial control operation has taken place and will be followed by a second operation in May / June 2009 (early dry season). Staff will be trained in aerial survey techniques and in the collection of life history information (age, sex, reproductive status), deoxyribonucleic acid (DNA) and blood sampling.

4.5.2 Fixed wing aerial survey

An aerial survey was undertaken between 20 and 29 October 2008 to estimate the abundance of feral animals in Kakadu. Information from the aerial surveys will be used to assess changes to feral animal populations since the last surveys, provide a benchmark for future surveys, and provide current data to calibrate the STAR model.

The survey was flown in a Cessna 182. A standard double count aerial survey methodology was used. Surveys were made during the first (AM session) and last (PM session) three hours of daylight, and between 10am and 1pm (Mid session). Transects were systematically placed 3 km apart and ran east-west across the width of the park. Transects were delineated into seven strips according to distance from the transect line using coloured tape and rope attached to the strut (Figure 5): Inside (<25 m), Yellow (50 m), Green (100 m), Blue (150 m), Black (200 m), Red (500 m), Outside (>500 m). The aircraft maintained a constant height of 250 ft above ground level (AGL) and speed of 100 knots where possible.

Observers recorded horses, pigs, buffalo, donkeys and feral cattle directly onto a gps-linked laptop with customised keypad (Figure 7), or onto a continuously running digital voice recorder. Buffalo damage and pig rooting was also recorded and classified into one of four categories: 1 (minor damage) – 4 (extensive damage). Data from the voice recorders are transcribed after filtering for background noise using the software program Audacity and entered into a Microsoft Access database. Observers on the same side are played back simultaneously to allow groups of animals to be recorded as having been seen by one or both observers. Where there is uncertainty whether a group was seen by both observers it is being treated as two separate groups.

Animals were counted in units of less than four using a keypad or onto the voice recorder, which are later summed to obtain a count for each group. When large numbers were seen in short periods, observers would obtain a minimum count using this technique rather than an estimate. If using the laptop, an additional field ‘more’ was used for any additional individuals seen that observers were unable to subitise.

Survey data shows that since the 2001–03, all feral animal populations across the region have increased: cattle (605%), buffalo (204%), donkey (73%) and horses (29%). These percentages are based on a direct comparison of numbers seen in a 2001-03 survey compared to the 2008 survey and are uncorrected for observer bias – animals not seen due to vegetation cover or activity (animals hiding). Data on the density of these species will not be available until mid-

2009 following verification surveys. A follow up fixed wing and helicopter survey is planned for mid-May 2009 to check and correct estimates derived from the 2008 aerial survey. Without a verification survey, the current data most likely underestimates the numbers of animals, particularly pigs which are hard to see from a fixed-wing airplane. Data collected on damage is not comparable with the 2001–03 data. In 2001–03 all damage was recorded regardless of age. In 2008, only fresh damage was recorded.

A simple real-time method of mapping all observations of horses, pigs, buffalo, cattle and donkeys was developed for Kakadu. This involved the development of a software package that allows recording of latitude, longitude, time, altitude, species, number, damage, damage rank (1–4), number of adults and juveniles, and distance category, direct to a laptop linked with a GPS using a customised keypad. The method was successful in providing a rapid, accurate and efficient means of recording all necessary information to allow repeatable measures of feral animal abundance in the park. The keyboard system was also successfully used to record information during the cull. Voice recorders were easy to use, but extremely time consuming to process the data after the survey and will not be used in future.

For further information see 'Kakadu Feral Animal Training Program and Aerial Survey 2008–2009' (Tracey et al 2009).

Figure 7 Layout of data recording system for aerial survey. A customised keyboard (unwanted keys removed) is connected to a small laptop with an in-built GPS recorder. Data is entered directly into the keyboard and downloaded following a survey session.

4.5.3 Control operation

A feral animal control operation took place across Kakadu from 3 to 14 November 2008. Effort was concentrated around water bodies where animals congregate during the late dry season. Priority was give to the most sensitive areas with high environmental, cultural, recreational and tourism values. Some areas were not included in the operation due to cultural sensitivities and budget constraints. Two helicopters (Bell Jet Ranger) operated each day.

Buffalo, horses, pigs, donkeys and feral cattle were shot using high powered firearms by appropriately trained and licensed park staff. The Northern Territory Tactical Response Unit provided additional shooters as a training exercise. The following animals were removed: pigs 2330 shot (3042 seen); horses 983 shot (2175 seen); donkey 533 shot (633 seen); buffalo 75 shot (138 seen); cattle (redskin) 62 shot (129 seen); cattle (Brahmin) 8 shot (56 seen). In addition, approximately 80 stray cattle were removed from the Park. The distribution of pigs and horses recorded during the cull is presented in Figure 8.

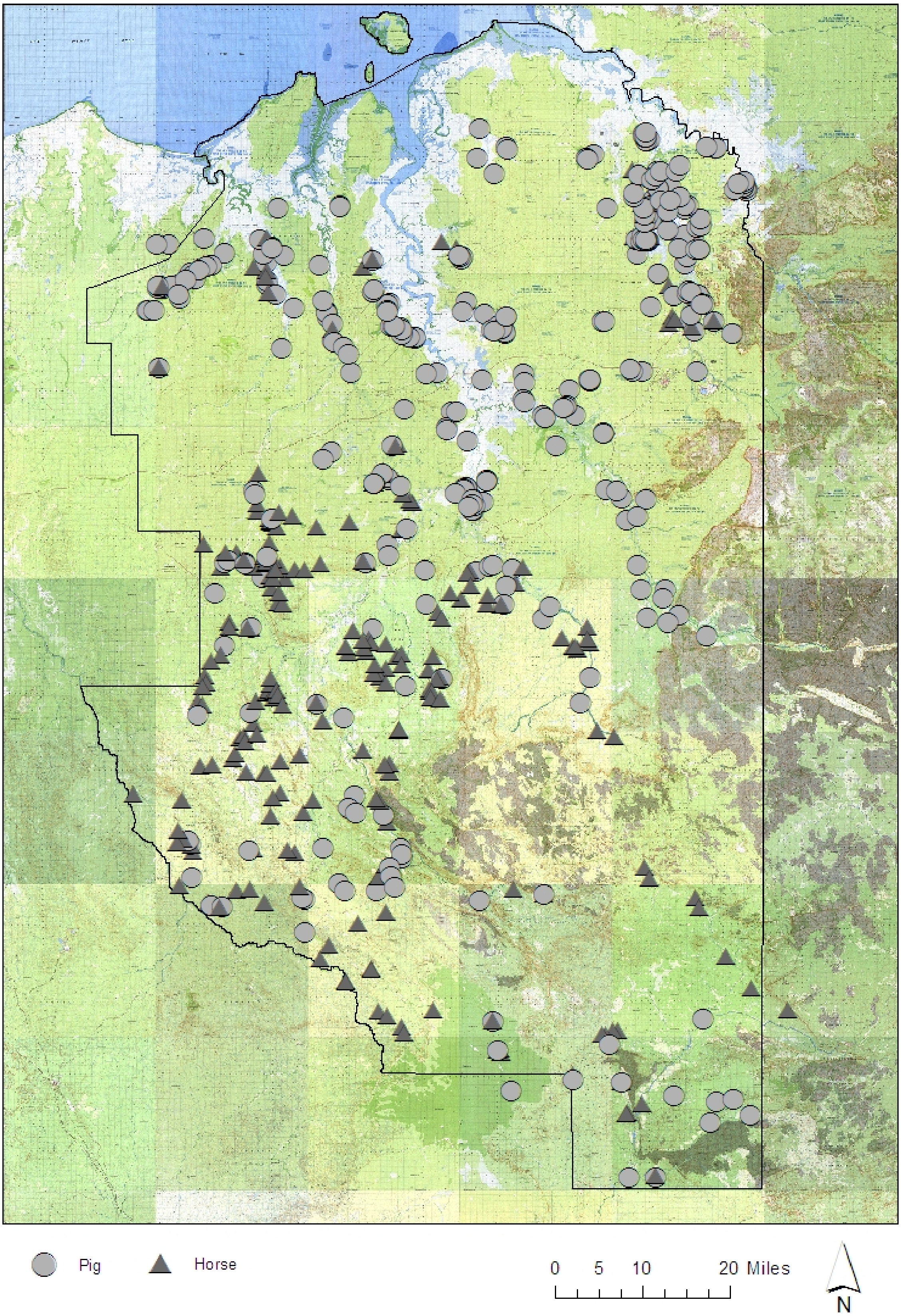

Figure 8 Each point on the map represents a group of either pigs or horses recorded during the November 2008 cull. Pigs and horses are by far the two most abundant feral animal species in Kakadu.

A staff member trained in aerial survey techniques accompanied each flight. The observer collected the following information directly onto a GPS linked laptop via a modified keyboard: GPS location, species, number of animals seen (adult, juvenile), number of animals removed (adult, juvenile), time in air, travel time and quantity of ammunition used. These data will enable the cost per animal and time per animal to be calculated. Comparing this information over successive shoots will provide a measure of the effectiveness of the program using the catch per unit effort as an index of relative abundance. With a successful program, over time fewer animals are sighted and removed for per hour of flight time, more time is spent searching and the cost per animal increases.

4.5.4 Staff training

Kakadu has worked in partnership with the Invasive Animals Cooperative Research Centre to develop and deliver a nationally accredited training package in aerial survey techniques. The training is designed to develop skills to conduct aerial counting of wildlife and wildlife damage. It involves one day of theory coupled with a minimum of six hours of aerial survey experience with a qualified assessor on board. So far ten Kakadu staff have completed the training with a further ten expected to participate next year. Trained observers collected significantly better quality data during the aerial shoot than untrained observers. The skills developed by staff will be used for a range of aerial surveys, such as for weeds.

4.5.6 Working with traditional owners

There are approximately 186 traditional owners of Kakadu National Park belonging to 18 clan groups. Each clan has custodianship of an area of land. Pigs were almost universally accepted by traditional owners as a pest animal that should be controlled. However, some traditional owners did not want horses, cattle, buffalo and donkeys shot and placed restrictions on where these animals could be controlled (Figure 9).

A large area was also excluded from control in the Mary River District where a commercial pet meat harvest is conducted for horses. This provides some returns to traditional owners, but, horse numbers and damage remain high and populations have grown whilst harvesting has taken place. Further discussion and negotiation will take place with the traditional owners. A feral animal newsletter was developed to help provide information back to traditional owners about the program, as well as presentations and discussion at community meetings, association meetings and with individuals.

4.5.7 Working with neighbours

It is essential for Kakadu to work in partnership with neighbours and regional stakeholders to manage invasive species which are wide ranging. Kakadu is surrounded by a range of neighbours, including national parks, defence training land, mining leases, cattle stations, safari hunting operations, and other private land including vast areas of aboriginal land and indigenous protected areas (Figure 9).

There was virtually no public concern expressed over the culling that took place in November 2008. A public notice was issued advising of the control operation before it commenced. All neighbouring properties were given an opportunity to check for and remove stray cattle prior to the shoot. Approximately 80 stray Brahmin cattle were mustered back to Carmor Plains Station.

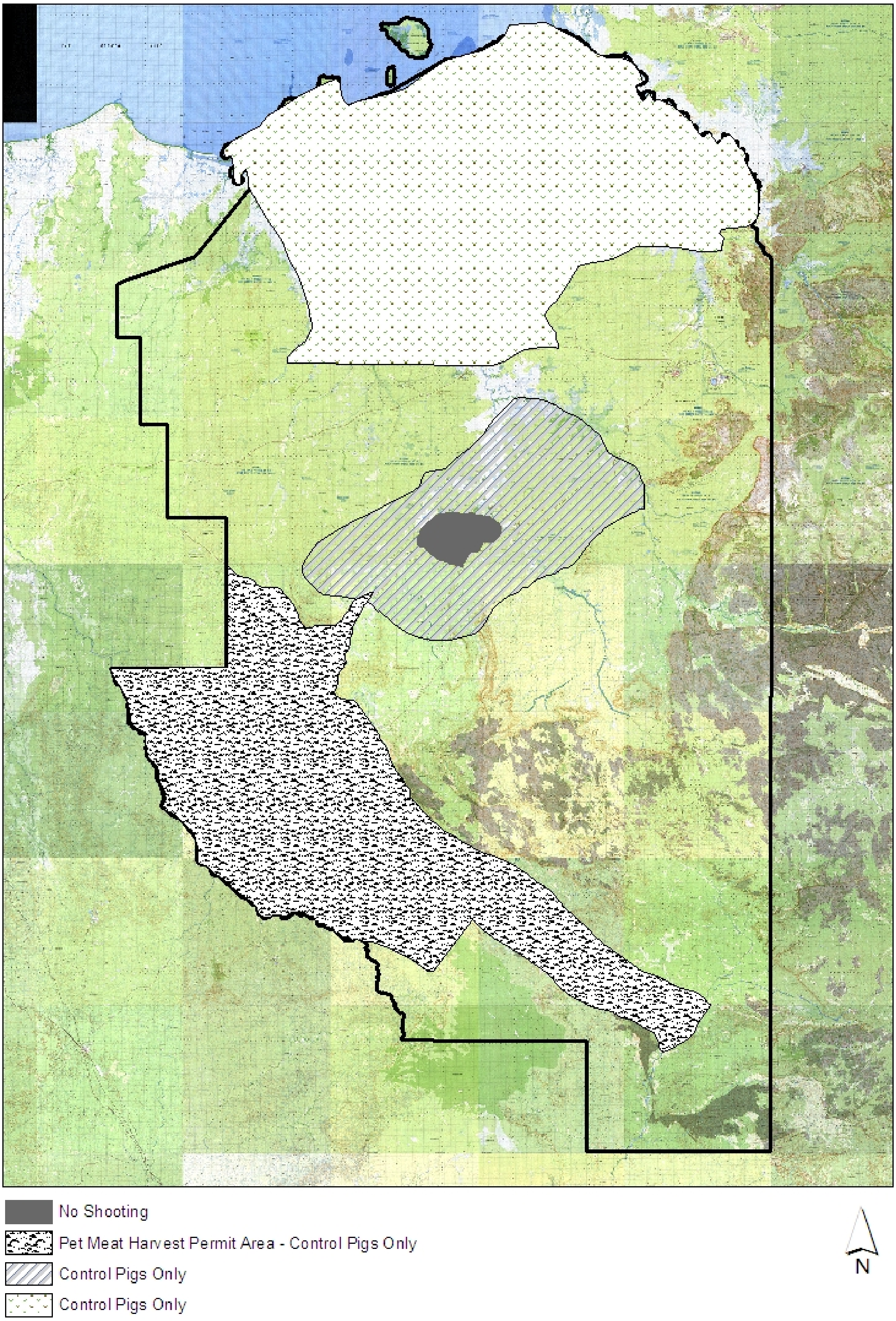

Figure 9 Pigs were almost universally accepted by traditional owners as a species that should be controlled. Restrictions were placed on other species in certain areas.

The Jabiluka Lease and Ranger Lease areas managed by Energy Resources Australia (ERA) were included in both the aerial survey and control operation. One hundred pigs were seen and 90 shot. Three horses were seen and one was shot from within the lease areas. Kakadu provided Warddeken Land Management Ltd with a ranger (shooter) for one week to assist with a control operation in late October 2008. Large numbers of buffalo were culled from a section of the Arnhem Land Plateau inside the Warddeken Indigenous Protected Area that borders the Park. Kakadu also provided assistance to the Australian Quarantine Inspection Service (AQIS) to conduct surveillance along the Kakadu coastline. AQIS and Kakadu staff worked together to collect blood samples and autopsy feral pigs shot during the control operation. Kakadu staff have had a long working relationship with AQIS and have been trained to collect samples and record observations.

Initial discussions were held with the Department of Defence. Large concentrations of feral species are located on or near the common borders of Kakadu and the Mount Bundy Defence Training Area. The Department of Defence has been operating a successful feral management program within the training area for the past 10 years. Defence claim that the success of their operations is due to a long-term coordinated approach and significant investment through recurrent funding. They conduct two to three aerial control operations per year. However, feral animal migration into the training area from adjacent properties remains problematic (Steve Chapman, pers com 2008). Further discussions will be held to investigate opportunities to coordinate activities.

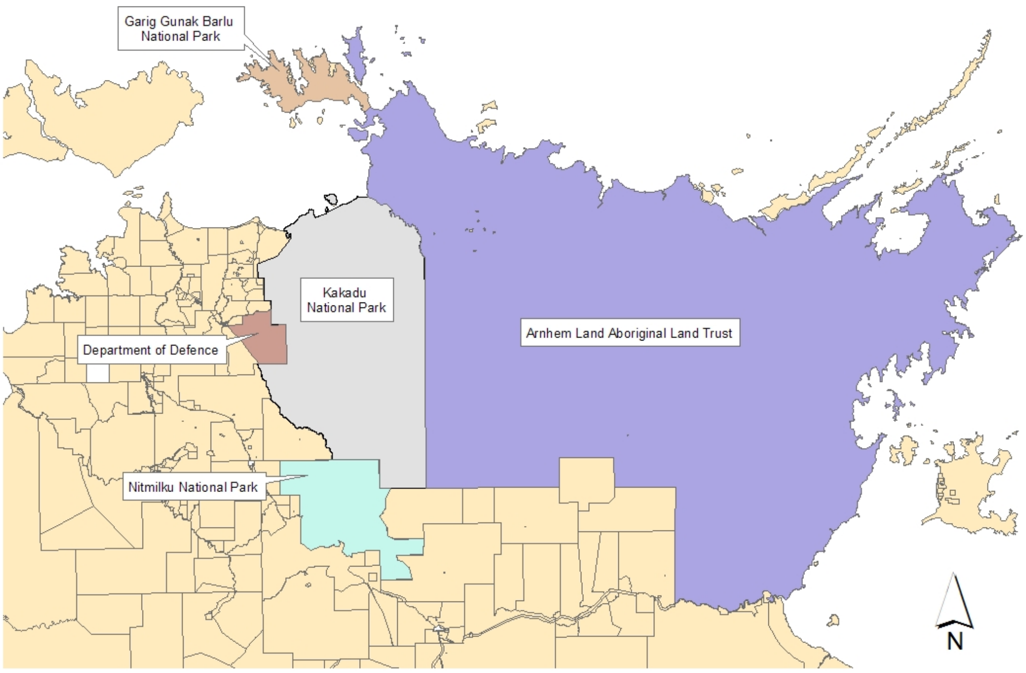

Figure 9 Kakadu is surrounded by a range of neighbours. Working closely with neighbours is essential to achieving good outcomes for feral animal management.

4.5.8 Research and knowledge gaps

Discussions were held with staff from Charles Darwin University (CDU) to identify priorities for data collection and research on feral animals. It was recommended that parks collect data on impacts, investigate the relationship between impact and population density, and collect biological information such as age class, reproductive and genetic information (skin). Methods suggested include the use of exclusion plots and high resolution satellite imagery to measure and monitor impacts, and the collection of life history data to improve our understanding of rates of population increase which are not well known for northern Australia. CDU are interested in identifying post-graduate research students and collaborative projects on feral animal management issues (Clive McMahon & Ian Fielding, pers com 2008).

4.6 Where to next?

As a priority, Kakadu will continue to work with traditional owners to set targets, plan and review how the program is implemented. This will include investigating the use of commercial mustering of horses and cattle in areas where traditional owners do not want these species shot during control operations. An assessment will need to be made of locations where it may be logistically and commercially viable to muster, able to be done with minimal impact to park values and have a population reduction to a level that would relieve the impact on the environment. In order to better prioritise areas and set targets for control, staff will work with traditional owners to continue to map high value areas (ecological, tourism, recreational, hunting and gathering, cultural, weed management areas), those most sensitive to impacts, and those where traditional owners have an interest in maintaining some feral animal populations or conducting commercial activities. Participatory planning techniques will be used to help foster better communication, participation and negotiation between the park and traditional owners.

Kakadu will take an integrated approach to feral animal control. A range of control methods will be considered. Aerial control operations will be followed by opportunistic ground shooting. A more coordinated approach to ground shooting and complimentary methods such as trapping and poison baits will be assessed. These methods may be useful to support aerial control and where aerial shooting is not possible. As funding becomes available for a sustained program, Kakadu will investigate the use of judas collar technique to improve efficiency in targeting pig populations, particularly as they become smaller and difficult to locate. Staff will aim to capture local knowledge on feral animal distribution, movements and habits. Staff experiences and methods used during the successful implementation of the Brucellosis Tuberculosis Eradication Campaign (BTEC) will be examined. Feral animal control will be coordinated to support the objectives of weed and fire management programs. For example, pigs will be culled from Mimosa pigra control areas as a priority since they enable the spread of this weed species.

Kakadu will develop rigorous but simple and cost effective methods to measure the success of the program. This will include collecting data (animals seen, animals shot, location, total flight time, transit time) during control operations to provide a catch per unit index against which to measure success over time. Staff will collect life history information from shot animals – particularly pigs – to improve our understanding of rates of increase. Pig age data will also provide a measure of success of the program. A successful control operation will result in the pig population structure change to a predominantly young population. Staff will assess the benefit of conducting an aerial survey every 5 years to understand feral animal population trends over the entire extent of the Park, particularly as large areas are potentially excluded from control. A simple, repeatable and cost effective aerial survey design will be developed. To ensure that feral animal control is achieving the ultimate goal of reducing pest damage, Kakadu will establish methods to measure changes to impacts of feral animals. This could include the use of visual damage assessment plots, photo points, exclusion plots and/or high resolution satellite imagery to measure changes in landscape condition (feral animal damage). Assessment in changes to damage will also improve our understanding of the relationship between population density and impact reduction, and improve our ability to set appropriate reduction targets.

Kakadu will develop contingency plans to deal with incursions of feral animal species not present in the Park. In addition, attention will paid to developing action plans for other feral animal species as identified in the KNP Feral Animal Strategy, most importantly for cats because of their potential role in the small mammal decline occurring in northern Australia.

Kakadu will continue to work with neighbours to support each other's programs.

4.7 Postscript

Culling operations in November 2008 and May 2009 removed 7029 pigs (60% overall reduction), 167 donkeys (53% reduction), 840 buffalo (32% reduction), 2312 horses (26% reduction), 18 Brahman cattle (20% reduction) and 78 red-skinned cattle (5% reduction). Smaller control operations took place in October 2009 and June 2010. Anecdotal evidence from rangers in 2010 is that few pigs are now seen in those areas where control has taken place. Altogether, 20 staff completed training in aerial survey techniques and eleven staff completed training in pig age data collection.

To help develop an action plan for feral animal control, Kakadu held a series of participatory modelling workshops in May 2010. Information collected from a series of clan based workshops, together with survey data and other information on feral animals, has been used to build a computer model of Kakadu called an Agent Based Model (ABM). The Agent Based Model brings together cultural, social, economic and environmental information. The model is visual and runs like a computer game. It shows what could happen to feral animal populations, important values such as turtle nesting sites, cost of control and income from feral animal harvests based on the decisions that are made by participants. The next step will be to use the model to improve joint decision making, helping facilitate key stakeholders to explore and discuss options for feral animal management.

4.8 Acknowledgments

Funding for the development and delivery of the aerial survey training package was provided by the Director of National Parks with significant in-kind contributions from the Invasive Animals Cooperative Research Centre and Industry and Investment NSW. Thank you to John Tracey, Peter Fleming, Brian Lukins, Steven McLeod,

Gavin Melville and Peter West for their excellent training, advice and support to complete the feral animal surveys. Thank you to Brett Ottley, Clive McMahon and Keith Saalfeld for useful discussions and expert technical advise on feral animal control and survey design. Thank you to Brett Ottley (ABS Scrofa Pty Ltd) for training rangers in the collection of pig age data and freely sharing his knowledge. And finally, a big thank you to all of the many skilled and committed Kakadu staff that made the survey and control operations a success, especially Sally-Anne Atkins, Ollie Scheibie, Andy Davies, Buck Salau and the Integrated Ferals Team.

4.9 Further reading

Brook BW & Bradshaw CJA 2006. *Spatio Temporal Animal Reduction (STAR) Model User's Manual*. School for Environmental Research, Charles Darwin University. Report submitted to the Department of Environment and Heritage, Canberra Australia.

Field IC, Bradshaw CJA & Haynes C 2006. *Feral Animals in Kakadu National Park: A Management Strategy for the Future.* School for Environmental Research, Charles Darwin University. Report submitted to the Department of Environment and Heritage, Canberra Australia.

Robinson CJ, Smyth D & Whitehead P 2006. *Managing for Country: Decision-making Guidelines for Joint Management of Feral Animals in Kakadu National Park*. Report to the Board of Management Kakadu National Park, Department of Environment and Heritage, Jabiru, NT.

Tracey J, Flemming P, Lukins B, McLeod S, Melvile G & West P 2009. *Kakadu Feral Animal Training Program and Aerial Survey 2008–2009*: *report to the Director of National Parks.* Invasive Animals Cooperative Research Centre, Vertebrate Pest Research Unit (VPRU), Primary Industries, Industry & Investment NSW.

5 Feral animal management in Laynhapuy indigenous protected area

D Preece[1]

5.1 Introduction

The Laynhapuy Indigenous Protected Area (IPA) consists of approximately 6900 km^2. of land area and 630 kms of coastline. This land portion encompasses 13% of the entire Arnhem Coast bioregion. Natural land systems are mostly undisturbed and are home to threatened species, and internationally significant wetlands and coastal landforms. Important as the natural values of the IPA are, the cultural values that Yolngu hold in the landscapes, plants and animals are the driving force of their relationship with their country.

The terrestrial biodiversity of the IPA is of very high conservation significance and the natural systems are in good condition (Panton 2005). The land area of the IPA provides habitat for a number of threatened species of plants and animals. The wetlands of the Gurrumuru floodplains and those formed by the Lutbanda, Durabudboi and Wyonga rivers flowing into Jalma, Grindal and Myaoola Bays in the southern section of the IPA are recognised as critical waterbird habitat of international significance (Chatto 2003). Panton (2005) observes that the IPA wetlands would easily satisfy the criteria for listing under the international RAMSAR Conservation on the Protection of Wetlands.

The most significant present threat to the terrestrial environment is the increasing incursions into wetland areas by feral water buffalo (*Bubalus bubalis*) and pigs (*Sus scrofa*) (Laynhapuy IPA Plan of Management 2006).

5.2 Monitoring

In order to be able to assess the impact feral animals are having on the IPA, several monitoring techniques have been employed. These are used to indicate changes in feral animal impact and are also an indicator to the success of feral animal control programs.

The first technique is aerial surveying the IPA for feral animals. These surveys work best for buffalo and are able to determine buffalo population size, and the distribution of buffalo across the IPA. This technique is not as accurate for pigs due to their nocturnal habit which usually finds them at rest in thicker vegetation during daylight hours.

On ground monitoring is done by the establishment of plots in areas of sensitive habitats, which are mainly wetland/floodplain areas. These plots have photo points, with photo data collected twice annually. Ground disturbance, ground cover, feral prints, faeces and diggings are recorded using transects within each plot. There are eight monitoring plots within the IPA. Data from the transects is recorded using a Cybertracker palm computer.

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Exclusion plots are also used to monitor feral impact on these sensitive vegetation types. These plots are fenced in areas measuring 8 m x 8 m. These plots give information about the rate of recovery of fauna and flora when ferals are excluded.

5.3 Data collection

All data relating to feral animal management is collected in the field using the Cyber tracker palm computer. Data is downloaded onto a database for later analysis and for use in reports. A Geographic Information System (GIS) will soon be used to represent data, and could also be used in the future planning of feral control activities. Photo point data is collected using digital cameras, and in the future aerial photography may be used for a more broad scale method of monitoring feral animal impact.

5.4 Control

Wide scale control of feral animals is an expensive and laborious task, and in order to be effective, a multi facetted approach is employed. For feral buffalo and pigs in high numbers, aerial control is the most effective and efficient method. In Laynhapuy IPA two control operations have been undertaken so far, but now that staff have been trained in aerial platform shooting it is anticipated that several aerial shooting operations per year will take place until populations diminish to the point where aerial control ceases to be efficient.

In addition to aerial control, opportunistic ground shooting is conducted year round in conjunction with other ranger work tasks. Approximately 15 rangers have been trained in firearm use, enabling both pigs and buffalo to be controlled when the opportunity arises.

Pig trapping is another method employed throughout the homelands. Sixteen pig traps are located in different areas and are regularly serviced by rangers. These traps are typically located quite close to homeland communities so that they are easier to service. Bait supplies have been an issue in the past, but now a staple of boiled sorghum grain and molasses is used and complemented by any additional food sourced locally.

In the near future we would like to experiment with a 1080 baiting program for feral pigs. This may be an efficient way to achieve effective pig control over large areas and twill hopefully be trialled in 2010.

5.5 References

Chatto R 2003. *The distribution and status of shorebirds around the coast and coastal wetlands of the Northern Territory*. Technical report no. 73. Parks and Wildlife Commission of the Northern Territory, Darwin NT.

Laynhapuy Homelands Association Incorporated 2006. *Laynhapuy Indigenous Protected Area Management Plan*.

Panton W 2005. Biodiversity and conservation values of the Laynhapuy IPA. Unpublished report, Parks and Wildlife Commission of the Northern Territory, Darwin NT.

6 Direct population control or focal-resource control for feral pigs?

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6.1 Introduction

Pest animal invasion and spread is a global conservation problem, but much of the research to date has been concerned with quantifying the scale of the problem rather than finding solutions (Hulme 2006). In Australia, a number of pest species are of serious environmental and economic concern, including feral pigs (*Sus scrofa*) – (Tisdell 1981, Reddiex & Forsyth 2006). In this work we sought to investigate the complex relationships that underpin a currently common control approach, direct population control, and to explore alternative solutions.

For conservation purposes, the improvement of the condition of invaded habitat is the usual objective in pest animal control programs (Reddiex et al 2006). Most control programs in conservation and agriculture are designed to directly control populations of the pest species of concern, following a rationale that direct population control will achieve the habitat improvement objective (Hone 2002). Carcass counts are often used as the index of success, being based on a number of often unstated assumptions; viz:

1 Culling will reduce the population spatially and temporally (ie that we know, or can accurately infer, the relationship between culling and population reduction);

2 There is a direct relationship between population reduction and achieving the habitat condition objective (ie behavioural and numerical responses and intraspecific interactions have no effect on this relationship);

3 Enough resources will be available to continue this type of control in perpetuity unless eradication is achieved.

It is possible that some of these assumptions, particularly 1 and 3, would be met under certain situations. Where culling pressure is sufficiently high and the population closed, eradication may be possible and assumptions 2 and 3 are void. In other cases, however (the norm), we argue that current control approaches have not been particularly effective. This assertion is supported by a number of studies (eg Reddiex et al 2006). Yet direct population control remains the most widely accepted approach to pest animal control, despite the fact that many 'controlled' pest animal species have continued to increase in distribution and abundance, and the impacts on the conservation estate are substantial and increasing - in some cases, such as feral pigs, beyond prediction (National Land and Water Resources Audit 2008). As such, the need to develop new approaches to pest animal management remains paramount.

To this end, we developed the following hypotheses:

1 Direct population culling across a landscape does not necessarily lead to a reduction of (long-term) impact.

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a Environmental variability, population responses and a lack of linearity between population density and impact all affect the relationship between culling effort and species impact.

2 Location specific culling effort can improve habitat condition, in a given habitat, regardless of total landscape population density.

a If that habitat is a focal resource, population density across the landscape will be negatively affected.

b Other discrete habitats may experience an increase in impact.

6.2 Methods

For this project we developed a theoretical framework that incorporated a number of key ecological elements – predator-prey dynamics and behavioural and numerical responses to predation (culling) pressure, interaction between landscape resource components and pest animal populations, and population dynamics. To link the theoretical framework to an applied pest animal problem we selected a case study at Curtis Island National Park near Gladstone in Central Queensland (Figure 1). The Curtis Island site is a matrix of leasehold and freehold grazing land and national park, encompassing an area of 54 000 hectares. The primary target pest species for the local park managers is the feral pig. We took one section of the park, covering approximately 200 km^2, for the model simulations. This section incorporates a marine plain wetland system, listed as high conservation value in the park's management plan. This section was subsequently referred to as 'whole-of-park' for modelling simulations, and individual habitats termed 'landscape elements'.

A map showing the broad vegetation boundaries was overlayed on a satellite photograph of the case study site. The broad habitat classes were categorised, and polygon colours across vegetation types unified to create a landscape of six key colours corresponding to six dominant ecosystems within the chosen section; woodland, wetland, swamp, dunes, vine thicket and mangrove (Figure 2).

Using population dynamics data and site specific data relating broad climatic variability and the general landscape function, we defined the system and the major components relating to R (rate of population increase) and R_{max} (maximum capacity for population increase). Management strategies and cull data for feral pigs were provided by park managers to inform the model.

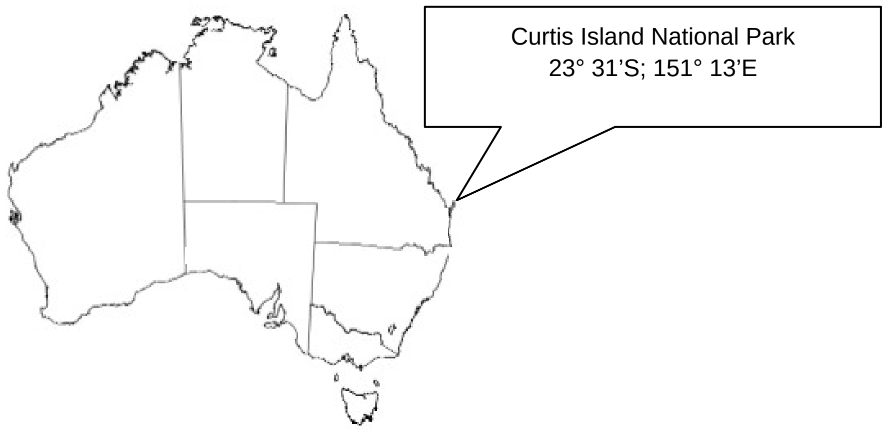

Figure 1 The location of the case study site

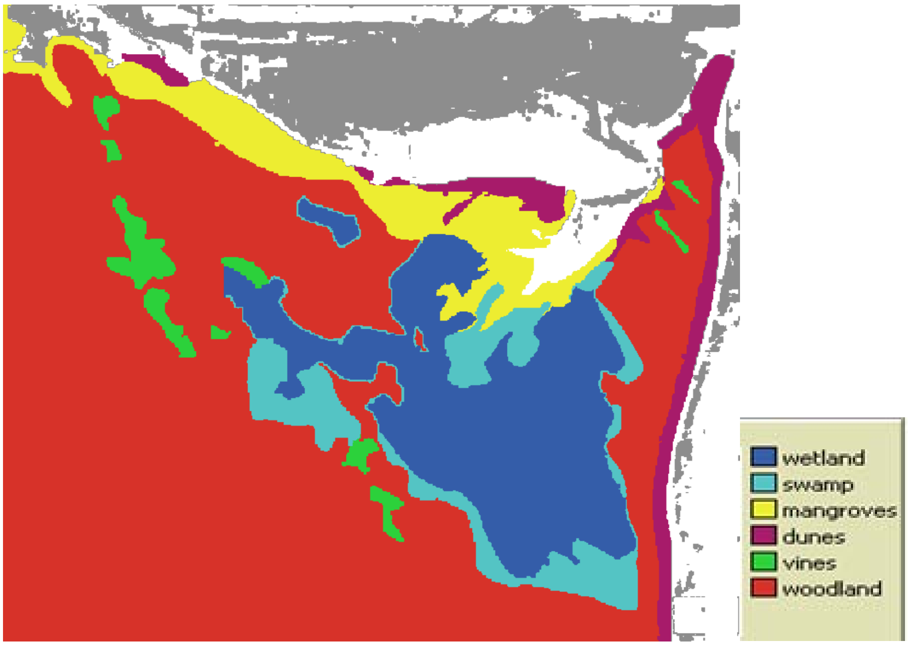

Figure 2 The transformed section of the case study, coined 'whole-of-park' in the model, with different landscape elements corresponding to major habitat types. Grey and white colours are marine environments.

6.2.1 Pig population dynamics and culling

The data for feral pig litter size and average survival rates, mortality patterns, age of sexual maturity and gestation were taken from the literature (eg Choquenot 1998, Bieber & Ruf 2005, Spencer et al 2005, Twigg et al 2005). Nutritional requirements were also extracted from the literature (Kyriazakis et al 1995, Sandberg et al 2005) and embedded in the model as available resources, as well as attributes of individual pigs. Energy allocations and costs for movement and breeding were standardised.

Culling probabilities were calculated for trapping and shooting, based on park management data.

6.2.2 Pig behaviour

Pig behaviour was coded to meet a series of conditions linked to proximity to hunters, proximity to other pigs and resource availability across the landscape. Movement was allocated an associated cost, and pigs were given an implied 'knowledge' of the landscape and its seasonal variability by being able to 'see' the landscape.

6.2.3 Landscape resource dynamics

Seasonal resource allocation was coded using qualitative data from Curtis Island. Seasonal variation was linked to stochastic rainfall events that alter resource allocation in a pre-determined manner. Stochastic rainfall events drive short and long-term resources in the landscape. Wetland resources are largely (though not wholly) rainfall dependent.

The model operates on a cycle that represents a 365 day year with four seasons – 'Wet', 'Late Wet', 'Dry' and 'Late Dry'. Resources (protein and energy) have an adjustable lag time to recovery once eaten by pigs. Energy and protein are indices of landscape condition, or 'health' as it is loosely termed in this paper.

6.2.4 Model runs

We ran several treatments of the model using various degrees of culling effort and trap and hunter location, and we recorded the five-year averages for a range of output measures to describe a temporal impact curve. Only the averages for the total of pigs, culling effort and protein for the wetland landscape element are shown in this short paper. We ran a range of simulations, including direct population culling (Figs 3–7) and focal-resource culling (Figure 7).

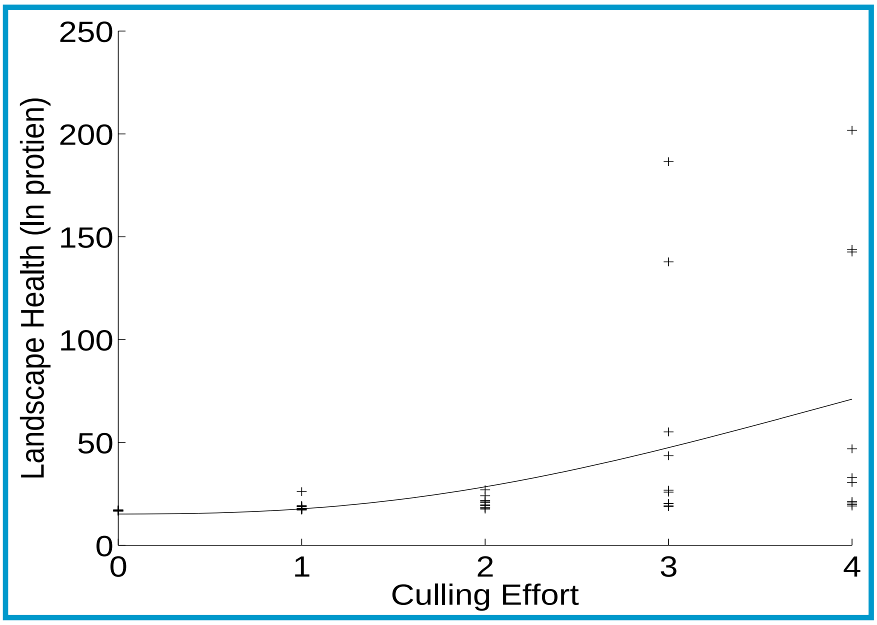

Figure 3 The impact of the number of traps (culling effort) used to cull pigs and the resulting five-year average protein-per-hectare on the wetland landscape element – higher protein signifies greater landscape health. More culling effort generally results in better landscape health.

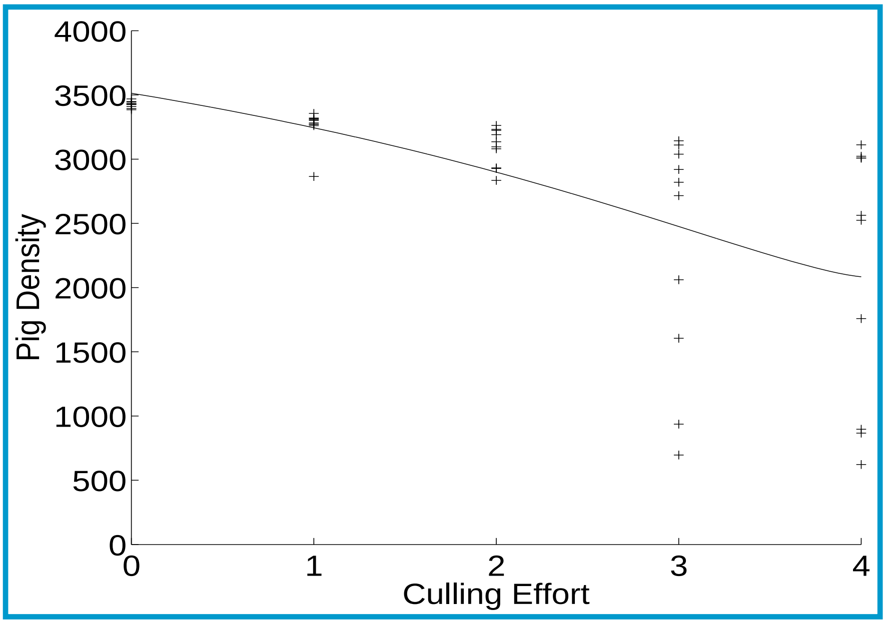

Figure 4 The impact of the number of traps (culling effort) used to cull pigs and the resulting five-year average pig count in the whole-of-park area. More culling effort generally results in fewer pigs. Stochastic rainfall variation accounts for the outliers – more pigs were removed in low-rainfall times.

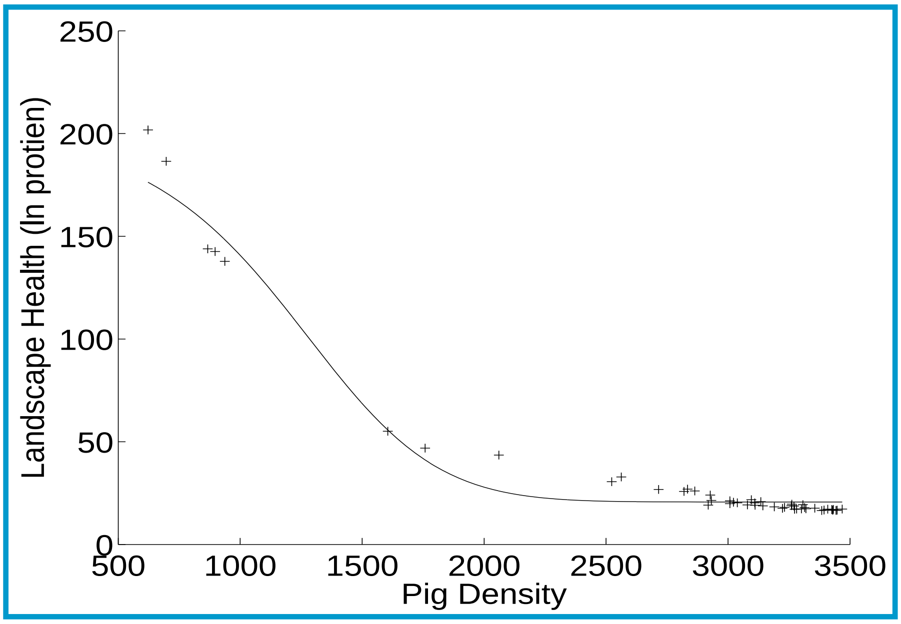

Figure 5 The five-year average pig count in the whole-of-park area and the resulting five-year average of protein-per-hectare in the wetlands – higher protein signifies greater health. Greater pig counts generally result in poorer landscape health to the point where degradation bottoms out.

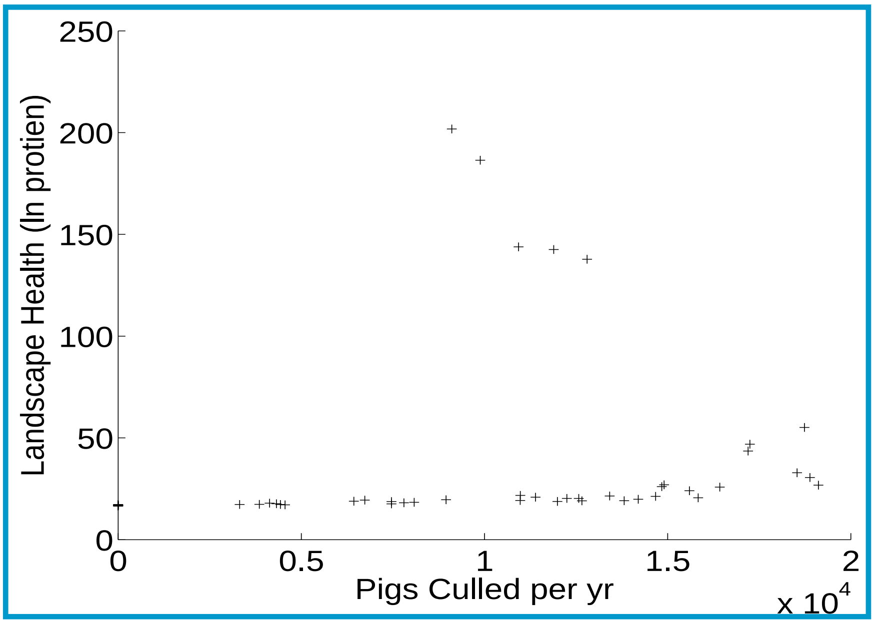

Figure 6 Culling was applied across the whole-of-park for this simulation. This figure shows five-year averages for total pig numbers and the wetland landscape element, across multiple simulations. Only occasionally does the wetland health cross a threshold that allows it to maintain relatively good condition.

6.3 Results

These simulation results can be presented in various ways to demonstrate key points. For example, Figure 3 depicts the commonly held view that increased culling effort improves landscape health. The same data set can be employed to show that this is caused by the impact of culling on pig density, as shown in Figure 4. These same dynamics can be further represented in Figure 5 in terms of pig density and landscape 'health'.

However, in Figure 6 we show that in fact the relationship between these two data sets (landscape health and pig populations) is non-linear, and the landscape health outcome is associated with important threshold effects of the pig population and landscape interactions. Figure 7 shows what can happen if the culling regime is changed from a whole-of-park direct population approach, to a focal-resource approach focused only on the wetlands. The impact of this change in management is to shift the pig population across a threshold and into a system with lower pig numbers and greater landscape health. Note that a level of impact is still recorded. Again, we stress that while these simulations are used here only to demonstrate the application of the model, they do demonstrate the power of this type of model for addressing landscape scale questions concerning culling effort, approaches and conservation outcomes.

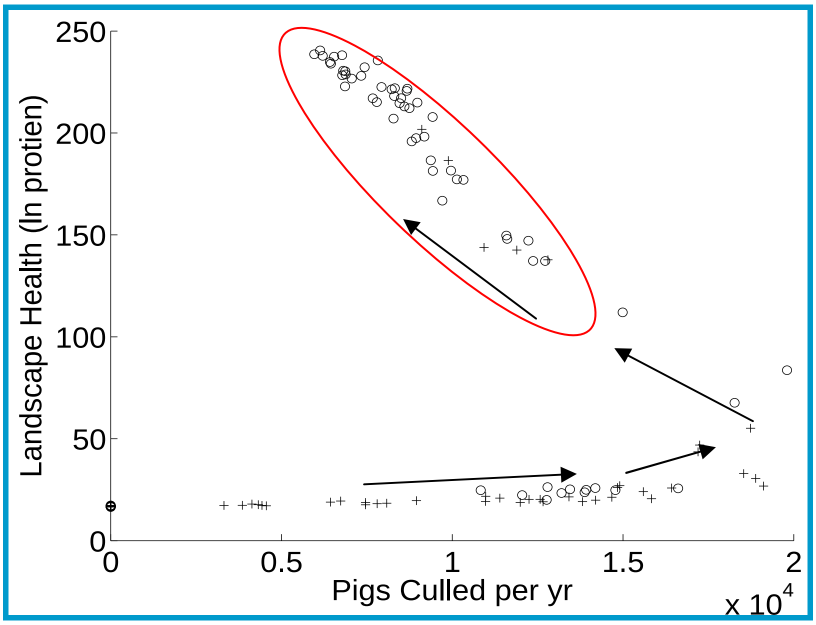

Figure 7 Five-year average pig culls are non-linearly related to landscape health in the wetlands. The circles (o) show the relationship when culling is focussed on the wetlands only, at different levels of culling effort. The crosses (+) show the same treatments and culling effort, but with culling effort across the whole-of-park (the same data as Figure 6). The circles record what happens when using a focal-resource approach – the health of the wetland landscape element is invariably greater, *but* substantially fewer pigs are culled over time compared to the direct population approach across the whole-of-park. This demonstrates that with same culling effort, and with the same landscape conditions, system dynamics can be exploited and the system crosses into a threshold where health of a selected resource improves substantially. The arrows notionally follow this threshold effect.

6.4 Discussion

The aim of the project was two-fold:

1. To design and build a model that is capable of exploring the complex relationships between landscapes, invasive animals, control agents and conservation outcomes.
2. To construct the model in such a way that the necessary inputs (eg transformed aerial photographs) can be accommodated with minimal technical expertise and software sophistication.

Further details of the modelling and results will be available in future publications, showing a series of complex interactions across the landscape in space and time. Presented here is a brief overview of the power of the model to unpack the complex nature of the relationships between pest animal populations, landscapes and control agents. It is important to note that models like these do not offer absolute answers, but can offer important insights into complex ecological relationships.

Two approaches are examined; the usual direct population approach, and an alternative approach we call the focal-resource approach. Both approaches utilise the same culling methods ie trapping and shooting, but differ significantly in their assumptions, required culling effort (for the same conservation outcome in selected landscape elements), and projected outcomes. The questions of interest were how to best utilise available resources for pest animal control to achieve a specified conservation goal, and whether or not it is even necessary to expend resources monitoring and measuring pest animal populations.

The latter is interesting, and possibly counter-intuitive. Our research suggests population data is of secondary importance, thus challenges much of the literature and contemporary thinking that population research and direct population control are key to conserving landscapes impacted by pest animals. Our results suggest this type of thinking is only appropriate given certain financial and ecological conditions eg (Hone 2002). Simply culling pest animals because they are there, when eradication is not possible and financial and human resources are finite, is too often simplistic. The focal-resource approach similarly has a set of conditions attached, but it inherently assigns the landscape 'agency' in the control program, weighting it as being of more direct importance than the pest animal population. This may also offer substantial costs savings, as collecting population data for direct population control is invariably extremely expensive (Choquenot 1995). It is also worth noting that the use of measures of ecological health, or condition, to drive production and conservation orientated decision-making is common practice in livestock and native herbivore management (eg Stokes et al 2006; Albon et al 2007), because the condition and health of the resources is the focus.

The focal-resource approach raises some interesting questions, and questions worth considering in all protected areas. Based on the assumption that human and financial resources are finite, what is going to be the priority area? The focal-resource approach explicitly states that not all landscape elements can be conserved, and even the ones that can will suffer a degree of impact. What level of impact is biologically, culturally or aesthetically acceptable? These are questions for land managers and conservation planners.

Both direct population and a focal-resource approach have an application. However, we show that the focal-resource approach is more specific and effective in improving selected landscape elements for conservation purposes, Also, if the location is a key resource for the species in question, the change in cost-benefit ratios to individual animals translates into long-term reductions in fitness and the ability of populations to sustain the same numbers across the landscape as a whole.

Direct population control can be superficially similar, using what is called 'targeted' culling in high density areas, along known movement corridors etc. However, the focal-resource approach does not use carcass counts as a measure of success and hence negates the need to monitor populations. Control continues regardless of how many animals are taken in the location, as it is the landscape that is being actively managed, not the pest animal population. In fact, carcass counts are invariably substantially lower in a focal-resource approach. This suggests that carcass counts offer a false sense of success or failure, even for direct population control.

Over time, a focal-resource approach could be a substantially more effective mechanism for the conservation of high-value landscape components.

6.4.1 Management implications

Accept that control has no end-point. Realistically assess the resources that are likely to be available year after year, decade after decade. A direct population approach is neither better nor worse than a focal-resource approach – the most appropriate choice should be based on careful assessment of the pre-requisite data collection, financial and ecological conditions.

Accept that some level of impact will always be present unless total eradication is possible. Explicitly state what level is considered acceptable.

Set highly specific targets for conservation of habitats and/or native species and select appropriate indices of impact and success. Work towards achieving those targets, and not towards carcass counts which are often meaningless.

Ensure that you have a control site where you can measure the same indices. This allows you to infer that your cull effort, rather than some other factor, is leading to improvement.

Projects (and funding) should be directed to record improvements in habitat condition as a measure of success, not numbers of animals culled.

Consider direct population control as a means to temporarily lowering numbers in relatively closed populations, and use focal resource approach to influence the density-dependant aspects of the animals' ecology, thus reducing the capacity of the populations to grow again.

Remember that where populations are not closed (such as Curtis Island NP), direct population control will be limited in use.

Use direct population control for eradication programs.

6.5 Acknowledgments

We would like to thank Luis Izquierdo from the University of Valladolid, Spain, for programming assistance, and Iain Gordon for ongoing input. We also acknowledge Queensland National Parks and Wildlife Service, in particular Andrew Congram, for their support of the project. This work was funded through the CSIRO Internal Venture Capital Fund.

6.6 References

Albon SD, Brewer MJ, O'Brien S, Nolan AJ & Cope D 2007. Quantifying the grazing impacts associated with different herbivores on rangelands. *Journal of Applied Ecology* 44, 1176–1187.

Bieber C & Ruf T 2005. Population dynamics in wild boar Sus scrofa: ecology, elasticity of growth rate and implications for the management of pulsed resource consumers. *Journal of Applied Ecology* 42, 1203–1213.

Choquenot D 1995. Assessing visibility bias associated with helicopter counts of feral pigs in Australia's semiarid rangelands. *Wildlife Research* 22, 569–578.

Choquenot D 1998. Testing the relative influence of intrinsic and extrinsic variation in food availability on feral pig populations in Australia's rangelands. *Journal of Animal Ecology* 67, 887–907.

Hone J 2002. Feral pigs in Namadgi National Park, Australia: dynamics, impacts and management. *Biological Conservation* 105, 231–242.

Hulme PE 2006. Beyond control: wider implications for the management of biological invasions. *Journal of Applied Ecology* 43, 835–847.

Kyriazakis I, Emmans GC & Anderson DH 1995. Do Breeds of pig differ in the efficiency with which they use a limiting protein supply. *British Journal of Nutrition* 74, 183–195.

National Land & Water Resources Audit and Invasive Animals Cooperative Research Centre 2008. *Assessing invasive animals in Australia 2008*, NLWRA, Canberra.

Reddiex B & Forsyth DM 2006. Control of pest mammals for biodiversity protection in Australia. II. Reliability of Knowledge. *Wildlife Research* 33, 711–717

Reddiex, B, Forsyth, DM, McDonald-Madden E, Einoder LD, Griffioen PA, Chick RR & Robley AJ 2006. Control of pest mammals for biodiversity protection in Australia. I. Patterns of control and monitoring. *Wildlife Research* 33, 691–709.

Sandberg FB, Emmans GC & Kyriazakis I 2005. Partitioning of limiting protein and energy in the growing pig: description of the problem, possible rules and their qualitative evaluation. *British Journal of Nutrition* 93, 205–212.

Spencer PB, Lapidge SJ, Hampton JO & Pluske JR 2005. The sociogenetic structure of a controlled feral pig population. *Wildlife Research* 32, 297–304.

Stokes CJ, McAllister RRJ, Ash AJ 2006. Fragmentation of Australian rangelands: processes, benefits and risks of changing patterns of land use. *Rangeland Journal* 28, 83–96.

Tisdell CA 1981. *Wild pigs: Environmental pest or economic resource?* Australian National University Press, Canberra.

Twigg LE, Lowe T, Martin G & Everett M 2005. Feral pigs in north-western Australia: basic biology, bait consumption, and the efficacy of 1080 baits. *Wildlife Research* 4, 281–296.

7 Pig control using the Judas technique

B Ottley[1], S Barker[1] & D Wurst[1]

7.1 What is Judas collaring

Judas-collaring or the Judas Technique refers to a management technique that at it's simplest works by using an animal to find other animals of the same species, therefore betraying the location of these animals to wildlife managers. In order for this technique to be of value the Judas animal must be marked in some way so that mangers can find it quickly and easily. Typically when used in vertebrate pest management animals are 'marked' by attaching a radio-collar which emits a radio signal that can be used to track the animal down. The primary focus of the technique is to reduce search effort, therefore time and money, when trying to locate animals of a specific species. The term Judas collaring is normally used in relation to management operations aimed at reducing the population of a pest species. This is achieved by tracking the collared animal, shooting all the animals it is travelling with, then, allow the collared animal to find and join up with more members of the species so the procedure can be repeated.

7.2 Equipment

To undertake Judas-collaring, the basic pieces of equipment required are collars containing radio transmitters (VHF), a receiver and an antenna. There are however, a great many variations in each of these pieces of equipment. This means that the proposed program needs to be carefully planned in order to choose the most appropriate design or model for each piece of equipment. Consideration needs to be given to: how long is the program to run; will it include ground tracking or only aerial tracking; the likely distances involved in the tracking program; the habits of the animal to be tracked; and vegetation topography, etc. An indication of some of the equipment costs are presented in Table 1.

Table 1 Indicative costs of components required for Judas-collaring

Component	Approximate indicative cost range (Aus $)	
Collar	250	300
Transmitter	130	200
Antenna	300	3000
Receiver	600	2000

Collars need to be appropriate for the size of the target animals and robust enough to survive the intended life of the program. The strength of the radio transmitter attached to the collar must be determined and this will depend on the environment in which the collar is to be deployed and the intended method/s of tracking. Finally, the receiver will be determined largely on the basis of cost and the number of additional functions it performs (auto-scanning , memory capability fine tuning, etc).

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There are several suppliers in Australia of telemetry equipment that can help to determine the most appropriate configuration of equipment required for specific or more general applications. When planning for a Judas-collaring program the cost of equipment can be significant but the cost of flying must also be considered and adequately budgeted for, otherwise collars can be allocated but not visited frequently enough. This can be a significant factor in deciding on whether to undertake a Judas-collaring project and must be considered thoroughly in the planning process prior to undertaking the program.

7.3 Judas-collaring and pigs

The use of Judas-collars has been used for many years in the Northern Territory by government and private wildlife managers as a tool to assist with managing pig populations. The use of the Judas technique has been found to work well with pigs and, as one of several management techniques employed, has enabled satisfactory management outcomes.

Pigs are suitable subjects for this form of management as they are generally communal and a collared animal will join up with other pigs when possible. Female pigs should be targeted for collaring as they are more likely to seek out and stay with a group of other pigs (ABS Scrofa unpublished data, McIlroy & Gifford 1997). Typically, sows between 2–4 years are ideal, as they generally stay in the area in which they have been caught and stay within a group. Young bores (up to the age of 3yrs) can be used, but rate of growth (collar fit) and behavioural characteristics (solitary nature, movement) quickly make them less desirable than sows. Typically we have found collars with a transmitter life (battery life) of approximately 2½ to 3 years as the most suitable. This provides a good period over which to track an animal and spreads the costs involved in the recovery or replacement of a collar.

The use of this technique in the management of a pig population can prove to be very effective, however, it should not be considered as the sole means to control or manage a population. It should form part of an overall management plan that includes several techniques to maximise the efficiency of the entire operation. The benefit of the technique is the ability to find quickly and easily a collared animal, when due to vegetation, seasonal climatic conditions or low density other means are inefficient or impossible. However the cost of setting up and running a project is not cheap, and the cost must be factored into the degree of management desired. This is why a strategic approach is required co-ordinating various techniques to maximise the efficiency of the entire program.

If the technique is to be used, pigs should be caught and collared from the area in which they are to be released early in the program, when they are abundant and effort to catch is minimised. If animals are caught elsewhere and brought in they may either try to return to where they were caught or may not join up with other pigs in a suitable time frame. Further, we have found that animals should be caught from separate drainages across the management area if possible, otherwise collared animals are likely to join up with others in one group, therefore wasting the use of one collar. Trapping or opportunistic shooting from either the ground or air can then take place leaving only the collared pigs.

The Judas collar technique should be used when a control program begins to become ineffective, as determined by a preset unit of measure, ie cost or effort per head, or degree of reduction in impact etc. It can also be applied where populations are scattered over a large area or in conjunction with shooting and trapping on a seasonal basis when conditions prevent access. McIlroy and Gifford (1997) found that the technique was also very useful to indicate where to locate baits for pigs occurring in low density after a prior control exercise provided an initial knock-down. This application of the technique, however, should be a final phase as the collared pig may also be removed by baits.

7.3.1 Additional information

The use of the Judas technique can be used to collect significant ecological data on pigs within a management area. This can be achieved by recording observations such as numbers seen, age class (by size) and locations when undertaking tracking or by taking more detailed age measurements, samples or sex ratios from culled animals. This information can greatly improve the knowledge on the ecology of local pig populations and how they use their environment. The use of Judas pigs on Defence estate at the Mount Bundy Training Area (ABS Scrofa unpublished data) indicated distinct seasonal movements of pigs along drainage lines and across property boundaries, which would not have otherwise been recognised. This provides data which could form the basis for future co-operative control measures, or at least indicates that effective long term control must consider management in areas outside the core management zone.

7.3.2 Disadvantages

The biggest disadvantage with this technique is the cost of setting up a program and the ongoing cost of searching for the collared pigs (helicopter time). Although the technology is improving, radio transmitters can still fail or collars can be removed by the collared animal. These problems can be minimised with the use of appropriate equipment and experienced advice, however problems will still occur. When buying collars and transmitters spares should be bought and carried in the field to be deployed as needed, potentially saving significant time. The investment in a Judas-collaring program is significant therefore the return for effort must be maximised by good forward planning. Depending on the management area and pig density, 10 collars with two spares, a simple yagi antenna and a mid range receiver could cost between $6000 and $8000, before a collar is even deployed. This cost could rise significantly if different antennas or more complex receivers are required.

Effective tracking from the air requires some skill but this can be quickly gained with direction from experienced operators and practice. Many helicopter pilots/ companies are familiar with this technique and can help with search techniques and antenna placement on aircraft.

7.4 References

McIlroy JC & Gifford EJ 1997. The ‘Judas’ pig technique: a method that could enhance control programmes against feral pigs, *Sus scrofa*. *Wildlife Research* 24 (4), 483–491.

8 Managing feral pig damage – creating a 'landscape of fear'

P Caley[1]

8.1 Introduction

The wild pig (*Sus scrofa*) is a formidable vertebrate pest. A good overview of managing wild pigs can be found in (Choquenot, McIlroy & Korn 1996). But briefly, reasons for their formidable pest status include:

- potentially high rates of increase, such that in good years, reductions of >55% are required to suppress populations for a single year (Caley 1993). In the floodplain habitats of the Top End, the reliability of the annual monsoonal season ensures that virtually every year is a 'good year';
- highly effective anti-predator defences. For example, wolves (*Canis lupus*) appear to only weakly limit wild boar density in Europe (Melis et al 2006), so don't expect too much from the smaller dingo (*Canis lupus dingo*) in Australia. Indeed, Corbett (1995) demonstrated that dingo populations within Kakadu National Park were unable to prevent about a two-fold increase in wild pig abundance resulting from the removal of swamp buffalo (*Bubalus bubalis*);
- a proportion of wild pigs will not eat poisoned bait (Hone 1983), enter traps (Choquenot, Kilgour & Lukins 1993) or be caught/cornered by dogs (Caley & Ottley 1995);
- wild pigs learn to avoid detection from a helicopter (Saunders & Bryant 1988) and a substantial proportion are predicted to survive the most intensive of helicopter shooting exercises (Choquenot, Hone & Saunders 1999).

The effectiveness of control techniques for wild pigs have mostly been gauged by the proportion of pigs removed. Using this metric, shooting from the ground and hunting with dogs has been judged less effective than other methods (Caley & Ottley 1995, McIlroy & Saillard 1989). The aims of pest control, however, should be to reduce pest damage, as opposed to pests *per se*, since reducing pest numbers does not always result in a reducing pest damage (Hone 2007). Where environmental assets to be managed are spatially clumped, the type of control in conjunction with the overall reduction in pig abundance may influence the reduction in damage, if any, to this asset. For example, wild pig control methods such as poisoning and trapping generate no behavioural avoidance of locations where control has been applied. Furthermore, in some instances the most effective location for traps or poisoned bait (eg near permanent water, within vegetative cover) and pre-feeding may conceivably concentrate pig activity in the very areas management is aiming to protect. In contrast, hunting techniques (shooting from the ground or a helicopter, catching/cornering with dogs) may leave surviving pigs with a fear of humans that they also associate with the location of control. Hunting is essentially a form of predation (trapping could also be construed as a 'sit and wait' type of predation although there is typically little chance of escape). Predation is recognised as being able to substantially alter the foraging decisions of herbivores. Such

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predation-sensitive foraging has been observed for animals small (Hik 1995) and large (Sinclair & Arcese 1995). A recent example is how wolves reintroduced to Yellowstone National Park have dramatically altered the foraging decisions of elk (*Cervus elaphus*), leading to plant regeneration not seen for centuries (Ripple & Beschta 2004, 2006, 2007).

So, is there evidence that wild pigs are predation-sensitive foragers? Despite their pest potential, there are many parts of Australia where feral pigs do not occur despite the environment being suitable. The reason for this is largely hunting pressure and human presence. The general consensus is that pigs attempting to live in these areas receive too much harassment for their liking. In the Northern Territory, billabongs subjected to regular recreational hunting pressure receive very few visits from pigs (personal observation). Examples include a large number of billabongs in the local Darwin/Koolpinyah area. The phenomenon is not restricted to open areas. During the 1980s, wild pigs ceased utilising the small rainforest patch at Howard Springs following regular hunting (Brett Ottley pers comm). So anecdotally, at a range of scales, it appears wild pigs may alter their distribution according to the perceived risks of predation.

8.2 Developing a landscape of fear in Kakadu

8.2.1 A possible application of predation-sensitive foraging

The predation by wild pigs on populations of the northern long-necked turtle (*Chelodina rugosa*) aestivating in the substrate of billabongs provides a potential case study in managing wild pig damage. Details of the problem can be found in Fordham, Georges and Brook (2008) and papers cited therein. Briefly, pest damage in this case is the loss of turtles aestivating in the mud as the billabong water levels recede during the dry season. Traditional owners also undertake customary harvests of these turtles and often arrive to find that the pigs have beaten them to it. This is an example of a pest damage being confined to highly localised areas, and appears a good opportunity to test the idea of changing the foraging habits of wild pigs at these billabongs, and hence loss of aestivating turtles, through targeted control efforts.

Currently in some floodplain/billabong areas of Kakadu, wild pigs feel relatively safe in the presence of humans. For example, sighting pigs at close range on evening boat cruises at Yellow Waters is commonplace. They clearly feel safe in that environment, or at least have judged that the foraging benefit outweighs any risk. For management to be effective, pigs need to learn that billabongs are a dangerous place, or at least that the risks outweigh the benefits. Of course, if the food source (in this case turtles) is judged by pigs as ‘worth dying for’, then no amount of control will dissuade them from foraging there.

8.2.2 Logistics

To be sustainable, the predominant control techniques would likely be ground-based (shooting from foot, spotlight shooting from vehicle at night, hunting with dogs). If a helicopter were locally available, possibly doing other work so as to minimise costs, it may be able to quickly ‘buzz’ quite a number of billabongs. It is probably not necessary, let alone possible, to consistently kill all pigs sighted at a billabong. In contrast, it may suffice to leave some survivors. Being reasonably long-lived and intelligent, surviving pigs may pass on learned behavioural avoidance to their offspring. Using well trained hunting dogs has the advantage of being able to quickly locate pigs that are camped in close proximity to a billabong but are not visible. For reasons of welfare, ‘bailing’ type dogs would be most appropriate.

So, can 40-odd rangers do the job of modifying wild pig foraging behaviour at billabongs in parts of Kakadu National Park? The answer depends on how much effort is needed to dissuade pigs from visiting a billabong, and how many billabongs there are to be made ‘dangerous’. The use of remote webcam technology could greatly decrease the number of patrols necessary. When pigs are sighted at a billabong, a response is initiated by the nearest available ranger. In the early stage this may be quite time consuming, but with time and learned avoidance behaviour of pigs, the number of responses should be less.

It could well be that to resource such a control program, a paradigm shift is required on how conduct vertebrate pest control in nature conservation areas with broader involvement of the community. Options could include allowing or even encouraging recreational hunting of wild pigs. Possibly campers could be asked to assist. For example, it may be necessary to *increase* human presence at high conservation value sites. This may require changes to where camping is permitted. Of course, increased human presence will achieve nothing if there is no control as the result will be habituation of wild pigs to humans.

8.2.3 Experimental evaluation

It is essential that pest control is subject to sound experimental evaluation. This should conform to the basics of good experimental design such as the random allocation of subjects (in this case billabongs) to experimental treatments (pig control/harassment). The type and frequency of control should be clearly specified, and what is actually undertaken is recorded. The pest damage response variable should be clear, (eg the number/density of aestivating turtles or yearly rate of change in the number of aestivating turtles, and covariates identified (eg degree of billabong draw down, proximity of billabong to pig refugia etc). The effect of the treatment on the pest, in this case the number of visits of pigs to billabongs, could also be measured to enable the damage function relationship between pest visitation and pest damage to be characterised. Measures must be taken to avoid confounding of treatments (eg pig control operations at billabongs allocated to no control) and interference with the response variable (eg unrecorded customary harvest of turtles).

Clearly the behavioural response elicited in pigs will influence the design. For example, will harassment result in pigs avoiding *all* billabongs within their home range, or just those billabongs where harassment occurs. If the former is the case, then the design must have experimental controls (ie billabongs free of harassment) outside the home range of pigs that encompass billabongs that are subject to harassment. Alternatively, the design could set out to explicitly estimate the effect of pig harassment on pig foraging behaviour at neighbouring billabongs not subject to control.

8.3 Conclusion

Reducing the damage by pigs to localised environmental assets may be possible by changing the foraging behaviour of wild pigs through sustained and targetted control activities. Good experimental evaluation is needed to test this approach.

8.4 References

Caley P 1993. Population dynamics of feral pigs (*Sus scrofa*) in a tropical riverine habitat complex. *Wildlife Research* 20, 625–36.

Caley P & Ottley B 1995. The effectiveness of hunting dogs for removing feral pigs (*Sus scrofa*). *Wildlife Research* 22, 147–54.

Choquenot D Hone J & Saunders G 1999. Using aspects of predator-prey theory to evaluate helicopter shooting for feral pig control. *Wildlife Research* 26, 251–61.

Choquenot D Kilgour RJ & Lukins BS 1993. An evaluation of feral pig trapping. *Wildlife Research* 20, 15–22.

Choquenot D McIlroy J & Korn T 1996. *Managing vertebrate pests: feral pigs*. Bureau of Rural Sciences, AGPS, Canberra.

Corbett L 1995. Does dingo predation or buffalo competition regulate feral pig populations in the Australian Wet-Dry Tropics? An experimental study. *Wildlife Research* 22, 65–74.

Fordham DA Georges A & Brook BW 2008. Indigenous harvest, exotic pig predation and local persistence of a long-lived vertebrate: managing a tropical freshwater turtle for sustainability and conservation. *Journal of Applied Ecology* 45, 52–62.

Hik DS 1995. Does risk of predation influence population dynamics? Evidence from the cyclic decline of snowshoe hares. *Wildlife Research* 115–29.

Hone J 1983. A short-term evaluation of feral pig eradication at Willandra in western New South Wales. *Australian Wildlife Research* 10, 269–75.

Hone J 2007. *Wildlife damage control*. CSIRO Publishing, Melbourne.

McIlroy JC & Saillard RJ 1989. The effect of hunting with dogs on the numbers and movements of feral pigs, *Sus scrofa*, and the subsequent success of poisoning exercises in Namadgi National Park, ACT. *Australian Wildlife Research* 16, 353–63.

Melis C Szafranska PA Jedrzejewska B & Barton K 2006. Biogeographical variation in the population density of wild boar (*Sus scrofa*) in western Eurasia. *Journal of Biogeography* 33, 803–11.

Ripple WJ & Beschta RL 2004. Wolves and the ecology of fear: Can predation risk structure ecosystems? *Bioscience* 54, 755–66.

Ripple WJ & Beschta RL 2006. Linking wolves to willows via risk-sensitive foraging by ungulates in the northern Yellowstone ecosystem. *Forest Ecology and Management* 230, 96–106.

Ripple WJ & Beschta RL 2007. Restoring Yellowstone's aspen with wolves. *Biological Conservation* 138, 514–19.

Saunders G & Bryant H 1988. The evaluation of a feral pig eradication program during a simulated exotic disease outbreak. *Australian Wildlife Research* 15, 73–81.

Sinclair ARE & Arcese P 1995. Population consequences of predation-sensitive foraging - the Serengeti wildebeest. *Ecology* 76, 882–91.

9 Buffalo and Kakadu: personal recollections on 24 years of living and working in Kakadu

B Salau[1]

I have spent 24 years working in Kakadu National Park and have seen many changes to the landscape during this time. I started work in the Jim Jim District in November 1984. Soon after, I joined the mimosa program. With four others I became part of the *Mimosa pigra* control team in 1985. Our sole job was to look for and destroy *Mimosa pigra* growing on the black soil plains, the areas where the feral water buffalo roam. All of my time was taken up working on and searching these Kakadu wetlands. This gave me an opportunity to observe the buffalo, which were a common site for the mimosa workers. Occasionally they would also be seen at the back of the park headquarters compound where the mimosa team lived. We did this work under contract until 1992 when four mimosa positions were made permanent. I continued on as part of the mimosa team until becoming the weeds management officer in 1994. A couple of years later, I was placed in charge of the mimosa program and have continued in this position ever since.

Buffalo where in large numbers in the early years of Kakadu and caused much damage to the environment. Many floodplains were grazed down and covered in buffalo pads (Figures 1 & 2). The water was muddy and yellow. Buffalo created swim channels allowing the flood plains to drain quickly and they spread weeds including mimosa (Figures 3 & 4). Many people claimed that buffalo kept mimosa down, but in my opinion they spread the weed. We would regularly find it growing in buffalo wallows and emerging from buffalo dung.

In the Kakadu region, buffalo were shot for their hides from the 1930s to the 1950s. From the 1950s onwards, two or three safari business were formed in the area. Buffalo management started in Kakadu soon after the Park was declared in 1979. Prior to this, buffalo control was undertaken by the Northern Territory Conservation Commission within Woolwonga Reserve (around the Alligator Billabong area). Dave Lindner was involved in the management of this reserve at the time. Thousands of buffalo were removed by the Conservation Commission.

Buffalo control was carried out in Kakadu using a number of methods in the 1980s and 1990s. Kakadu had two aerial platform shooters – Mick Alderson and James Wauchope. These shooters targeted areas that were impacted by huge numbers of buffalo and shot to waste. Contracts for pet meating were also issued during this period. Portable freezers were taken to the area where buffalo were shot and boned out. Buffalo were also mustered by commercial operators and processed for human consumption. The Park was divided into sections and the opportunity to muster buffalo was open to commercial operators through a tender process. Tenders were advertised annually.

The animals were caught using portable steel yards with hessian wings leading out from the entrance to the yard. The wings would funnel the animals into the yard. The opposite side of the yard had a gate to allow the animals to enter onto the trucks. Large herds of buffalo were mustered by helicopter towards the yards, then run into the yard using 'bull catchers' (Figures 5 & 6). These were cut down four wheel drive vehicles, some of which were fitted with bionic arms. The arms were mechanical and when the vehicle ran along side a buffalo the operator

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moved the arm around the buffalo's neck. The buffalo was directed back to the trap or tied to a tree to be picked up later by a truck.

Live animals were delivered to both the Mudjinberri and Point Stewart abattoirs.

Mudginberri meat works was being run by Jay Pendavis. There was residential housing and a social club for the workers there. It was during the 1980s that Mudjinberri meat works became famous for having a picket line on the East Alligator road to stop work over an industrial dispute.

Figure 1 A perfect example of buffalo getting into the water and rubbing against the trees. At times the trees would fall over. Photo by Gary Lindner.

Figure 2 Buffalo in high numbers would severely degrade the wetlands. Photo by Dave Lindner.

Figure 3 Swim channels created by buffalo. Photo by Buck Salau

Figure 4 Extensive swim channels along the lower Mary River. Photo by Dave Lindner.

Some of the buffalo catchers during this period were Donny Stewart and Geoff Pendavis, Alan and 'Skeater' Davis, Frank McCloud, and the Swartz brothers – all interesting people to talk to. These buffalo catchers would sometimes grade new roads to allow the semi trailers to access the areas where temporary yards were built. As a result, many of the remote areas in

Kakadu during this period had road access. Today many of these roads in the northern section of Kakadu are overgrown with vegetation and no longer exist.

When buffalo numbers became too low to support commercial mustering the contractors moved out leaving young animals and small herds. In around 1986, to further reduce buffalo numbers, contractors had to put up a bond to ensure that all animals were removed from their area. The bond was in addition to paying the tender price to work an area. The condition was that at the end of the muster the contractor had to shoot the remaining animals. After this was carried out, Kakadu staff flew over the area for a two hour inspection and if more than a certain number of animals were observed – I think it was 25 – the contractor had to remove the remaining animals or forfeit the bond.

In 1986, a contract was let to live muster buffalo from the Benbunga and Four Mile Hole areas. The buffalo in this area were very educated, having survived previous mustering and culling attempts, and moved into the thick paperbarks of the Benbunga swamp to avoid capture. This made them difficult to muster. However, that year was very dry and the swamp dried up. A small number of buffalo perished from lack of water. During mimosa surveys of the area, animals were often sighted standing around drying up water holes. Some of the weaker animals would become bogged and die (Figure 7). Approximately 4500 buffalo were mustered from the tender area that year. At the end of the mustering season Kakadu staff, inspecting the area from the air, sighted a large number of animals remaining. Two helicopters were used to cull a further 4000 buffalo.

In 1990, Kakadu was issued with a de-stock notice to eradicate all unfenced buffalo and cattle by 1997. This was called the BTEC, the Brucellosis and Tuberculosis Eradication Program. This was a wind fall for Kakadu as it was funded by the Australian Government. Assistance was also given to Kakadu by the Northern Territory Department of Primary Industry (DPI). They ran the program by. suppling aerial shooters, training for Kakadu staff, collars and staff to track the animals. Pat Carrick was the stock inspector. Animals were randomly sampled in the Park and in Arnhemland for Tuberculosis. Buffalo in Arnhem land were shot as well. However, in some areas of Arnhemland where the disease was not detected, the buffalo were left.

To illustrate the number of buffalo in the Park during the BTEC program, over 400 buffalo were removed in a single day from a small area at Binjilbinjil on the floodplain near where the Magela flows into the East Alligator river. Four choppers were used that day. As the buffalo numbers reduced, Pat Carrick became involved in the program, using tracking collars and the judas technique to find remaining buffalo herds. Using this method, a herd of buffalo were located and a buffalo cow was tranquilised to allow a tracking device on a collar to be placed around the cow’s neck. Many animals were collared and tracked from a helicopter with a receiving antenna. The collared animals would lead the shooters to a herd. The animals found with the cow were destroyed. The collared cow and her offspring were left to join another group of buffalo. After a while the cows become fairly cunning and started to hide, but the calves would often give them away. They would get a bit nervous and stick their heads out of the scrub. After a period of time the collars stopped transmitting. An old buffalo cow with drooping horns was sighted in 2005 wearing a old tracking collar. This animal was destroyed during an aerial cull in 2006.

Figure 5 Muster at Goodparla. Helicopters were used to muster the buffalo towards the holding yards. Photo by Gary Lindner.

Figure 6 Bull catchers can be seen in the background. These modified four wheel drives were used to run the animals into the holding yards. Photo by Gary Lindner.

Figure 7 During dry years, buffalo would often die of thirst. This photograph was taken in 1972 when thousdands of animals began to starve. Photo by Frank Woerle.

Eventually with few animals remaining, it became difficult to find cows to collar. Buffalo bulls were then also fitted with collars. At one stage, two buffalo bulls were purchased, fitted with tracking collars, transported in pens slung under helicopters and released over 100 kms away from their home. One of these buffalo returned home within the week. Not only did the owners get payed for their animal, they got it back as well. I think the bulls were both from Spring Peak.

With the buffalo population reduced, the Gagudu Association decided to set up a buffalo farm to keep a herd of buffalo behind wire to supply bush meat to its members. These animals were wild caught and supplied by the catching contractors. All of these animals were tested three times and declared Turbuculosis free. The Gagudu Association employed Dave Lindner to manage the buffalo farm. Today this farm is still operated by Dave Lindner and continues to supply bush meat to local Aboriginal people.

By the end of the BTEC program it was estimated that around 100 buffalo remained in Kakadu. The animals were very rarely seen by Kakadu staff for the next few years. Only the occasional wandering buffalo was sighted, usually escaped from a neighbouring property and sporting tipped horns and ear tags. These animals often turned up on the boundary fence of the buffalo farm looking to join a herd.

Buffalo numbers have increased over the past few years and sightings are becoming more regular in certain areas such as the Gimbat and Goodparla areas in the Mary River District of Kakadu. The Benbunga area on the western boundary of the park has a population of buffalo, but due to the area being a hot spot for mimosa and olive hymenachne, both weeds of national significance, buffalo are destroyed as often as possible to reduce the risk of spreading the weed infestation to other areas.

The removal of large numbers of buffalo made a remarkable change to the floodplains in the northern area of the Park where I worked. There is far more vegetation and perhaps the floodplains do not drain as quickly. Waterholes are much clearer. Benbunga is the greatest example of the change that has ocurred following the removal of buffalo. During the buffalo days, this area was bare ground, buffalo pads and grass cropped to a few centimetres. There were big, bare islands in the swamp with wallows that stank of buffalo. They are now almost non-existent. There are a lot more paperbarks around now. *Sesbania formosa*, a native species, was found in only a few patches and were always broken by buffalo. The buffalo like to rub up against it. This plant seems to have increased its range within the Park. These days we rarely find mimosa in buffalo wallows. Many of the buffalo wallows have filled in, though you can still see some around. The waterholes which were yellow from buffalo are now clear and growing waterlillies. The recovery of the southern end of the Park, which I am not so familiar with, has been much different to the northern section. Some southern areas of the Park have not recovered so well.

10 Buffalo and the perched wetlands of the Western Arnhem Land Plateau

F Hunter[1], D Yibarbuk[1] & P Cooke[1]

10.1 Introduction

The plateau is a vast area of high biodiversity that rises from what is now Kakadu National Park and extends eastward into Western Arnhem Land to around the headwaters of the Cadell River. Water buffalo *(Bubalus bubalis)* have had two quite different kinds of impact on the Western Arnhem Plateau over a period of more than 100 years. The first being the gradual depopulation of the Plateau, and the second being serious gully erosion damaging the unique 'perched wetlands' of the plateau.

The venerable Bardayal Nadjamerrek AO, the inspiration and driving force bringing indigenous land management back to the plateau, is able to tell us that the buffalo made the climb into the plateau landscape around World War II. The numbers of 'mountain buffalo' were not seriously reduced during the Brucellosis and Tuberculosis Eradication Campaign of the 1980s and the herds have multiplied, largely out of sight and out of mind of the plateau diaspora.

Buffalo management is a key focus for current management, particularly as landowners prepare to declare an Indigenous Protected Area of some 12 500 square kilometres in mid 2009. An adjoining Djelk IPA along Warddeken's eastern flank will create an aggregated indigenous protected area somewhat larger than Kakadu and Nitmiluk National parks combined, stretching from off-shore islands to the peaks of the plateau.

10.2 History of depopulation of the plateau

From late in the nineteenth century the thriving buffalo herds of the Alligator Rivers lowlands supported a buffalo hide industry that attracted white men from far afield. It also drew in black men and women, as families and as individuals, from closer locations. Aboriginal elders in Western Arnhem Land today say the attractions of the buffalo camps, tobacco not least amongst them, were key factors in a progressive depopulation of the *Warddewardde* or plateau country. This population movement had a dramatic impact on indigenous land management and particularly on fire management. Longstanding patterns of many small and relatively cool fires over the dry season gave way to a new regime of less frequent but more extensive and damaging hot fires.

Since 1996, landowners from the plateau lands have been working to bring back effective indigenous management to the plateau. With financial resources from carbon abatement offsets and a collaboration of black and white expertise, fire is coming back under control. In addition, grassy weeds are being addressed in a regional weed management strategy. The landowners have created a not-for-profit public company, Warddeken Land Management Limited, to gather resources and assist landowners with land management in one of the most inaccessible parts of Australia.

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10.3 Buffalo have different values

As outstations became established around the more accessible edges of the plateau, buffalo became an important and highly valued food source. In addition, landowner knowledge of returns from buffalo mustering and BTEC compensation paid elsewhere have created a view of buffalo as an economic asset, even though commercial harvesting is not economically viable on the plateau. This is not surprising for a people who, as a group, are amongst the poorest financially in this country. But the experience and observations of those indigenous and non-indigenous people overflying the plateau annually to conduct aerial prescribed burning, point to a view that the unharvestable remote buffalo herds are perhaps a serious liability rather than an asset. They are threatening biodiversity and the cultural inheritance of future indigenous generations. Damage from buffalo might also affect the potential of landowners to develop tourism, one of the few economic development options that could be feasible on the plateau.

10.4 Impacts of buffalo on perched wetlands

It is becoming obvious that buffalo are increasingly damaging what some of us believe may be a distinct ecological community. This community, that for want of an official descriptor may be called the perched wetlands of the Western Arnhem Land Plateau, is dependent on the stability of geomorphological and hydrological factors.

Buffalo are well dispersed in the wet season, but towards the end of the dry season they gather on those perched wetlands in densities that once devastated Kakadu’s lowland plains. Even where no surface water is visible in these areas at the end of the dry it is usually just below ground level, maintaining perennial vegetation of grasses, herbs and forbs in often boggy ground.

Large areas are seriously damaged by intense pugging by buffalo. When the wet comes, buffalo tracks gather water beginning a process of gully erosion. As gullies cut down into the sandy substrate a process of wetland draining begins. At their head, erosion gullies may move up and drain spring waterholes of great natural and cultural importance. Eroded sand washes down and infills other waterholes, sometimes plugging the sources of spring water there.

10.5 Recent aerial cull of buffalo

In 2008, with assistance from a number of sources, but specifically with funding from Bush Heritage Australia and the Federal Government’s IPA program, aerial culling was undertaken on four estates where landowners had given permission. In giving permission one landowner summed up his view by saying ‘kill them, they are killing our country’.

In October 2008, Fred Hunter, a plateau landowner, Warddeken director and Kakadu ranger, shot 711 buffalo on perched wetlands where intense damage was obvious. A week later, a helicopter overflight of these areas showed that some 307 buffalo had come back onto the same areas, demonstrating concentrations up to 30 beasts per sq km. The results of this culling exercise are set out in Tables 1–3.

Table 1 Summary of costs and number of animals removed during the 2008 cull

	Upper Malkawo Ck Map1	Djolok Valley Map 2	Nakarriken Springs Map 3	Kabulukdayo Drainage Map 3	Makkalarl Map 3	Total
Buff shot	306	100	187	31	87	711
Bullets	1200	360	561	89	258	2468
Chopper hrs	8.96	2.6	6.32	0.76	3.16	21.8
Chopper cost inc GST	6092	1768	4297	516	2148	14821
Fuel cost						4200
Centroid position	13*00' 133*49'	12*46' 134*05'	12*44' 133*35.5'	12*44.3' 133*36.2'	12*40' 133*40'	
Count live at 30/10/08	149	38	32	24	64	307

Chopper hours includes proportion of ferry to and from Jabiru 1.8 hours and non-shooting time en-route from Kabulwarnamyo Ranger Station to shooting areas

Table 2 Cost per animal

Item	Total cost	Per beast
Chopper ferry and shoot inc GST	$14,821	$20.84
Bullet cost ($2.00 each)	$4,936.	$6.94
Refly to count reoccupation	$1,360	$1.91
Fuel cost at October 2008 prices	$4,200	$5.90
	$25,317.00	$35.59

Table 3 Relative density of buffalo

	Upper Malkawo	Djolok Valley	Nakarriken Springs	Kabulukdayo Drainage	Makkalarl	Total
Buff	306	100	187	31	87	711
Area	13.5 sq km	5 sq km	7.5 sq km	2.5 sq km	6 sq km	34.5
Density per sq km	22.6	20	24.9	12.4	14.5	20.6
Include revisit	455/33.7	138/27.6	219/29.2	55/22	151/25.1	1018 /29.5

Almost all shooting took place within a 500m strip along drainage lines. Distance measurements were made on Fugawi maps of areas where most shooting took place. Areas shot were calculated using these figures. A second calculation was made using numbers from a revisit on 30 October. Buffalo counted on revisit are assumed to have been close by, but not seen, in forest during the shooting visit, as there was little time for the 'vacuum' of shooting to pull in distant buffalo between visits. The aggregated number is therefore assumed to be a minimum count of buffalo using the shot areas of environmentally fragile spring flats at this time of year.

10.6 Planning control and monitoring success

A strategic management approach is being developed and will be discussed widely with landowners during 2009.

In early 2009, it is planned to commission remotely sensed mapping of the wetlands, followed by an aerial survey to ground truth the mapping and provide data that will allow a 'triage' approach to management intervention and identify priority areas.

Trying to establish targets within a framework of aerial surveying would be costly to obtain and too imprecise to be of much management use. Therefore, the approach will be to use annual intensive aerial culling on select perched wetlands at a time of year when the majority of buffalo are gathered there. Experience gathered in 2008 suggests that two shoots separated by a period of around ten days at each sight would be effective. The late dry season is the optimal time to conduct control, when the buffalo are concentrated around the wetlands.

Data (eg cost per animal, number of animals shot per hour) will be collected during each culling operation to use as an index by which to measure success over time. In addition, since the cull Warddeken Rangers, assisted by ecologist Emilie-Jane Ens from the Centre for Aboriginal Economic Policy Research, have visited a number of culling locations and established monitoring sites and transects. These will be used to track the degree to which sites recover and to identify gullies gouged into the perched wetlands that may require mechanical intervention to arrest the process.

The decision whether this becomes a plateau-wide management approach is a matter for landowners. Initially the culling focus will be on perched wetland areas suffering serious damage. Areas that landowners want to keep for subsistence hunting will be avoided.

10.7 Funding

An annual program would require considerable funding indefinitely to pay for helicopter and ammunition costs. However, landowners expect to declare the Warddeken IPA during 2009. As part of the National Reserves System lands, such a feral control strategy for this high biodiversity value area seems a cost-effective management approach with significant public benefit.

As well as protecting the perched wetlands of the plateau, the removal of buffalo would also provide a significant saving in greenhouse gas emissions. Each buffalo burps a methane equivalent of around two tons of CO_2 each year. A buffalo can live for 20 to 25 years. If it were possible to find an offset buyer, and for such emissions abatement to be officially recognised, the abatement could provide a strong incentive for landowners to support culling and perhaps meet some of culling costs.

Figure 1 Buffalo damage on an extensive spring-fed 'perched wetland' near Nakarriken on the West Arnhem Plateau. Based on animals shot and a further count a week later, buffalo densities in this area were about 30 animals per sq kilometer. Mechanical earthworks may be needed to arrest the draining of the wetland.

Figure 2 Gully erosion on a west Arnhem Plateau perched wetland. The erosion starts with a buffalo pad and rapidly cuts down into the sandy sub-strate. The gully then begins to drain the spring waters associated with the wetland flat.

Figure 3 This gully erosion on a perched wetland of the west Arnhem Land Plateau began with buffalo pads similar to those visible at the sides of this gully. Water gathering in the buffalo pad during heavy wet season rains soon began the process of cutting into the sandy substrate.

10.8 Postscript

The Warddeken and Djelk Indigenous Protected Areas were officially declared on 24 and 25 September 2009 by Peter Garrett, the Minister for the Environment, Heritage and the Arts. These IPAs together with Kakadu and Nitmiluk National Parks create a huge conservation corridor stretching from Nitmiluk to the Arafura Sea.

11 Buffalo population dynamics: genetic studies informing management

CR McMahon[1]

11.1 Introduction

Invasive and feral species have been identified as an important driver of biodiversity loss (Grosholz 2005, Salo et al 2007). Australia, like many other isolated islands has developed an ancient, unique and diverse ecosystem (Bowman 1998). This unique ecosystem has been under extreme pressure ever since humans arrived around 40 000–60 000 years ago (Burney & Flannery 2005, Turney et al 2008). One of the more damaging and economically important introduced species in Australia is the Asian swamp buffalo (*Bubalus bubalis*) – (Bradshaw et al 2007). Ironically, swamp buffalo are listed as Endangered by the IUCN and current estimates suggest that there are probably less than 4000 in their native habitats in Asia (Hedges 1996).

Swamp buffalo are a major problem in Australia due mainly to the environmental damage they cause such as saltwater intrusion of wetlands and trampling of sensitive habitats (Werner 2005, Werner et al 2006, Braithwaite et al 1984, Petty et al 2007), their potential threat to Australia's livestock industry as hosts for disease (Ward et al 2007, Cousins & Roberts 2001, Thomson 1977, Standfas & Dyce 1972, Letts 1964), and the danger they pose to human safety (Altman 1987, Robinson & Whitehead 2003, Robinson et al 2005). Given these ecological, economic and social impacts, there is an urgent need to manage buffalo effectively and efficiently.

An important step to inform management of introduced and invasive species is to determine the history of introduction and quantify the rate of spread from introduction sites (Hampton et al 2004, Edwards et al 2004). Contemporary molecular techniques in conjunction with demographic and life history information are useful tools for understanding the dynamics, population structure, biology and colonisation dynamics of plants and animals including invasive species such as buffalo (Frankham et al 2002, Taylor et al 2000, Spencer et al 2005, Ramsey et al 2002, Sakai et al 2001). Little is known about the genetic population structure of buffalo, or how their rates of spread, carrying capacity and mating behaviour have changed over the course of successive genetic bottlenecks since introduction.

Recent genomic studies of swamp buffalo have detailed the genetic diversity and population structure of buffalo populations within south-east Asia, Australia, Nepal and India (Barker et al 1997a, Barker et al 1997b, Vijh et al 2008, Flamand et al 2003); however, a detailed and widespread analysis of genomic diversity and sub-population structure is not available for the largest population of wild swamp buffalo that now resides in Australia. We provide the first detailed analysis of the Asian swamp buffalo population from Australia using 10 microsatellites genotyped from 430 individuals from eight geographically distinct sub-populations. We aim to (1) establish the rate and most probable history of spread from detailed microsatellite data derived from the eight sub-populations, and (2) quantify the genetic distance and mixing rates between populations.

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11.2 Methods

A total of 430 6mm skin biopsies were collected from feral swamp buffalo from across the Northern Territory, Australia representing eight geographically distinct populations. Each sample was stored in 20% NaCl-saturated DMSO (dimethylsulfoxide) prior to DNA extraction. DNA was extracted and purified using standard SDS/proteinase K protocol and phenol-chloroform extraction techniques (Sambrook & Russell 2001). We used 10 polymorphic microsatellite loci for genotyping (Barker et al 1997b, Barker et al 1997a) and for quantifying relatedness between populations. The 10 polymorphic loci were: CSSM008, CSSM019, CSSM022, CSSM029, CSSM032, CSSM038, CSSM041, CSSM043, CSSM047 and CSSM057.

11.3 Results

Allelic diversity for swamp buffalo from the Northern Territory was depauperate when compared to allelic diversity from swamp buffalo in general. The allelic diversity (A) we observed at the 10 microsatellite loci examined to A observed at the same 10 loci from a previous global study of swamp buffalo genetic diversity (Barker et al 1997a) was low. Such low diversity is expected from a population that had a small founding population (< 80 buffalo (Barker et al 1997a)) and one that has experienced at least two bottlenecks since introduction. The within population microsatellite diversity of *Bubalus bubalis* populations in northern Australia was low, having between two and four alleles locus-1, with an average of 3.3 alleles locus-1 (SD = 0.68). However, because there is a strong relationship between the number of individuals sampled and the numbers of alleles observed, we determined allelic richness (allele diversity for each geographic area corrected for sample size); allelic richness remained low and varied from 2.3 to 2.7 alleles locus^{-1}.

Assignment test results revealed that recent migrations into the BTEC-bottlenecked populations of Kakadu and Oenpelli were high, with high influx too observed into the non-BTEC-targeted Bulman population that experiences regular density reductions from a dedicated harvest of ~ 3000 animals year^{-1}.

11.4 Discussion

As expected from a multiply bottlenecked population, genetic variation in swamp buffalo from northern Australia was low compared to the that found in swamp buffalo from India and South-East Asia (Barker et al 1997a, Vijh et al 2008). Despite this reduced genetic variation, the Australian population has thrived (Tulloch 1969, Tulloch 1970, Freeland & Boulton, 1990) and spread outwards from introduction sites and into culled sites at high rates over the last 160 years (covering ~224 000 km^2 in that time).

Although buffalo in Australia experienced two bottlenecks since their introduction, a small proportion (estimated at ~ 20%) escaped the second bottleneck in the eastern part of its northern Australia range. BTEC did not operate with uniformity across the entire range of buffalo, concentrating its destocking efforts in a general area from the western coast of the Northern Territory to west of the Mann River in Arnhem Land, and south roughly to Kakadu National Park's southern border. Coincidently and not surprisingly, it is in this area that we observe most migration activity.

The subpopulation structure we detected suggests that each population, while connected over generational time scales, generally remain in their immediate vicinity over the course of management-tractable periods. Therefore, management aimed at protecting Australia's lucrative livestock industry trading under Australia's disease-free status, will benefit directly from this knowledge. For example, the localised introduction and subsequent rapid detection of disease could be efficiently managed from local culls because short-term movements of long-distance are less likely. Our results showcase how management of animals for disease control can be effectively informed via genetic studies and so avoid the need for expensive broad-scale intervention.

11.5 References

Altman JC 1987. *Hunter-gatherers today: an aboriginal economy in Northern Australia.* Australian Institute of Aboriginal Studies, Canberra.

Barker JSF, Moore SS., Hetzel DJS, Evans D, Byrne K & Tan SG 1997a. Genetic diversity of Asian water buffalo (*Bubalus bubalis*): microsatellite variation and a comparison with protein-coding loci. *Animal Genetics* 28, 103–115.

Barker, JSF, Tan SG, Selvaraj OS & Mukherjee TK 1997b. Genetic variation within and relationships among populations of Asian water buffalo (*Bubalus bubalis*). *Animal Genetics* 28, 1–13.

Bowman D 1998. Tansley Review No. 101 – The impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140, 385–410.

Bradshaw, CJA, Field IC, Bowman DMJS, Haynes C & Brook BW 2007. Current and future threats from non-indigenous animal species in northern Australia: a spotlight on World Heritage Area Kakadu National Park. *Wildlife Research* 34, 419–436

Braithwaite RW, Dudzinski ML, Ridpath MG & Parker BS 1984. The impact of water buffalo on the monsoon forest ecosystem in Kakadu National Park. *Australian Journal of Ecology* 9, 309–322.

Burney DA & Flannery TF 2005. Fifty millennia of catastrophic extinctions after human contact. *Trends in Ecology & Evolution* 20, 395–401.

Cousins DV & Roberts JL 2001. Australia's campaign to eradicate bovine tuberculosis: the battle for freedom and beyond. *Tuberculosis* 81, 5–15.

Edwards GP, Pople AR, Saalfeld K & Caley P 2004. Introduced mammals in Australian rangelands: Future threats and the role of monitoring programmes in management strategies. *Austral Ecology* 29, 40–50.

Flamand JRB, Vankan D, Gairhe KP, Duong H & Barker JSF 2003. Genetic identification of wild Asian water buffalo in Nepal. *Animal Conservation* 6, 265–270.

Frankham R, Ballou JD & Briscoe DA 2002. *Introduction to conservation genetics.* Cambridge University Press, Cambridge.

Freeland WJ & Boulton WJ 1990. Feral water buffalo (*Bubalus bubalis*) in the major floodplains of the top end, Northern Territory, Australia: population growth and the brucellosis and tuberculosis eradication campaign. *Australian Wildlife Research* 17, 411–420.

Grosholz ED 2005. Recent biological invasion may hasten invasional meltdown by accelerating historical introductions. *Proceedings of the National Academy of Science USA* 102, 1088–1091.

Hampton JO, Spencer PBS., Alpers DL, Twigg LE, Woolnough AP, Doust J, Higgs T & Pluske J 2004. Molecular techniques, wildlife management and the importance of genetic population structure and dispersal: a case study with feral pigs. *Journal of Applied Ecology* 41, 735–743.

Hedges S 1996. *Bubalus bubalis*. 2007 IUCN Red List of Threatened Species. IUCN, www.iucnredlist.org. Downloaded on 08 January 2008.

Letts GA 1964. Feral animals in the Northern Territory. *Australian Veterinary Journal* 40, 84–88.

Petty AM, Werner PA, Lehmann CER. Riley JE, Banfai DS & Elliott LP 2007. Savanna responses to feral buffalo in Kakadu National Park. *Australia. Ecological Monographs* 77, 441–463.

Ramsey D, Spencer N, Caley P, Efford M, Hansen K, Lam M & Cooper D 2002 The effects of reducing population density on contact rates between brushtail possums: implications for transmission of bovine tuberculosis. *Journal of Applied Ecology* 39, 806–818.

Robinson CJ, Smyth D & Whitehead PJ 2005. Bush tucker, bush pets, and bush threats: Cooperative management of feral animals in Australia's Kakadu National Park. *Conservation Biology* 19, 1385–1391.

Robinson CJ & Whitehead P 2003. Cross-cultural management of pest animal damage: A case study of feral Buffalo control in Australia's Kakadu National Park. *Environmental Management* 32, 445–458.

Sakai AK, Allendorf FW, Holt JS, Lodge DM, Molofsky J, With KA, Baughman S, Cabin R. J, Cohen JE, Ellstrand NC, McCauley DE, O'Neil P, Parker IM, Thompson JN & Weller SG 2001. The population biology of invasive species. *Annual Review of Ecology and Systematics* 32, 305–332.

Salo P, Korpimaki E, Banks PB, Nordstrom M & Dickman CR 2007. Alien predators are more dangerous than native predators to prey populations. *Proceedings of the Royal Society B-Biological Science* 274, 1237–1243.

Sambrook J & Russell WD 2001. *Molecular cloning: a laboratory manual*. Cold Spring Harbor Press, New York.

Spencer PBS, Lapidge SJ, Hampton JO & Pluske JR 2005. *The sociogenetic structure of a controlled feral pig population*. Wildlife Research 32, 297–304.

Standfast HA & Dyce AL 1972. Potential vectors of arboviruses of cattle and buffalo in Australia. *Australian Veterinary Journal* 48, 224–227.

Taylor AC, Cowan PE, Fricke BL & Cooper DW 2000. Genetic analysis of the mating system of the common brushtail possum (*Trichosurus vulpecula*) in New Zealand farmland. *Molecular Ecology* 9, 869–879.

Thomson D 1977. Diseases of water buffalo in Northern Territory of Australia. *Australian Veterinary Practitioner* 7, 50–52.

Tulloch DG 1969. Home range of feral swamp buffalo, Bubalus bubalis Lydekker. *Australian Journal of Zoology* 17, 143–152.

Tulloch DG 1970. Seasonal movements and distribution of the sexes in the water buffalo, Bubalus bubalis, in the Northern Territory. *Australian Journal of Zoology* 18, 399–414.

Turney CSM, Flannery TF, Roberts RG, Reid C, Fifield LK, Higham TFG, Jacobs Z, Kemp N, Colhoun EA, Kalin RM & Ogle N 2008. Late-surviving megafauna in Tasmania, Australia, implicate human involvement in their extinction. *Proceedings of the National Academy of Sciences* 105, 12150–12153.

Vijh RK, Tantia MS, Mishra B & Kumar STB 2008. Genetic relationship and diversity analysis of Indian water buffalo (*Bubalus bubalis*). *Journal of Animal Science* 86, 1495–1502.

Ward MP, Laffan SW & Highfield LD 2007. The potential role of wild and feral animals as reservoirs of foot-and-mouth disease. *Preventive Veterinary Medicine,* 80, 9–23.

Werner PA 2005. Impact of feral water buffalo and fire on growth and survival of mature savanna trees: An experimental field study in Kakadu National Park, northern Australia. *Austral Ecology* 30, 625–647.

Werner PA, Cowie ID & Cusack JS 2006. Juvenile tree growth and demography in response to feral water buffalo in savannas of northern Australia: an experimental field study in Kakadu National Park. *Australian Journal of Botany* 54, 283–296.

12 Under the radar? The occurrence, impact and management of feral cats and black rats in Kakadu

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12.1 Introduction

Most exotic mammals, such as buffalo, are highly conspicuous and their environmental impacts may be obvious. They have a high profile, are writ large in management planning, and may be relatively straightforward to control. When most park managers think of pest management, it is of buffalo, pigs, donkeys, cattle or horses. These are indeed pests, and it is appropriate that managers attempt to control them. But there are other pests in this region that are far less conspicuous, are rarely considered in management plans, and for which control actions are at best occasional and incidental – and consequently typically ineffective. Here, we consider the feral cat (*Felis cattus)* and the black rat (*Rattus rattus)*. We briefly review the limited information on the occurrence and impacts of these species, and provide some recommendations for management.

12.2 The species and occurrence in the region

Feral cats occur across the entire Australian mainland and many offshore islands. There has been considerable argument about whether cats preceded European settlement of Australia, with suggestions of arrival up to several centuries earlier either with Macassan trepangers to northern Australia or from shipwrecks on the Western Australian coast. However, the most thorough recent review of the historical record strongly suggests that the evidence for prior arrival is unconvincing, and that instead they spread from multiple sources subsequent to European settlement (Abbott 2002). Early records from the Top End include around the Port Essington settlement (Cobourg Peninsula) in 1845 (although it is not clear that this record refers to feral individuals) and around 1880 in the Pine Creek area (Abbott 2002). In describing the mammal fauna observed in the Darwin – Pine Creek area in the 1920s, the collector Charles Hoy reported that 'the domestic cat ... is very plentiful and was the only introduced pest met with' (Short & Calaby 2001). It is possible that the distribution of feral cats increased with the outstation movement in the 1960s and 1970s, as pet cats were commonly taken to newly established outstations for their role in protection from snakes. There is some anecdotal evidence for a recent increase in their abundance in some areas including Kakadu. There have been no detailed published studies of the abundance of feral cats in the Kakadu area, but some information is available from incomplete or unpublished studies by Michelle Watson, Laurie Corbett and Alicia Cameron. Estimating the abundance and distribution of cats may be difficult: They are not readily detected during standard wildlife surveys, are relatively secretive and may be difficult to trap. The occurrence of tracks in regularly monitored sand plots appears to be the most effective technique for the assessment of distribution and abundance.

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The black rat (*Rattus rattus)* is a European rodent that is now widespread but patchily distributed across much of higher rainfall and coastal Australia. Its history in northern Australia is very imprecisely known. Black rats were common in many ships in the eighteenth and nineteenth century, and probably colonised most early settlements. In the 1890s, Dahl (1897) reported that the black rat was 'observed in Arnhem Land, and frequently found in the dwellings of colonists. Except in these houses and their immediate surroundings, I did not observe it'. It remains very abundant in Darwin suburbs and surrounding bushland, and has been regularly reported in some other town areas (including Katherine, Gove and Jabiru), but there have been relatively few records in the Top End bushland until the last two decades, during which extensive wildlife surveys have allowed for a far better appreciation of its occurrence away from town areas. Recent records include Elsey National Park (near Mataranka), Macadam Range (upper Daly area), Victoria River (Gregory National Park area), Truant Island (English Company group), Flora River (Katherine area), Kabulwarnamyo (Arnhem Land plateau), and several areas in Kakadu, including near Mary River ranger station and distant from infrastructure in the Wildman River area (Griffiths 1997; Woinarski 2000; JW unpubl.). Its incidence in fixed fauna monitoring plots in Kakadu has increased over the last 10 years, one of the few mammal species to show such a trend; and its occurrence around Kabulwarnamyo is very recent (last 2–3 years). However, there are no adequate data available to estimate population size, density or precise distribution in wild populations in Kakadu or elsewhere in the Top End.

12.3 Impacts and evidence

There is damning evidence of the detrimental impacts of feral cats and black rats upon biodiversity in many parts of their range. 'Predation by feral cats' is a listed key threatening process under the *Environment Protection and Biodiversity Conservation Act*, with a threat abatement plan (www.environment.gov.au/biodiversity/threatened/publications/tap/cats/index.html) that prioritises management actions, particularly for Commonwealth and World Heritage areas. Black rats per se are not so listed, but 'Predation by exotic rats on Australian offshore islands of less than 1000 km^2' is listed, and a review of known impacts is available at www.environment.gov.au/biodiversity/threatened/ktp/island-rats.html. Note that the restriction of this key threatening process to islands is not because there is less impact on mainland areas, but rather because it was deemed unfeasible to eliminate the threat on mainland areas.

Feral predators (foxes and cats) are widely accepted to have been important contributing factors in the extinction of about 15 species of mammals in Australia over the last 100 years, and a wide range of recent studies (mostly using predator exclosure fencing or intensive baiting) has provided compelling evidence of the continuing impact of feral predators on native wildlife, particularly mammals, but also birds and reptiles (Johnson 2006).

In the Top End region, there is little evidence against which their impact can be assessed. The most intriguing and concerning evidence is the highly significant decline in native mammals in Kakadu and other areas evident in recent monitoring programs (Woinarski unpubl.), with this decline largely occurring in those groups of mammals that have proven particularly susceptible to feral predators elsewhere in Australia (bandicoots, possums, larger rodents, larger dasyurids).

There is some circumstantial evidence that several threatened mammal species, notably including northern brush-tailed phascogale (*Phascogale pirata)* and brush-tailed rabbit-rat (*Conilurus penicillatus*), declined or disappeared from islands in the Sir Edward Pellew group over the last few decades coincident with the introduction of cats to those islands (Taylor et al

2004). Populations of northern quolls (*Dasyurus hallucatus)* translocated to two islands off north-eastern Arnhem Land reached within five years of their introduction densities far surpassing those of any known mainland populations (Rankmore et al 2007). Such population density may reflect lack of interspecific competition and/or lack of predation by feral cats; but it may also be due to particular habitat suitability, absence of disease or superabundant food resources.

Radio-tracking studies focusing on potential prey species provide a good independent measure of the impacts of predation by feral cats, but there have been relatively few such studies in Kakadu or elsewhere in the Top End region. A detailed 10 month study by Sweet (2007) of the tree monitors (goannas) (*Varanus tristis)* and (*V. scalaris)* in Kakadu (Baroalba area) involved radio-tracking of 50 individuals (but for transmitter failure or other reasons, most of these were tracked for appreciably less than 10 months). Of these 50 individuals, six were killed by feral cats, by far the largest source of mortality. Dividing the total tracking time (5685 'monitor-days') by this cat predation rate suggests that a monitor would, on average, be expected to live for 2.6 years after initial capture before being killed by a cat, a relatively short span for what would normally be a relatively long-lived animal (Greer 1989).

In a study prior to the arrival of cane toads in the Kapalga area of Kakadu, predation by feral cats was the cause of death for two of 15 radio-tracked northern quolls for which mortality source was determined, surpassed as a mortality source only by dingoes (4) and vehicles (3) (Oakwood 2000). In this study, predation rates were heightened in extensively burnt areas.

Feral cats may have impact on native wildlife not only through predation but also through spread of disease, particularly toxoplasmosis. There has been little assessment of this impact in the Kakadu region, with but one limited study of northern quolls suggesting low incidence of toxoplasmosis (Oakwood & Pritchard 1999).

We acknowledge the qualm that if feral cats have been present in the Kakadu area for perhaps 100 years or so, why should the decline in native mammals over the last 10–30 years be blamed on cats? If cats are contributing to the decline, then this riddle may be explained by a recent increase in cat numbers, by a recent increase in cat hunting efficiency (such as through decline in the number of hollow logs, or increase in extensively burnt areas), by a change in cat hunting behaviours, or by additional threatening factors now compounding cat impact. We acknowledge that these explanations are speculative. However, there is much evidence that even small populations of cats can have large impacts on native fauna, and that there is a recurring pattern of native mammals remaining reasonably abundant in the face of threat for some decades before then suddenly crashing (Johnson 2006).

Black rats are known to have very significant destructive impacts on a broad range of wildlife species, particularly on nesting birds and on islands. In island faunas this is particularly through predation. However, black rats are also vectors for a range of diseases, notably including salmonellosis, leptospirosis and bubonic plague, and it is feasible that their main impact on native fauna may be through spreading exotic diseases (Watts & Aslin 1981). There is reasonable circumstantial evidence of this in some cases, notably the extinction of two rodents endemic to Christmas Island within a decade or so of the arrival of black rats (Aplin 2008). There have been no studies in the Northern Territory of the disease status of black rats.

12.4 Management

To some extent, the management of cats and black rats in Kakadu (and elsewhere in the Top End) has been caught in a snag – there has been little research and hence little compelling evidence of impact, and hence little management and little incentive to do research. For example, they are given cursory attention only in the otherwise detailed recent feral animals strategy for Kakadu (Field et al 2006). This problem is exacerbated by the relative 'invisibility' of these species relative to the larger feral animals or the far more conspicuous cane toads. Further, many managers and others may have difficulty distinguishing black rats from similar-looking native rodents. Additionally, further disincentives for developing management programs for these two species are the relatively high cost and somewhat dauntingly low probability of success.

We suggest that this unconcern is not justifiable, and that an integrated research and management program should be established targetting these two species.

For feral cats, we suggest:

- that one or more moderately large exclosures be established that can serve to demonstrate unequivocally the impact of cats in this region, and (presumably) provide ongoing conservation benefit;
- an intensive study of some additional native mammal species likely to be affected by cat predation, such as northern brush-tailed phascogale, and intensive study of cats themselves including their disease status;
- a broad-scale assessment and monitoring program based on sand plots could be developed to provide indication of trends in cat numbers and identify key areas that could be specific foci for targeted control;
- experimental trials should be conducted to identify the most effective control mechanisms;
- fire regimes be maintained that minimise extensive areas of hot fire;
- an appropriate communication program be implemented to dissuade people keeping cats in Kakadu.

For black rats, we suggest:

- a study be established at one site to determine the ecology of black rats in native vegetation;
- the disease status of all known populations be examined;
- options for control measures be investigated; and
- known populations in Kakadu be exterminated.

12.5 References

Abbott I 2002. Origin and spread of the cat, *Felis catus*, on mainland Australia, with a discussion of the magnitude of its early impact on native fauna. *Wildlife Research* 29, 51–74.

Aplin K 2008. Bulldog Rat *Rattus nativitatis*, Maclear's Rat *Rattus macleari*. In *The mammals of Australia. Third edition*, eds Van Dyck S & Strahan R, Reed New Holland, Sydney, 693–696.

Dahl K 1897. Biological notes on north-Australian mammalia. *The Zoologist* 671, 189–216.

Field IC, Bradshaw CJA & Haynes C 2006. *Feral animals in Kakadu National Park: a management strategy for the future*. Charles Darwin University, Darwin.

Greer AE 1989. *The biology and evolution of Australian lizards*. Surrey Beatty & Sons, Chipping Norton.

Griffiths AD 1997. Records of two introduced rodents, *Mus musculus* and *Rattus rattus*, from Bushland in Elsey National Park. *Northern Territory Naturalist* 15, 12–15.

Johnson C 2006. *Australia's mammal extinctions: a 50,000 year history*. Cambridge University Press, Cambridge.

Oakwood M 2000. Reproduction and demography of the northern quoll, *Dasyurus hallucatus*, in the lowland savanna of northern Australia. *Australian Journal of Zoology* 48, 519–539.

Oakwood M & Pritchard D 1999. Little evidence of toxoplasmosis in a declining species, the northern quoll (*Dasyurus hallucatus*). *Wildlife Research* 26, 329–333.

Rankmore RP, Griffiths AD, Woinarski JCZ, Ganambarr BL, Taylor R, Brennan K, Firestone K & Cardoso M 2008. Island translocation of the northern quoll *Dasyurus hallucatus* as a conservation response to the spread of the cane toad *Chaunus* (*Bufo*) *marinus* in the Northern Territory, Australia. Report to the Natural Heritage Trust. Department of Natural Resources, Environment and The Arts, Darwin.

Short J & Calaby JH 2001. The status of Australian mammals in 1922 – collections and field notes of museum collector Charles Hoy. *Australian Zoologist* 31, 533–562.

Sweet SS 2007. Comparative spatial ecology of two small arboreal monitors in northern Australia. In *Advances in monitor research III. Mertensiella 16*, eds Horn H-G, Boehme W & Krebs U, Rheinbach, 378–402.

Taylor R, Woinarski J, Charlie A, Dixon R, Pracy D & Rhind S 2004. *Report on mammal survey of the Pellew Islands, October 2003*. NT Department of Infrastructure Planning and Environment: Darwin.

Woinarski JCZ 2000. The conservation status of rodents in the monsoonal tropics of the Northern Territory. *Wildlife Research* 27, 421–435.

13 Feral cats: monitoring and control

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13.1 The threat from feral cats

Feral cats are listed as a known or perceived threatening process for 58 native species under the *Environment Protection and Biodiversity Conservation Act 1999*. Today there are about 18 million feral cats in Australia (McLeod 2004), distributed through all habitats (except some of the wettest rainforests) in Australia including the Top End. Feral cats can colonise a wide range of habitats. As carnivores, they eat a wide range of prey and can survive with limited access to drinking water. The survival rate of kittens is not high, but cats can breed in any season, allowing rapid increases in numbers.

Cats have direct impacts on native fauna through predation. They can kill vertebrates weighing as much as 3 kg (Dickman 1996), but preferentially kill mammals weighing less than 220 g and birds less than 200g. They also kill and eat reptiles, amphibians and invertebrates (Dickman 1996). Cats can also have indirect effects on native fauna by carrying and transmitting infectious diseases (DEH 2004).

Figure 1 Stomach contents of a feral cat showing a range of species, sometimes almost intact

Control of feral cats is difficult as they are found in very low densities over large home ranges, making them difficult to locate. This paper explores current and developing methods to monitor feral cat populations, particularly pre- and post-control work. It also discusses a the development of a new feral cat bait for broad-scale control applications.

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13.2 Monitoring methods

Detecting changes in feral cat abundance, and consequently the impact on native species, is crucial to designing an effective control program. The Arthur Rylah Institute for Environmental Research (Robley et al 2008) has undertaken a study to estimate the probability of detecting feral cats with various detection devices and methods, ie track counts, cage traps, leg-hold traps, camera based techniques, and DNA based techniques.

13.2.1 Monitoring study

The trial was conducted at the Alcoa lease area (6600 ha) adjacent to the town of Anglesea in south-western Victoria. Ten feral cats were trapped and a VHF/GPS data-logging collar was attached. The GPS units were programmed to collect positional information every two hours for 90 days. This information determined the home range of each cat.

Radio tracking of the collared feral cats twice a day allowed a ‘core area’ (where the cat was 50% of the time) of activity for the feral cat and a ‘peripheral area’ (where the cat was 90% of the time) to be determined. The project set up a series of detection devices (cage traps, DNA samplers, heat-in-motion cameras, and sand plots) with remote cameras to record the visits by the feral cats in different areas of their home ranges. Lures of food, scent and audio lures were used in conjunction with the traps. Details of the method is given in Robley et al (2008).

Figure 2 Remote cameras for assessing feral cat visits to detection devices

13.2.2 Results

Overall radio-tracking results and detection by devices was low and the study will be repeated in 2009. However, the results showed cat home ranges were between 1 km^2 and 60 km^2 with a median of 9 km^2. Five cats were detected by the cameras but only one was detected by the loggers at the cage trap/DNA sampler despite obtaining several photos of cats investigating the trap. Two cats were detected by the loggers at the leg-hold devices, and photographs of five cats were taken at leg-hold devices.

Based on the simulation modelling from the results, 49 cameras placed in a 6 km x 6 km grid spaced at 1 km intervals and left in-situ for 20 days would be a reasonable protocol to use for assessing changes in feral cat abundance. Caution should be used in applying the suggested protocol because there is a degree of uncertainty in the derived estimates due to the low level of detections and the small sample size. The approach has a number of advantages, including the ease of establishment and operation of cameras and lower labour costs compared to cage and leg-hold trapping. All other devices have significantly more complexity in operation. For example, leg-hold traps and DNA analysis require technical experts, and DNA samplers, cage traps and leg-hold traps have to be checked each day, which increases the costs of monitoring. Cameras are essentially set-and-forget devices requiring minimal servicing in the field, but they have substantial set-up cost, require maintenance, and can be stolen.

13.3 Feasible baiting regimes for broad-scale control

Control of cats is difficult because they are found in very low densities over large home ranges, making them difficult to target. The Western Australian Department of Environment and Conservation (formerly the Department of Conservation and Land Management) is working on a feral cat control research program with the objective of designing and developing an operationally feasible bait and baiting regime to provide effective and cost-efficient broad-scale control of feral cats, particularly in the arid and semi-arid regions of Western Australia.

The first Threat Abatement Plan for predation by feral cats (Environment Australia, 1999) listed the following actions as required to improve the effectiveness of feral cat control methods and delivery systems:

1 Identify the most attractive bait materials for use with feral cats;

2 Assess existing delivery systems for their effectiveness in delivering control substances;

3 Identify and develop the most attractive bait(s).

13.3.1 Bait development

Feral cats do not readily consume standard baits for other species such as dogs and foxes. Following comprehensive pen trials with stray cats and field trials with feral cats a bait has been developed. The bait, called Eradicat®, is similar to a chipolata sausage in appearance, approximately 20 g wet-weight, dried to 15 g, blanched (that is, placed in boiling water for one minute) and then frozen. The bait is composed of 70% kangaroo mince meat, 20% chicken fat and 10% digest and flavour enhancers. These baits are now routinely manufactured at the Department of Environment and Conservation bait factory.

Figure 3 Eradicat baits

In WA, toxic feral cat baits are dosed at 4.5 mg of sodium monofloroacetate (1080) per bait. Prior to laying, feral cat baits are generally thawed and placed in direct sunlight. This process, termed ‘sweating’, causes the oils and lipid-soluble digest material to exude from the surface of the bait. All feral cat baits are sprayed, during the sweating process, with an ant deterrent compound (Coopex®) at a concentration of 12.5 g per litre Coopex as per the manufacturer’s instructions). This process is aimed at preventing bait degradation by ant attack and the deterrent to bait acceptance from the physical presence of ants on and around the bait medium.

13.3.2 Baiting optimisation

The research into the time of the year to bait has focused on semi-arid and arid regions. In semi-arid regions, the temporal variability is correlated with the availability of prey, which is a function of season/rainfall. In these areas, the optimum baiting period occurs in the drier autumn/early winter before the onset of winter rains when young, predator-vulnerable prey are not present. In the arid zone, where rainfall is unreliable, the optimum baiting period is the cool, dry conditions of late autumn/winter because rainfall is less likely to occur, prey types are at their lowest abundance and activity, and bait degradation due to rainfall, ants, and to hot dry weather is reduced.

Baiting intensity research has been undertaken by a series of trials. A baiting density of 50 baits per km^2 is effective. Trials to date have shown a efficacy of 80 to 100 % at this density. Further research is planned.

Once the baiting intensity has been finalised, it will be possible to assess the baiting frequency required to provide cost-effective control over time. Re-introduction of native species to strategic areas can only occur if sustained, long-term feral cat control is demonstrated.

Further details can be found in Algar (2006).

13.4 Curiosity feral cat bait

The national Threat Abatement Plan for predation by feral cats (DEWHA 2008) has an objective of improving the effectiveness, target specificity, humaneness and integration of control options for feral cats. A key action is the development of an effective toxin-bait for cats. A project to address this problem has been running for ten years as a collaborative research program between the Australian Government, the Department of Sustainability and Environment Victoria and the Department of Environment and Conservation Western Australia. Scientec Research Pty Ltd are a key part of the development of the hard shelled delivery vehicle – a plastic pellet that encapsulates the toxin.

The bait and toxicant for feral cats which has been developed – Curiosity Feral Cat Bait – has required considerable research effort in multi-disciplinary fields. The Curiosity feral cat bait uses the Eradicat® kangaroo bait and the toxicant para-aminopropiophenone (PAPP). Pen trials have demonstrated humane toxicosis is achieved following voluntary consumption of this bait. The toxin is encapsulated in a pellet with a tough outer coat that dissolves in the stomach of the cat to release a pulse of the toxin. The use of a pellet improves the target specificity to feral cats when using surface laid baits. Cats, having no molar teeth, consume large chunks of meat so readily swallow the pellet imbedded in the bait. Most native species nibble and chew so encounter the pellet and reject it as a ‘stone’ or similar. A number of native species have been tested for pellet rejection. Further testing is required prior to mainland trials of the bait.

Figure 4 Hard Shelled Delivery Vehicle (pellet) with PAPP toxin prior to placing in the Eradicat bait

The first trial of the product took place in April 2008 on French Island, Victoria. Of the ten feral cats fitted with radio/GPS tracking collars, two died prior to baiting, six died from bait consumption and two survived. Of the two survivors, GPS tracking showed the cats to be out of the baited area for the majority of the time when the baits would have been palatable. A second trial has commenced on Christmas Island and will be complete in early 2009.

The Curiosity feral cat bait requires approval by the Australian Pesticides and Veterinary Medicines Authority (APVMA) prior to any release of the product for use in conservation settings.

13.5 References

Algar D 2006. An overview of baiting strategies for feral cat control. In *Feral animals, threatened species and the role of the community*: Conference Convened by the Threatened Species Network, Tasmania, Hobart, March 2005, Threatened Species Network, Hobart. 13–21.

Department of the Environment, Water, Heritage and the Arts (DEWHA) 2008. *Threat abatement plan for predation by feral cats*. DEWHA, Canberra.

Dickman CR 1996. Overview of the impact of feral cats on Australian native fauna. Report to the Australian Nature Conservation Agency, Canberra.

Environment Australia 1999. *Threat Abatement Plan for predation by feral cats*. Department of the Environment and Heritage, Canberra.

McLeod R 2004. *Counting the cost: impact of invasive animals in Australia*. Cooperative Research Centre for Pest Animal Control, Canberra.

Robley A, Ramsey D, Woodford L, Lindeman M, Johnston M, & Forsyth D 2008. *Evaluation of detection methods and sampling designs used to determine the abundance of feral cats*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 181, Department of Sustainability and Environment, Heidelberg, Victoria.

14 The impact of cane toads on native wildlife, and developments in toad control

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14.1 The impact of toads on native wildlife

In 2002, van Dam et al presented a risk assessment of the threat posed by cane toads to the biodiversity, cultural, and tourism values of Kakadu National Park. Following a careful analysis of the potential impacts of toads on native wildlife, they concluded that the state of knowledge on toad impacts was still in its infancy. Despite toads being present in Australia for more than 65 years, the enormous logistical difficulties associated with demonstrating population-level impacts, and a lack of baseline data, had stymied many research efforts. Since 2002, however, toads have spread through Kakadu and towards Darwin. In doing so, toads have invaded areas where researchers had been able to collect baseline data in advance of the toad arrival. Additionally, in 2004 a large, well-resourced research program on toads and their impacts – headed by Richard Shine at the University of Sydney – was initiated (Shine et al 2006). These two facts have ensured that the state of knowledge on toads and their impacts has improved considerably in recent years.

Freeland (1987) pointed out that toads can have an impact in three ways: by poisoning native wildlife that attempt to eat them; by preying on smaller wildlife; and by competing with natives. To this list, we should add indirect effects as a fourth mechanism of impact. For example, if toads remove an important predator they may have indirect effects on that predator's normal prey (eg, Doody et al 2006). By their nature, indirect effects will be difficult or impossible to predict, and very difficult to prove. Nonetheless, these indirect effects will ramify through a community, and may prove to have the most far-reaching impacts. For example, recent experimental work (Greenlees et al 2006) suggests that the arrival of toads increases the predation pressure on insects. Although difficult to scale these results up to the landscape level, it is possible that toads depress insect numbers and thus reduce prey availability for many insectivorous species (eg, other frogs, lizards, small dasyurids etc.). Further work would be needed to assess this possibility, but it remains a potentially very large indirect effect of toads that we presently do not know much about.

Similarly, the effect of toads through direct competition remains poorly known. Greenlees et al (2007) show that the presence of toads depresses the activity of one species of native frog, *Cyclorana australis*, which may lead to reduced feeding opportunities for this species. Other native frog species have not been assessed. In southern Queensland, interference competition resulted in heightened nestling mortality in ground-nesting rainbow bee-eaters. Toads blocked nest entrances and caused nestlings to starve to death (Boland 2004). Other ground-nesting birds may also be affected, but have not been assessed.

By far the most well-understood mechanism of toad impact is the effect of toads on predators that are poisoned whilst trying to eat them. Toxicological studies suggest that most Australian predators – naïve to the potent cardiac toxins found in toad skin – have a similar, very low resistance to toad toxins (Phillips et al 2003, Smith & Phillips 2006, J Webb unpub data).

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Importantly, almost all life-history stages of the toad pack these toxins, so toads can poison a surprising diversity of predators. Recent work shows that toad eggs are particularly dangerous, poisoning a wide variety of fish, tadpole, and turtle species (Crossland et al 2008, Greenlees & Shine unpub data). Tadpoles appear to be somewhat less dangerous because they are obviously distasteful, therefore often manage to elicit aversion learning in predators that attempt to eat them (Crossland 2001, Nelson unpub data). Metamorph toads are dangerous too. Many native frogs are aggressive predators on other frogs and so have the potential to be severely affected by masses of small, toxic toads emerging from waterbodies. Indeed, when native frogs of various species were offered small toads in the laboratory, many native species exhibited high mortality rates as a consequence of ingesting toads (Greenlees, unpub. data). Lastly, as toads grow larger and disproportionately more toxic (Phillips & Shine 2006a), they fall prey to, and often poison, larger predators such as snakes, goannas, freshwater crocodiles, and dasyurids (eg, Burnett 1997, Letnic et al 2008, Webb et al 2008, Phillips unpub data).

At this point, it is important to note that demonstrated individual impacts (through competition, predation, or poisoning) do not necessarily translate to population level impacts. Frogs, for example, often exhibit extremely high fecundity, high natural mortality, and strong density dependence. Though counterintuitive, an additional high mortality imposed by toads on such a population may have no discernible impact on the population as a whole. Quolls, on the other hand, are short-lived, low-fecundity species evolved for low levels of natural mortality. Even a small additional toad induced mortality on such a species can have dramatic effects on the population as a whole. So it is important, when considering toad impacts, to not only demonstrate the mechanism of impact, but also to examine changes in populations of toad-susceptible natives.

Since Van Dam et al's review, several population-level declines have, in fact, been demonstrated. Oakwood's (2003) work on Quolls suggests that, although quolls have been declining across northern Australia for poorly understood reasons (Braithwaite & Griffiths 1994, Woinarski et al 2001), cane toads may have been the nail in the coffin for many populations. Several goanna species (*V. mertensi, V. panoptes, V. mitchelli*) have also shown dramatic reductions in population size associated with the arrival of toads (Griffiths & McKay 2007, Doody et al 2008, Madsen & Ujvari, unpub data). Lastly, recent work on floodplain death adders shows high mortality of these snakes in the presence of toads, and consequent large reductions in population size (Phillips & Greenlees unpub data).

Toads impact native species in various ways, and the dual life history of toads (aquatic and terrestrial) means that this impact is distributed across a surprisingly large portion of the native biota. In recent years, population level impacts have been demonstrated for many taxa thought to be most at risk from toads (quolls, goannas, and snakes). Research has also unearthed individual-level impacts in many species previously of little concern. Whether these individual-level impacts will develop into population-level impacts is currently unknown, although for frogs at least, there is some evidence that populations have remained unaffected (Grigg et al 2006) despite clear individual level impacts.

14.2 Developments in cane toad control

Over the last three years, the largest concerted attempt to control toads in Australian history has been underway. In a valiant effort to keep toads out of Western Australia, several community groups, and the WA Government have combined to contribute more than 1 million person hours to manually catch and kill an estimated 422 000 adult toads. Unfortunately, this spectacularly massive effort has had only humble results. The average rate of invasion for cane toads between Katherine and Darwin (between which, no effort was made to stop them) was around 55km per year and ranged from 20–80 km/year across years (Phillips et al 2007). The average rate of advance for the toad population towards the WA border, where this massive control effort has been directed, has been about 45 km per year (WA Department of Conservation, unpub. data). If this small difference in spread rate is due to the efforts of toad control, and not simply natural variation in invasion rate, then this massive control effort has slowed the toad invasion by about 10 km/year and delayed the arrival of toads into WA by approximately three months. Why, then, has this massive control campaign had such limited effect?

The reasons are twofold. Firstly, toads move surprisingly far, surprisingly fast. Secondly, toads have an immense reproductive capacity. No other frog or toad anywhere in the world disperses at the rates observed for cane toads in the NT. These amazingly high dispersal rates have evolved on the toad invasion front over the last seventy years, and mean that it is not uncommon for an individual toad to show displacement of more than fifty kilometres in a single wet season (Phillips et al 2006, Phillips et al 2008). In practice, this means that if you remove toads from around a pond on Monday, you will have toads at your pond on Tuesday, and these toads may have come from a kilometre away. On a broader scale, this means that in the absence of a barrier to toad movement, local control efforts will continually be swamped by new toads coming from areas up to fifty kilometres away. You cannot effect local control unless you also direct that control at all populations within 50 km of your target, and ultimately at populations within 50 km of those peripheral populations, and so on. Numerous techniques have been developed in recent years to remove toads (Shannon & Bayliss 2008), but because of the rate at which toads move, none of these techniques will be effective on a landscape scale.

Toads are difficult to control because of their immense reproductive capacity. Clutch sizes of 5000–15 000 eggs are common in the NT, but clutch sizes of up to 45 000 have been recorded (Gabriel & Brown, unpub data). Only a very small percentage of these eggs ever survive to adulthood, but the proportion that do survive depends strongly upon how many other toads are around (young toads and tadpoles are cannibalistic, and readily eat smaller individuals and toad eggs (Lampo & Deleo 1998, Pizzato & Shine 2008). When there are few other toads around, more of these eggs will survive. This density dependent survival coupled with the immense reproductive capacity of toads makes them very hard to eradicate. If you remove 50% of the toads from a closed area, the other 50% will leave a lot of offspring behind. For toads, it has been estimated that eradication of a closed population would require removal of at least 40% of the population every year for many years (Thresher & Bax 2006).

In recent years, a large number of new control options have been proposed. These new control options have been well summarised and reviewed by Shannon and Bayliss (2008) and so will not be reviewed here. Initial modelling suggests that none of the control options could possibly eradicate toads from mainland Australia. Further, the majority of control options will only be effective for local control and, as alluded to above, will not be particularly useful for control efforts in the NT except in 'closed' (island or fenced) populations. The only control options that might potentially lead to broadscale control (rather than eradication) of toads are either (a) the discovery of a naturally occurring pathogen such as myxomatosis in rabbits, or (b) daughterless male technology. Currently, no money or effort is being directed at a search for a naturally occurring disease, and daughterless male technology will require a lot of government investment, many years of development, requires continuous re-stocking and has no sure chance of success.

14.3 Management of toads in Kakadu

In the face of this reasonably grim prognosis, what should Kakadu National Park do to manage toads? A clear priority is to keep islands toad free, although Kakadu's island holdings are modest. Field and Barron Islands should be monitored regularly for toads, and, if detected, toads should be eradicated from these islands.

The only other management option possibly within Kakadu's power would be a fenced toad-free section of the park. Although such an area would clearly require a large investment and ongoing maintenance, it could act as a mainland refuge for quolls as well as several impacted goanna and snake species. Refuges can be managed to produce, in the long-term (20–40 years), toad-smart native species capable of being reintroduced back into areas with toads. Native species can both learn and evolve behaviour/morphology/physiology to deal with toads (Phillips et al 2004, Phillips & Shine 2006b). Refuge areas that are managed under a regime of gentle toad-relevant natural selection will eventually produce strains of native species that are toad-competent, environment-competent, and thus able to recolonise areas where populations had previously gone extinct. Given that toads will never be eradicated and probably never effectively controlled on mainland Australia, this kind of pro-active management of refuge areas is probably the only effective response we can have.

14.4 References

Boland C.R.J 2004. Introduced cane toads Bufo marinus are active predators and competitors of rainbow bee-eaters *Merops ornatus*: observational and experimental evidence. *Biological Conservation* 120, 53–62.

Braithwaite RW & Griffiths AD 1994. Demographic variation and range contraction in the Northern Quoll, *Dasyurus-Hallactus* (Marsupialia, Dasyuridae). *Wildlife Research* 21, 203–217.

Burnett S 1997. Colonizing cane toads cause population declines in native predators: reliable anecdotal information and management implications. *Pacific Conservation Biology* 3, 65–72.

Crossland MR 2001. Ability of predatory native Australian fishes to learn to avoid toxic larvae of the introduced toad Bufo marinus. *Journal of Fish Biology* 59, 319–329.

Crossland M.R, Brown GP, Anstis M, Shilton C & Shine R 2008. Mass mortality of native anuran tadpoles in tropical Australia due to the invasive cane toad (*Bufo marinus*). *Biological Conservation*, in press.

Doody JS, Green B, Rhind D, Castellano C, Simms R & Robinson T 2008. Population-level declines in Australian predators caused by an invasive species. *Animal Conservation*, in press.

Doody JS, Green B, Sims R, Rhind D, West P & Steer D 2006. Indirect impacts of invasive cane toads (Bufo marinus) on nest predation in pig-nosed turtles (*Carettochelys insculpta*). *Wildlife Research* 33, 349–354.

Freeland WJ 1987. Cane toads and the balance of nature. *Wildlife Australia 24* 12–15.

Greenlees MJ, Brown GP, Webb JK, Phillips BL & Shine R 2006. Effects of an invasive anuran (the cane toad, *Bufo marinus*) on the invertebrate fauna of a tropical Australian floodplain. *Animal Conservation* 9, 431–438.

Greenlees MJ, Brown GP, Webb JK, Phillips BL & Shine R 2007. Do invasive cane toads (*Chaunus marinus*) compete with Australian frogs (Cyclorana australis)? *Austral Ecology* 32, 900–907.

Griffiths AD & McKay JL 2007. Cane toads reduce the abundance and site occupancy of Merten's water monitor (*Varanus mertensi*). *Wildlife Research* 34, 609–615.

Grigg GC, Taylor A., McCallum H & Fletcher L 2006. Monitoring the impact of cane toads (*Bufo marinus*) on Northern Territory frogs – a progress report. In *Science of cane toad invasion and control. Proceedings of the Invasive Animals*, CRC/CSIRO/Qld NRM&W cane toad workshop, eds Molloy K & Henderson W, 47–54.

Lampo M & Deleo GA 1998. The invasion ecology of the toad *Bufo marinus* – from South America to Australia. *Ecological Applications* 8, 388–396.

Letnic M, Webb JK & Shine R 2008. Invasive cane toads (*Bufo marinus*) cause mass mortality of freshwater crocodiles (*Crocodylus johnstoni*) in tropical Australia. *Biological Conservation* 141, 1773–1782.

Oakwood M 2003. The effect of cane toads on a marsupial carnivore, the northern quoll, *Dasyurus hallucatus*. Internal Report, Parks Australia North.

Phillips BL, Brown GP, Greenlees M, Webb JK & Shine R 2007. Rapid expansion of the cane toad (*Bufo marinus*) invasion front in tropical Australia. *Austral Ecology* 32, 169–176.

Phillips BL, Brown GP & Shine R 2003. Assessing the potential impact of cane toads on Australian snakes. *Conservation Biology* 17, 1738–1747.

Phillips B.L, Brown GP & Shine R 2004. Assessing the potential for an evolutionary response to rapid environmental change: invasive toads and an Australian snake. *Evolutionary Ecology Research* 6, 799–811.

Phillips BL, Brown GP, Travis JMJ & Shine R 2008. Reid's paradox revisited: the evolution of dispersal in range-shifting populations. *The American Naturalis*t 172, S34–S48.

Phillips BL, Brown GP, Webb JK & Shine R 2006. Invasion and the evolution of speed in toads. *Nature* 439, 803.

Phillips BL & Shine R 2006a. Allometry and selection in a novel predator/prey system: Australian snakes and the invading cane toad. *Oikos* 112, 122–130.

Phillips BL & Shine R 2006b. An invasive species induces rapid adaptive change in a native predator: cane toads and black snakes in Australia. Proceedings of the Royal Society of London – Series B: *Biological Sciences* 273, 1545–1550.

Pizzato L & Shine R 2008. The behavioural ecology of cannibalism in cane toads (*Bufo marinus*). *Behavioural Ecology and Sociobiology,* in press.

Shannon MF & Bayliss P 2008. Review of the CSIRO biological control of cane toad program to April 2008. Internal Report, Australian Government Department of the Environment, Water, Heritage and the Arts.

Shine R, Brown GP, Phillips BL, Webb JK & Hagman M 2006. The biology, control and impact of cane toads: an overview of the University of Sydney's research program. In: Science of cane toad invasion and control. *Proceedings of the Invasive Animals CRC/*CSIRO*/QLD NRM&W Cane toad workshop*, eds Molloy K & Henderson W. Invasive animals CRC, Brisbane.

Smith JG & Phillips BL 2006. Toxic tucker: the potential impact of cane toads on Australia's reptiles. *Pacific Conservation Biology* 12, 40–49.

Thresher R & Bax N 2006. Comparative analysis of genetic options for controlling invasive populations of the cane toad, *Bufo marinus*. In: Science of cane toad invasion and control: *Proceedings of the Invasive Animals Cooperative Research Centre /C SIRO/Qld NRM&W Cane Toad Workshop,* eds Molloy K & Henderson W, Invasive animals CRC, Brisbane, 47–54.

van Dam RA, Walden DJ & Begg GW 2002. *A preliminary risk assessment of cane toads in Kakadu National Park*. Scientist Report 164, Supervising Scientist, Darwin, NT.

Webb JK, Brown GP, Child T, Greenlees M, Phillips BL & Shine R 2008. A native dasyurid predator (common planigale, *Planigale maculata*) rapidly learns to avoid a toxic invader. *Austral Ecology* 33, 821–829.

Woinarski JCZ, Milne DJ & Wanganeen G 2001. Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. *Austral Ecology* 26, 360–370.

15 The invasion of exotic ants: implications for native flora and fauna, with specific reference to the Northern Territory

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15.1 Introduction

Exotic ants are presently a worldwide problem and may potentially cause irreparable damage to the natural environment by directly preying on or competing with native ants and other organisms (Cole et al 1992). Studies indicate exotic ant species have caused declines in native invertebrate and vertebrate fauna, decreases in seed dispersal (with implications on the structure of native vegetation), losses in agricultural productivity (due to increased incidences of scale insects, as well as losses in labour), and significant public discontentment as a result of the painful sting inflicted by these species. There are a number of particularly environmentally damaging exotic ants that threaten biodiversity in the Northern Territory, including the Big-headed ant, the Ginger ant, the Yellow Crazy ant, the Red Imported Fire ant (not currently in the NT), and the Electric ant (not currently in the NT). The current distribution of these species is not well known in the NT.

Exotic ants share several biological traits that may aid in their colonisation of previously uninhabited locations (Passera 1994). These ants tend to display high levels of aggression, yet often this aggression is not observed between colonies (Tsutsui et al 2000, Tsutsui & Case 2001). Other important characteristics include large population sizes (Walters & Mackay 2005), an omnivorous diet which allows these ants to exploit a wide range of habitats, small body size enabling utilisation of a number of niches, and polygynous behaviour which permits the development of considerably larger colonies (Morrison 2000, Holway & Suarez 2004).

15.2 Exotic ants in Australia, with specific reference to the NT

A number of exotic ants have become established in the Northern Territory. In a survey of fifty rainforest areas in the Darwin and Katherine regions, Reichel and Andersen (1996) found six introduced species, including the Yellow Crazy ant (*Anoplolepis longipes*), Brownish-red flower ant *(Monomorium floricola),* Hairy ant *(Paratrechina longicornis),* Big-headed ant *(Pheidole megacephala),* Guinea ant *(Tetramorium bicarinatum)* and *Tetramorium simillimum.* In addition, Ginger ants (*Soleopsis geminata)* (Hoffmann & O'Connor 2004), Ghost ants (*Tapinoma melanocephalum)* (Shattuck & Barnett 2001) and Pharaoh's ants (*Monomorium pharaonis)* (Andersen et al 2004) have been recorded in the Territory (Table 1, end of this paper).

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15.3 Impacts and evidence

15.3.1 Impacts on the native ant community

The introduction of an intruder ant species has been shown to severely disrupt the activity patterns of the native ant community, resulting in the development of new interactions, which may impact the community via the extinction of weaker competitors, the displacement of weaker competitors, or by avoiding exotic species (Jusino-Atresino & Phillips 1994). Hoffmann et al (1999) observed that the first species to be excluded from the Northern Territory study sites were large and subordinate species, presumably because these species share similar habitat requirements with Big-headed ants. As the abundance of Big-headed ants increased, only cryptic species and small opportunist ants were able to persist in low numbers, and overall species richness decreased by between 95 and 97% (Hoffmann et al 1999).

15.3.2 Impacts on the non-ant community

The ant community is an important contributor to the biodiversity of many habitats and can profoundly influence the distribution and abundance of other invertebrates (Majer 1985). The introduction of an exotic ant species may result in alterations to the composition and abundance of many native invertebrates, in most cases decreasing the numbers of species inhabiting the invaded areas. The primary mechanism for native invertebrate displacement by tramp ant species appears to be through predation; however competition, interrupted foraging activity, and dependence upon organisms displaced by invasive ants may also impact local communities (Human & Gordon 1997).

At present, ecologists working on Christmas Island are concerned about the future of the native red land crabs (*Gecarcoidea natalis*), which are under threat from Yellow Crazy ants (O'Dowd et al 2003). Previous exclusion studies demonstrated that removal of these crabs resulted in reduced rates of litter turnover, which is coupled with decreased levels of nutrient cycling (Green et al 1999). Despite the fact that Yellow Crazy ants have been present on Christmas Island since the 1930's, it is only recently that its impact on native flora and fauna has become a threat. It is thought that this is because Yellow Crazy ants protect sap-sucking scale insects, which are causing the forest canopy to die back as a result of increased herbivory, and several species of bird, such as Abbot's booby and the Christmas Island hawk owl, are in danger of habitat modification and direct attack by these ants (Thwaites 1999).

15.3.3 Impacts on the plant community

In Australia, ants play an essential role in the seed dispersal of many native plants. Numerous Australian plants, especially the peas (Fabaceae) and wattles (Mimosaceae) have evolved seeds with fleshy elaiosomes that attract ants. Ants collect seeds and carry them to their nests where they feed on the elaiosome, leaving the seed to germinate in safe conditions (Hughes 1990, Davidson & Morton 1981, Majer 1994, French & Westoby 1996). Many exotic ant species do not collect seeds and transport them to their nests (Christian 2001). In some instances, these species will damage seeds, rendering them incapable of germinating. Thus, the introduction of exotic ants may have severe consequences for the entire ecosystem (Quilichini & Debussche 2000).

15.4 Management

Exotic ants can be managed in a number of ways. The most commonly used method for the control of exotic ants is through chemical baiting of invaded sites using:

- Fipronil has been used for yellow crazy ants (Abbott & Green 2007)
- Diazinon has been used to control ginger ants (Hoffmann & O'Connor 2004)
- Methoprene has been successful in the management of big-headed ants (Horwood 1988)
- Hydramethylnon has proven effective in the control of red imported fire ants and big-headed ants (Hoffmann & O'Connor 2004)

However, the effectiveness of these chemicals will vary with the ant species being targeted. Other potential control methods include hot water (King & Tschinkel 2006) and biological control (*Wolbachia*) – (Bouwma et al 2006). These methods have limited success.

The best means of managing invasive ant species is through prevention, since other control methods are either not completely effective, or are damaging to the natural environment (van Schagen et al 1994, Williams 1994, Ulloa-Chacon & Cherix 1994). Prevention can be best achieved by ensuring efficient quarantine processes as well as reducing the level of disturbance to pristine locations (Reimer 1994). Once areas are disrupted by human development, exotic ant species are more likely to become established due to their ability to colonise such localities, and because native ant fauna may be eliminated or weakened, and thus displaced by the invasive species.

15.5 References

Abbott KL & Green PT 2007. Collapse of an ant-scale mutualism in a rainforest on Christmas Island. *Oikos* 116, 1238–1246.

Andersen AN, Woinarski JCZ & Hoffmann BD 2004. Biogeography of the ant fauna of the Tiwi Islands, in northern Australia's monsoonal tropics. *Australian Journal of Zoology* 52, 97–110.

Bouwma AM, Ahrens ME, DeHeer CJ & DeWayne Shoemaker D 2006. Distribution and prevalence of Wolbachia in introduced populations of the fire ant *Solenopsis invicta*. *Insect Molecular Biology* 15, 89–93.

Christian CE 2001. Consequences of a biological invasion reveal the importance of mutualism for plant communities. *Nature* 413, 635–639.

Cole FR, Mederios AC, Loope LL & Zuehlke WW 1992. Effects of the Argentine ant on Arthropod fauna of Hawaiian high-elevation shrubland. *Ecology* 73, 1313–1322.

Davidson DW & Morton SR 1981. Myrmecochory in some plants (F. chenopodiaceae) of the Australian Arid Zone. *Oecologia* 50, 357–366.

French K & Westoby M 1996. Vertebrate-dispersed species in a fire-prone environment. *Australian Journal of Ecology* 21, 379-385.

Green PT, Lake PS & O'Dowd DJ 1999. Monopolization of litter processing by a dominant land crab on a tropical oceanic island. *Oecologia* 119, 435–444.

Henshaw MT, Kunzmann N, Vanderwoude C, Sanetra M & Crozier RH 2005. Population genetics and history of the introduced fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), in Australia. *Australian Journal of Entomology* 44, 37–44.

Heterick B, Casella J & Majer J 2000. Influence of Argentine and coastal brown ant (Hymenoptera: Formicidae) invasions on ant communities in Perth gardens, Western Australia. *Urban Ecosystems* 4, 277–292.

Hoffmann BD, Andersen AN, & Hill GJE 1999. Impact of an introduced ant on native rain forest invertebrates: *Pheidole megacephala* in monsoonal Australia. *Oecologia* 120, 595–604.

Hoffmann BD & O'Connor S 2004. Eradication of two exotic ants from Kakadu National Park. *Ecological Management and Restoration* 5, 98–105.

Holway DA, Lach L, Suarez AV, Tsutsui ND & Case T 2002. The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics* 33, 181–233.

Holway DA & Suarez AV 2004. Colony structure variation and interspecific competitive ability in the invasive Argentine ant. *Oecologia* 138, 216–222.

Horwood MA 1988. Control of *Pheidole megacephala* (F.) (Hymenoptera: Formicidae) using methoprene baits. *Journal of the Australian Entomological Society* 27, 257–258.

Hughes L 1990. The relocation of ant nest entrances: Potential consequences for ant-dispersed seeds. *Australian Journal of Ecology* 16, 207–214.

Human KG & Gordon DM 1997. Effects of *L. humile* on invertebrate biodiversity in Northern California. *Conservation Biology* 11, 1242–1248.

Jusino-Atresino R & Phillips SA 1994. Impact of Red Imported Fire Ants on the Ant Fauna of Central Texas. In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 259–268.

King JR & Tschinkel WR 2006. Experimental evidence that the introduced fire ant, *Solenopsis invicta*, does not competitively suppress co-occurring ants in a disturbed habitat. *Journal of Animal Ecology* 75, 1370–1378.

Majer JD 1985. Recolonization by ants of rehabilitated mineral sand mines on North Stradbroke Island, Queensland, with particular reference to seed removal. *Australian Journal of Ecology* 10, 31–48.

Majer JD 1994. Spread of *L. humile* (*Linepithema humile*), with special reference to Western Australia. In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 163–173.

McGlynn TP 1999. Non-native ants are smaller than related native ants. *The American Naturalist* 154, 690–699.

Morrison LW 2000. Mechanisms of interspecific competition among an invasive and two native fire ants. *Oikos* 90, 238–252.

O'Dowd DJ, Green PT & Lake PS 1999. *Status, impact, and recommendations for research and management of exotic invasive ants in Christmas Island National Park*. Centre for the Analysis and Management of Biological Invasions, Clayton Victoria, Australia.

O'Dowd DJ, Green PT & Lake PS 2003. Invasional 'meltdown' on an oceanic island. *Ecology Letters* 6, 812–817.

Passera L 1994. Characteristics of Tramp Species. In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 23–43.

Quilichini A & Debussche M 2000. Seed dispersal and germination patterns in a rare Mediterranean island endemic (*Anchusa crispa* Viv., Boraginaceae). *Acta Oecologia* 21, 303–313.

Reichel H & Andersen AN 1996. The Rainforest Ant Fauna of Australia's Northern Territory. *Australian Journal of Zoology* 44, 81-95.

Reimer NJ 1994. Distribution and Impact of Alien Ants in Vulnerable Hawaiian Ecosystems. In: *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 11–22.

Rowles AD & O'Dowd DJ 2006. Interference competition by Argentine ants displaces native ants: implications for biotic resistance to invasion. *Biological Invasions* 9, 73–85.

Shattuck SO & Barnett NJ 2001. Genus Tapinoma (Subfamily Dolichoderinae): melanocephalum (Fabricius) Australian Ants Online, CSIRO.

Tsutsui ND, Suarez AV, Holway DA & Case TJ 2000. Reduced genetic variation and the success of an invasive species. *Proceedings of the National Academy of Sciences of an invasive species* 97, 5948–5953.

Tsutsui ND & Case TJ 2001. Population genetics and colony structure of the Argentine ant (*Linepithema humile*) in its native and introduced ranges. *Evolution* 55, 976–985.

Ulloa-Chacon P & Cherix D 1994. Perspectives on control of the little fire ant (*Wasmannia auropunctata*) on the Galapagos Islands. In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 63–79.

van Schagen JJ, Davis PR & Widmer MA 1994. Ant pests of Western Australia with particular reference to the Argentine ant (*Linepithema humile*). In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 174–180.

Walters AC & Mackay DA 2003. An experimental study of the relative humidity preference and survival of the Argentine ant, *Linepithema humile* (Hymenoptera, Formicidae): comparisons with a native Iridomyrmex species in South Australia. *Insectes Sociaux* 50, 355-–60.

Walters AC & Mackay DA 2005. Importance of large colony size for successful invasion by Argentine ants (Hymenoptera: Formicidae): Evidence for biotic resistance by native ants. *Austral Ecology* 30, 395–406.

Williams DF 1994. Control of the introduced pest *Solenopsis Invicta* in the United States. In *Exotic ants: biology, impact and control of introduced species*, ed Williams DF, Westview, Boulder, 282–292.

Table 1 Review of the significant tramp ants in Australia, with particular reference to the Northern Territory

Ant species	Origin	Distribution in Australia	Comment	Reference
Solenopsis invicta (The Red Imported Fire Ant)		Queensland*	First discovered February 2001 in Brisbane. Two colonies were discovered and these were found to have been introduced during two separate invasion events.	Henshaw et al 2005
Wasmannia auropunctata (Electric Ant, Little Fire Ant)	Central and South America	Queensland*	It has been introduced into parts of Africa (including Gabon and Cameroon), North America (including Canada) and South America. It has been introduced onto some islands in the Caribbean and the Pacific Ocean (including New Caledonia, Vanuatu, Tahiti and some islands in the Galapagos, Hawai'ian and Solomon islands)	McGlynn 1999 Holway et al 2002a
Pheidole megacephala (African big-headed ant Coastal Brown Ant)	Southern Africa	Northern Territory, Western Australia, Queensland, New South Wales, Victoria	First discovered in the mid-1980's, but may have arrived as early as the 1930s. It is now widespread throughout the temperate and tropical zones of the world.	Hoffmann and O'Connor 2004 Heterick et al 2000 Reichel and Andersen 1996
Solenopsis geminata (Tropical fire ant, Ginger ant)	Uncertain. It is currently distributed throughout southern America.	Northern Territory, Western Australia	First discovered in the NT in 1939. Its range has been extended almost world-wide. It has been introduced into parts of Africa and Asia (including India and Japan). It has been introduced onto some Indian Ocean islands (including Madagascar) and various Pacific Ocean islands (including New Caledonia and the Hawaiian and Galapagos archipelagos)	Hoffmann and O'Connor 2004 McGlynn 1999 Holway et al 2002a
Anoplolepis longipes (Yellow Crazy Ant)	Uncertain. It may have originated from Africa or Asia.	Northern Territory, Queensland	Introduced into parts of Africa (including South Africa), Asia (including India, Myanmar, Malaysia, Indonesia, New Guinea and Sri Lanka), South America (including Brazil) and Australia. It has been introduced onto some Caribbean islands, some Indian Ocean islands (including the Seychelles, Madagascar, Mauritius, Reunion, the Cocos Islands and the Christmas Islands) and some Pacific islands (including New Caledonia, Hawai'i, French Polynesia, Okinawa, Vanuatu, Micronesia and the Galapagos archipelago)	O'Dowd et al 1999 Reichel and Andersen 1996
Monomorium floricola (Brownish-red flower ant)	Origin is not known.	Northern Territory, Queensland		Reichel and Andersen 1996

Table 1 (cont) Review of the significant tramp ants in Australia, with particular reference to the Northern Territory

Ant species	Origin	Distribution in Australia	Comment	Reference
Monomorium pharaonis (Pharaohs ant)	West Africa	Tiwi Islands	It has been introduced into Asia (including Japan, India and Saudi Arabia), Australia, North, Central and South America, Europe. It has been introduced onto some islands in the Indian Ocean (including Madagascar) and the Pacific Ocean (including New Zealand and some islands in the Hawaiian and Galapagos archipelagos)	McGlynn 1999 Andersen et al 2004
Monomorium destructor (Singapore ant)	India	Northern Territory, Western Australia, Queensland	Australasia-Pacific, North America, and South America	http://www.issg.org/database
Paratrechina longicornis (Crazy ant, long-horned ant, hairy ant, slender crazy ant)	Africa and Asia	Northern Territory	Has been introduced to the Australasia-Pacific Region, Europe, North America, and South America	Reichel and Andersen 1996
Tetramorium bicarinatum (Guinea ant, Japanese ant)	South-east Asia	Northern Territory, Western Australia, Queensland, New South Wales		Reichel and Andersen 1996
Tetramorium simillimum	Africa	Northern Territory, Queensland		Reichel and Andersen 1996
Tapinoma melanocephalum (Ghost ant)	Asia or Africa	Northern Territory, Western Australia, Queensland	Has been introduced to the Australasia-Pacific, Europe, North America, and South America	Shattuck and Barnett 2001
Linepithema humile (Argentine ant)	South America	South Australia, Western Australia, Victoria, New South Wales	Mediterranean-climate specialist so not a threat to tropical regions. Argentine ants now occur throughout the world, with at least 28 separate introductions known from six continents and many oceanic islands.	Walters and Mackay 2003 Heterick et al 2000 Rowles and O'Dowd 2006
Technomyrmex albipes (white-footed house ant)	Indo-Pacific area		Introduced to the United States, Australia, New Zealand, Ghana, Madagascar, India, China, Saudi Arabia, and the West Indies	http://www.issg.org/database

* denotes not yet present in the Northern Territory

16 Feral ant detection, eradication and control

B Salau[1], B Hoffmann[2] & S O'Connor[3]

16.1 Introduction

The African big-headed ant (*Pheidole megacephala*), listed among the world's 100 worst invasive species, was first identified in Kakadu National Park in June 2001. It was found in Jabiru, a small mining town located within the park. The African big-headed ant has been long established in Darwin and environs, and its eradication from this region is not realistic. However, eradication of confined infestations is highly feasible. The campaign implemented in Kakadu in 2001 demonstrates the ability to eradicate this species from a large national park containing small settlements. This paper summarises the key steps taken to achieve eradication. Full details and discussion of the program can be found in 'Eradication of two exotic ants from Kakadu National Park' (Hoffmann & O'Connor 2004).

16.2 Initial survey

Immediately upon discovery, a public campaign was launched to raise awareness of the big-headed ant and the environmental threat it posed. Public awareness was essential in encouraging residents and tourists to report sightings, allow access to areas, and assist with preventing re-infestation. Notices were placed around Jabiru and in rooms at Cooinda Tourist Resort. Articles also appeared in the local community newsletter.

The the reproductives of the African big-headed ant have lost their ability to fly, and instead depend on people for dispersal to new locations. It is therefore only found in developed areas and this is where surveys were concentrated. Over three weeks, the township of Jabiru, all ranger stations, mining leases, residential areas, aboriginal outstations and tourist areas in Kakadu were surveyed to locate potential infestations. All main tourist stops along the Arnhem Highway leading to the park were also inspected during the project.

The survey method involved visual searches for the distinct ground workings of the species. Searches were conducted in the cooler morning and late afternoon when the ants were most likely to be active. Attention was given to areas that the ants are known to prefer such as shaded and irrigated areas, gardens, pot plants, footpaths and edges of buildings. The African big-headed ant forms super-colonies of continuous multi-queen infestations. Emphasis was therefore placed on identifying the extent of infestations rather than individual nests. If a visual search did not detect the species in an area where they were likely to be, an attractive lure (tuna) was used. A small amount of tuna was placed on the ground and marked by a satay stick with flagging tape attached. Lures were placed every few meters. In Jabiru's residential areas the survey was conducted by placing lures on the roadside edge of properties, since established infestations often cover entire streets. If the big-headed ant were undetected, the property was searched more thoroughly for small infestations. Positive identification was essential as Kakadu has around 20 species of native big-headed ant.

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[2] CSIRO, PMB 44 Winnellie NT 0822 Australia
[3] Biosecurity New Zealand, PO Box 2526 Wellington New Zealand

The surveys detected the ant in 24 locations within Jabiru, Cooinda Tourist Resort, and East Alligator and Nourlangie ranger residences. The 24 infestations covered 30 ha in total, and ranged in size from a small pot plant to 10 ha. It was also detected at one tourist location along the Arnhem Highway outside of Kakadu.

16.3 Treatment

Areas infested with the ant were treated with a commercially available formicide Amdro® (hydramethylnon in a cracked corn base). Amdro® was chosen because it is known to be effective at eradicating the African big-headed ant, kills within 24 hours, has low toxicity to terrestrial vertebrates, and breaks down quickly with exposure to light. Rain dissolves the treatment, so the treatment was conducted during the dry season. Irrigation systems were turned off one day prior to and after treatment. There were no waterways within the areas that were treated. Where the ant had spread into surrounding savanna, the area was burnt two weeks prior to treatment to improve access, reduce the surface area for foraging and increase bait uptake.

Amdro® was dispersed by hand at the rate of 2.5kg/ha by a team of people aligned in a row, walking from one side of each infestation to the other. Treatment was carried out in the cool of the evening. African big-headed ants do not like the heat, so are most active early morning or evening. The ants readily came to the Amdro® granules and could be observed taking the corn back to the nest.

A 5 m buffer zone was also treated around infested areas. In residential areas the buffer zone included the houses either side of an infested property.

16.4 Post control monitoring and treatment

Affected areas were inspected three months after treatment using tuna lures. If African big-headed ants were found, the area was treated again using Amdro®. This species establishes new colonies within walking distance of the parent colony, and so new nests are always in the vicinity of the main nest. Ants nesting in large amounts of leaf litter or in areas that contained logs and rubble were the most difficult to eradicate and subsequent treatment was usually needed.Cooinda was one site that required a number of applications to eradicate the ants.

The success of the program was measured in the 24 months post-treatment. For the first twelve months inspections involved using baits placed in a grid 5 m apart over entire treated areas and inspected after 15 min. Assessments took place every three months. Less labour-intensive visual assessments were used after the initial 12 months. Two years of monitoring is adequate to confirm a successful eradication since in the tropics ants quickly establish large populations that are easily detected.

Reports of the big-headed ant are still received from various locations within Kakadu, and inspections of these areas are undertaken. However, the majority of ants reported prove to be native species of big-headed ant.

16.5 Conclusion

This program showed that large-scale eradication of African big-headed ant is possible from point locations, particularly where there are large distances between settlements. Eradication should be given priority in conservation areas, especially while this species is in the early stages of invasion. Pot plants are a major concern, since African big-headed ants are found in large numbers in Darwin and can be readily transported in the soil of pot plants. This highlights the need for continuing and increasing public awareness, as well as continually monitoring to detect possible re-invasions.

16.6 Acknowledgments

The mapping, eradication and post-treatment surveys were conducted by Simon O'Connor (Kakadu National Park Pest Management Officer at the time), Ben Hoffmann (CSIRO Sustainable Ecosystems Research Scientis), and a team of park rangers. Tropical Fire Ant (*Solenopsis geminata*) was also treated at the same time as the African big-headed ant. Details of this can be found in Hoffmann and O'Connor (2004).

16.7 References

Hoffmann BD, O'Connor S 2004. Eradication of two exotic ants from Kakadu National Park. *Ecological Management & Restoration* 5, 98–105.

17 Feral animals and disease: an overview of the Northern Australia Quarantine Strategy, a program of AQIS

J Schmidt[1]

17.1 Introduction

The aim of the Australian Quarantine Inspection Service (AQIS) is to prevent the introduction of new pests and diseases, and to facilitate and certify exports. The North Australian Quarantine Service (NAQS) is a branch of AQIS, charged with the duty to:

- manage the quarantine aspects of border movements through the Torres Strait,
- identify and evaluate the unique quarantine risks facing northern Australia,
- develop and implement measures for the early detection of targeted pests and diseases, and
- strengthen Australia's quarantine through collaborative capacity building activities in Papua New Guinea, Indonesia and Timor Leste.

NAQS looks for exotic animal and plant diseases, exotic insects and weeds. NAQS tests feral animals during surveillance activities, including populations of feral pigs, deer, goats, horses, cattle and dogs. Feral animals are potential hosts or reservoirs for pests and diseases. Feral animal populations are mobile and often interact with domestic livestock animals important to agriculture and industry. They occur in remote areas that are seldom visited and where disease could remain undetected, establish and spread.

17.2 Unique quarantine risks in northern Australia

Northern Australia has unique quarantine risks that include:

- Proximity to northern neighbours. It is only 3.6 km from Papua New Guinea to Saibai Island in the Torres Strait (Figures 1 & 2);
- Traditional trade and movement of people and goods in the Torres Strait;
- Animals and insects entering Australia from northern high risk areas including migratory and nomadic birds;
- Close proximity to countries with different plant and animal pest and disease status from Australia;
- Unauthorised entry, for example, of foreign fishing vessels;
- Increased difficulty of disease detection due to the remoteness of Australia's northern coastline and a low human population density;
- High feral animal populations in Australia's north that may act as a host for exotic disease.

1 AQIS, PO Box 37846 Winnellie NT 0821

Figure 1 The Torres Straight area

Figure 2 Papua New Guinea can be viewed from Sabai Island in the Torres Straight. This photo illustrates the proximity of our nearest neighbour.

17.3 How is this huge area surveyed?

17.3.1 Risk assessments

The NAQS program uses a risk based approach to allocate priorities. Northern Australia is divided into risk management zones (Figure 3). Areas with greatest risk are surveyed at a high frequency and those with the least risk at a lower frequency. Each zone is assessed according to risk of entry, establishment, spread and consequence of each pest or disease. Taken into consideration are routes of entry and the numbers of both feral and domestic animals in area, and seasonal risks such as vectors and prevailing wind. This determines the level of focus on each 'zone' and the surveillance strategies that are used.

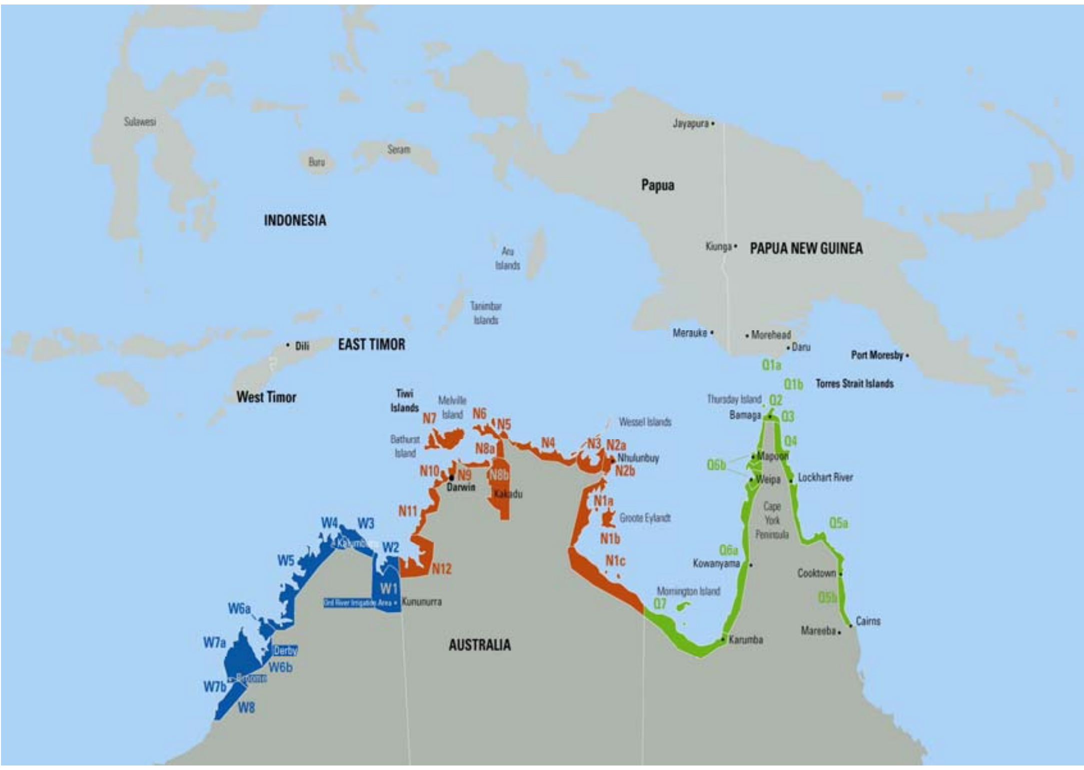


Figure 3 NAQS risk management zones

17.3.2 Types of activities and surveillance

Monitoring methods include:

- Sentinel herds and vector surveillance. NQIS works closely with the National Arbovirus Monitoring Program (NAMP) for Bluetongue virus monitoring.
- Promoting public awareness and reporting of threats through programs such as Topwatch and the Disease Hotline.
- Offshore surveys including Indonesia, PNG, Timor Leste
- Onshore surveys for Avian Influenza, and of domestic and feral animals (Figure 4).

Figure 4 A cannon net is set up to catch wild birds to test for avian influenza. This is a non-destructive method. The birds are tagged and released after a sample is taken.

17.3.3 Role of communities and rangers in surveillance

In the Northern Territory, NAQS is dependent on assistance from rangers and communities. This includes Aboriginal land and sea management groups (Figure 5), Parks Australia North staff, NT Parks and Wildlife staff and pastoralists. Eighteen indigenous ranger groups in the NT that have a working contract with AQIS/NAQS. This engagement is facilitated by NAQS community liaison officers. Indigenous ranger groups are trained to collect blood samples and carry out postmortum on feral animals.

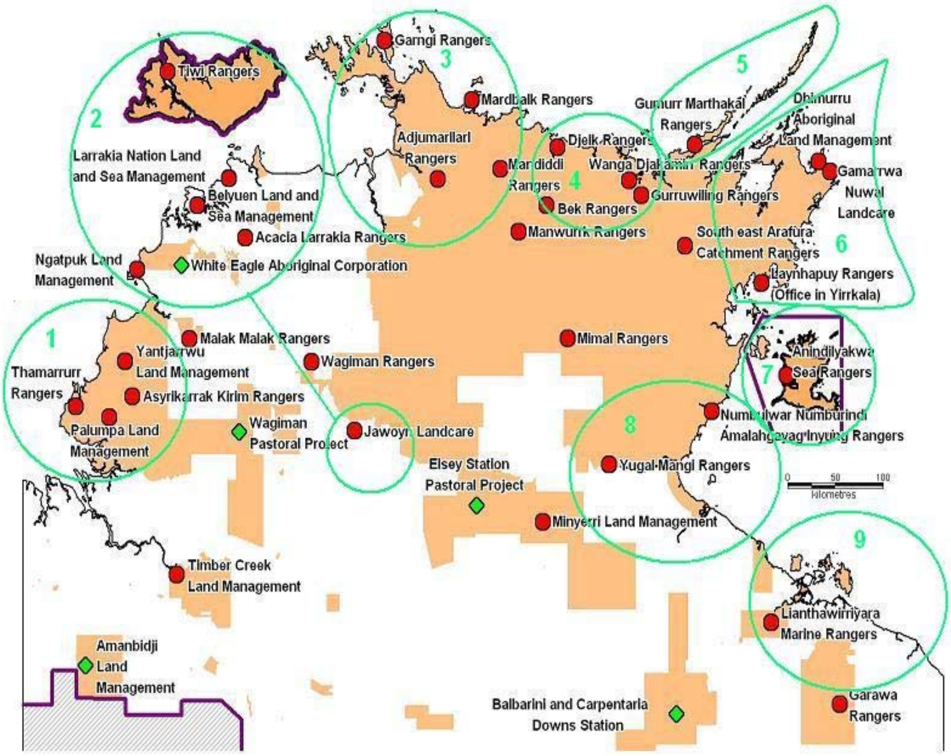


Figure 5 Aboriginal land and sea management groups involved in NAQS survey program

These activities occur twice a year in specific NAQS zones. Indigenous ranger groups are paid a fee to provide this service for NAQS. Their work is a major component of the NAQS passive surveillance. Land management groups are the front line for NAQS. They are trained to look out for and report signs and unusual occurrence amongst animals that could indicate a disease. In addition to detecting disease, survey work undertaken by NAQS can also provide incidental information on feral animal populations, such as the condition of populations and what they are eating. For example, autopsy of feral pigs can provide some information on the types and quantities of native species that feral pigs are consuming (Figures 6 & 7). Incidental information like this can show how destructive feral animals such as pigs are to native fauna and flora.

Figure 6 Common floodplain toadlets found in the stomach of a pig at Bradshaw military base. Animal autopsy undertaken during NAQS surveys can provide useful information to natural resource managers about feral animals.

Figure 7 Flat back turtle hatchlings found in the stomach of a pig in Lakefield National Park, Cape York Peninsular. Findings like these show how destructive feral pigs are to native fauna and flora, and assist with funding for control operations.

17.4 Diseases of interest to NAQS

There are 23 animal diseases on the NAQS target list which can be viewed at www.aqis.gov.au/quarantine/naqs/target-list. These cover diseases of cattle, horses, pigs, poultry and honeybees. Several of these diseases also affect people. The diseases described below are commonly looked for in feral animals sampled during NAQS surveys.

17.4.1 Foot and mouth disease

Foot and mouth disease is a viral disease and is one of the most contagious diseases of livestock. It affects cloven-footed animals including cattle, buffalo, pigs, goats, deer, sheep and camels. It is found in parts of Asia, Africa and South America, with occasional outbreaks in normally disease-free areas such as the Netherlands, France, Ireland and the United Kingdom in 2001. Australia has been free of foot and mouth disease since 1872. An uncontrolled outbreak of foot and mouth disease could lead to key beef. lamb and pork export markets being closed for more than a year. Control costs would be between $8 billion and $13 billion, and the consequences of an outbreak would be felt for up to a 10 years. The economic and social effects would be felt in other sectors, including tourism.

Affected animals have blisters and sores on the feet and tongue, and the snout of pigs. Because they have sore feet they do not want to move. They can also drool excessively (Figures 8 to 12).

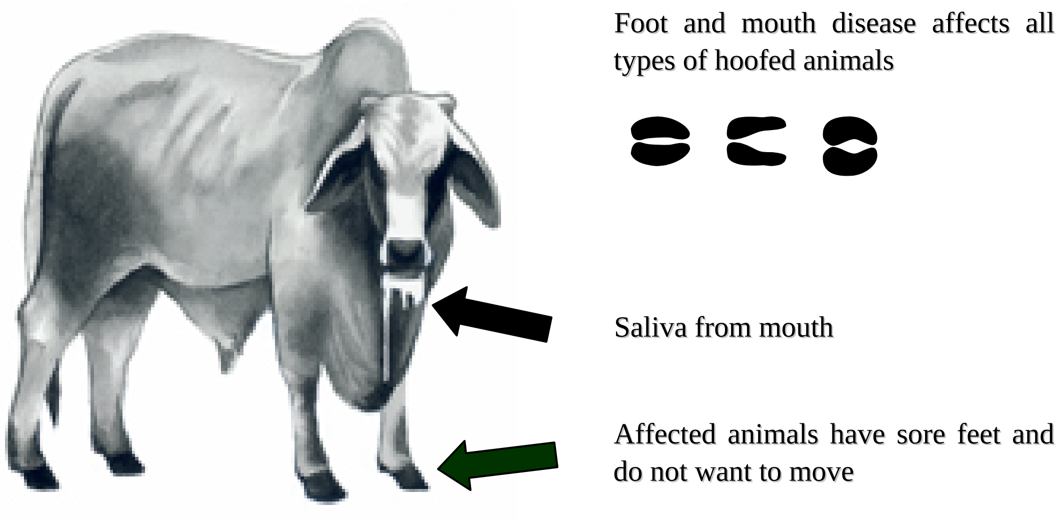
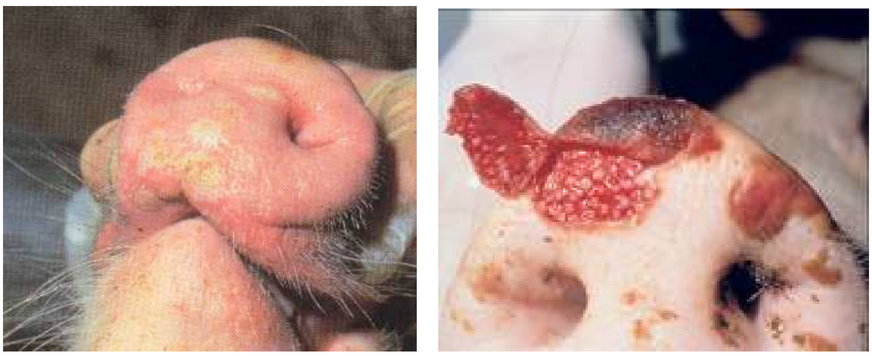


Figure 8 Symptoms of animals affected by foot and mouth disease include blisters and sores on feet and on pigs' snouts, and excessive saliva from the mouth



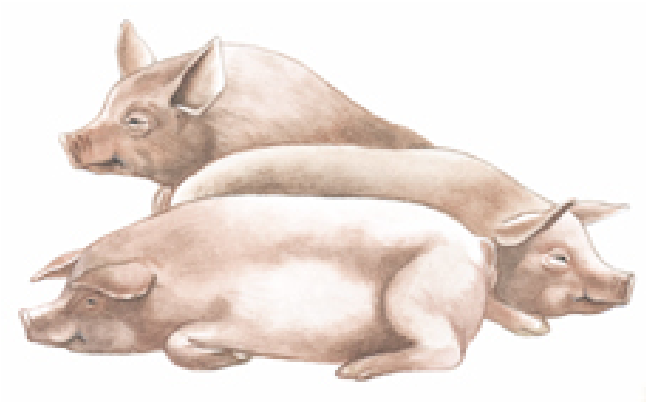
Figures 9 & 10
Blisters on a pig's snout

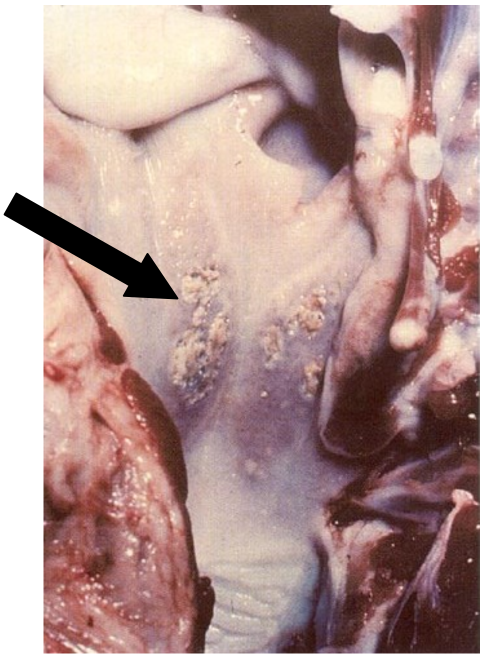
Figures 11 & 12 Blisters and sores on the feet

17.4.2 Classical swine fever

Classical swine fever is a highly contagious viral disease of pigs. There have been several outbreaks in Australia that have been eradicated, but no outbreaks since 1961. While infected pigs spread the disease, the virus can also survive for a long time in frozen pig carcasses and cured or salted pork. It can stay alive in contaminated pig pens for up to two weeks and can be carried on clothing, shoes or vehicles. Sometimes pigs can be infected without showing signs, and if they are moved to another area they can spread the disease further.

Pigs with the acute disease appear drowsy and depressed. They huddle together, stagger when forced to move and can have convulsions and trembling. First they are constipated, but vomiting and diarrhoea are also common. They may have gummy eyelids and red or purple blotching on the ears, snout, limbs and body. Death usually follows (Figures 13 to 16).





Figures 13 & 14 Amongst other symptoms, pigs infected with classical swine fever huddle together; trembling and unwilling to move and have abscess (puss) on the tonsils

Figure 15 Pigs infected with classical swine fever have red patches along the edge of the spleen

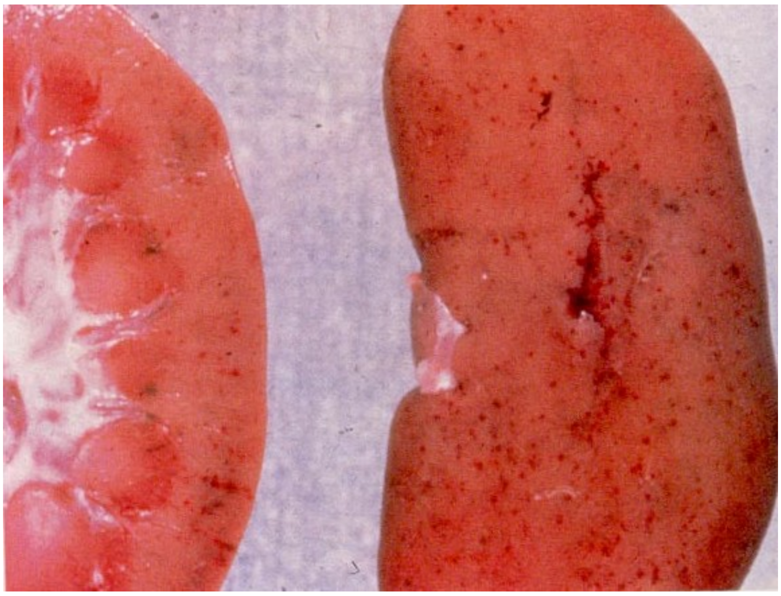


Figure 16 The kidneys of pigs infected with classical swine fever have small red patches as a result of heamorrhage

If classical swine fever got into Australia's wild pig population, it could spread into the domestic pig population, resulting in disease and death for many animals and the loss of millions of dollars for the pork industry. If the disease entered Australia, it could spread quickly and wipe out large sections of our pig industry.

17.4.3 Screw-worm fly

Screw-worm fly has flesh-eating maggots that infest and can even kill animals and people. Spread of this pest from New Guinea is one of the major quarantine threats to northern Australia. It could cost our livestock industries close to $500 million a year in lost production and control measures. The fly lays up to 250 eggs on a wound or opening in a warm-blooded animal. When the eggs hatch, maggots crawl into the wound and make it bigger by feeding on the living flesh. Small scratches, branding marks or castration wounds can all be infested, and one injury can be struck many times.

Screw-worm fly looks just like an Australian blowfly with a shiny blue-green body and a yellow face. You may not be sure if a fly is a screw-worm fly, but if you look closely at a fly struck animal you'll see live maggots deep in the wound. After six or seven days, the maggots drop out and grow into pupae with a hard brown shell (Figures 17).

The flies can multiply quickly – maggots hatch within 24 hours. Animals die from loss of tissue fluid and infection. If the fly were to establish in Australia, it would have disastrous effects on our livestock industry (particularly cattle and sheep), but could also threaten our native wildlife and human health.

Figures 17 Screw worm affects a range of animals and humans. Symptoms include deep, smelly wounds infested with maggots.

17.4.4 Surra

Surra affects many animals including horses, buffalo, cattle, deer and dogs. It might also affect wallabies. Surra is caused by a parasite (worm) that lives in the blood called a trypanosome. They are very small and can only be seen with a microscope. It can be spread between animals by the bite of a march fly. Animals with surra become very thin and are anaemic. Their gums look very white. They can have a fever. Some animals with Surra are sick for a long time and do not improve, others can die quickly, especially horses (Figures 18 to 21).

Figures 18 & 19 Animals affected by surra become very thin and anaemic

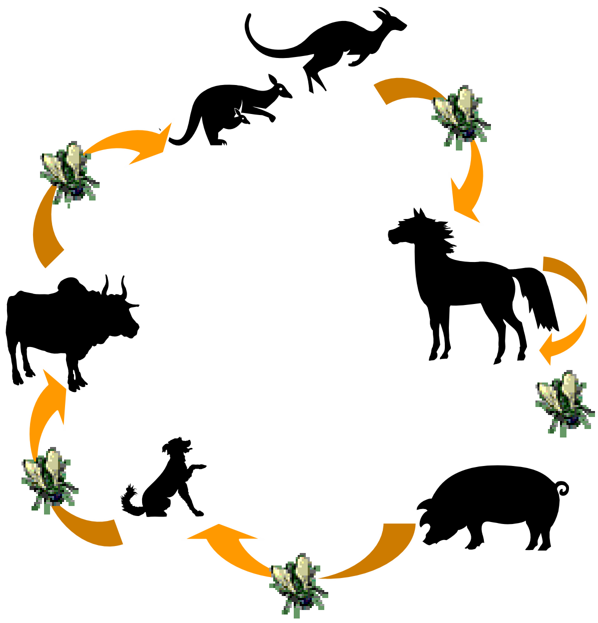


Figure 20 March flies can spread surra between animals

Figure 21 Trypanosomes in the blood of a sick dog

17.4.5 Rabies

Rabies is a fatal disease affecting cats, dogs, cattle, deer, pigs, horses and humans (Figure 22). It is a serious viral disease which affects the central nervous system of warm blooded mammals. It is almost always fatal once clinical signs have appeared. Rabies is transmitted from infected animals through saliva. Humans or other animals can be infected by bites or scratches from other animals. The virus present in saliva can infect humans or other animals through bites or scratches. The annual number of human deaths worldwide caused by rabies is estimated to be between 40 000 and 70 000. An estimated 10 million people receive post-exposure treatments each year after being exposed to rabies suspect animals. In Australia the only deaths from rabies have been rare cases of people who have acquired the infection overseas.

Animals infected with rabies may not present signs for anything from two weeks to many months. Foaming at the mouth and erratic behaviour are two common signs of 'furious' rabies where animals may attack stationary objects, other animals or gnaw their own limbs (Figures 23 to 25). Animals with ‘dumb’ rabies may retreat to isolated places and exhibit signs of paralysis including drooping head, paralysed hind limbs and sagging jaw.

Australia does not have endemic rabies. However, there is concern that if rabies becomes established in New Guinea it could cross to Australia. There is concern that rabies could become established in bats, dingoes, wild dogs and their hybrids and even possums, putting humans at risk.

Figure 22 (left) Rabies is a fatal disease affecting cats, dogs, cattle, deer, pigs, horses and humans. **Figures 23 to 25** Foaming at the mouth and erratic behaviour are two common signs of rabies

17.5 Who to call if you suspect an exotic disease

National Emergency Disease Watch Hotline 1800 675 88

AQIS Quarantine Topwatch 1800 020 504

For further information about AQIS’ Northern Australia Quarantine Strategy or NAQS target pests and diseases contact: Darwin Regional Office (08) 8920 7000 or visit www.aqis.gov.au/topwatch.

18 Climate change and invasive species

S Garnett[1]

18.1 Introduction

Climate change is going to affect natural systems at many different levels. At a genetic level there will be natural selection for animals and plants that can survive extended periods of higher temperatures, changed water regimes or even have strategies that can allow them to prosper in the face of increased cyclone strength. At the level of the ecological community changes in temperature and rainfall will affect which species can associate together – some will be favoured over others leading to changes in the structure of animal and plant communities. Finally, at the landscape level, there will be major changes in the forces that shape the earth – rain, wind, sunshine and sea level. Feral animals will be players at every level, often in ways that are unexpected.

Feral animals also play a small part in causing climate change, and therein also lies a possibility of finding synergies between feral animal control and climate change mitigation. Feral herbivores, particularly cattle and buffalo but also horses and donkeys, produce methane through enteric fermentation. The control of these feral animals can thus result in a reduction in greenhouse gas production.

In this paper I examine a few examples of the potential interaction between climate change and feral animals and explore opportunities for park management to link feral animal control to greenhouse gas mitigation

18.2 Effect of climate change on existing feral animals

18.2.1 Case study 1: toads

As noted in Garnett and Woinarski (2009) in this series, the cane toad (*Chaunus marinus)* has reached a physiological limit on the inland edge of its range where maximum daily temperatures exceed 37.7°C (Urban et al 2007). This physiological ceiling could eventually limit their abundance in Kakadu National Park if the temperature increases as predicted. Such changes, however, will also affect many other animals and plants in ways that are almost impossible to predict, advantaging a few but disadvantaging most.

18.2.2 Case study 2: feral herbivores

A rise in temperature will also affect other feral animals, as well as domestic ones. Heat stress is known to reduce the fertility of cattle (Santos et al 2004). As temperature rises, the reproductive output of feral cattle, and probably buffaloes, may decline. While there will be selection for animals that can reproduce at higher temperatures, physiological limits can be expected, as with the toads, or else reproduction may be increasingly confined to cooler months.

One of the causes of climate change, an increase in the level of atmospheric carbon dioxide, will also cause problems for the large herbivores because higher carbon dioxide levels result in a decline in the nitrogen concentration in fodder (Weigel & Manderscheid 2005). As

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Australian tropical pastures are already extremely low in nitrogen during the dry season, fewer cattle and buffalo may survive each year. Again there will be selection for animals that can survive on low nutrient levels, but their reproductive rate is likely to decline.

18.3 Climate change and new feral animals

18.3.1 Case study 1: Tilapia

Tilapia are a highly fecund and competitive group of fish from Africa of the genera *Oreachromis, Tilapia* and *Sarotheradon* that have been introduced through the aquarium trade to numerous sites round Australia including north Queensland. Because tilapia are relatively tolerant of salt water they have managed to move between all the eastern-flowing catchments from the Burdekin to Cooktown. They already cause millions of dollars worth of damage to north Queensland waters through reducing water quality, sometimes to a point where it is unfit for human consumption (Greiner & Gregg 2008). In January 2008, this species, which had previously been confined to eastward flowing rivers, was found in a tributary of the westward flowing Walsh River (Department of Primary Industries 2008). The Walsh River feeds the Mitchell River which empties into the Gulf of Carpentaria through a delta that, in wet years, is effectively joined to the deltas of other rivers flowing into the Gulf of Carpentaria almost as far west as Tarrant Point south of Mornington Island in the Gulf of Carpentaria.

Under the existing climate it might be expected that the spread of the fish would pause at this point because there are few major creeks flowing into the sea between Tarrant Point and the McArthur River estuary. Under some climate change scenarios, however, this coast is among the most vulnerable to change in Australia. The rise in sea level together with a predicted increase and intensification of wet season rainfall could allow spread of the fish westward. Like the cane toad (*Chaunus marinus)* before it, once this biogeographic barrier has been overcome there is little to stop the fish from moving up the Roper River and down the Daly River. Though it might take a little longer to reach the northward flowing streams of Kakadu, the headwaters of the Roper and Alligator are close in wet years or else it will work its way around the coast from estuary to estuary. Though there is little evidence that biodiversity or even fishing catch will be affected (Greiner & Gregg 2008), the arrival of tilapia would have serious implications for water quality.

18.3.2 Case study 2: Insects

Most feral animal control programs are aimed at vertebrates. Because they have relatively long generation times, control programs can target individuals and there is a lag time between arrival and full ecological impact. Among the first species to respond to a changed climate, however, will be insects. At this stage we do not know what the potential invaders will be. While there is a fear of species like screw-worm fly because of their potential impact on the pastoral industry, there are more likely to be invasions from herbivorous species like aphids, either naturally from high winds associated with cyclones or via inadvertent anthropogenic transmission. While the threat of new insect arrivals is always present, climate change presents new opportunities because plant defences will already be stressed. An example of the flow-on effects of climate stress and insect proliferation is on Christmas Island in the Indian Ocean. There plants stressed by unusually dry weather produced excessive amounts of sugar that caused scale insects to proliferate. A mutualistic relationship between the insects and yellow crazy ants meant that the scale insects continued to stress the plants while the ants formed supercolonies and began to unravel the whole ecological structure of the island

(O'Dowd 2003). Under rapid climate change, feedback mechanisms that have limited large fluctuations in insect abundance in the past are likely to break down in just the same way they have on Christmas Island. This will be particularly true of new insects where local species have limited inherent resistance. While we do not know what the pest species will be, we do know that climate-driven ecological cascades are inevitable.

18.4 Opportunities from climate change

In the Northern Territory feral animals contribute substantially to greenhouse gas emissions and considerable sums are spent each year by both government and the private sector reducing the number of feral camels, horses, donkeys and buffalo because they compete with domestic cattle and cause environmental harm. Some species hold cultural significance to some people but a reduction in their numbers would also result in protection of cultural sites and landscapes. Culling of feral animals also reduces the amount of greenhouse gas they emit. The Department of Climate Change assumes that each buffalo produces 55 kg of methane per year (Australian Greenhouse Office 2007). This is the equivalent of approximately 1 tonne of CO_2 per year, given that one unit of methane has a climate-forcing effect equivalent to 23 units of CO_2. The equivalent figures for horses and donkeys are 18 kg and 10 kg respectively. Taking the methane production figures and conversion rates applied by the Australian Greenhouse Office to domestic equivalents and estimates of population size from the Department of Natural Resources, Environment and the Arts, feral animal emissions from the Northern Territory were about 0.6 Mt in 2006[2]. Although this figure excludes contributions from feral cattle, pigs and rabbits, it exceeds a quarter of the emissions estimated to be produced by domestic stock and, together with the effects of added nitrogen to soils, would represent about 5% of the Territory's emissions.

For Kakadu this means that each buffalo killed reduces the emissions by about a tonne of $CO_{2\text{-}e}$ for that year. Given that buffalo can live over 20 years and will reproduce during that period, each buffalo killed without replacement will result in at least 20 tonnes of emissions reduction, and probably many more. There might be some concern that emissions from the helicopter while shooting buffalo will mean that there is no net gain in greenhouse gas emission reduction. However it is possible to calculate that a Robinson-44 helicopter, the type usually used for aerial culling, generates 0.145 t $CO_{2\text{-}e}$ per hour. Thus it is only necessary to shoot one buffalo every 100 hours, or two horses or three donkeys to balance the carbon budget of culling.

To pay for the culling it may even be possible to find a buyer for the carbon saved on the voluntary carbon market provided that the carbon savings can be validated and the cull effectiveness verified. Assuming a price return of $20 per tonne on the carbon equivalents saved and a wet hire cost of the helicopter of $790 per hour, it would be necessary to shoot an average of 1.37 buffalo, 5.21 horses or 7.51 donkeys per hour under such a scheme to break even. Given that feral animal control is currently paid entirely from government appropriations on public lands in the Northern Territory, including Kakadu, any return from the carbon credits can only be to the park's advantage.

The carbon benefits are likely to increase once the research is available on the influence of feral animal grazing on soil carbon stocks. Based on work done in the American rangelands, the Chicago Carbon Exchange already offers a carbon offset product for soil carbon – ie

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[2] Camel (212,587 head, 46 kg CH_4/yr); Donkey (142,425, 10 kg); Horse (420,688, 18); Buffalo (149,479, 55)

buyers can enter into a contract with another party to undertake actions that are believed to increase soil carbon to offset their own emissions of carbon. However, because the science is currently uncertain, the price of carbon under such schemes is currently worth less than $2.00 per tonne. Better science should lead to higher prices, particularly if tied to social and biodiversity benefits.

18.5 What are the information gaps?

The world is undertaking an unreplicated, unrepeatable experiment in climate manipulation. The impact of this on feral animals and the impacts that feral animals have on the environment is just one of a host of almost unknowable factors that will affect the environmental values and management of Kakadu National Park. The research needed to anticipate changes and so devise responses falls into four areas:

- Physiological responses of feral animals to changed climates, particularly increased temperature. While there will be selection for a different range of tolerances as climate changes, limits to adaptation could be determined to understand at what point control is no longer necessary.
- Modelling of impacts of feral animals under different climate change scenarios. Kakadu has been blessed with some excellent studies of the interaction of feral animals and vegetation structure. Parameterisation of models using these studies will help understand where and what impacts control strategies are likely to have on environmental values.
- Sustained monitoring with sufficient sampling and statistical strength to detect change in both vertebrate and invertebrate dynamics, particularly to detect new insects but also to detect changes in local insect dynamics. Management can rarely respond directly to such events, but targeted protection of key species and other values may be possible if detection is sufficiently early.
- Modelling of the impacts of feral animal control on methane production within the park. The figures produced here are very preliminary, based on limited data available to the Australian Greenhouse Office. More sophisticated modelling taking into account reproductive rates and density dependence would be essential as part of the validation process needed to develop feral animal reduction as a product on the voluntary carbon market. There also needs to be more detailed analysis of methane production by buffalo which is likely to vary according to forage type and a number of other factors for which data are currently lacking.

Of these the last gap is the easiest to fill and could also augment arguments to control feral animals in Kakadu for other reasons. As with the fire abatement project in western Arnhem Land, it can be anticipated that it will take ten years to validate and find a buyer for carbon abated through feral animal control. The sooner the research begins the sooner that market can provide benefits for the park.

18.6 References

Department of Primary Industries 2008. Tilapia control program underway in Gulf. Department of Primary Industries Press Release. http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/30_9093_ENA_HTML.htm.

Australian Greenhouse Office 2007a. National Greenhouse Gas Inventory 2005, available at www.greenhouse.gov.au/Inventory [April 2008].

Garnett ST & Woinarski JCZ 2009 Potential impacts of climate change on terrestrial biodiversity. In Kakadu National Park Landscape Symposia Series 2007–2009. Symposium 4: Climate change. ed Winderlich S, 6–7 August 2008, Gagudju Crocodile Holiday Inn, Kakadu National Park. Internal Report 567, January, Supervising Scientist, Darwin, 64–68.

Greiner R & Gregg D 2008. *Tilapia in north Queensland waterways: Risks and potential economic impacts*. Report prepared for the Australian Freshwater Research Centre, James Cook University, Townsville, Queensland. http://www.riverconsulting.com.au/reports/Greiner-Gregg_2008_Tilapia.pdf

O'Dowd DJ 2003. Invasional 'meltdown' on an oceanic island. *Ecology Letters* 6, 812–817

Santos JEP, Thatcher WW, Chebel RC, Cerri RLA & Galvão KN 2004. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. *Animal Reproduction Science* 82–83, 513–535

Urban MC, Phillips BL, Skelly DK & Shine R 2007 The cane toad's (*Chaunus* [Bufo] *marinus*) increasing ability to invade Australia is revealed by a dynamically updated range model. Proceedings of the Royal Society B. *Biological Sciences* 274, 1413–1419.

Weigel HJ & Manderscheid R 2005. CO2 enrichment effects on forage and grain nitrogen content of pasture and cereal plants. *Journal of Crop Improvement* 13, 73–89.

19 Can commercial harvesting be an effective control method?

SR McLeod[1]

19.1 Introduction

There are many vertebrate pests in Kakadu National Park. Ongoing pest control programs to manage their impacts are expensive. Commercial harvesting of pests may provide income to offset some of the expense of these control programs. The idea that commercial harvesting is a cost-effective way of managing vertebrate pests is not a new one. Nevertheless, this idea is largely untested and there are few successful examples to use as a guide.

Commercial harvesting of pests needs to balance two goals; maximising the profit from harvested animals, while minimising the damage that the pests cause. The main impediment to achieving successful pest control using commercial harvesting is that the goals of profit maximisation (for commercial use) and damage minimisation (for pest control) potentially require very different population sizes. In most cases, commercial use of a pest population will require a high population size so that the cost of harvesting can be kept as low as possible. The population size that allows the population to be harvested profitably may lead too unacceptably high damage levels.

The purpose of this paper is to provide some rules-of-thumb regarding the suitability of using commercial harvesting to manage the vertebrate pests in Kakadu National Park, in particular buffalo, horses and wild cattle.

19.2 Elements of commercial use of a pest population

The effectiveness of commercial harvesting as a pest management tool is determined by three relationships; i) the relationship between pest density and the damage they cause, ii) the yield that can be sustainably harvested from the population, and iii) the cost of harvesting individuals.

19.3 Density-damage relationship

There are three main types of density-damage relationships; linear, concave-up and concave-down (Figure 1). A linear density-damage relationship occurs when the pest does not impact on the productive capacity of the resource. For example, an animal that eats fruit that falls from a tree will not affect the capacity of the tree to produce more fruit. The amount of fruit that the tree produces is independent of the number of fallen fruits that are eaten. A concave-up relationship can occur when the resource can compensate for damage caused when the pest is at low to medium density. When the pest is at high density the resource can no longer compensate and the level of damage increases rapidly. An example of this type of density-damage relationship occurs when generalist herbivores graze on pastures. Finally, a concave-down relationship occurs when the pest has high level of impact even at low pest density. A

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predator, such as a cat, feeding on a prey species with a low rate of increase will produce this type of density-damage relationship.

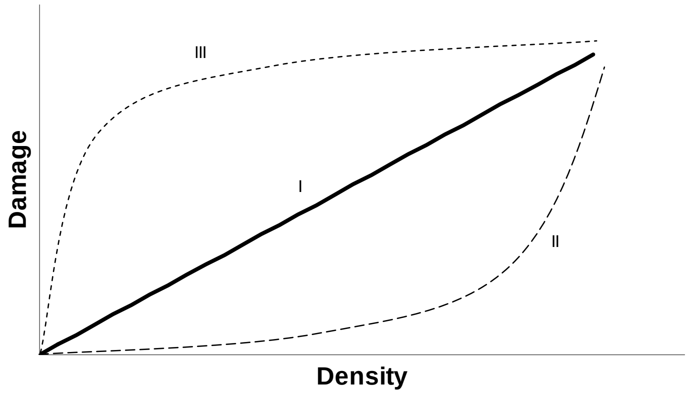

Figure 1 Three general types of density-damage relationships. Relationship I demonstrates a linear increase in damage. The amount of pest damage is directly proportional to pest density. Relationship II indicates that when the pest is at low to medium density, damage occurs at a low level and increases at a slow rate as pest density increases. At higher densities damage increases rapidly. A relationship of type III occurs when damage increases rapidly at low density then asymptotes quickly to its maximum value.

19.4 Yield-population size relationship

The pattern of population growth for large mammals can be modelled using a logistic model (eg Eberhardt 1987). One use of this model is the calculation of the productivity of the population at various densities (Figure 2). This is known as a yield curve, indicating the sustained harvest that can be taken from the modelled population while holding it at an equilibrium density below carrying capacity. The maximum point of the yield curve is the maximum sustained yield (MSY). Assuming logistic growth, the MSY is at half the carrying capacity. Other yields can also be taken sustainably, but these yields will be less than at the MSY.

The points A and B (Figure 2) represent two equal yields from a hypothetical pest population. Yield A occurs at a much lower population size than yield B. A pest control program would try to achieve a low population size, so would be most likely to aim for a population size closer to A.

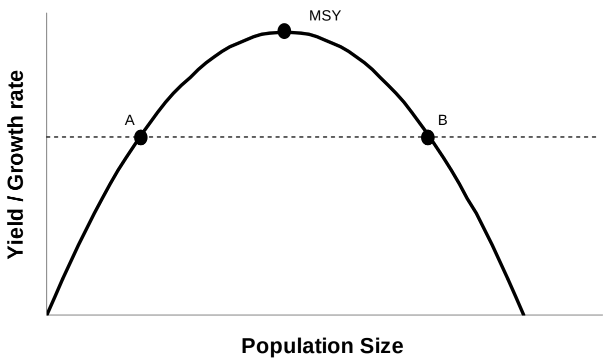

Figure 2 The relationship between population size and yield (or population growth) for a hypothetical pest. A yield curve modelled by a logistic growth function. The maximum sustained yield (MSY) is the largest yield that can be sustainably harvested from the population. Other sustainable yields (such as A and B) can also be taken.

19.5 Cost of harvesting

A major cost of commercial harvesting is the cost of searching and finding animals for harvesting. At high pest density little time is spent searching and most costs are due to procuring animals. Consequently, at high density the cost per animal harvested is usually low (Figure 3). As the population is reduced in size, the cost per animal increases since more time must be spent finding animals.

Comparing Figures 2 and 3 indicates that at high pest density (point B) the cost per animal harvested is much lower than at low pest density (point A) even though the yields are the same. From a financial perspective it would be more profitable to keep the pest population at a higher density. But this higher density is less likely to satisfy the goal of minimising damage caused by the pest. Holding the population size at point A is more likely to satisfy the goal of minimising damage but may not be profitable, and therefore not a sustainable form of management.

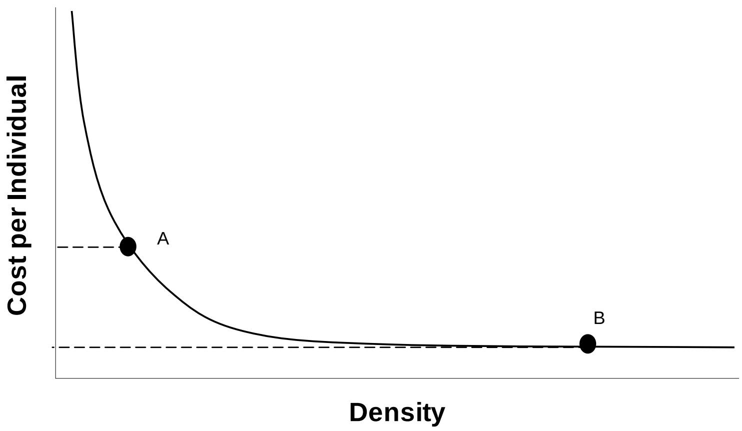

Figure 3 The relationship between pest density and the cost of harvesting an individual. Points A and B correspond to A and B in Figure 2.

19.6 Conclusion

Commercial harvesting can be an effective method of pest control but requires balancing 3 relationships; density-damage, yield-population size and cost of harvesting. Without knowledge of these relationships it is not possible to accurately predict if commercial harvesting may be an effective control method at Kakadu National Park. Nevertheless, we can make some broad predictions.

Prediction 1: If the density-damage relationship is concave-up (type II in Figure 1) then commercial harvesting may be an effective control method. This type of density damage relationship might occur if the impacts of buffalo, horses and feral cattle are mainly due to their overall grazing and trampling on vegetation, and they do not impact disproportionately on one plant species.

Prediction 2: If the density-damage relationship is linear or concave-down (types I and III in Figure 1) then it is unlikely that commercial harvesting will be an effective method of managing pest impacts. In these cases, the impacts of buffalo, horses and feral cattle are likely to be disproportionately large when these pests are at low density.

Without an understanding of the relationship between pest density and damage it is unlikely that we can make a prediction regarding the effectiveness of pest control by commercial harvesting. In the absence of information we should err on the side of caution and presume that these pests have a concave-down density-damage relationship. In which case these pests need to be held at low density and it is unlikely that commercial harvesting can be an effective, and sustainable, pest management method. Where appropriate, commercial use may be useful as an initial control method to reduce populations from high density but is unlikely to be an effective long-term method. Given that any decision regarding the potential effectiveness of commercial harvesting relies on determining the shape of density-damage relationship, a priority topic for future research should be determining the relationship between these pest species and their impacts.

19.7 References

Eberhardt LL 1987. Population projections from simple models. *Journal of Applied Ecology* 24, 103–118.

Hone J 1994. *Analysis of vertebrate pest control*. Cambridge University Press, Cambridge.