

A REVIEW OF THE IMPACT AND CONTROL OF CANE TOADS IN AUSTRALIA WITH RECOMMENDATIONS FOR FUTURE RESEARCH AND MANAGEMENT APPROACHES



**A Report to the Vertebrate Pests Committee
from
the National Cane Toad Taskforce**



**Edited by
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CONTENTS

AUTHORS.....	iii
MEMBERSHIP OF THE NATIONAL CANE TOAD TASKFORCE	iv
ACKNOWLEDGEMENTS	iv
SUMMARY	v
DISCLAIMER.....	xii
1. INTRODUCTION <i>Glenn Edwards</i>.....	1
2. THE CURRENT THREAT POSED BY CANE TOADS <i>Damian McRae, Rod Kennett and Robert Taylor</i>.....	3
2.1 Existing literature reviews of cane toad impacts	3
2.2 Environmental impacts of cane toads	3
2.3 Social impacts of cane toads	10
2.4 Economic impact of cane toads	16
2.5 Recommendations.....	17
3. SHORT-TERM OR LOCAL THREAT ABATEMENT	19
3.1 Traps and attractants <i>Ross Alford</i>	19
3.2 Enclosures as a means of controlling the impact of cane toads <i>Barry W. Brook and Peter J. Whitehead</i>	25
3.3 The use of bonus or bounty schemes as a means of pest control <i>Peter Mawson</i> ..	33
3.4 Community participation in cane toad control <i>Graham Sawyer and Robert Taylor</i>	35
3.5 Mechanisms of toad dispersal to islands and its implications for biosecurity protocols and choice of islands for translocation of impacted species <i>Robert Taylor and Frank Keenan</i>	42
3.6 Identification of high priority sites for exclusion or control of cane toads <i>Robert Taylor</i>	46
3.7 Control via limiting resources <i>Robert Taylor and Ross Alford</i>	48
4. LONG-TERM AND/OR WIDESPREAD THREAT ABATEMENT	50
4.1 Search for <i>Bufo</i> -specific pathogens <i>Tony Robinson, Hamish McCallum and Ross Alford</i>	50
4.2 Control of cane toads by the sterile male approach <i>Michael Mahony and John Chulow</i>	54
4.3 Cane toad specific toxins <i>Tony Robinson and Ross Alford</i>	62
4.4 Disseminating and non-disseminating GMOs <i>Tony Robinson</i>	64
4.5 Models to explore the ecological and evolutionary feasibility of potential biological control strategies <i>Hamish McCallum</i>	66
5. CURRENT MANAGEMENT OF CANE TOADS IN THE STATES AND TERRITORY AND OVERSEAS	69

5.1 New South Wales <i>Ron Haering</i>	69
5.2 Queensland <i>Frank Keenan</i>	72
5.3 Northern Territory <i>Robert Taylor and Keith Saalfeld</i>	74
5.4 Western Australia <i>Peter Mawson</i>	79
5.5 International <i>Robert Taylor</i>	81
6. RECOMMENDATIONS FOR BEST PRACTICE MANAGEMENT AND PRIORITY RESEARCH	84
6.1 Cost-benefit analysis <i>Hamish McCallum</i>	84
6.2 Best practice management <i>National Cane Toad Taskforce</i>	85
6.3 Priority research projects <i>National Cane Toad Taskforce</i>	88
7. REFERENCES	97

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SUMMARY

The National Cane Toad Taskforce was formed in September 2004 as a subcommittee of the Vertebrate Pests Committee. This resulted from a request from the Northern Territory Minister for the Environment to the Natural Resource Management Ministerial Council (NRMMC) that a national task force be set up to coordinate a response to the threat from cane toads. The NRMMC requested that the Taskforce produce a report that would:

- REVIEW the current threat posed by cane toads
- REVIEW the states of research into developing tools to abate those threats
- IDENTIFY any gaps in current approaches
- ASSESS costs and benefits of options for priority joint national action.

IMPACTS OF THE CANE TOAD

The cane toad (*Bufo marinus*) was introduced to Queensland in 1935 in an attempt to control beetle pests of sugar cane. Since its introduction, the cane toad has proved to be a highly invasive pest and is still spreading across northern and eastern Australia. The potential distribution of the cane toad is shown in the figure below.

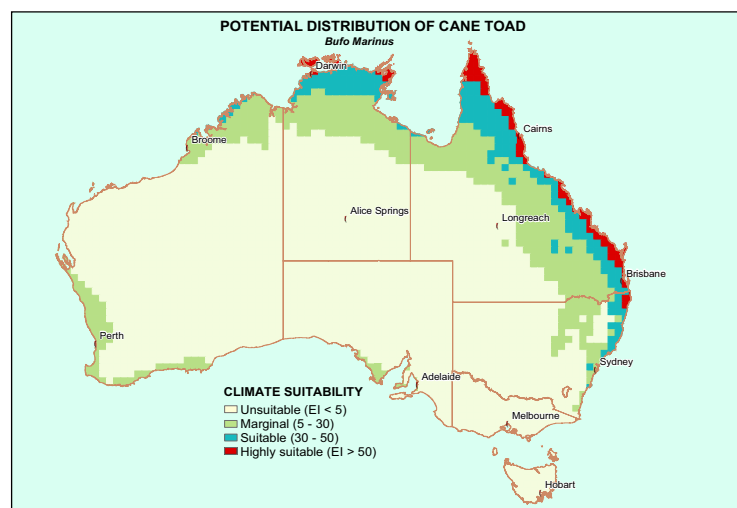


Figure a. Potential Australian distribution predicted from Climex on the basis of the distribution of cane toads in Queensland in 2004

The cane toad is poisonous in all of its life stages: eggs, tadpoles, juveniles and adults. A number of native species are considered to have experienced impacts from cane toads, most notably in relation to lethal ingestion of cane toad toxin. However, much of the research to date remains inconclusive at a species and population level. It is uncertain to what degree species that initially decline may build up populations again in the longer-term.

The most compelling case is that of the northern quoll. Local populations of this species have been shown to decline to extinction in two studies in the Northern Territory. It is estimated that the cane toad will, in the foreseeable future, colonise

almost the entire mainland range of the northern quoll and the species will continue to decline as a result. Although there has been no widespread recovery of the species in Queensland, there are small scattered areas where the species has either persisted or recovered.

There are, to date, insufficient data quantifying the impacts from cane toad predation (e.g. on aquatic and terrestrial invertebrates) and the impacts that may occur on native species due to competition with cane toads for food and shelter. While it is suspected that predation and competition play a significant role in reducing populations of native species, and altering ecosystems, data investigating such impacts are neither complete nor comprehensive.

SHORT-TERM OR LOCAL CONTROL

Traps and attractants

Trapping can potentially provide a useful tool for reducing the density of a local population of cane toads or helping to prevent the entry of toads to an area or detecting the presence of vanguard colonising toads. There are a variety of potential attractants that can be used to lure toads to traps. Toads are very dependent on the presence of moisture, particularly at the end of the dry season in areas with a monsoon climate. At this time they congregate around water sources. This behaviour may be able to be exploited to achieve significant population reduction. Toads are also readily attracted to light traps due to the large numbers of insects that are drawn to the light. Many types of toad traps have been designed. Recent trials of cage traps by Frogwatch in Darwin have been encouraging. However, information on the spacing and numbers of traps required to achieve significant population reduction of toads in different situations is lacking.

Exclosures

Fences can theoretically be used to exclude cane toads and hence protect biodiversity. However, no trials have been undertaken to see whether an exclosure can be designed that can effectively exclude cane toads on a large scale taking into account issues such as drainage, creek crossings and uneven terrain. Exclosures used to protect populations of most wildlife species need to be large in order to encompass enough animals to support a viable population. This leads to large costs for establishment and maintenance. In some situations, natural features could be used to reduce the amount of fencing needed. An example is a peninsula with cliffs all around it, where a short fence across the neck could be effective and affordable. Exclosures may be more feasible and cost effective for populations of threatened invertebrates with restricted distributions.

Bounty schemes

Bounty schemes, where a payment is given for animals collected, have been shown many times to be ineffective and are not recommended.

Community participation

Community interest in controlling cane toads has frequently been harnessed in Australia in so called “toad buster” campaigns. These have met with varying success. Large scale campaigns are more likely to fail than small scale local ones. The objectives for engagement with the community by government or conservation organisations in such campaigns often focus on education rather than population reduction or biodiversity outcomes. There has never been a study that examines whether community programs to reduce toad numbers have had any biodiversity outcomes. It may be the case that the level of density reduction required and the time period over which this density reduction needs to be maintained have not been adequate to achieve any biodiversity benefit. This obviously needs to be examined. One key factor in determining success will be the extent to which community involvement can be maintained in a project over the long-term. Community involvement will be crucial in maintaining island biosecurity.

Island colonisation and biosecurity

Islands are strategically important for conserving biodiversity in areas free of cane toads. Colonisation of some islands by cane toads occurs naturally through animals being washed there in floodwaters. Other islands have been colonised through individuals being inadvertently transported there in cargo, building materials being a common source. Monitoring for the presence of vanguard colonising individuals needs to be undertaken so that animals can be removed prior to a population establishing. Biosecurity protocols are also required to prevent transport of cane toads to islands in cargo.

Priority sites for exclusion or control

The high cost of controlling cane toads means that this will only be attempted in a limited number of areas. The following factors would need to be considered in deciding where control might be attempted:

- the abundance and/or diversity of impacted species present or likely to be present in the absence of cane toads
- the ease and cost of controlling or excluding cane toads
- the proximity of a community willing to be involved in control activities.

Control via limiting resources

Limiting the access of cane toads to a resource that is limiting population numbers may be an efficient way to control cane toads. In areas with a monsoon climate, controlling access to moisture in areas where this is limited in occurrence at the end of the dry season may keep population numbers low. Controlling access to breeding habitat may be an efficient way to reduce populations in areas where such habitat is limited.

LONG-TERM AND/OR WIDESPREAD CONTROL

Four approaches to long-term control of cane toads were identified i.e. a *Bufo*-specific pathogen, release of sterile males, a cane toad specific toxin and a disseminating or

non-disseminating genetically-modified organism (GMO). All of these potential control technologies are at least theoretically possible. Mathematical modelling of the likely impact and long-term consequences of each of these control strategies is an important component in establishing their feasibility. Modelling should be able to guide the research towards strategies most likely to be effective in the field.

The deployment of a naturally occurring *Bufo marinus*-specific pathogen capable of reducing populations on a continental scale would be the most cost-effective control method for cane toads. Over the past twenty years, there have been a number of attempts to identify a cane toad specific pathogen within the natural range of the species overseas and within Australia but no candidate has been found. Taking into account the example of myxomatosis in the control of rabbits, a suitable control agent may be present in a species currently outside the natural range of the cane toad. The discovery of such an agent, however, is problematical and a systematic search for potential biocontrol agents in other species would be a daunting logistical and financially prohibitive exercise. It is more likely that such an agent would be discovered serendipitously rather than uncovered in a systematic search. A watching brief and the strengthening of links with amphibian experts overseas would be a useful first step in maximising the chances of discovering such an agent.

A cane toad specific toxin would be a useful addition to the tool kit for local control of toads. Although no specific toxin or toxin target has been identified, it was considered worthwhile to pursue this approach, possibly in combination with attractants and traps.

The production and introduction of sterile males has the advantage that it does not require the introduction of an infectious organism, is highly species specific and does not require extensive testing to confirm that it does not impact native species. It also offers no concern for international biosecurity.

The fourth approach to long-term control, the production of a GMO that would interfere with the development of the cane toad, is being actively pursued by CSIRO and the Australian Department of Environment and Heritage. The successful construction of such an agent would have the same advantages as a naturally occurring pathogen in that it could potentially operate on a continental scale. An intermediate strategy is to engineer a non-disseminating agent. A barrier to success could be the time taken to gain approval for the release of such an agent.

As all these projects are at the discovery end of the innovation pipeline, they carry with them a high degree of uncertainty and as such no estimate of probability of success is possible. A means to manage the uncertainty and increase the probability of success would be to regularly review progress and re-direct resources accordingly. All would require investments over five to ten years.

CURRENT MANAGEMENT OF CANE TOADS

New South Wales

The primary objective of management in New South Wales has been to prevent cane toads establishing outside their existing range. This objective has generally been

implemented through the promotion of community education and awareness programs at the state and local level. The Lord Howe Island Board is working to improve quarantine measures to minimise the risk of cane toads reaching the island through transportation in cargo.

Queensland

Cane toads are not a declared pest in Queensland as there is currently no practical broad scale control/eradication method available. Declaration would place a legal obligation on all landholders (including State land managers) to undertake reasonable control measures on their land. Some local community groups are involved in “Toad Buster” activities; however, this is not an official activity. Data on the distribution and frequency of *B. marinus* are collected as part of Queensland’s Annual Pest Assessment process.

Northern Territory

The focus of the Northern Territory program is on the documentation of status of impacted species on islands and implementation of biosecurity measures to ensure that cane toads do not get to islands. The involvement of indigenous communities on islands to look out for vanguard colonising toads is being actively pursued. Northern quolls, a highly impacted species, have been translocated to two islands. A public education program is being undertaken and assistance provided to Frogwatch to engage the community in control programs in the greater Darwin region. A cane toad trap competition has been run and funds provided to assist with development of long-term control. The Northern Territory sponsored the setting up of the National Cane Toad Taskforce to advise on, and co-ordinate, a response to the threat from cane toads.

Western Australia

The initial focus of the Western Australian program is to slow the progress of cane toads through the Northern Territory towards the Western Australian border. This involves stepping up border quarantine inspections and searching for outlier populations ahead of the front of the main population. An education program is being run in the Kimberley. Funds have been requested to conduct surveys of islands in the Kimberley region to assess the status of important fauna on these islands. Collaborative projects with universities are also being formulated which would gather baseline data on fauna populations prior to the arrival of cane toads.

International

Despite having been introduced to about forty countries, only one example could be found where control of cane toads is being contemplated. A plan is being formulated to eradicate cane toads from Viwa Island in Fiji.

RESEARCH RECOMMENDATIONS

Determination of what research or management to pursue should ideally involve assessment of the costs and benefits of action. However, the use of cost-benefit analysis requires the development of ecological models able to predict, with appropriate levels of uncertainty, the consequences of the various management actions. In turn, these ecological models must rest on good experimental data about the impacts of cane toads and ecological field studies capable of estimating the various population parameters involved in the ecological models. The required modelling has not yet been undertaken to inform such analyses.

The following research projects were recommended as a high priority and were ranked in order of priority within three key areas. Indicative costings are provided in the report.

Impacts of cane toads on biodiversity

Projects in order of priority are:

- Determine the factors associated with persistence or recovery of northern quoll populations within the range of cane toads in Queensland
- Investigate impacts on threatened invertebrate taxa likely to be put at risk from cane toads (e.g. restricted camaenid snails in Northern Territory and Western Australia)
- Investigate the status of populations of impacted species in areas in Queensland that have had cane toads for a long period. Priority groups would be goannas and frog-eating snakes
- Quantify the impact of cane toads on availability of bush tucker for an indigenous community and document any other cultural impacts
- Complete the assessment of the likelihood of different groups and species being impacted by cane toads (for those groups not already comprehensively assessed)
- Add unpublished cane toad reports to the feral species information website of the Invasive Animals CRC (www.feral.org.au).

Short-term control

Island arks and biosecurity. Priority 1.

- Review of the conservation potential of islands in relation to impacted species
- Identify the key characteristics of islands that would make eradication of cane toads potentially achievable. Undertake trial eradication on a suitable island
- Review the occurrence of toads on islands in Queensland and the Northern Territory and the mechanism for their arrival on these islands.

High priority places for protection. Priority 2.

- Examine sites where quolls have persisted within the range of the toad (equivalent to project listed under Impacts)
- Examine the degree of population reduction or exclusion of cane toads required to achieve biodiversity outcomes
- Identify sites with highly restricted invertebrates that may be adversely impacted by toads (equivalent to project listed under Impacts)

- Identify sites where abundance or diversity of impacted species is high and where toad control is feasible and practical.

Traps and attractants. Priority 2.

Evaluate how to best use traps and attractants to control cane toads. Key areas to investigate should include:

- Are traps capable of catching all colonising toads and hence forming a protective barrier?
- Can traps be used in conjunction with physical barriers to eliminate problems with leakage of toads across them?
- What distance apart should traps be placed to catch all toads or to achieve some acceptable density of toads?
- Is it possible to use traps and attractants to reduce toad densities to acceptably low levels in areas selected to serve as refugia for fauna impacted by toads?

Community participation. Priority 2.

- Test whether community action can achieve the objective of protection of biodiversity.

Limiting resources. Priority 3.

- Examine whether water sources in the dry season are a limiting resource in some areas and whether fencing or trapping of these areas can achieve population control.

Exclosure fences. Priority 3.

- Test potential designs on a small scale in different situations.

Long-term control

Modelling of four potential long-term control methods was an overarching priority to determine their feasibility in the field and guide the direction of proposed approaches. It was considered that a first approximation of the potential of each approach could be provided within a year. The four approaches were all considered to be worth pursuing and hence were ranked equally until the results of the modelling became available.

The four approaches were:

- Cane toad specific pathogen
 - Stage 1 – Literature review, search criteria, collaborator identification
 - Stage 2 – Characterisation of candidate pathogen
 - Stage 3 – Registration, release and monitoring
- Genetically modified organism
 - Stage 1 - Continuation of the current CSIRO project – discovery of target metamorphosis genes and testing in vector viruses
 - Stage 2 – Registration, release and monitoring
- Cane toad specific toxin
 - Stage 1 - Identification and testing of potential toxins
 - Stage 2 - Registration
- Sterile male

- Stage 1 - Production of triploids (sterile male approach). Production of tetraploid individuals (sterile offspring approach). Investigate the sex determining system
- Stage 2 - Determine viability and libido of triploid and tetraploid individuals, and investigate gonadal development in the polyploid constructs
- Stage 3 - Field-testing of triploid sterile males (enclosure studies). Field-testing of tetraploid males.

MANAGEMENT RECOMMENDATIONS

The highest priority management action is to try to keep cane toads out of areas where they will not reach naturally (i.e. many of our islands or areas such as south-west Western Australia where climatic barriers exist to movement from the north and east) and areas where they will not reach by natural movement for a long time (i.e. detecting hitch hiker toads well ahead of the front). Involvement of the community in the detection of toads outside their present range is essential. This would require education and awareness campaigns and following up on reports.

A range of best practice management actions are outlined under the following headings:

- Islands
- Island biosecurity
- Education
- Community input and participation
- Communication and coordination
- Exclusion areas
- Population reduction
- Monitoring and biosecurity on the mainland.

DISCLAIMER

The opinions expressed in this report are those of the authors. All costings in this report are indicative only and have neither been validated nor endorsed by governments.

1. INTRODUCTION

Glenn Edwards

The cane toad (*Bufo marinus*) was introduced to Queensland in 1935 in an attempt to control beetle pests of sugar cane. Since its introduction, the cane toad has proved to be a highly invasive pest and is still spreading across northern and eastern Australia. They presently extend from northern New South Wales to the north-west of the Northern Territory. Cane toads are spreading at around 3-4 km per year in northern NSW (section 5.1) and 27 km a year in northern Australia (Freeland and Martin 1985). However, they have been recorded moving up to 80 km in some years (G. Sawyer, pers. comm). Cane toads will reach the Northern Territory-Western Australian border over the next few years.

Prior government sponsored research and inquiries

In 1986, the State and Federal conservation agencies' ministerial council of the time, CONCOM, commissioned research at James Cook University to investigate the population ecology and diseases of the cane toad in Australia with the view to developing control strategies. Approximately \$400,000 was committed over three years divided equally between New South Wales, Queensland, Western Australia, the Northern Territory and the Commonwealth (see section 4.1 for further details). A review of this project in March 1990 recommended that the search for a potential biocontrol agent for cane toads be extended to Latin America and include species of *Bufo* other than *Bufo marinus*. In July 1990 CONCOM established a national cane toad working party to oversee future research directions.

From 1990 to 1993, Australian researchers embarked on a \$1.25 million project to investigate the ecology of cane toads in Venezuela, Brazil and Australia. The work succeeded in isolating a number of viruses from the virus family Iridoviridae and genus *Ranavirus* that could potentially be used as biological control agents for cane toads. From 1993 to 1997, a further \$2 million was spent in this area. This research found that the viruses were not cane toad specific. In early 2000, Senator Robert Hill, the then Minister for the Environment and Heritage, lent his support to ongoing funding of research into possible biological controls for cane toads (\$1 million over two years). This research involved the development of a recombinant ranavirus for the potential control of Australian cane toads.

In February 2004, a workshop was held in Brisbane to take stock of previous research into the biological control of cane toads. The key recommendations of this workshop were:

- Establish a national cane toad group to coordinate research
- Collate and document all current knowledge on the short and long-term impacts of cane toads
- Identify and implement short-term control and damage mitigation measures
- Identify research gaps in short and long-term control methods.

The National Cane Toad Taskforce

In 2004, with cane toads on the outskirts of Darwin's rural area, the Northern Territory Minister for the Environment, Dr Chris Burns sponsored a recommendation to the Natural Resource Management Ministerial Council (NRMMC) that a national task force be set up to coordinate a response to the threat from cane toads. In March 2004, the NRMMC agreed to the draft cane toad agenda paper put forward by the Northern Territory and indicated that the matter be progressed through the Vertebrate Pests Committee (VPC). The VPC was formally asked to undertake a review of cane toad impacts, research and management. Specifically, the VPC was asked to:

- REVIEW the current threat posed by cane toads
- REVIEW the states of research into developing tools to abate those threats
- IDENTIFY any gaps in current approaches
- ASSESS costs and benefits of options for priority joint national action.

The VPC considered the cane toad issue at its May 2004 meeting. An investigative sub-committee or taskforce was established to undertake the allotted tasks and asked to report back to the VPC by the end of October 2004. The taskforce is comprised of government representatives from the Northern Territory, Queensland, New South Wales, Western Australia and the Commonwealth (both the Department of Environment and Heritage and Parks Australia), scientific experts from the Universities of Newcastle, Queensland, James Cook and from CSIRO and community representation from Frogwatch and World Wide Fund for Nature.

The Taskforce advised the NRMMC in September 2004 that a report on the tasks that it had been set would not be finalised until April 2005. The taskforce met on the 21-22 October in Darwin and has held several phone conferences following that meeting.

2. THE CURRENT THREAT POSED BY CANE TOADS

Damian McRae, Rod Kennett and Robert Taylor

2.1 EXISTING LITERATURE REVIEWS OF CANE TOAD IMPACTS

A number of reports have provided comprehensive reviews of the biology of cane toads and their known and anticipated impacts on Australian native wildlife and identified knowledge gaps. These include Freeland (1984, 2004), Jacklyn (1992), ERA (1998), van Dam *et al.* (2002) and Webb and Glanzig (2004). In this current review we provide updated information where available. However, our main focus is on highlighting major gaps in our current knowledge.

2.2 ENVIRONMENTAL IMPACTS OF CANE TOADS

Cane toads eat a wide variety of prey, breed opportunistically, have a far greater fecundity than native frogs and develop rapidly, particularly in warmer waters. They are an extreme generalist with a tolerance for a broad range of environmental and climatic conditions and are potentially able to occupy many habitats. Cane toads possess highly toxic chemical predator defenses and all life stages from eggs to adults contain toxin. There is considerable concern over the impact of the cane toad on native species through predation, competition and poisoning.

Impacts due to predation

Cane toads attain high population densities after colonisation and feed on a broad variety of small prey items, predominantly invertebrates but they also consume vertebrates that are able to be caught and swallowed. Larval cane toads are primarily algal, detritus and suspension feeders. Cane toads also eat non-living matter e.g. dog food, human faeces, rotting garbage (Lever 2001).

Most of the information on predation is anecdotal and unquantified. This consists simply of observations of cane toads eating a range of organisms (Table 2.1). Predation on frogs and frogs eggs appears to be uncommon in Australia. Significant mortality has been shown to result from predation in rainbow bee-eaters, *Merops ornatus*, (Boland 2004). This mortality is associated with use of ground nests by the bee-eaters. Boland (2004) speculates that cane toads could potentially be significantly impacting on a range of other ground nesting bird species. A reduction in the abundance of geckos and beetles has been shown in different studies (Catling *et al.* 1999; Watson and Woinarski 2003). These impacts are presumed to have been associated with predation by cane toads. No studies have been conducted on individual species of invertebrates. Invertebrate species particularly at risk may be those that are restricted in occurrence. Such species are often classified as threatened e.g. camaenid snails (Wilson 2002a,b).

Table 2.1. Evidence of the impacts of predation by cane toads (CT) on biodiversity.

Group/species	Evidence of impact	Reference
<i>Planigale maculatus</i>	Dietary item.	Covacevich & Archer 1975
Rainbow bee-eater	44% of nests that failed were due to cane toads (=33% of nest attempts).	Boland 2004
Skinks	Dietary item.	Bailey 1976
Geckos	Dietary item. Declines after CT invasion.	Grant 1996, Watson & Woinarski 2003
Small snakes	Dietary item.	Covacevich & Archer 1975, Caudell <i>et al.</i> 2000
Frogs	CT tadpoles were not significant predators of eggs, tadpoles or hatchlings of frogs.	Crossland 1998
Invertebrates	Wide range of groups included in diet (e.g. beetles, ants, termites, snails earthworms, centipedes, scorpions, spiders).	Van Beurden 1980, Freeland <i>et al.</i> 1986, Werren 1993, Lever 2001
Beetles	Reduction in abundance (comparison using Before After Control Impact design).	Catling <i>et al.</i> 1999

Impacts due to competition with cane toads for food or shelter

Cane toads have the potential to compete with native species for food and shelter sites. The ability of the cane toad to rapidly expand both its range and density and to consume relatively large numbers of a wide variety of prey has led to concern that the cane toad is a key factor in the decline of many native species.

Evidence suggests that competition in the tadpole stage can be significant for some native frogs in some circumstances (Table 2.2). However evidence of any impacts from studies on adult populations is equivocal or anecdotal. Small reptile populations have been shown to decline after the arrival of cane toads and competition for food was inferred as the causal factor (Catling *et al.* 1999). There have been no studies of the possible competitive impacts of cane toads on predatory invertebrates. In northern Australia, competition between cane toads and native species for food and shelter sites is likely to be highest near permanent water bodies during the dry season. Cane toads are likely to reach their highest densities in such situations (Freeland 1986; Alford *et al.* 1995).

Table 2.2. Evidence of the impacts on biodiversity due to competition from cane toads (CT).

Group/species	Evidence of impact	Reference
<i>Limnodynastes ornatus</i>	No survival of tadpoles in ponds when CT tadpoles present before them. Direct predation on tadpoles is not significant therefore competition inferred.	Crossland 1997
Frogs	Reduced tadpole growth in artificial ponds in the presence of CT for 3 species, no impact for fourth species. Little overlap of pool use with CT. CT used only small number of breeding sites. No impact on habitat use or food use for 3 species of <i>Litoria</i> . Decline found over the period of CT invasion but start of decline preceded their arrival. Decline in numbers of the green tree frog reported since the arrival of CT in NSW.	Williamson 1999, Freeland & Kerin 1988, Grigg <i>et al</i> 2003, van Beurden 1978, Seabrook 1991
Native species	Inferred competition for shelter sites due to high densities of CT.	Schwarzkopf & Alford 1996
Reptiles	Declines in small terrestrial species coincided with increase in CT population. Competition for food and/or shelter inferred.	Schultze-Westrum 1970
Small reptiles	Reduction in abundance (comparison using Before After Control Impact design). Food competition inferred.	Catling <i>et al.</i> 1999

Impacts due to poisoning from ingestion of cane toads

All stages of the cane toad's life cycle (eggs, tadpoles, toadlets and adult toads) are poisonous. Cane toads have venom-secreting poison glands (known as parotoid glands) on each shoulder where poison is released when they are threatened. If ingested, this venom can cause rapid heartbeat, excessive salivation, convulsions and paralysis and can result in death for many native animals.

There are some species that have been shown to be immune to the poison of cane toads (e.g. keelbacks, *Tropidonophis mairii*, Phillips *et al.* 2003) or that avoid ingestion of poisonous parts (e.g. ravens, *Corvus* spp., Covacevich and Archer 1975) or that reject the eggs or tadpoles if they are caught (e.g. barramundi, Crossland 1997). However, there are numerous anecdotal reports of mortality of a wide range of species from ingestion of cane toads (Table 2.3). Anecdotal reports also exist of population declines of species that prey on cane toads. There are also anecdotal reports of population recovery after an initial decline.

Table 2.3. Evidence of the impacts on biodiversity due to poisoning from cane toads (CT).

Group/species	Evidence of impact	Reference
Dingo, <i>Canis lupus dingo</i>	Reduction in abundance.	Catling <i>et al.</i> 1999
Northern quoll, <i>Dasyurus hallucatus</i>	Population extinction after colonisation by CT. However, co-occurrence with CT reported at Mareeba Wetlands (near Cairns) and in rocky areas around Cooktown.	Watson & Woinarski 2003 Oakwood 2004 A. Krockenberger pers. comm.
Birds	Following arrival of CT death of individuals after ingestion reported for crow, kookaburras, <i>Dacelo</i> spp., little and black bittern, <i>Ixobrychus</i> spp. However other species can eat CT without effect either due to immunity or avoidance of toxic parts. Anecdotal reports of bird declines following CT arrival.	Covacevich & Archer 1975, Seebrook 1991, Van Beurden 1980, Rayward 1974
Goannas	Locally extinct or reduction in numbers based on anecdotal information. 64% decrease in survival of <i>Varanus panoptes</i> in 7 month period following the arrival of CT. 77% drop in <i>V. panoptes</i> counts in the year following the arrival of CT. No decline in <i>V. mitchelli</i> or <i>V. mertensi</i> in same period. 85% of all Australian varanid species potentially at risk based on diet, distribution and susceptibility to the toxin. However, recovery of some populations reported after a long period. This is supported by experiments where individuals from areas without CT will eat them and die whereas individuals from areas that have had CT for a long period will not attack them.	Burnett 1997, Rayward 1974 Griffiths <i>et al.</i> 2004, Doody <i>et al.</i> 2004, Smith & Phillips in press, Freeland 1990
Dragons (agamids)	Observations of declines of frilled-neck lizards, <i>Chlamydosaurus kingii</i> , after CT arrival Population decline in Gilberts dragon, <i>Lophognathus gilberti</i> , after CT arrival. 59% of all Australian agamid species potentially at risk based on diet, distribution and susceptibility to the toxin.	Breeden 1963, Watson & Woinarski 2003, Smith & Phillips in press
Freshwater crocodile, <i>Crocodylus johnstoni</i>	Death of individuals reported. No change in abundance.	Begg <i>et al.</i> 2000, Catling <i>et al.</i> 1999, Doody <i>et al.</i> 2004,
Frogs	Tadpoles of 3 species had high mortality after ingestion of CT tadpoles, 1 species not affected.	Crossland 1997, Crossland & Alford 1998

Table 2.3 (continued).

Group/species	Evidence of impact	Reference
Frog-eating snakes	Individuals of most frog-eating species die after ingestion. 30% of all snake species potentially seriously affected in Australia. Red-bellied black snakes, <i>Pseudechis porphyriacus</i> , from within the CT's range have higher levels of resistance to CT toxin than do those outside the CT's range. Reduction in gape size and increase in body length with time since exposure to toads in toad-vulnerable species- red-bellied blacksnake and green tree snake, <i>Dendrelaphis punctulata</i> .	Phillips <i>et al.</i> 2003 Phillips, pers. comm. Phillips & Shine 2004
Saltwater crocodile, <i>Crocodylus porosus</i>	No mortality from ingestion. Less susceptible to toxin than is freshwater crocodile.	Covacevich & Archer 1975, Smith & Phillips in press
Turtles	Appear unaffected by ingestion. Aborigines report impacts. All Australian species potentially at risk based on diet, distribution and susceptibility to the toxin.	Covacevich & Archer 1975, Crossland & Alford 1998, Hamley & Georges 1985, Evans 1999, Begg <i>et al.</i> 2000 Smith & Phillips in press
Freshwater fish	Most species ignore or detect toxin and reject. Some species die after consumption (e.g. fly-specked hardyhead, spangled grunter, <i>Scortum</i> spp).	Voris & Bacon 1996, Crossland & Alford 1998, Hearnden 1991
Freshwater invertebrates	Variable mortality rates after consuming CT eggs, tadpoles and/or hatchlings for native snails, water beetle larvae, backswimmers, leeches. No mortality of water scorpions, giant water bugs, dragonflies, freshwater prawn, crab, crayfish.	Crossland & Alford 1998

There are very few studies that present any data on population consequences of mortality from poisoning. There are some studies of species that shown mortality after ingestion where no changes to population levels were detectable after arrival of cane toads (e.g. freshwater crocodiles, *Crocodylus johnstoni*, Catling *et al.* 1999). Some goanna species have been shown to decline and there is antidotal evidence of this in snakes such as the northern death adder, *Acanthophis praelongus*. However, anecdotal reports of subsequent recovery or the continued persistence of such species in Queensland is taken as evidence that these species are not threatened in the long-term (Freeland 2004). Evolution of a greater tolerance to the poison and changes in morphology in some snake species indicate some population recovery is likely to have occurred over time (Phillips pers. comm.; Phillips and Shine 2004). The most compelling evidence of decline is for

the northern quoll, *Dasyurus hallucatus*, where complete elimination of the species after cane toad arrival has been documented (Oakwood 2004; Watson and Woinarski 2003). Anecdotal evidence from Queensland also indicates that a general population recovery has not occurred in this species. This information was used to justify its listing as an endangered species under the Environment Protection and Biodiversity Conservation Act (EPBC Act) in April 2005. However there are reports of populations persisting in a small number of locations where cane toads are known to be present (A. Krockenberger, pers. comm.).

Although some aquatic invertebrates have been shown to suffer a very high mortality from ingestion of cane toad eggs or tadpoles (e.g. 100% mortality of a freshwater snail, Crossland and Alford 1998) there have been no studies to assess population impacts in this group.

Impacts at the ecosystem level

Impacts of cane toads on biodiversity can potentially have flow on effects through an ecosystem (Table 2.4). For example, if large reductions occur to some termite populations (termites are a large component of the diet in many places e.g. Freeland *et al.* 1986) then the biomass of grasses in the dry season may increase with a resulting increase in intensity of fires. Freeland (1994) has found that the incidence of parasitism of a python by a tapeworm reduced as time after colonization increased (from 25% after 1 year of colonization to <1% after 47 years). An intermediate host for the tapeworm, the native frog, *Litoria pallida*, also showed a dramatic reduction in prevalence of infection. The cane toad appears to disrupt the life cycle of the tapeworm as snakes do not eat the toads. Freeland (1994) has ascribed a decrease in the stability of the dry season frog community to the reduction in the abundance of the tapeworm. Reductions in the populations of predators such as northern quolls and goannas could potentially lead to increases in populations of their prey. Doody *et al.* (2004) have speculated that an increase in recruitment of pig-nosed turtle, *Carettochelys insculpta*, will result from a reduction in goanna populations due to their being poisoned by cane toads.

Table 2.4. Evidence of ecosystem level impacts on biodiversity from cane toads (CT).

Group/species	Evidence of impact	Reference
Plant community	Speculation that predation of key species (e.g. pollinators, seed harvesters) would lead to changes in plant species composition and consequent changes to fire regimes.	Anderson & Braithwaite 1996, Van Dam <i>et al.</i> 2002
Proteocephalid tapeworm of the python, <i>Ataresia maculosus</i>	Reduced parasitism after CT arrival and a decline in the inter-annual similarity of frog communities.	Freeland 1994
Turtle	Recruitment of pig-nosed turtle, <i>Carettochelys insculpta</i> , hatchlings predicted to increase due to reduction in predation from goannas.	Doody <i>et al.</i> 2004

Other potential environmental impacts

The *Draft threat abatement plan for the infection of amphibians with chytrid fungus resulting in chytridiomycosis* notes that chytridiomycosis has been found in the cane toad. It also recognises that amphibians sold and moved for scientific studies can be a potential infection risk. Within Australia the cane toad is the major amphibian sold for scientific purposes. As a result the draft plan recommends that the likelihood of cane toads introducing chytridiomycosis into chytrid-free areas, particularly in Northern Territory and Western Australia and into Tasmania, be evaluated (Commonwealth of Australia, 2004). It is not known to what extent cane toads may act as carriers for other amphibian diseases.

Cane toad control activities undertaken by the community may also potentially have a negative impact on native frogs. There have been occasions where untrained community volunteers have mistakenly killed native frogs (particularly ground dwelling frogs) in the belief that they were cane toads.

Conclusions concerning the environmental threat

The cane toad is a highly invasive species that has colonised substantial areas of the Australian continent, occupying the habitats of many native species. As a result, a number of native species are considered to have experienced adverse impacts from cane toads, most notably in relation to lethal ingestion of cane toad toxin. Much of the research to date remains inconclusive at a species and population level and it is uncertain to what degree species may survive short-term crashes into the longer term.

Recent experimental evidence suggests that immediately following colonisation of their habitat some predator species undergo dramatic and potentially threatening declines in abundance as a result of fatal poisoning by cane toads. However, it is evident that many species continue to maintain populations throughout their range, even in the presence of the cane toad, and there are some anecdotal reports that the wildlife impacts of cane toads may diminish over time. In the case of the northern quoll, it appears that there has been no general recovery in areas where cane toads have been present for a long time. It is estimated that the cane toad will, in the foreseeable future, colonise almost the entire mainland range of the northern quoll and that the species will continue to decline as a result. In April 2004, on the basis of documented impacts of cane toads on the northern quoll, the minister for Environment and Heritage, Senator Ian Campbell, indicated that ‘the biological effects, including lethal toxic ingestion, caused by cane toads (*Bufo marinus*)’ was eligible for listing as a key threatening process under the EPBC Act.

While it is suspected that predation by and competition with cane toads may play significant roles in reducing biodiversity of native species, and altering ecosystems, data concerning such impacts is neither comprehensive nor complete. Risk assessment studies can provide an important indication of the species likely to be at risk from cane toads but such assessments are often compromised by a lack of ecological data for many species.

To date, there is insufficient information to adequately quantify the likely extent of declines of many affected species. For some native species, cane toad impacts may be minor and inconsequential in the longer term, despite marked short-term declines.

Alternatively, species may experience little immediate response but be either directly or indirectly impacted in the longer term. Most fauna populations undergo population fluctuations of varying magnitude and it is difficult to interpret changes from a baseline to a single subsequent re-sampling period. Longer-term population trends can only be discerned from natural fluctuations over a series of monitoring periods. It is considered that further research on the precise nature of both short and longer-term impacts of cane toads on native species is required, including the impacts that are likely to come from predation and competition. A comparatively large number of toad impact studies are currently underway or proposed for the Northern Territory (Table 2.5). When available, results from these studies should increase our knowledge markedly. However there are many gaps that will still need filling.

2.3. SOCIAL IMPACTS OF CANE TOADS

The report *Issues associated with the progressive entry into the Northern Territory of cane toads* (Sessional Committee on Environment and Sustainable Development 2003) outlines some of the potential socio-economic impacts that cane toads may have on local communities:

- dangers posed to unaware adults
- dangers posed to children
- dangers posed to domestic pets unfamiliar with cane toads
- blocking of drains
- fouling of swimming pools;
- visual impacts (unattractive and in large numbers)
- lower prevalence of native species (e.g. lizards and monitors) in urban areas
- potential transmission of human disease as cane toads are known to consume human and other animal faeces
- potential dangers from the substance abuse of cane toad toxin.

Impact on hunting practices of Traditional Owners

Declines in bush tucker species such as monitor lizards, snakes and turtles are likely to have significant cultural and economic impacts upon Aboriginal communities. For example, van Dam *et al.* (2002) notes that in some regions of the Northern Territory, traditional ceremonies have been altered to request the spirits to replenish important food and/or totemic species (e.g. freshwater crocodile) which have declined since cane toads arrived. Concerns have also been raised that the health of Aboriginal communities may be affected as a result of reduced physical activity associated with reduced hunting effort and increased reliance on meat bought from a store (Sessional Committee on Environment and Sustainable Development 2003). An increased reliance on store-bought food may also impose a significant economic burden on some remote communities.

Table 2.5. Summary of current studies on cane toad impacts on native fauna in the Northern Territory.

Type 1 Studies - dedicated population studies usually involving mark-recapture and/or radio telemetry designed to estimate the impact of cane toads on population parameters such as densities, size structures, mortality and survivorship.					
Taxon	Location	Agency/person responsible	Type of study	Status	Notes
<i>Varanus</i> spp.	Kakadu National Park	KCTWM and PAN	Radio telemetry, population size estimates and road surveys	In progress	Intensive radio tracking study of ca. 50 individuals of <i>V. panoptes</i> , plus captures and sightings data on <i>V. gouldii</i> , <i>V. mertensi</i> and <i>V. mitchelli</i> . Preliminary results indicate 50-70% decline in <i>V. panoptes</i> .
<i>Varanus</i> and other species subject to indigenous harvest	Near Darwin and Maningrida	Tony Griffiths, Tim Schultz (KCTWM)	Radio telemetry and population census	In progress	Baseline data (some long-term) on pre-toad densities.
Dragon (<i>Lophognathus temporalis</i>)	Near Darwin	Tony Griffiths, Tim Schultz (KCTWM)	Mark-recapture	In progress	Baseline data on pre-toad densities.
Dusky rats (<i>Rattus colletti</i>)	Fogg Dam / Adelaide River floodplain	Thomas Madsen, Beata Ujvari (University of Wollongong)	Mark-recapture	In progress	Cane toads may become one of the major predators on these native rodents. Dusky rats are a predominant food item for many reptiles and hence a decline in rats may impact significantly on the floodplain fauna.
File snakes (<i>Achrocurdus arafurae</i>)	Djukbinj National Park / Adelaide River floodplain	Thomas Madsen, Beata Ujvari (University of Wollongong)	Mark-recapture and genetic studies	In progress	File snakes do not feed on amphibians. However, this taxon may become indirectly affected if their main prey (catfish) is affected by the arrival of toads.
Water pythons (<i>Liasis fuscus</i>)	Fogg Dam	Thomas Madsen, Beata Ujvari (University of Wollongong)	Mark-recapture	In progress	Water pythons will most likely not feed on cane toads but this taxon may be affected by a decline in dusky rats due to toad predation (see above).

Table 2.5 (continued).

Taxon	Location	Agency/person responsible	Type of study	Status	Notes
<i>Varamus panoptes</i>	Adelaide River floodplain	Thomas Madsen, Beata Ujvari (University of Wollongong)	Mark-recapture and telemetry	In progress	To determine the direct effects of cane toads on predator numbers.
Frilled-neck lizard (<i>Chlamydosaurus kingii</i>)	Fogg Dam	Thomas Madsen, Beata Ujvari (University of Wollongong)	Mark-recapture	In progress	To determine possible the direct effects of on cane toads in predator numbers.
Terrestrial reptiles	Fogg Dam, Adelaide River floodplain	Thomas Madsen, Beata Ujvari (University of Wollongong)	Population genetics	In progress	Investigate population genetic variability of all the common species presently found in the area and compare the genetic data of pre-toad invasion with that of post-toad invasion.
Freshwater crocodiles, <i>Crocodylus johnstoni</i> , and fish	McKinlay River	Grahame Webb (WMI)	Mark recapture	In progress	Original survey and estimates from 1980s compared to recent survey results pre and post toads will provide estimates of changes in densities and mortality rates. Will also be able to quantify changes in varanid predation rates on freshwater crocodile eggs as toads arrive. Also examining distribution of fish species in billabongs from 1978 onward so should be able to quantify losses. Recapture sessions undertaken in 2003-2004
Snakes and frogs	Fogg Dam	Rick Shine, Greg Brown, Ben Phillips (University of Sydney)	Long-term surveys and mark-recapture. Prey preference and toxin tolerance of reptiles. Toad impact on invertebrates, Toad activity, mark-recapture	In progress	Long-term surveys and mark-recapture studies of water pythons (<i>Liasis fuscus</i>), keelbacks (<i>Tropidonophis mairii</i>) and slatey-grey snakes (<i>Stegonotus cucullatus</i>). Also have long-term data from nightly surveys on abundances of other snakes, and native frogs. Direct quantification of prey preference and toad toxin resistance in floodplain herpetofauna. Risk assessment of toad impact and likely long-term (evolutionary and plastic) response by various species.

Table 2.5 (continued).

Taxon	Location	Agency/person responsible	Type of study	Status	Notes
Freshwater turtles (<i>Chelodina rugosa</i> and <i>Elseya dentata</i>)	Darwin and Douglas River	Rod Kennett and Tony Griffiths (KCTWM and PAN)	Mark recapture	In progress and planning	Baseline data (detailed mark-recapture) on population densities and survivorship from 1989-1992. Populations resampled (pre-toad) in 2003 by mark-recapture. Post-toad sampling to occur in 2004-2005.
Freshwater turtles (<i>Chelodina rugosa</i>)	Maningrida and surrounding floodplains	Arthur Georges, Damien Fordham (University of Canberra/CDU)	Mark recapture and harvest rates by Aboriginal hunters	In progress	Provide data on population changes and impacts on Aboriginal hunting success.
Small mammals	Darwin	Brooke Rankmore, Owen Price, Peter Whitehead (BC/KCTWM)	Mark recapture studies	Complete	Pre-toad baseline surveys.
Quolls	Kakadu National Park	Meri Oakwood (PAN)	Density estimates and radio telemetry	In progress	Quoll populations monitored by radio tracking and trapping at two sites (EAR and MRR). Quolls declined to potential local extinction at the MRR site following toad arrival. Quoll numbers at EAR reduced to 25% following toad colonisation and decline expected to continue. Attempted ingestion of toads identified as major increase in mortality.
Type 2 Studies - surveys using standardized census methods before and after that allow assessment of changes in abundance and/or distribution following cane toad colonization. There is usually a planned intention to conduct post-toad follow up.					
Frogs	Roper River and Kakadu National Park	Gordon Grigg, Hamish McCallum, Andrew Taylor (University of Queensland)	Automated recording of frog calls	In progress	Five pairs of sites between Mataranka and 120 km east on Roper Valley Hwy. Six sites within KNP, replicates in each of three habitats. Counts of relative abundances, based on calling frequencies, will allow detection of gross changes in frog populations before and after toads.
Frogs and invertebrates	Adelaide River floodplain	Rick Shine, Matt Greenlees (University of Sydney)	Field enclosure studies	In progress	Experimental study using field enclosures on the Adelaide River floodplain. Impacts of toads on invertebrate biomass and diversity; effects of toad size and abundance on such impacts; and effects of toads on foraging behaviour and shelter-site use of native anurans.
Skinks, frogs, small mammals, birds)	Top End including Kakadu	John Woinarski (BC) and PAN	Standardised census surveys	Ongoing	Analysis of short-term impacts in Kakadu completed. Baseline data for areas not yet affected by toads.

Table 2.5 (continued).

Taxon	Location	Agency/person responsible	Type of study	Status	Notes
Terrestrial fauna (reptiles, frogs, mammals, birds, invertebrates)	Mt Bunday Training Area (abuts KNP)	Department of Defence, CSIG – NT/K. Project conducted by EWL Sciences.	Wet and post-wet season surveys (2002-2004)	Study completed. Inquiries to Ted Easton-8935 4677 or Erica Eastick-8935 4676.	Methods included small mammal trapping, pitfall trapping, spotlight counts, diurnal searches, dingo tracking, bird counts. Used standardised survey methodology at 24 sites in four major habitats. Pre-toad surveys undertaken. The study targeted the following indicator species/groups: <ul style="list-style-type: none"> • Predators eating cane toads: dingo, quoll, predatory birds, snakes and large goannas; • Prey eaten by cane toads: beetles and other invertebrates; • Species competing (for food and breeding resources): frogs, small reptiles particularly skinks.
Terrestrial fauna (reptiles, frogs, mammals, birds, invertebrates) and aquatic fauna (invertebrates, fishes, waterbirds)	Mining leases and reference sites in KNP.	ERA Ltd - Ranger Mine. Conducted by EWL Sciences.	Wet and dry season surveys in 1994/95 and 2000/01.	Study completed. Report in preparation.	Methods included small mammal trapping, pitfall trapping (vertebrates & invertebrates), spotlight counts, diurnal searches, bird counts. Used standardised survey methodology. The data set comprises records from the same sites using similar methods, and thus provides information on changes in species richness and relative abundance over time (6 years). Future planned surveys will provide information on cane toad impacts with allowance for natural temporal changes.
Terrestrial fauna (reptiles, frogs, mammals, birds, invertebrates) and aquatic fauna (fishes, waterbirds)	Bradshaw Field Training Area (600km southwest of Darwin)	Department of Defence, CSIG – NT/K, Conducted by EWL Sciences.	Wet and dry season surveys 1996-99.	Study with several reports completed.	Methods included small mammal trapping, pitfall trapping (vertebrates & invertebrates), spotlight counts, diurnal searches, bird counts. Used standardised survey methodology. Pre-impact baseline will allow planned future monitoring surveys to provide information on cane toad impacts.
Terrestrial fauna (reptiles, frogs, mammals, bush birds, and invertebrates).	Kapalga in KNP	CSIRO. Surveys conducted by Laurie Corbett.	Fourteen wet and dry season surveys (1988 – 95)	Study completed.	Small mammal trapping, pitfall trapping (vertebrates & invertebrates), spotlight counts, diurnal searches, bird counts. Used standardised survey methodology. Extensive data set (20,000 records over 8 years) on fire impacts that may be useful as a pre-cane toad baseline incorporating natural temporal variation in richness and abundance. Any future monitoring surveys will provide information on cane toad impacts.

Table 2.5 (continued).

Type 3 Studies - surveys usually involving standardized methods that provide some pre-toad baseline data which could be used to assess toad impacts. There are no plans for post-toad follow up work at the present time					
Taxon	Location	Agency/person responsible	Type of study	Status	Notes
<i>Varanus tristis</i> and <i>Varanus scalaris</i>	Kakadu National Park	Sam Sweet (University of California)	Radio telemetry	Complete	Little likely temporal or spatial overlap between foraging goannas and juvenile (prey-sized) toads in woodlands distant from water. However, both species are likely to be impacted where their home range overlaps wet habitats that can support toad breeding or toadlet activity.
Frill-necked lizards	Darwin area	Tony Griffiths (KCTWM)	Census (Mark-recapture)	Initial survey completed	Provides baseline data on abundance
Frogs and reptiles	Mary River	Kerry Beggs, Peter Whitehead (CDU/BC)	Habitat and fauna surveys	Initial survey completed	Provides data on reptile/toad interactions and toad capacity to exploit grasslands of different ground cover/stem densities and hence the species that will be at risk.
Frogs	Sites within and close to the Darwin region	Keith Christian, Jeanne Young, Lorrae McArthur (CDU)	Visual encounter and call surveys at specific field sites.	Initial survey completed	Visual encounter and call surveys at specific field sites. Data have been collected from September 2000 for pre-cane toad estimates of the relative abundance of native species at several sites. Data will continue to be collected for this study until 2004 and will provide baseline data for a number of native species in the Darwin area.

PAN – Parks Australia North

KCTWM - Key Centre for Tropical Wildlife Management, Charles Darwin University

CDU – Charles Darwin University

WMI - Wildlife Management International

BC- Biodiversity Conservation, Northern Territory Department of Infrastructure, Planning and Environment

CSIG – NT/K – Corporate Services and Infrastructure group, Northern Territory and Kimberley region, Dept. of Defence

KNP – Kakadu National Park

Human health impacts

van Dam *et al.* (2002) notes the following in relation to the potential impacts of cane toads on Human Health:

“Cane toads are known to feed on human faeces, and as a result they may harbour human strains of *Salmonella* and other bacteria. The eggs of human parasites are also spread via toad faeces. In areas where modern sanitation practices are lacking, the presence of large numbers of cane toads could represent a health hazard. Another health-related issue is the potential for substance abuse of the cane toad toxin, a habit forming practice that is established in northern Queensland and in countries such as Fiji.”

2.4 ECONOMIC IMPACT OF CANE TOADS

Impact on tourism

van Dam *et al.* (2002) predicted that cane toads were unlikely to have a negative impact on the general economy and tourism income of Kakadu National Park. They note that some tourists express deep concern about cane toads, especially in World Heritage sites such as Kakadu. Tour operators in Kakadu had similar concerns and this concern is now emerging from some tourism operators in Western Australia’s Kimberley region.

It is not known if there will be a substantial decrease in the level of tourism to Kakadu National Park and other key tourist attractions following the invasion of cane toads. Similarly it is not known what impacts cane toads will have on the World Heritage values of places such as Kakadu National Park. In its submission to the report *Issues associated with the progressive entry into the Northern Territory of cane toads* (Sessional Committee on Environment and Sustainable Development 2003) the Northern Territory Tourist Commission submitted that: “Queensland has contended with the cane toad for many decades with no noticeable effect on tourism”. For many tourists the main impact of cane toads will probably be on the tourist amenities as cane toads will congregate in numbers at campgrounds and the like, where they will be attracted to the open terrain and lights (van Dam *et al.* 2002).

Impact on natural resource management

The ongoing management of cane toads has the potential to place a significant drain on the financial resources available to land managers. In addition to the often unquantifiable cost of a native species or community being damaged, killed or threatened with extinction, are the costs associated with implementing control operations and the lost opportunity to invest these resources elsewhere. Some of the ongoing costs associated with the control of cane toads will include:

- education and awareness raising campaigns
- monitoring of impacted native species and ecological communities
- translocation and management of impacted native species threatened with local extinction

- development and implementation of quarantine protocols to prevent cane toads from reaching new areas, particularly islands
- development and implementation of cane toad control methods.

2.5 RECOMMENDATIONS

As indicated above, there are a myriad of studies that are required on the impacts of cane toads. Below are listed only a few high priority ones or ones that will ensure availability of information on impacts.

- Undertake surveys (field based and email/telephone surveys) to determine the locations, size, history and population parameters of remnant northern quoll populations within areas in Queensland where cane toads have been present for a long time. Conduct targeted field investigations at identified locations to determine the factors favouring quoll persistence or recovery in sympatry with cane toads.
Cost: \$200,000 over two years
- There have been several studies that have shown that there are species of invertebrates, both terrestrial and aquatic, that are likely to be impacted. It would be an impossible task to try to predict which species might be most impacted. However, threatened invertebrate taxa with restricted distributions likely to be impacted by cane toads should be studied as a priority. One such group is the restricted camaenid snails in Northern Territory and Western Australia. These species could be studied pre and post-cane toad arrival and with some populations protected from cane toads by exclosures.
Cost: \$350,000 over 3 years
- There are many observations of various species dying after ingestion of cane toads. However, there are few studies that have documented impacts at a population level. There are also reports of populations of some species eventually recovering after cane toads have been present for a long time. However, most of these are anecdotal. Examination of persisting populations of purportedly susceptible native species in areas of Queensland where the toad has been present for a long time would seem an efficient way to determine the long-term impacts of toads. This would be particularly useful in areas where historical pre-toad survey data were available. Priority taxa would be goannas and frog-eating snakes.
Cost: \$200,000 over 2 years
- Indigenous communities are likely to suffer directly from the impact that cane toads have on species used as food (e.g. goannas) and also possibly at the cultural level. There is some limited data available on changes to harvest rates of some species. However there has been no comprehensive assessment undertaken. One area where such an assessment could be conducted is Maningrida. There have been two studies of harvesting of fauna for bush tucker undertaken here in 1979/80 (Altman 1987) and 2002/03. Cane toads arrived at some of the sites during the 2002 sample. Repeating this work now that cane toads are in large numbers would provide some indication of their impact on bush tucker. Documentation of any other cultural impacts could also be undertaken at the same time.
Cost: \$70,000
- There have been several comprehensive threat assessments undertaken for specific faunal groups (e.g. snakes, Phillips *et al.* 2003; crocodiles, turtles goannas and dragon

lizards, Smith and Phillips in press) or for specific areas (Van Dam *et al.* 2002 for Kakadu National Park). These have taken account of the diet, distribution and susceptibility to the toxin of cane toads. A study covering other vertebrates, which additionally included the conservation status of species, would provide information of use to management agencies in responding to public enquires and in developing threat abatement and toad impact monitoring and management strategies.

Cost: \$100,000

- There are numerous unpublished reports on the cane toad. These include overview assessments, committee reports and documentation of anecdotal observations. Collation of all available material into a single web-accessed format would greatly improve access to information. The CRC for Australasian Invasive Animals has a site for holding information on feral pests (www.feral.org.au) which would be ideal for the cane toad material. Each institution with relevant material could arrange to upload their own reports.

Cost: \$15,000.

3. SHORT-TERM OR LOCAL THREAT ABATEMENT

Short-term is used to mean a one to three year time frame. Local refers to a specific geographic feature such as a small wetland, a small hill or an urban park or a small social structure such as a local landcare group.

3.1 TRAPS AND ATTRACTANTS

Ross Alford

Adult toads are very vagile and are nomadic (Alford *et al.* 1995; Seebacher and Alford 1999; Schwarzkopf and Alford 2002). They disperse along resource gradients during the wet seasons and only remain relatively bound to a temporary home range during dry seasons, when they aggregate near water sources which they require for rehydration (Cohen and Alford 1996; Schwarzkopf and Alford 1996; Seebacher and Alford 2002). At all seasons of the year they forage actively on many, though not all, nights, and spend substantial amounts of time in retreat sites (Cohen and Alford 1996; Seebacher and Alford 2002; Schwarzkopf and Alford 2002). They investigate their environments thoroughly, and move frequently to new retreat sites (Cohen and Alford 1996; Schwarzkopf and Alford 2002). These characteristics should make them vulnerable to capture in a variety of traps: cage and pitfall type traps will be entered during their normal movements in search of food and new retreat sites; and artificial shelter traps will be entered and used as diurnal retreats.

Attractants

Toads may be encouraged to enter traps by providing attractants. Possible attractants include:

Light

A great deal of anecdotal observation indicates that they are attracted to lights at night, possibly to feed on insects that are themselves attracted to light. Artificial lighting may therefore serve as an attractant to increase the number of toads captured in traps.

Olfactory attractants

Until 1999 no anuran had been documented to use chemical communication in social or reproductive interactions, but since then, a few instances have been documented (Wabnitz *et al.* 1999; Kikuyama *et al.* 2002; Lee and Waldman 2002). These studies span a range of taxa, including very ancestral ones, and it appears that chemical signaling, and the use of olfactory cues in general, is more widespread and important in anurans than had previously been thought. Extensive experience with cane toads in the field (R. Alford, personal observation) suggests that male cane toads may use olfactory cues as one means to distinguish female cane toads from other objects of similar size. Male toads are notorious for their propensity to enter into amplexus with any object with a size and shape at all similar to a toad. Cane toads have been observed entering amplexus with other male toads, juvenile toads, rocks, frogs of various other species, mated pairs of frogs of other species, items of field equipment, and dead cane toads: male, female, and juvenile. Male toads have a specialized release call that immediately alerts other males

that they have clasped an inappropriate partner, and cause them to release their hold. Males that enter amplexus with juvenile toads, other objects, other frog species, or with dead male or juvenile toads, tend to continue their efforts for several minutes, but abandon them in a relatively short period. Many of these objects may be released in part because their texture, size, or shape is eventually recognized as not matching that of a female. Males that enter amplexus with dead females, however, often continue clasping them for hours, and I have seen instances where they remained in the same location for at least 24 hours. Thus, a lack of behavioural reinforcement does not deter male toads from very prolonged attempts to mate. This suggests that female behaviour is not responsible for the greater persistence of males mating with dead female toads as opposed to other objects. It also appears that texture and colour are not important, since up to 90mm in snout-vent length, the texture and markings of juvenile cane toads are indistinguishable from those of females. The most parsimonious explanation for the ability of male toads to recognize even dead females seems to be that they recognize olfactory cues or pheromones emitted by females. In other anuran taxa (Wabnitz *et al.* 1999), females use olfactory cues to locate and approach males, so it is possible that pheromonal lures could attract individuals of both sexes. In addition to their possible use in locating and discriminating mates, there is also anecdotal evidence that toads may use olfaction for locating and discriminating food. They have frequently been observed consuming inanimate food, for example eating cat and dog food from dishes provided for pets. This is unusual as most frog species are thought to require living prey, and their visual systems are thought to be adapted to discriminate and target moving prey items. It has been suggested that they recognise pet food as being edible through olfaction. Boland (2004) carried out a series of experiments that indicated that tunnels constructed to resemble the nest tunnels of rainbow bee-eaters were more likely to be occupied by cane toads if they contained small pieces of uncooked chicken meat than if they did not.

Experiments are underway at James Cook University in Townsville examining the degree to which toads may be attracted by the scent of conspecifics and food items. Trials are conducted using a pair of Y-mazes, 2.4 metres in length, in which potential attractants are positioned in the arms of the Y in compartments allowing only olfactory stimuli to escape, and toads are released at the base and their behaviour is videotaped for 30 minutes. Thus far, the results of these experiments are not promising. The data do suggest that male toads may respond positively to cues given off by females, but their responses are not strong, and given that the distances involved are short, it seems likely that pheromones may not work as long-distance attractants. There is thus far no evidence that food (PAL brand dog food) attracts toads. These are only preliminary results, carried out during the dry season, and may change with greater replication and in the wet season when toads are more likely to be attracted to potential mates. "Cafeteria" style trials are also being conducted where, toads are presented with several possible food sources including a variety of pet foods and meats, and allowing them to choose which, if any, they approach in larger arenas. The results of these trials so far suggest that the presence of ants on food may be the cue that actually attracts toads, rather than the odour of the food itself. Again, further trials are needed before attraction via food odours can be ruled out, but preliminary results are not promising. Further trials of the sort already mentioned will be carried out during 2005 to increase the statistical rigour of the results, and additional trials will be carried out examining whether males do use odour to discriminate females from other objects at short ranges.

Acoustic signaling

Male cane toads vocalize near water to attract mates. In other anuran species (Wells 1988; Rothmair 1994; Brooke *et al.* 2000) choruses of calling males form because of positive feedback loops; calling males are attracted to other calling males, and emit calls in response to the calls of others. Work of this nature has not been done on cane toads, but field observations indicate that choruses can form near water bodies in any month of the year, at a variety of temperatures and moon phases, and in wet or dry conditions. This suggests that social facilitation is an important component of chorus initiation in cane toads. James Cook University will experimentally examine the aggregative responses of toads to playbacks of toad choruses. Previous work on other species (references in Ryan 2001) has shown that anuran hearing systems are optimized to receive and respond to conspecific vocalizations, and that in some cases, only components of those vocalizations are needed to attract conspecifics. It may be possible to construct an artificial call that will serve as a superstimulus for attracting males, females, or both to the source of the vocalization.

Experiments on the responses of cane toads to call playbacks are being conducted at James Cook University, and preliminary results are encouraging. During the wet season (no dry season trials have yet been conducted), both male and female toads respond positively to playbacks of recorded calls, almost always moving towards them when trialled in an 8 m diameter outdoor arena. Over the next few months we will carry out dry season trials as well as controlled field experiments using traps at field sites to determine whether their catch rate is increased by playbacks.

Moisture

Several observational and experimental studies (Cohen and Alford 1996; Seebacher and Alford 1999, 2002; Schwarzkopf and Alford 1996) indicate that toads are strongly attracted to retreat sites containing moist soil, so, particularly in the dry season, increased soil moisture might serve as an attractant. Cohen and Alford (1996) used very simple artificial shelter sites in a pen experiment, and were able to manipulate which sites were used by toads by manipulating levels of soil moisture.

Moisture is being included in trials of olfactory attractants being conducted by James Cook University researchers, and will also be included in their field trials of traps. There are no results from these trials as yet but results are expected by mid-2005.

Traps

Many styles of toad traps have been designed. These fall into two general categories. With pitfall traps the trap is embedded into the ground and toads either fall into it accidentally while moving about the environment or are attracted to it by, for example, the presence of water or insects hovering around a light. With cage traps the toads enter a cage or other container above the ground surface and are prevented from leaving it by some means. Information on traps currently in use is summarised on the Web page of the Darwin Frogwatch group at:

http://www.frogwatch.org.au/index.cfm?attributes.fuseaction=viewResearch&research_id=101

The Northern Territory Biodiversity Conservation Unit recently conducted a design competition for cane toad traps. Details of the competition can be found at: <http://www.ipe.nt.gov.au/haveyoursay/canetoadtrap/>

Criteria identified as desirable for toad traps entered in this competition were developed in consultation with researchers and field workers and include:

- **portability** (a fold up trap would rate higher than an equivalent trap that did not fold up)
- **ease of use** (a trap that could be placed on the ground would be rated higher than one that required a large hole to be dug)
- **size** (a smaller trap is preferable to a larger trap)
- **impact on native species** (a trap that does not catch native species is preferred to one that does. If a trap were to catch native species then an escape route for them may be able to be included that would allow their escape but would retain toads.)
- **cost** (a cheap trap is preferable to an expensive one)
- **ability to withstand the elements** if set in the bush (a trap that is fire proof is preferable to one that would be destroyed in a bushfire)
- **animal ethics considerations** (no suffering of animals should occur as a result of trapping. For example, a trap may need to be shaded if it is not checked first thing each morning).

The last criterion is likely to present difficulties for almost any trap design if traps are to be placed in the field for long-term monitoring. In long-term monitoring programs, the cost of checking traps daily, preferably early in the morning before heat buildup causes injury to trapped toads and any by-catch animals, is likely to be prohibitive. It would be ideal to have some form of trap that could be placed in the field in locations in advance of the arrival of toads and be checked periodically to determine whether toads have arrived. Such traps could also be used in remote locations that cannot be visited daily. At the National Cane Toad Taskforce meeting in October this problem was discussed, and one possibility emerged, which is being explored as part of research at James Cook University—the design of artificial shelter sites that will be particularly suited for and attractive to *Bufo marinus*. These would concentrate toads, making hand capture easy, but would not prevent the exit of animals. Hence the animals would not be harmed by them if they were not checked regularly, and animals of non-target species could exit at will and simply not be collected when the “traps” were cleared.

Winning designs submitted to the competition will be constructed and tested using replicated field experiments.

In addition to the work stimulated by the trap design competition and the James Cook University research, extensive work has already been performed by the Darwin Frogwatch group. Frogwatch have designed a highly effective and inexpensive trap, and have tested their design and several others. A summary of their work and results as of January 2005 appears in the boxed section below.

Work on traps by Frogwatch in Darwin

Graeme Sawyer

A range of trap types have been trialled using lights and water as attractants. Frogwatch is interested in using traps as a means of assisting in the control of cane toads in community action programs.

Trap tested

Several different sorts of traps have been set up and tested in a number of locations.

Pitfall traps

Pitfall traps we trialled have a plastic lining with water in the bottom that acts as an attractant in the dry season. They caught toads in all three locations where they were trialled. There were issues with by-catch but no casualties of non-target organisms were observed. The by-catch was simply released. This does mean that these sorts of traps need to be regularly checked. We ceased pitfall trap trials because of the by-catch issue and because another trap was more successful.

Bundaberg trap

These traps are produced commercially in Bundaberg. They are based on the same principal as a crab pot with funnels present on the sides. However we found that toads could get out of them.

Maschke pitfall traps

This trap is a lid for a pitfall trap. It has a series of holes that are covered by a plate that swings around when a toad steps on it. It needs to be used in conjunction with an attractant such as a light source. On one night this trap caught one toad but another escaped. The trap needs to be set over a hole at least 400 mm deep to stop toads jumping out. Other toads, wind and native frogs can cause the pot lid to open allowing a captive toad to jump out if the hole is not deep enough.

Cage traps with clear finger one-way gates

The cage traps were first trialled with a single door installed and with an insect blacklight flouro tube on top of the cage. The door is made up of fingers of plastic that can only be pushed inwards. It was noticed that a number of toads were feeding around the sides of the trap. Hence in later versions gates were placed on all sides. The traps were also increased in size to make sure the toads needed to enter the trap to get the insects attracted by the light. By making them larger we were also able to trap more toads and leave them in place before they needed checking. By placing water and shelter in the trap we were able to ensure that animal welfare considerations were taken into account enabling the trap to be left for many days before it needed to be checked. The figure below shows the catch of toads in our latest version of the trap that we have named the “supertrap”. These traps are easy to transport and set up and can be moved from location to location.

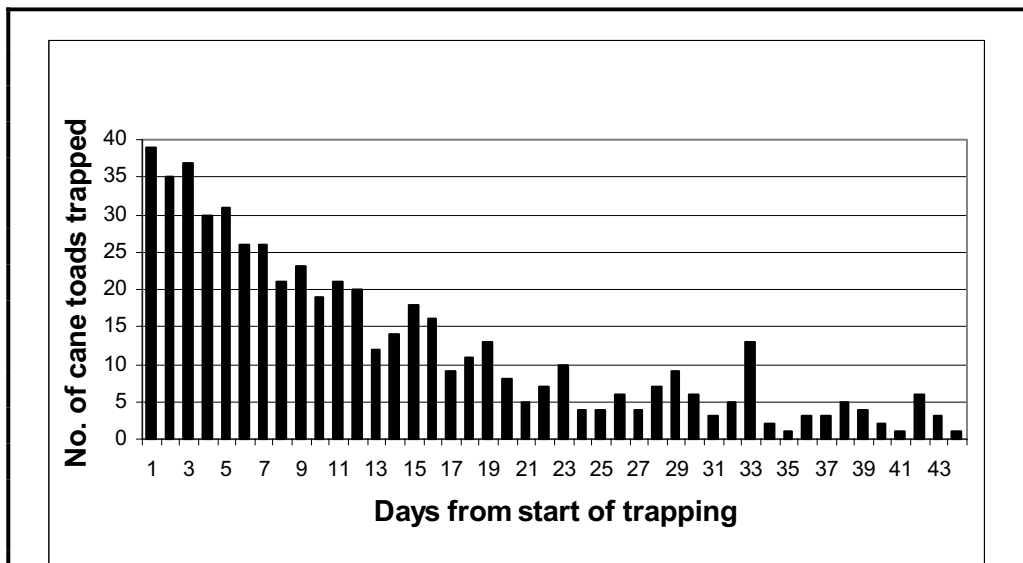


Figure 3.1. Numbers of cane toads caught in the “Supertrap” over successive days between 28 November 2004 to 12 January 2005 at the homestead area on Bonrook Station

Conclusion

Toads can be trapped successfully and in significant numbers in well designed traps. The traps trialled are reasonably easy to set up and maintain and the best of the designs appear to offer a solution to toads within a given localised area. The traps begin catching toads on the first night and can catch the majority of toads in an area within a few weeks. Importantly, as new toads move into an area they seem to be quickly caught in the traps. This suggests there will be benefits from having such traps set up in areas where the toads are arriving for the first time. We are confident that the results we have seen so far mean we have strategies with a good chance of success for the campaign against toads in the built up areas around major residential areas at least. However, there is also an indication that the traps could have a broader application for management e.g. detecting the presence of colonising toads on islands.

Recommendations

A trap and attractant competition was run by the Northern Territory government and research on attractants is being undertaken by several universities (James Cook and Sydney). No recommendations are made in relation to these matters. After the attractant research is completed and trap designs have been finalised, field trials will need to be conducted to determine how traps and attractants can be used efficiently in an operational sense and what objectives they are capable of achieving. For example, are they capable of catching all colonising toads and hence forming a protective barrier? Can they be used in conjunction with physical barriers to eliminate problems with leakage of toads across them? What distance apart should they be placed to catch all toads or to achieve some acceptable density of toads? Is it possible to use traps and attractants to reduce toad densities to acceptably low levels in areas selected to serve as refugia for fauna impacted by toads?

Cost: An effective start to answer these questions would require approximately \$180,000.

3.2 EXCLOSURES AS A MEANS OF CONTROLLING THE IMPACT OF CANE TOADS

Barry W. Brook and Peter J. Whitehead

Here we address the exclusion strategy as a means of mitigating cane toad impacts and provide estimates of the cost of isolating long-term viable populations of potentially susceptible native fauna, and managing these areas to remain free of cane toads. We also describe briefly the physical means of applying exclusion structures and analyse the potential capital and recurring costs.

Viable wildlife populations

Our estimates of what constitutes a minimum viable population (MVP; defined here as having a >90% probability of persisting for 100 years) required for realistically sized exclosures are based on Population Viability Analysis (PVA) modelling and associated statistical analysis of a large compilation of 1198 well-studied, long-monitored species from across the globe with good information on population dynamics (Brook *et al.* 2004). The results of the model-averaged simulation work on MVP were then approximated using a multivariate generalized linear mixed model (GLMM). This GLMM model was used to determine the MVPs for the candidate taxa evaluated in this report, after arriving at adequate estimates of three composite predictor variables (body weight, ecological flexibility, and demographics (see Brook *et al.* 2004 for details). Minimum habitat areas (MHAs) were determined as the product of the estimated MVP for a given species and the habitat area required per individual (based on known or inferred home range size or average density).

For a worked example, consider the northern quoll, which has an average home range size for females of 2.3 ha (Schmitt *et al.* 1989). The estimated MVP for this species for a <10% risk of extinction over 100 years was 19,100 individuals. The minimum habitat area, assuming overlap of male and female home ranges, would be determined as follows:

$$\text{MHA} = 19100 \times 2.3 \times 0.5 [\text{sex ratio}] = 21,965 \text{ hectares} = 220 \text{ km}^2, \text{ or a fenced area of roughly } 14.8 \text{ km} \times 14.8 \text{ km}.$$

It is important to recognise that these estimates are based on mean trends, and observations of populations occupying smaller areas are not necessarily inconsistent with the theory underpinning such analyses or their use as informative predictors of risk, and especially relative risk of failure of small populations (see Reed *et al.* 2004). In addition, we deliberately used figures for “average” rather than optimal habitats. Densities – and hence home range - vary markedly with habitat quality. The rocky habitat that characterises many offshore islands may be of superior quality for quolls and thus require a relatively smaller area to support the same population size. In addition, small populations on small islands remain inherently vulnerable to stochastic extinctions over the long-term, irrespective of observations of a few populations on many hundreds of islands. If one accepts that clusters of offshore islands actually operate as a metapopulation for many species, with low rates of mainland/inter-island dispersal

(assumed implicitly for cane toads under the scenario of dispersal to islands in rafts of debris), one would expect to see a number of small sites with extant populations in a large system of subpopulations at equilibrium at any given time.

Minimum habitat areas

Our results (summarised in Table 3.1, below) reveal a relatively wide disparity across different taxa in the minimum habitat areas required for long-term persistence, ranging from as little as 16 km² for mangrove monitors, to 220 km² for northern quolls, to vast areas of up to 50,000 km² for wide ranging species such as wedge-tailed eagles. The differences amongst the different species in their MVP tend to arise because of contrasting modes of reproduction and patterns of survival (e.g. a strategy of producing many offspring with low survival rates [reptiles] versus few, well nurtured offspring [mammals]), generation length, body size, environmental variability etc. (Gilpin and Soule 1986; Reed *et al.* 2003). MVPs vary by almost an order of magnitude across the 12 species, with the general result being that we should be thinking in terms of several thousands of individuals if our goal is to maintain viable populations of these vertebrates. Smaller populations may be viable under more intensive interventionist management regimes (e.g. food supplementation during adverse environmental conditions).

Species with small home range requirements or high average densities tend to require relatively small areas to maintain viable populations (e.g. only 15 km² for the frill-neck lizard, equivalent to a square enclosure with a boundary fence of only 4 km length on each side). Conversely, wide ranging and sparsely distributed species (e.g. top avian predators such as the wedge-tailed eagle) have huge area requirements that could not be feasibly enclosed by any boundary exclusion (Table 3.1). Moreover, from a practical standpoint, species with very high dispersal capabilities via flight are unlikely to confine their movements to enclosures. In this case, it is more a question of providing sufficient natural prey, such as small mammals and reptiles, in toad free areas. To provide some perspective of scale to the habitat area requirements cited in Table 3.1, the entire extent of Kakadu National Park is 19,804 km², and the Cobourg Peninsula is 2,207 km² (Garig Gunak Barlu National Park), which could be conceivably isolated from cane toads by means of a relatively short boundary fence along its narrowest point of connection to Arnhem Land.

Table 3.1. Minimum habitat area (MHA in km²) estimates for the 12 candidate species that are suspected to be vulnerable to cane toad impacts and using two different risk/time definitions. MVPs (female only) can be derived from these data by dividing the MHA estimates by the home range size (HR) for the species. Perimeter = length (km) of the total perimeter of a rectangular fenced enclosure required to encompass the MHA for each species.

Species	HR km ²	20% in 20 yr		10% in 100 yr	
		MHA	Perimeter	MHA	Perimeter
Wedge tailed eagle	35	8,750	374	38,500	785
Dingo	39	9,750	395	44,850	847
Black necked stork	10	3,500	237	16,000	506
Australian Bustard	25	10,000	400	45,000	849
Northern Sand Goanna*	0.143	43	26	191	55
Black headed python	0.32	176	53	800	113
Black bittern	5	3,000	219	13,500	465
Mangrove monitor*	0.009	3.6	7.6	16	16
Blue winged Kookaburra	0.4	280	67	1,240	141
Frill necked lizard*	0.007	3.3	7.2	15	16
Northern Death Adder	0.25	213	58	938	123
Northern Quoll	0.023	50	28	220	59

* 2:1 female to male sex ratio is assumed

Exclusion as a conservation strategy

Exclusion of threatening processes from areas of habitat for species of special concern is a well-established and critical conservation tool. The general approach has been applied to a range of influences, including endemic or exotic zoonotic or other animal disease, exclusion of fire, management of legal or illegal harvest, or invasion of exotic animals and plants additional to the cane toad. Methods can be equally diverse, encompassing destruction of the hosts or vectors of disease agents, removal of habitat features critical for invasive organisms or fostering other conditions that make habitat less favourable, direct killing of invaders, or biological control through predators or parasites.

During 2003, the Sessional Committee of the Environment and Sustainable Development of the Northern Territory Legislative Assembly inquired into issues associated with the entry of cane toads into the Northern Territory. A number of submissions to the Committee dealt with the issue of exclusion. Proposals and related argument covered two very different scales. First, there was material on steps that householders could take to keep their yards toad free. As these sorts of measures are unlikely to contribute significantly to the protection of viable populations of the native fauna known to be at greatest risk from toads, they are not considered further here, but are dealt with elsewhere in this paper. Second, there were proposals for erecting a barrier to exclude toads from

Cobourg Peninsula, the site of Garig Banuk Barlu National Park. This proposal was supported by the Garig Board, and was under active consideration by the Parks and Wildlife Service (PWS) of the Northern Territory. As a consequence some work was done by the Department of Infrastructure, Planning and Environment (DIPE) to explore the feasibility of such a barrier.

Design of cane toad barriers

Estimates of costs of barriers capable of excluding toads are based on designs made by DIPE (Lyle Campbell, personal communication). The proposed barriers were to be constructed of sheets of compressed fibre panel, 12 mm thick and 1.2 m wide, linked by metal angle and capped with metal flashing. The panels were to be placed in 30 cm deep trenches, refilled with rammed earth or concrete. The panels would thus stand 90 cm above the substrate, high enough to prevent adult toads jumping over them, with their surface being sufficiently smooth to prevent climbing. The panels were likely to be resistant to minor impacts, but will crack or shatter under impacts from larger falling branches or trees, vehicles or large feral animals like buffalo or horses. Animals that dig deeply, like feral pigs, or burrow like a range of native species (goannas, small mammals) may undermine or tunnel under panels. Toads may use or enlarge such excavations. Costs of construction are increased by the need for additional arrangements at points where vehicle entry is required, at drainage lines and, if the barrier is combined with natural barriers, where it abuts those features. Particular challenges arise where marine systems abut the barrier. We have based estimates for these additional features on information provided by DIPE, or where they are unavailable assumed that average costs will increase 10-fold around habitat discontinuities. At least occasional failure of elements of such facilities is inevitable. As a consequence, barriers will require regular and relatively close, fine-scale monitoring to maintain their integrity. Estimates have been made of the cost of such monitoring based on stated assumptions (see Tables and Brook *et al.* 2004).

The cost of exclusion

Cost estimates for all structures given below were based on use of new materials and full commercial costs for fabrication and erection. In order to expand the range of plausible options considered, we also provide estimates assuming that costs could be halved by use of second hand materials and some voluntary labour. For exclusion options such as small islands that may appear to be too small to maintain vulnerable fauna over the long-term, we have also provided some preliminary estimates of the cost of maintaining separate populations of relevant fauna in captive breeding colonies, which might be used to supplement island populations as required.

Estimates of the costs of exclusion are given in Tables 3.2 and 3.3. An extended discussion of the key assumptions, operational considerations and parameter estimation limitations of our estimates is presented in Brook *et al.* (2004), and an Excel spreadsheet with all costings and associated calculations are available from Barry Brook at Charles Darwin University.

Table 3.2. Costs of exclusion of cane toads from an area (Garig Gunak Barlu National Park, Cobourg Peninsula) large enough to support populations of the northern quoll and other co-occurring vulnerable species with equivalent or lower area needs (northern sand goanna, black headed python, mangrove monitor, blue winged kookaburra, frill neck lizard and northern death adders). For instance, the minimum area of savanna required to support a viable population of quolls and at a probability of persistence of 90% over 100 years, without supplementation from other populations, is 220 km² (Table 1), where as the total area of Garig is 2207 km². Total costs are calculated over 15 years (for options 1 and 3, see description in Table for details on how these differ) or 20 years (option 2). Option 4 is a cheaper structure based partially on second hand materials and using some volunteer labour. An interest rate of 5% is applied to the capital cost over the life of the project and incorporated in estimates of average annual cost.

Situation	Area (km ²)	Item	Quantity	Description	Cost of structure	Annual cost
Peninsula (Garig Gunak Barlu National Park)	2207	Construction of fence, including labour	6 km	Based on structure of compressed fibre board on steel supports and with metal capping, with 15-20 year life (before total replacement required) and 5% interest rate. Costs include initial clearing of line. Option 1 involves trenching to bury panels to 30 cm and repacking with earth. Option 2 uses concrete footings throughout. Option 3 uses concrete in vulnerable areas and rammed earth over most of length	(1) \$3.45 million (2) \$5.86 million (3) \$3.64 million (4) \$1.81 million	(1) \$229,700 (2) \$292,900 (3) \$242,400 (4) \$121,200
		Construction of gates	2	Double gate and associated structures over main access road to permit vehicle entry but limit toad access, plus gates over separate access track.		
		Tidal zone protection	2	Barrier for tidal zone at both northern and southern margins of the peninsula		
		Maintenance of firebreaks	12 km	Annual maintenance of firebreaks to limit damage by tree fall or fire		
		Repairs and maintenance of structures	6 km	Repairs to major and minor damage from floods, vehicle damage, feral animal damage and tree fall.		

Table 3.2 (continued).

Situation	Area (km ²)	Item	Quantity	Description	Cost of structure	Annual cost
		Inspection and surveillance of structures and surrounds	6 km	Regular inspection to promptly detect breaks and mobilise repairs, as well as identify and intervene in potential sources of damage (e.g. developing drainage changes)		\$28,141
		Surveys for detection of toads inside barrier, including in the absence of known breaches in barrier	weekly	Inspections of entire fenceline using pitfalls and other traps and inspections of all known waterbodies persisting during dry within 2 km of fenceline. More frequent (twice weekly) inspections during wet season. Also includes ad hoc inspections and interviews with visiting boats, commercial and recreation users of the park		\$39,854
		Responses to entry of toads	As necessary	Includes aggressive interventions to control intruding toads, plus comprehensive investigation of all reports. Methods to include hand capture at waterbodies plus trapping. Assumes probability of significant and well established entry is low, and figures average high cost responses over long periods.		\$28,006
		Surveys of populations of vulnerable fauna	Annual	Surveys to provide assurance that populations of fauna of concern are actually being maintained		\$11,196
		Maintaining captive populations	Ongoing	Maintaining captive populations of relevant provenance as “insurance”	\$1.69 million	\$510,127 for quolls
TOTAL				without “insurance” with “insurance” for one (most vulnerable) species	~\$3.6 million ~\$5.70 million	~ \$410,000 ~ \$920,000

Table 3.3. Comparison of annual costs for a number of exclusion scenarios for a range of vulnerable species in northern Australia.

Situation	Vulnerable species	Annual costs (\$000)	Issues
Peninsula	Northern quoll and varanids, snakes and frill-necked lizards, non-migratory birds	\$410	Probability of higher rates of toad entry, by both sea and land, than some alternatives. Considerable uncertainty regarding ability to effectively “close” coastal margins of cross-peninsula barrier If exclusion is successful, such sites likely to be large enough to be confident of protecting many species In the example used, costs are contained by access to existing infrastructure and staffing in an existing national park. This will not always be the case, and costs could be considerably higher in other situations.
Non-estuarine island	Northern quoll (introduced)	\$198	Difficult to institutionalise inspections of boats because of lack of facilities in remote locations, so heavy dependence on regular on-site surveys for toads. Frequency of use or residence on islands increases with size, so larger islands face greater risk of cane toad introductions. Island selected should be isolated from major rivers so that risk of toads reaching them in wet season floods is low. Small uninhabited islands face lower risk of cane toad establishment (e.g. Astell Island at 12.7 km ²) as example, but unlikely to support populations of wildlife viable over the long-term, required for species’ persistence in perpetuity, therefore requiring insurance of captive population
Mainland exclosures of “average” habitat	Northern quoll Varanids Snakes Non-migratory birds	\$3,121 \$860-1023 \$5902-6424 \$7364	Calculations of area required for MVPs (e.g. northern quoll 220 km ²) are based on average habitat which will mostly be made up of patches of favourable habitat in a matrix of marginal or even hostile habitat. Hence costs of enclosing a single block of typical savanna habitat for quolls may be high. Yet even exclosures of this size may fail to enclose viable populations of other affected species even if site also contains habitat favourable for those species

Table 3.3 (continued).

Situation	Vulnerable species	Annual costs (\$000)	Issues
Mainland exclosures of high quality habitat	Northern quoll	\$1,775	Areas required for MVPs may be greatly reduced in areas of highly favourable habitat in which high densities may be attained, including rocky areas for quolls. There is a need to take account of higher costs of both construction and maintenance in some favourable habitat types (rocky areas, wetlands, mangroves).
Captive populations alone	Northern quoll	\$510	For comparison with costs and benefits of exclosure strategies, and to permit exploration of “hybrid” strategies (below). Captive population large enough to avoid significant genetic risks.
	Reptiles	\$104	
Mixed strategy – exclosures plus captive breeding insurance	Northern quoll	\$1,782	Tradeoffs between robustness of enclosed populations and costs of protecting their integrity may warrant consideration of mixed strategies that take advantage of lower cost options. For purpose of calculations assume an area of the most favourable habitat half that required if no supplementation from captive populations

Conclusions

An area the size of the Coburg Peninsula (2,207 km²), which would be relatively cost-effective to isolate as a landscape-scale exclosure, appears to be large enough to support viable populations of most small mammal and reptile species such as quolls, goannas and predatory snakes (and presumably most amphibians and insects, which also have relatively small home range requirements or high average densities). However, it would still fail to capture fully the areas for some of the largest free-ranging species, including most top avian predators such as wedge-tailed eagles. For Garig, the cost of construction of a exclosure fence across the neck of the peninsula of 6 km length would be approximately \$3.6–5.7 million, with annual maintenance costs in the range of \$0.4–0.9 million. In reality, the situation is more complex, because capital and recurring costs for the construction and maintenance of fencing are governed not only by the size of the area to be enclosed, but also by the choice of location (e.g. it is more efficient to fence off the neck of a natural partial exclosure such as the Cobourge Peninsula than it is to create a perimeter around an inland site) and the nature of the materials used in construction (e.g. sourcing local or recycled building materials is more cost-effective). Overall costs could also be reduced by creating secure area exclosures that encompass the ranges of multiple species for which such conservation action is deemed warranted.

Although the results presented herein represent preliminary estimates for the logistics of the “secure area” strategy of cane toad impact mitigation, they do nevertheless provide wildlife managers with some of the key information required to rationally and efficiently allocate time, money and habitat areas to maximise conservation benefits in the face of cane toad encroachments.

Recommendations

Because of the huge costs of construction and maintenance of enclosures for large areas, it makes sense to test some potential designs on a small scale in a variety of situations, to evaluate experimentally if they can work. Such test areas should include situations where drainage issues need to be addressed, and a natural promontory situation where cane toads could potentially invade the area from the sea.

Cost: Cost of the fence would depend on the design, the length and the type of country it was used in. Cost of regular inspection and searching for toads inside of the enclosure is estimated at \$110,000 over 3 years.

3.3 THE USE OF BONUS OR BOUNTY SCHEMES AS A MEANS OF PEST CONTROL

Peter Mawson

Bonus or bounty schemes involve the payment of a reward (cash or some other reward) for killing pest animals, usually on presentation of evidence such as scalps or beaks. The bonus payment is intended as reimbursement for expenditure on destruction measures by those directly affected by the pest species. Bonus schemes have traditionally been established to mitigate damage to primary production. There is also the added potential to induce those people not directly responsible for the primary production (that section of the community usually affected by pest species) to undertake the destruction of pest species.

In Australia during the early and mid-1900s bonus schemes were common and they were operated in every State and Territory in Australia (with the possible exception of the Australian Capital Territory). In Western Australia bonus schemes have been run for pest species such as dingoes/wild dogs, foxes, wedge-tailed eagles and emus. Bonus schemes have also been widely used in other parts of the world. By the late 1950s bonus schemes were seldom used in Australia, but they have made rare appearances in the past decade [e.g. Fox Lotto bonus scheme in Victoria (where the payment was made in the form of a lotto scratch-and-win ticket) (Anon 2003) and a limited dingo scalp bonus for dogs taken in the north-eastern Goldfields of Western Australia (Thomson 2002).]

Arguments raised in favour of bonus schemes include:

- They assist farmers and pastoralists to control pest species by meeting part of the costs
- They are an incentive to employees to carry out more destructive work than would normally occur
- They also induce many other people who would not normally be interested to become part-time pest controllers
- When bonuses are offered for individual problem pest animals at a high rate, they attract the most skilled persons
- Scalps/beaks received are concrete evidence of destruction that indicates pest control work is actually being carried out
- In the absence of any better control programs, bonuses are better than nothing.

Arguments raised against bonus schemes include:

- Bonuses create a tendency for the landowners most affected by pests to expect or rely on others to carry out basic control work on their behalf in order to receive the bonus. If the problems caused by the pests become worse then raising the bonus will provide greater incentive to the other people involved, possibly leading to a relaxation in effort by the landholders
- Any bonus scheme is an open target for fraud, misrepresentation and exploitation
- The commercializing of any pest is normally opposed to effective control. In most cases it is necessary to destroy over 80 percent of a pest species to achieve control. The reality is that in most cases, long before this figure is achieved destruction would cease to be economic as far as bonus hunters are concerned
- The higher the bonus the more it pays hunters to concentrate on individual pests instead of any mass destruction technique. It also results in the increased use of destruction techniques (such as trapping) that guarantee that all bodies (and hence scalps/beaks) are recovered – something that is unlikely with mass destruction techniques such as poisoning.

Local and State governments often consider bonus schemes attractive when they believe that they have nothing better to offer landholders who are complaining about a lack of assistance. This shows a lack of understanding by the authorities or a desire to find a quick fix. Landholders are often reluctant to take on ‘new’ control methods until they have been shown to be effective. If such techniques need to be developed and tested then this is a clear role for governments (Local and State). Once efficient techniques have been developed pest control is likely to be most efficient if authorities then provide direct assistance to landholders by assisting in organizing carefully planned control programs. If these steps have been carried out, then and only then, could bonus schemes be considered assuming additional funds were available to support such actions.

In summary, bonus schemes often receive tremendous support from those primary producers affected by pest animal species and they are often backed by local and State/Territory government authorities. Animal pest control authorities throughout the world do not support bonus schemes because they are expensive to administer, seldom, if ever, lead to a significant reduction in pest animal populations and draw away limited resources from legitimate control programs (Anon 1998). Bonus schemes are also readily defrauded by people submitting scalps/beaks for animals taken from areas (or States) outside of the area of operation for a particular scheme (Tomlinson 1958). For example, a common criticism of the Victorian Fox Lotto scheme is that foxes shot in NSW were being presented for payment in Victoria and there was no evidence to indicate that the scheme was having any impact on fox numbers or their impact on livestock or native fauna.

Would the establishment of a bonus scheme help in controlling the spread and impact of cane toads in Australia?

If a bonus scheme were to work in assisting with control of cane toads then it would be expected that over time the number of toads submitted for payment would decline. Any cane toad bonus scheme would have to overcome the cane toad’s high level of fecundity

and the fact that there are already many millions of toads in the wild. In light of the size of the toad population and the current modest level of funding that the whole cane toad issue has received (ca. \$6 million to date) the unit price paid per toad would have to be low to ensure that the scheme did not run out of funds very quickly. A low bonus payment provides no incentive to would-be collectors.

The climatic attributes of the northern Australia with its hot dry periods punctuated by intense wet periods with local or regional flooding, coupled with a small and sparsely distributed human population do not provide a viable capacity to effect any broad-scale control strategy based on physical destruction or capture of cane toads.

Another major problem with a cane toad bonus scheme is that if it were offered across Australia and included parts of Australia where cane toads turn up occasionally but are not yet established (e.g. Western Australia), then there is a real risk that cane toads will actually be imported into that State by people intent on collecting the bonus. This would greatly increase the risk of cane toads reaching parts of Australia that they do not currently occupy and even parts of the country that they would normally not occupy due to inappropriate habitat.

Any funds that might be available to establish a bonus scheme would be better directed towards public education and programs to limit the spread of cane toads and to reduce their impact on the native fauna of Australia.

Misidentification

Misidentification can be a particular problem with bounties on cane toads. The experience of a community group north of Brisbane who offered a bounty for cane toads was that over-enthusiastic school children were also capturing brown native frogs, freezing them and bringing them in with their cane toads to collect bounties. This program was rapidly terminated.

3.4 COMMUNITY PARTICIPATION IN CANE TOAD CONTROL

Graham Sawyer and Robert Taylor

There is a great deal of concern in the community about cane toads. This often involves a concern for impacts on biodiversity but can simply be annoyance at having to have such ugly, poisonous creatures sharing living space with humans. This concern leads to a desire to do something. In response, government and/or non-government authorities have often organised programs to reduce numbers of cane toads. These have lasted for varying periods of time and have covered varying areas and have involved differing numbers of people.

To assess whether such campaigns have been effective it is first necessary to determine the objectives of a program. Objectives can either be related to biodiversity or social goals or both. If the goal is simply to allow people to participate in a group activity that gives them a sense of achievement in reducing the numbers of toads, irrespective of what reductions in their biodiversity impact might be achieved, then assessing direct biodiversity outcomes is not relevant. To our knowledge there has never been a proper

scientific assessment of the value to biodiversity of control campaigns involving community participation. Objectives of community participation in relation to control of cane toad populations have to date been focused on reduction in population numbers. However, Frogwatch in Darwin have recently enunciated the objective of using community participation to stop the spread of cane toads into rural and urban areas of the Darwin region.

In order to gather some information on people's perceptions of how effective their control campaigns had been a number of groups and individuals who had had previous involvement with projects utilising public participation in attempts to control cane toads were contacted. These groups included Brisbane Frog Group, Townsville Frog Group, Cairns Frog Hospital and people working for New South Wales Parks and Wildlife Service.

There appears to be consensus amongst the people contacted that cane toad collection by members of the public does have a noticeable impact on cane toad numbers for at least the short-term and longer if the effort is maintained. Brisbane Botanical Gardens and a number of related areas in Brisbane where local action groups have conducted toad collection nights have reported reduced numbers of toads. However we were unable to obtain any hard data to back up these claims.

Gladstone, Cairns and Townsville have all reported similar findings, that reasonable numbers of volunteers can catch toads, in numbers sufficient to impact on the local population density. One example cited was 75 volunteers collecting 1017 toads in New South Wales. Wildlife officers also report that they feel that the public involvement provides an important information gathering opportunity and that it does help to reduce toad numbers in the local area. In NSW it has been an element of a control strategy around Port Macquarie. It is supplemented by other control work such as contractors working in specific areas or Green Corps projects.

There appears to be a high level of public interest in cane toads that can be used as a motivator to participate. There is a belief that enough people working at it can provide enough local control to reduce toad numbers. However, there were many issues raised by the groups contacted, maintaining the effort being the predominant one. Over time toads tend to move in to the cleared areas from surrounding areas or breed and numbers increase again.

Most of the community programs involving cane toad control focus on collection of adults. There is also evidence of people successfully removing eggs from ponds and wetlands to limit toad numbers. This has been used on some islands (Hayman) as well as in national parks and local areas. However, a number of people reported using traps of one sort or another and Frogwatch (Darwin) has been trialing various designs (see section 3.1). These trials have shown that traps can rapidly reduce toad numbers in a given locality. A combination of manual collection and trapping could potentially be used in community programs.

A number of comments were made about the use of toad proof enclosures, mainly relating to toad exclusion pens to keep pets in and barriers to stop them getting into frog ponds. The main type was shade cloth or plastic over a mesh panel. A cover running

about 600 mm up the fence and buried 10 cm into the ground forms an effective barrier. Wire has also been used successfully but it needs a curled flap at the top to prevent toads from climbing it. These have been used to keep toads out of school ponds in Townsville and other locations. The advantage of the wire is that it does not disrupt native animals as much as a solid barrier.

Community involvement has been sought in the Northern Territory to protect islands from cane toads that stow away in goods and are taken inadvertently to islands. A few anecdotal reports also exist of children taking toads to islands as pets. We have asked for cooperation of island communities and mainland residents who visit islands to be vigilant for stow-away cane toads. Nearly all islands in the NT are under traditional Aboriginal ownership and hence most of the work of government officers on this issue is undertaken with Aboriginal people. Aboriginal ranger groups exist in many of the homelands and they have proved particularly useful in communicating the message to communities.

Island communities have also played a role in reporting new incursions on islands and rounding up any colonisers. This has occurred on Milingimbi and Elcho Islands. On Milingimbi the school coordinated a round up effort. It remains to be seen whether this prevented a population establishing.

Below are some comments provided on community action against cane toads.

David Newell (Southern Cross University)

“We have run community cane toad musters in northern New South Wales in the past and they have been very useful, for two reasons. Firstly, many people who would not normally talk to you about frog conservation are more that happy to tell you the strange methods that they employ to dispose of cane toads. This provides a unique opportunity to talk with them about native frogs. Equally, cane toad musters generate lots of media coverage / interest so there is a great opportunity to talk about the bigger picture. Hence, the Trojan toad! Secondly, there is a good opportunity to map the distribution of toads annually. However, the situation we are dealing with in New South Wales is very different to the one in the Northern Territory in terms of dispersal. Toads appear to move at about 3-4 km/yr in northern New South Wales compared with the 30 km or more in the Northern Territory.

In terms of control, toads can be excluded from waterbodies at a small scale (ponds / farm dams) through rigorous collection (consecutive nights) and habitat modification (dense vegetation) and this can be valuable if a population is acting as a source for dispersal into new areas.”

Jeff Thomas, Pest Management Officer, North Coast region, New South Wales Department of Environment and Conservation

“We have done community cane toad roundups since 1999. Our strategy has been to hold one or two community roundups per year plus collections by staff, volunteers, Greencorp teams and contractors. Our initial focus has been to stop the spread into the northern edge of Yuraygir National Park as

in 1999 they had only penetrated about 0.5km into the park. Repeated collections in this area and to about 1km north have been successful in reducing numbers in this area with only about 15-25% of the original numbers being collected and no further expansion. We have since expanded collections further north into urban areas and urban/bushland interface of Yamba where big numbers are being collected (e.g. 1447 in 1.5hrs by 74 people last February, Yamba Golf Course). Our department is seen as having the responsibility and has coordinated many cane toad community control programs in NSW. Locally we could do a lot more if we had the resources but off-park work has to compete with other on park pest programs and other activities. “

Evaluating public cane toad eradication programs

Jean-Marc Hero

The cane toad invasion of Australia has been followed by varied responses from the general public. For obvious biological reasons cane toads have been negatively portrayed in information provided by government agencies (federal, state and local) and the media. These have focused on why the cane toad is bad (i.e. it is toxic to humans and pets) rather than the biological consequences of reducing the number of snakes and other reptile and mammalian predators that have been severely impacted by cane toads – primarily outside urban areas.

In Brisbane “Toad Buster” evenings were promoted in the early 1990’s as “a real family affair” (The Courier Mail, January 4, 1994). While some of these cane toad hunts were supervised by Brisbane Forest Park rangers (Fig. 3.2) their impacts on cane toads have not been critically evaluated. Subsequently public cane toad eradication programs (e.g. “Cane Toad musters” and “Toad Buster” public activities) have been executed in major cities along the east coast of Australia (Brisbane, Mackay, Townsville, Yamba and more recently in the Northern Territory).

Herein I will examine the perceived impacts of cane toads in urban areas, the objectives and effectiveness of public participation in cane toads harvesting programs, and the ethical considerations of these programs.

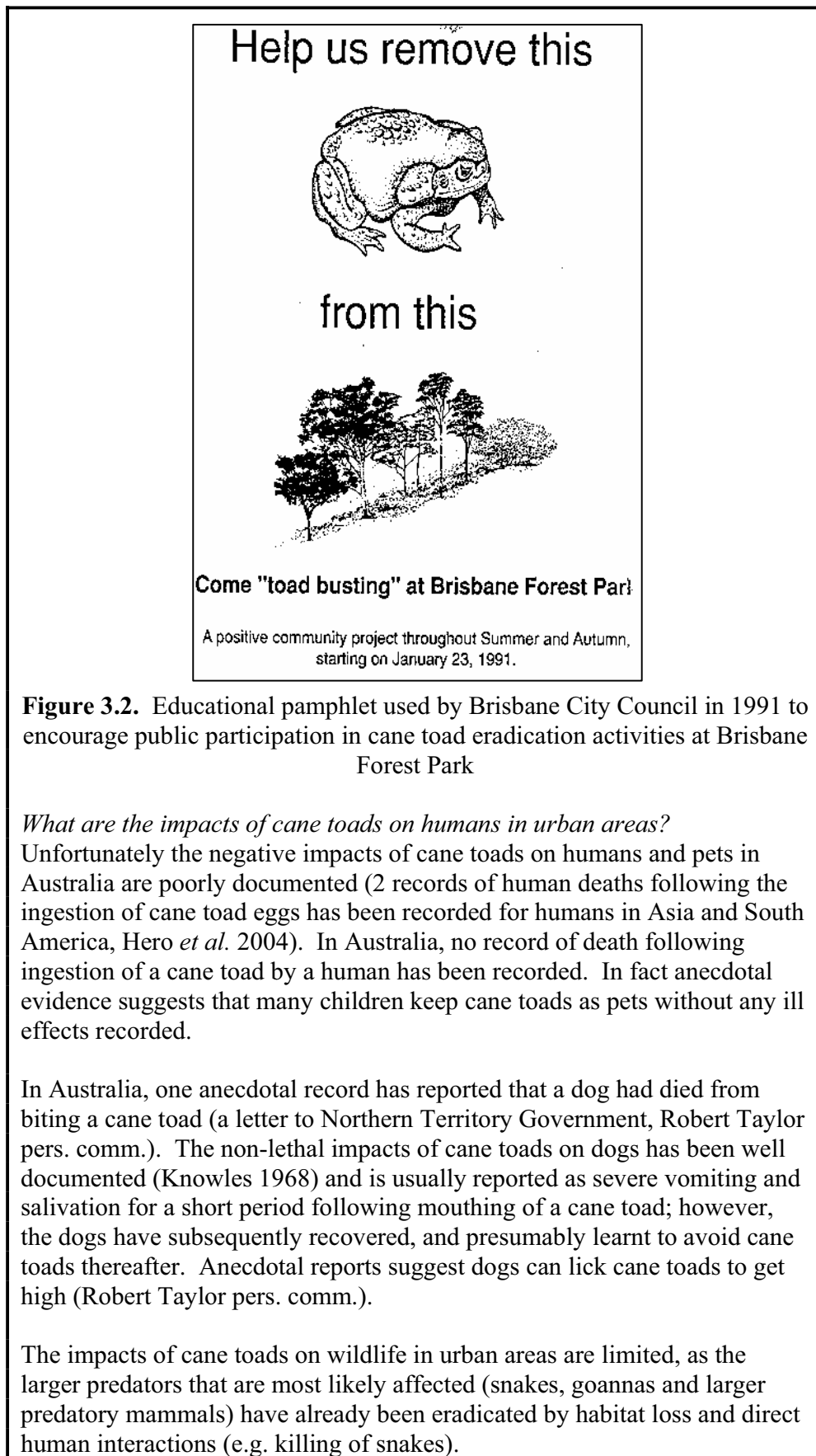


Figure 3.2. Educational pamphlet used by Brisbane City Council in 1991 to encourage public participation in cane toad eradication activities at Brisbane Forest Park

What are the impacts of cane toads on humans in urban areas?

Unfortunately the negative impacts of cane toads on humans and pets in Australia are poorly documented (2 records of human deaths following the ingestion of cane toad eggs has been recorded for humans in Asia and South America, Hero *et al.* 2004). In Australia, no record of death following ingestion of a cane toad by a human has been recorded. In fact anecdotal evidence suggests that many children keep cane toads as pets without any ill effects recorded.

In Australia, one anecdotal record has reported that a dog had died from biting a cane toad (a letter to Northern Territory Government, Robert Taylor pers. comm.). The non-lethal impacts of cane toads on dogs has been well documented (Knowles 1968) and is usually reported as severe vomiting and salivation for a short period following mouthing of a cane toad; however, the dogs have subsequently recovered, and presumably learnt to avoid cane toads thereafter. Anecdotal reports suggest dogs can lick cane toads to get high (Robert Taylor pers. comm.).

The impacts of cane toads on wildlife in urban areas are limited, as the larger predators that are most likely affected (snakes, goannas and larger predatory mammals) have already been eradicated by habitat loss and direct human interactions (e.g. killing of snakes).

What are the objectives of cane toad eradication programs?

Public cane toad eradication programs have been executed in major cities along the east coast of Australia (Brisbane, Mackay, Townsville, Yamba and more recently in the Northern Territory); however the objectives are rarely specified. Various agencies have reported specific events where large numbers of cane toads were collected, however there is no information on how this has impacted on the local populations in the long term. The general objective seems to be “to reduce the impacts of cane toads”.

Some indications suggest that locally cane toads numbers can decrease in the short term. However, the long term benefits are likely to be negligible. Anecdotal evidence that numbers have reduced is expected from those who remove them from their personal space (i.e. remove them from their yard or local park). However no data have been collected at the population level. Anecdotal decreases in cane toads within urban areas are likely to be due to natural influences (e.g. decreased activity in periods of low rainfall) and the continued destruction of breeding habitat as urbanisation becomes more intense (i.e. the inevitable increase in density of houses and people through time). Separating these confounding influences on the perceived number of cane toads (reflecting cane toad activity rather than actual abundance) would require undertaking expensive research.

Are cane toad eradication programs effective?

To date, cane toad harvests have been short-term projects, focused on small geographic regions (e.g. small parks in the Brisbane region). These control programs have been ineffective for several reasons:

- a. The actual number of toads collected is unlikely to have an impact on the population. Using a harvesting model for the Gold Coast we predict that if the population of cane toads in this region is 1 million then 330,000 animals/year will need to remove before there will be an impact on the abundance of this species (calculated as the maximum sustainable yield). These numbers are unlikely to be reached in a single year. Due to their extremely high fecundity (up to 30,000 eggs /female/year) cane toad numbers will recover quickly to pre-harvesting levels.
- b. To be an effective control agent, harvesting must be sustained on a continuing basis (i.e. ad-indefinitum). The problem is that, while these cane toad harvests have been initiated and funded by local councils, no research has been done to evaluate their effectiveness.

What are the ethical considerations of cane toad eradication programs?

Methods of collecting, euthanasia and disposing of cane toads are issues that must be evaluated before any cane toad harvest begins. Freezing has been recommended as the principal method for killing cane toads (Brisbane City Council 1993, Northern Territory Government 2004). However; this method is no longer recognised as humane (ANZCCART 2001). The Australian and New Zealand Council for the Care of Animals in Research and Teaching recommends using pentobarbitone sodium, MS 222 benzocaine and chloral hydrate as the most suitable techniques for the humane destruction of amphibians(ANZCCART 2001). In Queensland

these methods may only be done by veterinarians, inspectors under the *Queensland Animal Care and Protection Act 2001*, or prescribed entities. ANZCCART (2001) does not recommend the physical methods of hypothermia (freezing) and decapitation alone.

Another associated issue is that encouragement of killing cane toads has led some adults and children to promote a cult in Queensland of killing cane toads using golf clubs and cricket bats (personal observation). The long-term social impacts of training the public to kill wildlife has not been investigated but is likely to have a negative impact on all Australian wildlife. A disregard for the value of wildlife will also be exacerbated by the problem of misidentification. Volunteers may accidentally kill native frogs, an issue that can only be overcome by training the participants in frog and toad identification. Identification of adult toads is relatively easy and may be done using written information leaflets. However, juvenile toads and tadpoles can closely resemble native frogs and an experienced frog biologist is needed to confirm their identification before eradication.

Positive outcomes of public cane toad harvests?

The reported positive outcomes of cane toad harvests (see David Newell's comments above) are not cane toad control, but rather public education and public participation in collecting information on cane toad densities, and the potential to monitor their impacts on native fauna and current distribution to the south (New South Wales) and west (Northern Territory). However these objectives can more appropriately be met without harvesting operations. Public participation in monitoring programs could be used to evaluate cane toad densities and the abundance of other native wildlife (i.e. frogs, snakes and other vertebrate predators) that are likely to be negatively impacted by the presence of cane toads.

Recommendations

Public cane toad eradication programs are unlikely to succeed unless they are funded and maintained in perpetuity. The ethical issues involved outweigh the potential benefits that are also minimal.

Harvesting of cane toads should only be encouraged in areas where they are likely to be an effective control measure (e.g. islands and other isolated areas of mainland Australia (see section 3.6).

Public monitoring programs could be used to evaluate the current distribution and abundance of cane toads throughout their current range and also in areas in front of the expanding populations (i.e. northern New South Wales and western Northern Territory). Furthermore these programs could be used to monitor the impacts of cane toads on local wildlife.

Recommendations

If minimisation of impacts of cane toads on fauna species that are susceptible to the presence of toads is the objective of community action (as opposed to purely social goals) then work is required to test whether such action can achieve this goal. This would involve a biologist working with a community group to assess the degree to which toad numbers could be reduced and whether any biodiversity benefits are gained.

Cost: \$160,000 to assess community action at several sites.

3.5 MECHANISMS OF TOAD DISPERSAL TO ISLANDS AND ITS IMPLICATIONS FOR BIOSECURITY PROTOCOLS AND CHOICE OF ISLANDS FOR TRANSLOCATION OF IMPACTED SPECIES

Robert Taylor and Frank Keenan

Islands, because of their isolation from the mainland, can potentially provide refuges for species that are adversely affected by cane toads. They can also provide sites to which impacted species can be translocated so that their conservation status can be improved. Such refuge populations can also provide a source of animals to repopulate mainland sites if in the future a broadscale control mechanism for cane toads were to be found.

However, cane toads can potentially reach islands by two mechanisms i.e. natural dispersal and by “hitch-hiking” in goods taken to islands. It is extremely important that we understand these mechanisms so that we can determine which islands are unlikely to be colonised naturally by cane toads. Appropriate biosecurity measures can then be put in place on islands that cane toads will not reach naturally to reduce the chance of colonization events by hitch-hiking toads.

Lever (2001) quotes several observations of cane toads spawning in brackish water, calling on tidal mudflats, swimming in the sea and crossing 600 m of salt water between two islands (possibly in response to the occurrence of a freshwater pond on the island). Adults are able to survive in salinities of up to 40% sea water (Liggins and Grigg 1985).

Occurrence on Queensland islands

There are 1165 islands and cays in Queensland. Cane toads occur on most islands with tourist infrastructure and many uninhabited National Parks. However for most small, uninhabited islands the status is unknown.

In the Mornington Group, cane toads are on Sweers and Bentinck Islands but not Mornington Island. Staff at the Council office on Mornington Island confirmed their absence. However, Rex Whitehead recalled seeing toads on this island in the 1970s. Thus it is possible that a small number got to this island and did not survive. A Council worker feared they could get to Mornington as they are present on the mainland around the site where the barge to Mornington is loaded. Rex Whitehead (pers. comm.) saw them on Bentinck Island about 10 to 15 years ago prior to the island being inhabited. Lyn Battle (pers. comm.) from Sweers Island (over 30 km from the mainland) believes that toads were transported to the island after flooding in 1974. Toads were not recorded during an environmental study of the island in 1972 by Prof. Peter Saenger of Southern Cross University. Lyn Battle noted their presence on the island in 1976. There was little

if any boat traffic to the island prior to their being discovered there. Freshwater plumes floating on top of the saltwater approach very close to the island during times of heavy flooding, according to the prawn spotters. Guests at the resort on the island have reported seeing toads in the water and large trees get washed onto the islands from the mainland during floods. A cane toad has also been found in the stomach of a reef fish caught two kilometres from Sweers Island in the early 90s. Status of the other islands in this group is unknown.

In the Torres Strait cane toads are on Thursday, Horn and York Islands. Status of the other islands is unknown, however locals are aware of the cane toad menace and are likely to undertake local action. There have been several introductions onto York Island that have not survived for long. The source of these infestations is reported to be from barges from the mainland.

A small number of cane toads got to Lizard Island in the early 90s in a shipment brought to the island on a barge (Lyle Viall pers. comm. to Ian Morris). All the toads were caught and destroyed.

Dunk, Orpheus and Magnetic Island are popular tourist destinations. Cane toads are thought to have been introduced with building materials. It is possible that the disappearance of northern quolls from Magnetic Island was linked to the arrival of the cane toads. Cane toads are not on Heron Island, another tourist island. However, within two weeks of the introduction of roll-on, roll-off barging of cargo in the late 1970s, a cane toad was captured on the island (Limpus *et al.* 1999). On Gloucester Island National Park, the source of cane toads is thought to have been camping gear. However other sources cannot be ruled out.

Popular tourist destinations of Long, Hamilton, South Molle and Hayman Islands in the Whitsundays, Shaw, Thomas and Lindeman Islands near Mackay, and North Keppel, Fraser and Bribie Islands all have populations of cane toads. Curtis Island, very close to the mainland, and Facing Island both north of Gladstone have toads as does Woody Island near Fraser Island. For many of the other islands in these areas the status is unknown but it is highly likely they are also present. A person who used to work on Hayman Island reported to us that the toads were brought from the mainland to the island in soil used when the tourist facilities were being upgraded.

All the major islands of Moreton Bay (North Stradbroke, South Stradbroke, Peel, Russell, Coochiemudlo, Coomera) have cane toad populations. Moreton Island is the furthest out to sea and anecdotal reports indicate they have only had cane toads over the past six years. This coincides with an upsurge of building activity and they were slow to establish.

Other islands with toads include Boyne, Bulwer, Hummock Hill, Kangaroo, Karragarra, Lamb and Woogoompha islands.

Occurrence on Northern Territory islands

Pellew Islands

The Sir Edward Pellew Islands in the Gulf of Carpentaria were colonised by cane toads in late wet season of 2001/02 (Steve Johnston pers. comm.) after several heavy rainfall events which cut off the town of Boorooloolo on the adjacent mainland for several months. It appears highly likely that the toads were swept out to sea in the floodwaters of the McArthur River, the delta of which is adjacent to the islands. Toads have now been recorded on all of the major islands in the group (West, South West, Centre, North and Vanderlin) (Taylor *et al.* 2004). It is not known how many of the smaller islands in this group have cane toads. North Island is the most distant of the larger islands in the group from the mainland (25 km).

Elcho

Elcho Island, at its closest point is less than 1 km from the mainland where cane toads are known to occur. Strong currents in this narrow channel have afforded some barrier to invasion. However, during the wet season of 2003/04 three dead cane toads were discovered washed ashore and a single live male was killed on a remote bush track. Subsequent night-time searches throughout the island found no other evidence of live cane toads (W. Panton pers. comm.). A report was also obtained of a child bringing a cane toad to the island in a can as a pet.

Milingimbi

Milingimbi occurs in a river delta close to the mainland and is highly vulnerable to cane toad invasion. Surveys along roads over two nights in May 2004 found a single male cane toad (W. Panton pers. comm.). Community members reported large numbers of cane toads during the 03/04 wet season and occasional sightings since. Over 50 cane toads were destroyed by the school during the 03/04 wet season.

Occurrence on islands internationally

Cane toads occur on a large numbers of islands overseas but were deliberately released onto most of them in attempt to control pest insects (Lever 2001). However, Lever (2001) reports a case of toads being inadvertently taken to islands in gravel taken on barges (Carriacou Island) and being found on a beach with riverine vegetation debris on Cayo Santiago 1 km off the coast of Puerto Rico after flooding as a result of a hurricane.

Mechanisms for island colonisation

There are many examples of accidental spread of cane toads on the mainland through being inadvertently transported in vehicles or in cargo (Seabrook 1991, 1993). These sometimes result in populations establishing in front of the main wave of colonisation which eventually fuses with the contiguous population front. Evidence above indicates that inadvertent transport of cane toads also occurs to islands. Transport in soil and in building products appear to be a common way for toads to be transported to islands. Flushing of animals in floodwaters or direct swimming to closer islands is also responsible for some colonisation events.

Recommendations

It is recommended that three projects are undertaken in relation to islands.

Review of the conservation potential of islands in relation to impacted species

This would involve documenting the occurrence on islands of species likely to be highly impacted by cane toads. An assessment would also be undertaken of the suitability of islands for translocation of impacted species. This would involve an examination of the occurrence of suitable habitat and the area of this habitat in terms of providing a minimum viable population size. Since not all islands have been adequately surveyed this project could also include fauna surveys of islands to determine whether impacted species are present on poorly surveyed islands. It would also be necessary to use the results from the project below to determine which islands were likely to remain free of toads.

Cost: This could be undertaken as either a desktop study or be more detailed by undertaking fauna surveys on those islands large enough to be useful for species conservation in the long-term. A desktop study would cost in the order of \$50,000. The more detailed work involving fauna survey would cost millions.

A review of the occurrence of toads on islands in Queensland and the Northern Territory and the mechanism for their arrival on these islands

This project would try to document all of the occurrences of toads on islands in Australia. However, this will not be known for many uninhabited islands in Queensland so higher costs would be involved if the project covered travel to islands to check for the occurrence rather than just checking with as many people who are familiar with islands as possible. Information on the time of arrival of toads and the mechanism for their arrival would be solicited.

Cost: A project that involved contacting many people who could potentially provide information on the occurrence of toads on islands would cost around \$10,000. A project that involved physically checking many of the islands where there was no information on whether toads occurred or not would cost \$200,000+ depending on how thoroughly this was documented.

Eradication of a cane toad population from an island

Unlike a mainland situation, if eradication of cane toads can be achieved on an island then the area is likely to remain free of toads. This will especially be true for islands where the toad population established through colonisation by “hitchhikers” rather than through a flooding event. Work could be undertaken to assess the characteristics of islands relevant to the ease of eradication (e.g. area, degree of complexity of topography, number and permanence of water sources, presence of a community to assist) where toads are present as a result of hitchhiking.

Cost: \$350,000 over three years.

3.6 IDENTIFICATION OF HIGH PRIORITY SITES FOR EXCLUSION OR CONTROL OF CANE TOADS

Robert Taylor

Given that broad scale long-term control of cane toads is not presently an option, control responses will be limited to local control for the foreseeable future. There are four major considerations that will determine where and how this response is undertaken:

- the potential for success in eliminating, reducing or excluding cane toads
- cost
- availability of labour (particularly the potential for community involvement)
- the degree to which the impact on biodiversity can be reduced.

To assess this last consideration requires a knowledge of what species are most impacted by the cane toad and their distribution and habitat requirements. A knowledge of the viable population size of a species may also be required if an exclusion fencing option is considered where a population may be isolated from other populations of the same species. It will also be necessary to know the extent to which cane toads need to be reduced or excluded to achieve the protection of biodiversity outcome sought. This then needs to be combined with the other factors to determine a course of action.

Our knowledge of what species are impacted is rapidly developing and should be increased considerably with the arrival of cane toads at Fog Dam and the research being conducted there by researchers from the University of Sydney (see Table 2.5). An optimal strategy would be to pick sites where many of the impacted species occurred. For example, a small wetland with a rocky area beside it with an adjoining area of savanna could potentially contain species of impacted frog, snake, goanna and quoll. Other sites may need to focus on protecting only a single species. For example, species of snails that are highly restricted and typically associated with limestone outcrops or moist areas such as small pockets of monsoon forest or even single fig trees (Solem and McKenzie 1991; Wilson 2002 a,b).

There may be areas where toads are less prevalent or easier to control and thus where the chances of protecting an impacted species are greater. For example with northern quolls, as they prefer rocky country that often occurs on hills, there may be areas of optimum habitat for this species where no free water persists in the dry season and where no pools of water form in the wet season. Such areas may need to be reinvaded each wet by new colonising cane toads. It would be easier to keep numbers down or cane toads excluded from such areas than in situations where a breeding population is present.

The northern quoll appears to have survived or even recolonised a limited number of areas within the distribution of cane toads in Queensland (A. Krockenberger pers. comm., section 2). Those areas where they have survived may offer some insights into areas where cane toad control or exclusion may be easiest. For example if the quolls have persisted in dry hillsides with no free water that are a long distance from sites where cane toads can breed then situations similar to this could be searched for to undertake control or exclusion in other places.

Recommendations

Several projects are required to implement the suggestions given above.

Examination of sites where quolls have persisted within the range of the toad
See section 2.5.

Identification of sites where highly restricted invertebrates occur that may be adversely impacted by toads

Nature conservation agencies would have information on known locations of some highly restricted species. As a precautionary measure some sites for each species should be protected, probably with exclusion fencing. Studies could optionally be undertaken of the value of this fencing by comparing populations of invertebrates in and outside of such enclosures, preferably prior to and after colonisation by toads.

Cost: Assessment of the efficacy of fencing and hence the impact of the cane toads would be of the order of \$350,000 if sampling both pre and post colonisation at multiple locations for multiple species was undertaken.

Identification of sites where occurrence of impacted species is high and where toad control is feasible and practical

A project to identify where high numbers of impacted species occur could be undertaken using data in State and Territory fauna atlas databases in combination with vegetation maps and other GIS layers useful for predicting the occurrence of impacted species. This would then need to be combined with an examination of what control methods were able to be used in each situation, the availability of personnel (government and community) and funds to undertake control.

Cost: ~ \$350,000 over 3 years for the identification of sites for a region, depending on the availability of data and knowledge of the requirements of impacted species.

Examination of level of population reduction required for cane toads to achieve biodiversity outcomes

In cases where control, rather than exclusion, will be undertaken it is important to determine what level of population reduction is required to achieve biodiversity outcomes. This may differ for different highly impacted species. It could be the case that even low densities of toads would be sufficient to lead to local extinction of some susceptible species.

If undertaken thoroughly this would require cane toads to be controlled to differing densities (including elimination) and the response of the targeted susceptible species assessed. This could require species' reintroductions if the species at risk have been eliminated from the area. However the work could also be undertaken in an area as the cane toad invaded. This version of the project would examine the extent to which toads had to be excluded to maintain populations of impacted species. Is total exclusion necessary or can some "leakage" through a control barrier occur and be mopped up later?
Cost: \$350,000 over 3 years not including the costs of control.

3.7 CONTROL VIA LIMITING RESOURCES

Robert Taylor and Ross Alford

The numbers in a population are sometimes limited by the amount of one particular resource. For example, the amount of food available or the number of shelters available at physically demanding times of the year might limit numbers. In population control of pests, such limiting resources are often referred to as the “Achilles’ heel” of the species. In other words these are weaknesses that can be exploited to effect population control. If access to these limiting resources can be controlled then population numbers can be reduced. Does the cane toad have an Achilles’ heel?

Cane toads are relatively poorly adapted to monsoon climates where there is no rain for a significant part of the year. They have no special mechanisms for conserving water or surviving dry periods and their skin is very permeable to water. Cane toads lose water continuously at the same rate as an open dish of water with the same surface area (Schwarzkopf and Alford 1996). Cane toads do not drink, but take up water through their permeable skin on their lower surface. They do not hibernate or aestivate during the dry season, and because of their continual need for water, they are forced to remain in or near moist habitats during dry periods (Cohen and Alford 1996). Thus the population is likely to be concentrated around water sources in the dry. If access to water by toads during the dry season can be prevented, a high mortality is likely to result. Zug and Zug (1979) considered that desiccation plays an important role in mortality in seasonal tropical regions.

It should be possible to greatly reduce toad populations in areas where water sources are limited. In such areas, two control methods may be applicable. Firstly, intensive trapping could be undertaken around the water source. Secondly, exclusion fencing could be used to prevent access by cane toads to the source of moisture. However, due to the high reproductive rate of cane toads (Lever 2001) numbers can build up quickly even if only a few adults survive. This approach is also only feasible in highly seasonal environments. It will not be of use in areas where rain is relatively evenly spread over the year.

Breeding habitat may also potentially be limiting. Cane toads need water sources that will be present for about a month to allow the eggs to hatch and the tadpoles to metamorphose into juvenile toads. If an area has only limited sources of free water, toads may be able to be prevented from breeding by exclusion fences or intensive checking for eggs and removing any that are laid. An example of the use of this technique as part of a planned eradication on an island in Fiji is presented in section 5.5.

Recommendations

To test whether control at water sources is feasible and will reduce the population enough to prevent a bounce back in the next wet season, a search is required to find situations where the availability of water is restricted. Ideally this would be a single water source supplying moisture to toads that would be present in a much larger geographic area in the wet. Testing of fencing and trapping of these areas would then be needed to see to what

extent population control could be achieved and whether a bounce back of the population occurred.

Cost: \$180,000 over 2 years.

4. LONG-TERM AND/OR WIDESPREAD THREAT ABATEMENT

4.1 SEARCH FOR *BUFO*-SPECIFIC PATHOGENS

Tony Robinson, Hamish McCallum and Ross Alford

There is no doubt that the discovery of a pathogen capable of acting as a control agent would be ideal for controlling cane toads as it would likely be self disseminating and thus impose no cost once released. This is the major advantage of self disseminating biocontrol agents over non-disseminating agents and toxins. However, the likelihood of finding such an agent is low. Some background on the history of the search for biological control agents in cane toads and on the discovery of biocontrol agents for vertebrates generally is useful to place this strategy into context and to underline the difficulty of the approach.

History of cane toad biocontrol research

Searches for biocontrol agents for cane toads have been undertaken on a number of occasions. In early 1986, the State and Federal conservation agencies' ministerial council of the time, CONCOM, commissioned research at James Cook University to investigate the population ecology and diseases of the cane toad in Australia with the view to developing control strategies. Approximately \$400,000 was committed over three years divided equally between New South Wales, Queensland, Western Australia, the Northern Territory and the Commonwealth. The disease component of the study was aimed at identifying a biocontrol agent and had three parts:

- (1) compilation of a comprehensive review of all diseases recorded in the cane toad worldwide
- (2) a survey of diseases and parasites in Australian anurans including detailed necropsies of cane toads from northern and eastern Australia
- (3) the isolation and identification of infective agents and assessment of their pathogenicity.

The review of the literature for possible biocontrol agents was comprehensive and could find no serious candidate for immediate use as a biocontrol agent. In addition, a number of macro-parasites and infectious micro-organisms were found in cane toads during the study, both in Australia and in Costa Rica but none were considered suitable as biocontrol agents.

Following a review of this project in March 1990 it was recommended that the search for a potential biocontrol agent be extended to Latin America and include species of *Bufo* other than *Bufo marinus*. It was further recommended that the biology of a ranavirus, *Bohle iridovirus* (BIV), that had been isolated during the study from metamorphs of a native ornate burrowing frog be further investigated and that virologists in other Australian institutions be also asked to take part in future investigations.

In March 1990, shortly after the review, \$1.25M over three years was given to CSIRO to revisit the search for a biocontrol agent and conduct ecological studies on *Bufo marinus* in Latin America. This was to be matched with a further \$300,000 from CONCOM. After a call for projects, \$510,000 was allocated to a virology project which was established in Caracas, Venezuela at the Instituto Venezolano de Investigaciones Cientificas (IVIC) to search for cane toad pathogens. A Phase 2 proposal from James Cook University that would have (1) undertaken epidemiology, pathogenicity and host specificity of BIV, Frog Virus 3 and Frog Erythrocytic Virus, (2) investigated wasting syndrome and (3) described and catalogued diseases found in cane toad including those found on specimens from Papua New Guinea, Fiji and Hawaii, was not supported at this time.

The virological studies in Venezuela revealed a number of putative iridoviruses from sick toads as well as a range of bacterial isolates. The bacterial isolates included a number of salmonella species, none of which were considered useful as biocontrol agents.

In 1993 a further \$2M was provided to CSIRO to continue ecological studies and to further characterise the viruses isolated in Venezuela. The six isolates from IVIC were imported into the Australian Animal Health Laboratory (AAHL) and were all confirmed as iridoviruses. Animal transmission studies also confirmed that, typical of iridoviruses, they were not specific for the cane toad. They infected and caused death in native frogs. It was clear that they could not be used, unmodified, as biocontrol agents. During this project, a watching brief was maintained for reports of unusual mortality events in *Bufo marinus* and related species overseas and a number of international amphibian experts were consulted in an attempt to uncover previously undiscovered micro-organisms that might have potential as biocontrol agents. No positive leads were forthcoming.

Given this history, a further search for naturally occurring pathogens specific for the cane toad was considered unlikely to be productive. This is one of the reasons why CSIRO elected to investigate a GMO strategy which, although long-term and also carrying with it a risk of failure, was considered more likely to succeed than finding a naturally occurring host-specific pathogen.

Nevertheless, there is the possibility that a pathogen specific to the family *Bufonidae* (of which the cane toad is the only member found in Australia) might be an appropriate control agent.

Success with other vertebrate biocontrols

To put the search for cane toad pathogens further into context it is instructive to review the success or otherwise of searches for pathogens for use as biocontrol agents for other vertebrate pest species. The only examples of species-specific, or limited host-range, pathogens being found and used successfully as biocontrol agents for vertebrate pests on a continental scale are myxoma virus (restricted to a few species of lagomorphs) and rabbit haemorrhagic disease (RHD) virus (restricted to the European rabbit, *Oryctolagus cuniculus*), both for use in pest rabbit control. On a much smaller scale, feline panleucopaenia virus was used as a component of the successful campaign to exterminate cats on subantarctic Marion island but as this virus is endemic in most cat populations worldwide its general value as a biocontrol agent for cats is very limited.

Both myxomatosis and RHD were discovered serendipitously rather than as the result of a deliberate biocontrol-agent hunting exercise. Myxomatosis was discovered in the 1890's in Uruguay as a result of susceptible domestic European rabbits being introduced into a newly established Institute of Hygiene in that country and rabbit haemorrhagic disease arose, apparently spontaneously, in 1988 in farmed rabbits in China probably as a result of a mutation(s) in a benign form of the virus. In the case of myxomatosis it took thirty years to characterise the infectious agent and its biology. With RHDV it took ten years. Both are still the subject of research into their efficacy and biology. A major reason why both pathogens initially caused such high mortality in rabbits is that they were pathogens novel to rabbits, and coevolutionary attenuation in virulence had not occurred.

Searches have been conducted for species-specific biocontrol agents for other pest species, without success. A long history of searching for biocontrol-agents of Australian pest species such as red foxes, wild dogs, and cats have been singularly unsuccessful as has the search for a pathogen of possums in New Zealand.

A strategy for the future

If we were to head down this route again for cane toads, how would one modify the approach taken in the earlier projects to increase the chance of finding something useful? If we take a lesson from the discovery of myxomatosis and rabbit haemorrhagic disease we would need to rely on detecting a disease in *Bufo marinus* in areas where they had just been introduced, either in the wild or in captivity, or the sudden appearance of a high mortality event in areas where toads had been for some time. Alternatively, given the myxomatosis experience, a potential strategy would be to screen other *Bufo* spp. particularly in areas where *Bufo marinus* is **not** present for micro-organisms with the potential for biocontrol of *Bufo marinus*. By analogy with the myxomatosis experience, such micro organisms would not necessarily produce large scale mortality in their natural hosts.

If we were to rely on unexplained unusual mortality/morbidity events in *Bufo marinus* or even other *Bufo* spp., how would one go about identifying the cause? Such events could easily be caused by agents other than infectious micro-organisms. Early on in the investigation one would need to eliminate toxins and other environmental factors as a cause. If the event did appear to be caused by an infectious agent we would then need to decide on how we would isolate the causal agent. There are a number of strategies that could be used but the one that we would favour would be the direct inoculation of tissue extracts from sick toads into healthy toads in a controlled environment in an attempt to reproduce directly the pathology. Other strategies such as direct isolation of an agent in cell culture is a possibility but would restrict the search to cytopathic agents and would favour fast growing agents over slower growing ones and may detect organisms that were simply adventitious. Cell culture isolation would be a second step in our view. If an infectious agent were discovered that caused morbidity/mortality in toads, it would be prudent to move rapidly to the inoculation of a number of native frog species to eliminate at an early stage agents that were not species-specific.

If the decision were made to re-establish the search for a natural biocontrol agent we would suggest a two stage approach:

Stage 1 (watching brief)

1. Update the literature review on potential pathogens of cane toads to ensure there is nothing that has been missed.
2. Conduct a literature review and survey of amphibian disease laboratories to identify any bufonid specific pathogens.
3. Make a list of countries and areas where cane toads exist (use information in Lever 2001).
4. Contact ecologists/pathologists/amphibian experts in those countries asking if they would keep a look out for any evidence of unexplained cane toad or other *Bufo* species sickness or deaths (tadpoles and adults), either in the field or in captive colonies, that could be attributable to an infectious microbial agent.
5. Maintain links with researchers investigating the phenomenon of amphibian population declines. This is clearly a field that may lead to promising clues regarding causes of large-scale mortality in amphibians, and a much greater understanding of host-pathogen biology in amphibian host systems.

Cost: \$37,000 for one year with a lesser cost in subsequent years to maintain links.

Stage 2 (active follow-up)

6. Follow-up on any leads and establish a means of getting samples i.e. rely on locals to collect samples or send Australian staff to do the collecting, and shipping (see also 5).
7. Send samples back to the Australian Animal Health Laboratory. We could possibly process samples at a local lab but this would probably be too expensive and could be unreliable. (The idea of using overseas laboratories to undertake this analysis could be considered at the time, depending on the facilities available, but our view is that it would best be done in Australia).
8. Inoculate cane toad tadpoles and adults with tissue extracts.
9. For materials containing agents that gave a pathogenic effect, inoculate sick-toad material into a number of species of native frogs (tadpoles and adults).
10. If there were no apparent immediate effects in native frogs, expand the project into a full scale species-specificity project.
11. Characterise the agent (pursued in parallel with 8).

Cost: \$242,000/year. Three years in first instance with continuation beyond 3 years depending on progress.

Stage 3 (registration)

12. If the pathogen was successful then registration with the Australian Pesticides & Veterinary Medicines Authority (APVMA) would be required before it could be released.

Cost: \$1 M+.

4.2 CONTROL OF CANE TOADS BY THE STERILE MALE APPROACH

Michael Mahony and John Clulow

Background

The concept of population control by release of Sterile Males relies on the basic principle that underpins any form of biological control – the control method must be specific to the organism that is targeted. A feature that is specific to any organism is that males and females mate only with members of their own species. Thus if there is a means by which the majority of males can be rendered sterile then most matings will fail to produce offspring.

Specificity is the greatest strength of this approach; it means there is no need to test whether the mechanism affects native frogs or other native organisms. Unlike a released disease (either natural or genetically engineered) or poison that must be tested against a wide variety of native animals to ensure they are safe, the sterile male approach can be adopted with security. This in turn saves a considerable amount of time and cost in the deployment of the biological control agent. There is the added advantage of biosecurity, because there is no opportunity for a disease to escape or be transported from Australia.

Other methods of biocontrol allied to the sterile male approach are the sterile offspring and daughterless male approaches. The first relies on a means to produce fertile males whose offspring are infertile such that they would provide a means of driving down the size of a population. The second would be the release of males who produce only males (so called daughterless male approach). The significant advantage of this latter approach would be that the effect could extend for several generations, and is to some degree disseminating.

The release of Sterile Males to control populations has been most effectively applied to insects (e.g. Screw Worm Fly). The general approach is to swamp a population with sterile males so that the eggs of females are not fertilized.

This method works most effectively in organisms that are not highly mobile, where reproduction is restricted to single pair copulation, where reproductive output is high, and the life cycle relatively short. The method has not been applied to vertebrate pests because they often do not meet these criteria. However, the cane toad meets several of these criteria, and in these features is more akin to the insect models than other vertebrates. The cane toad has a high reproductive output (up to 40,000 eggs per mating), reproduction for the female, as far as is known, is restricted to one single partner per mating, and perhaps only one mating per season, and adults are relatively sedentary around established breeding sites. A male may achieve several matings in a season.

It is postulated that an effective way to control a highly fecund species, such as the cane toad, would be to reduce their reproductive potential. Our objective is to investigate genetic methods to produce sterile male cane toads that 1) have libidos equal to or greater than normal males, and 2) males that confer sterility on their offspring.

In the early 1990s we investigated this approach and identified a number of methods where sterility with high libido could possibly be achieved by altering the chromosomal make up

of toads. Similar methods have been successfully applied in aquaculture (fish and shell fish) where triploidy is used along with sex reversal to produce all female stock. A significant feature of the aquaculture success is that it shows the methods can be geared up to large-scale production that would be necessary in a control program. Our studies showed that it is possible to create triploid toads whose growth and development through metamorphosis was normal.

Our studies did not address whether the population dynamics of the toad are amenable to the sterile male approach. We adopted the position that it is first necessary to determine whether sterile males can be produced, before the question of population dynamics could be investigated with experimental trials.

Advantages of this approach

- It does not involve introducing viral pathogens or the testing of specificities of any pathogen (i.e. it does not involve introducing a disease to kill toads or the need to test a large array of native animals to ascertain whether the disease is harmless to them)
- It does not require a vector or the research effort necessary to find an appropriate vector (i.e. there is no need to spread an introduced disease)
- It does not involve genetically engineered pathogens
- There are no national or international biosecurity issues associated with the deployment of sterile males or males that confer sterility on their offspring
- It does not involve the use of toxins or poisons or the testing of specificities of any poison (i.e. it does not involve the need to test a large array of native animals to ascertain whether a poison is harmless to them)
- The method of producing triploids does not require any harmful reagents
- It is humane, safe and cost effective.

Disadvantages of this approach

- The greatest problem for this approach is that its effectiveness is related to the density of sterile animals needed to reduce and eventually remove populations. Competition is intense in cane toad populations, particularly during the larval stage, such that a very small percentage of individuals survive to metamorphose and then reach adulthood. If the reproductive output of nine out of ten females was neutralised by sterile males the one female to achieve a normal mating could replace the reproductive output of all nine because her offspring would face reduced competition. It should be clear that this same limitation applies to all non-disseminating mechanisms of control whether it is a poison, traps, or non-disseminating viral GMO
- Large numbers of sterile animals would be released into nature. These would add to the impacts of cane toads on the environment in the short-term.

How would a Sterile Male release work?

- Large numbers of tadpoles that grow into sterile males would be released into known breeding ponds. These would grow and develop into sterile males. The animals released would be triploids that grow only into males
- Previous studies have shown that the first cane toad tadpoles in a pond in the breeding

season prey on the eggs and tadpoles of subsequent matings, thus it would be desirable to release 'sterile tadpoles' early in the breeding season

- The release could be in the advancing zone of the toad to act as a buffer or in zones where control was considered highly desirable.

How would a release of males that produces sterile offspring work?

- Large numbers of tadpoles that grow into fertile males that produce sterile offspring would be released into known breeding ponds. The basic approach would be to produce tetraploid males that when mated with wild type females (diploid females) result in offspring that are triploid. Such offspring would be sterile and act in the manner described above
- Previous studies have shown that the first cane toad tadpoles in a pond in the breeding season predate on the eggs and tadpoles of subsequent matings, thus it would be desirable to release 'sterile tadpoles' early in the breeding season
- The release could be in the advancing zone of the toad to act as a buffer or in zones where control was considered highly desirable.

What Research is needed?

Proof of Concept

In 1994-95 we conducted research to determine whether sterile male cane toads with normal libido could be produced. The research objective was to determine whether this could be achieved by producing triploid males that grow normally and have normal testes with respect to the production of male hormones, but which produce abnormal sperm. When triploid males mate with a wild type female (diploid) their sperm are either not capable of fertilizing eggs or development will not proceed.

Triploidy is known to result in sterility in numerous animal groups including amphibians. Triploid individuals have three sets of chromosomes rather than two, and this results in sterility because not all homologous chromosomes can find a pair at pachytene during meiosis I cell division in the testes. The result is abnormal sperm and subsequent sterility. However, the somatic cells of the testes that are responsible for the production of hormones related to libido function normally because homologous chromosome pairing does not occur in mitotic cell division.

To achieve this outcome a number of steps were shown to be possible in the cane toad:

- 1) Can triploid cane toads be produced? We demonstrated that triploid toads can be produced by using the simple method of cooling toad eggs immediately after fertilization. The technology that would be needed to gear up to produce the necessary numbers for a sterile male in a release program is already applied in some sections of the aquaculture industry
- 2) Do triploid toads grow and develop normally? We have grown a small number of triploid toads through the larval stage to beyond metamorphosis and there appears to be no major impediment to the concept at this stage of the life cycle. We have not grown young toads through to adulthood to confirm that this is possible
- 3) Do triploid toads have normal libido? If triploids toads grow to adulthood we would need to assess whether they have normal libido (hormone profiles and microscopic

examination of testes)

- 4) Are triploid adult males sterile? It still needs to be demonstrated that any sperm produced are abnormal. We would predict that no sperm are produced but there is a slight chance that some abnormal sperm would be produced.

Another related matter that would be clarified in these studies and one that offers considerable potential for other means of biological control of toads is elucidating the means of sex determination in the cane toad. For the biocontrol method we propose it is critical that only sterile males are produced. The sex determination mechanism in toads is not known and would require investigation. The experiments required here are readily achievable and we have provided a brief outline in the section on background information of the theoretical possibilities (see below).

Methods for producing triploids

Two methods offer the greatest possibility to obtain large numbers of viable and hormonal competent but sterile triploids:

1) Production of triploids by shock treatment

Step one: Artificial stimulation of gravid females to lay eggs. Achieved by hormonal injection of gonadotrophin.

Step two: *In vitro* fertilisation of eggs with sperm suspensions. Achieved by standard protocols.

Step three: Shock treatment of eggs immediately following fertilisation to prevent the extrusion of the second polar body from the egg. This effectively produces a diploid egg, with the incorporation of the sperm nucleus the zygote will be triploid. Shock treatment usually involves sudden temperature or pressure change. We have successfully used cold shock treatment to achieve rates of > 70% triploidy.

Step four: Investigate growth and development of the triploids.

2) Production of triploids via intermediate tetraploidy.

Step one & two are the same as above.

Step three: Following fertilisation of the eggs, shock or chemical treatment (Colchicine) applied at the time of first cleavage to produce autotetraploid individuals. Success tested by chromosomal analysis. Growth and development of the tetraploids needs to be investigated.

Step four: Cross tetraploids to diploids (*in vitro* fertilisation) to produce triploid offspring. This method has the advantage over the first of resulting in 100% triploid offspring but relies on the production of tetraploid breeding stock.

If tetraploids could be successfully produced the possibility of releasing all male tetraploids becomes a possibility. There are good theoretical reasons to believe that tetraploids could be all male (dependent on the sex determining mechanism of toads). Tetraploid males when mated with wild type diploid females would produce triploid offspring (males and females) all of which would be sterile. Tetraploidy occurs naturally in a small number of fish and amphibians so there is evidence that such animals could be functional in nature.

What we know

Production of triploids by shock treatment

Step one: Artificial stimulation of gravid females to lay eggs. We have developed the necessary protocols in our laboratory with the cane toad.

Hormonal induction of ovulation and *in vitro* fertilisation with testicular spermatozoa are established procedures that have been used for many years with Anurans (Rugh 1962; Hollinger and Corton 1980; Fontdevila *et al.* 1991). Induction of ovulation is a critical event for IVF in Anurans as only oviductal oocytes are capable of fertilisation.

Ovulation in *Xenopus laevis* and the Bufonidae has been achieved by either injection of gravid females with homologous pituitaries (usually 1 to 6 pituitaries, depending on the species, sex and season) or with mammalian gonadotrophin such as HCG (Rugh 1962; Carbada *et al.* 1989; Verhoeff-de Femery and Griffin; Omata 1993). For the Bufonidae (e.g. *Bufo japonicus* and *B. arenarum*) recent IVF work has tended to rely on homologous pituitaries for induction of ovulation (Carbada *et al.* 1989; Omata 1993). At least seven species of the Bufonidae have been successfully ovulated using pituitary extracts (Rugh 1962; Omata 1993).

Step two: *In vitro* fertilisation of eggs with sperm suspensions. We have developed the necessary protocols in our laboratory with the cane toad.

Collection of motile, viable spermatozoa for IVF is generally achieved by the maceration of testes into amphibian Ringer's solution of low osmotic pressures (Hollinger and Corton 1980) in the region of 50-100 mOsm kg⁻¹. Very high fertilisation rates (in the order of 90%) can be obtained in Bufonidae and *Xenopus* with IVF using hormonal induced oocytes and testicular sperm (Hollinger and Corton 1980).

We have established basic IVF as a routine technique with *Bufo marinus* using pituitary extracts for ovulation and testicular sperm. IVF procedures work well with *B. marinus* after initial experimental work to optimise conditions.

Work we have conducted shows that viable and motile testicular sperm from *B. marinus* may be collected at any time of the year (and activated in media of low osmotic pressure). However, mature oocytes are only available from females during the breeding season (August - March). There is a need to further refine our basic IVF procedures for *B. marinus* by attempting to induce ovarian growth and oocyte maturation in non-seasonal females using gonadotrophin and oestradiol treatments (Wallace and Bergink 1974; Wallace 1985; Kwon *et al.* 1991). We also need to investigate other hormonal procedures for the induction of ovulation and testicular sperm release using HCG (Hollinger and Corton 1980; Verhoeff-de Femery and Griffin 1989), progesterone (Wright 1961; Schuetz 1971), and dopamine and adrenalin (Minucci *et al.* 1993), as well as investigating the use of arginine vasotocin (AVT)(=oxytocin) to induce oviposition (La Pointe 1977).

Step three: Shock treatment of eggs immediately following fertilisation to prevent the extrusion of the second polar body from the egg. We have developed the necessary protocols in our laboratory with the cane toad.

This effectively produces a diploid egg, with the incorporation of the sperm nucleus the zygote will be triploid. Shock treatment usually involves sudden temperature or pressure change (see Nishioka and Ueda 1983 and reference therein). We have successfully used cold temperature shock to produce triploid cane toads. This method is not optimal and the use of pressure treatment, as used on a large scale in the aquaculture industry, may be most effective.

Mature triploids have been obtained in numerous urodeles and anurans (see Kashiwagi 1993 for a review). For example in three species of *Hyla* and four species of *Rana*, triploids were obtained by exposing eggs to low temperatures of 0 - 2°C for two hours, 20 minutes after insemination (Nishioka 1972; Nishioka and Ueda 1983; Kawamura 1951a,b; Kawamura *et al.* 1983; Kashiwagi 1993). Standard practice in the production of triploid salmon and trout is to use of hydrostatic pressure for a period of two hours, thirty minutes after artificial fertilisation (Purdom 1983), but heat shock has also been successfully applied (Johnstone 1985; Purdom *et al.* 1985).

Using cold shock on artificially inseminated eggs of *Rana rugosa*, Kashiwagi (1993) produced 82% triploid offspring. The majority of these were raised to sexual maturity. No significant differences were observed between the triploids and control diploids in development and growth rate. All the triploids were male or hermaphrodites, which transformed into males, indicating that in this species the male is the heterogametic sex. IVF using sperm from eleven of these triploid males with eggs (2272) from normal diploid females resulted in 6% forming tadpoles, of which only one reached metamorphosis, i.e., they are effectively sterile. Chromosome counts revealed that the majority of the tadpoles were aneuploid.

Female heterogamety has been reported in two species of the genus *Bufo* (*B. bufo* and *B. japonicus*) (Ponse 1942; Muto 1952). Muto (1952) found that the majority of triploids raised from cold-treated or heat-treated eggs were females. It is highly probably that in these species triploid females are ZZW or ZWW, and males ZZZ. If this is also the case in *B. marinus* it will be necessary to produce a stock of sex-reversed males (genetically male ZZ, but female phenotype). This can be achieved by surgical removal of the testes in the sexually mature male toad. The Bidder's organ, which is located in the anterior part of the testes is the incompletely involuted cortex of the embryonic gonad. It has been compared to the rudimentary ovary. Furthermore, the Mullerian duct has been conserved. When the testis is removed, the Bidder's organ develops into a functional ovary and the Mullerian duct enlarges. Injection with female hormones would be expected to enhance the success of such animals.

Step four: Monitoring growth and development of the triploids. This step has not been conducted in our laboratory.

Growth would need to be compared with the developmental stages of control diploids. Chromosome counts could be made on small sections of epithelium taken from the tail. The extracts are soaked in a hypotonic colchicine solution for three hours and then squashed in acetic acid and orcein stain. Measurements of erythrocytes and specific staining of the nucleolus organiser region in the nuclei can be used to determine the

ploidy of individuals (Mahony and Robinson 1981). Histology would follow standard procedures.

Production of triploids via intermediate tetraploidy

Basic research is required to refine this method and prove that it possible with cane toads.

Step one & two are the same as above.

Step three: Following fertilisation of the eggs, shock treatment is applied at the time of first cleavage to produce autotetraploid individuals. Another approach to obtain tetraploids is the use of mitotic arresters such as colchicine at the time of first cleavage. Success is tested by chromosomal analysis. Growth and development of the tetraploids would be examined.

Step four: Tetraploids crossed to diploid (*in vitro* fertilisation) will produce triploid offspring. Similar issues relating to sex determination, so that only males are released, would need to be considered, as outlined above for the triploid scenario.

Is it possible to breed and produce large number of sterile male cane toads for release?

It is important to be aware that triploid salmon and trout are produced in the tens of thousands in aquaculture for release into natural waters. There are several commercial and environmental reasons that hatcheries produce these animals. The important take home message is that large numbers of sterile males can be produced on a routine basis because it is already done in commercial hatcheries.

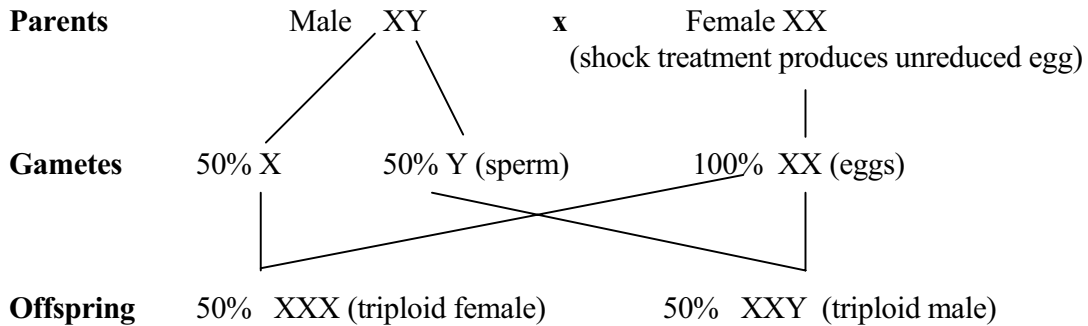
Background information

What is the sex determining mechanism of cane toads?

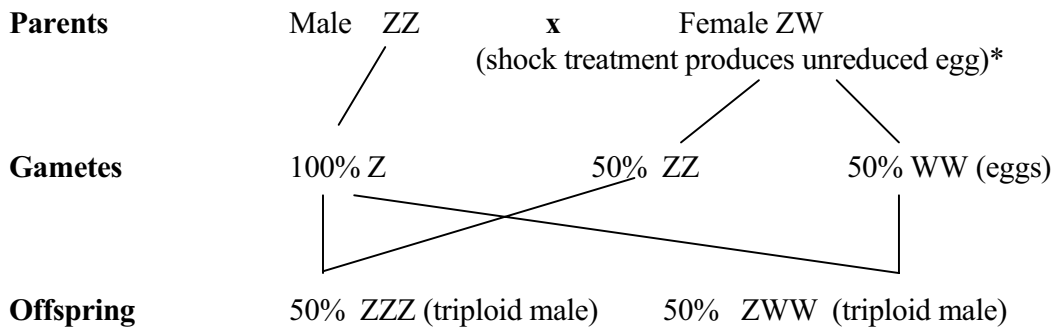
Heteromorphic sex chromosomes do not occur in *Bufo marinus* (Schmid 1978). In *Bufo bufo* and *B. japonicus* the female is known to be the heterogametic sex (ZW) (Ponse 1942; Muto 1952). If this is also the case in *B. marinus* it is predicted that half the triploids produced from diploid (ZW) females will be female. Although it is possible that one dose of the male determining gene (on the Z) will result in all male triploid offspring (see figure below). If this is the case then all offspring will be sterile males. If this is not the case it may be desirable to produce sex-reversed females that are genetically ZZ, which when fertilised by a normal sperm (Z) will result in all male triploid offspring (ZZZ) (see Figures 4.1 – 4.3 below). This leads to the possibility of producing all male triploids by sex reversal of the homogametic sex, thus avoiding any wastage of animals and the need to sex triploids. If the homogametic sex is the female, then treatment with testosterone during development should result in a male which is genetically female. If, however, the homogametic sex is the male, surgical removal of the testes will enable the bidders organ to develop and a female which is genetically male will be the result (Schmid *et al.* 1991).

Figure 4.1. Basic schematic of the production of triploid sterile males based on chromosome manipulation

a. Production of triploid males if the Male is the heterogametic sex

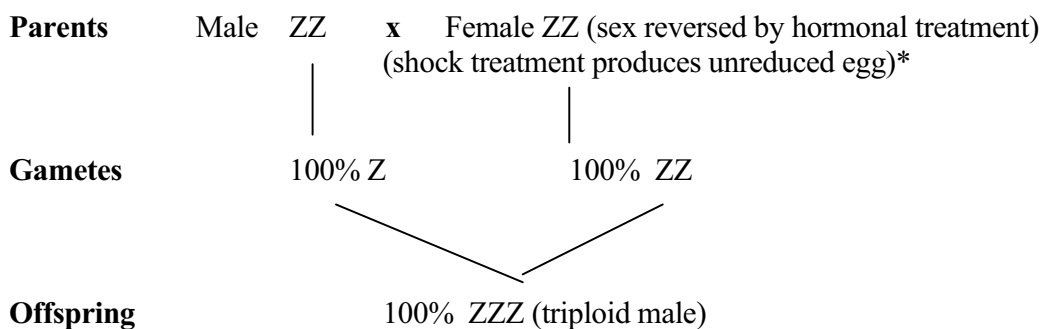


b. Production of triploid males if the Female is the heterogametic sex



All offspring would be triploid males

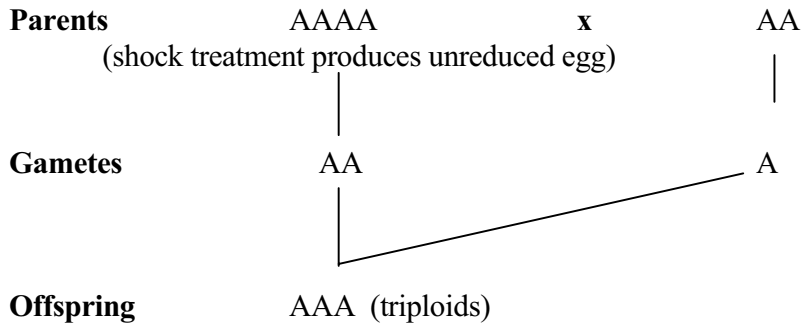
c. Production of triploid males using sex reversed males, if the female is the heterogametic sex



All offspring would be triploid males

*(this assumes the second polar body is retained in the shock treatment. It is also possible to prevent first cleavage of the zygote and produce polyploid individuals).

d. Release of tetraploid individuals.



Recommendation

Develop a sterile male approach to cane toad control. This would be undertaken in three stages:

Stage 1. Production of triploid individuals (sterile male approach). Production of tetraploid individuals (sterile offspring approach). Investigate the sex determining system of cane toads

Stage 2. Determine viability and libido of triploid and tetraploid individuals, and investigate gonadal development in the polyploid constructs

Stage 3. Field-testing of triploid sterile males (enclosure studies). Field-testing of tetraploid males.

Cost: \$250,000/year for 3 years in the first instance to provide proof of concept. If the concept is successful implementation would take approximately \$100,000/year for at least ten years.

4.3 CANE TOAD SPECIFIC TOXINS

Tony Robinson and Ross Alford

There are advantages and disadvantages of a toxin approach. One advantage is that it is non-disseminating and provided there was no persistence in the environment its use could be tightly controlled. If species-specificity can be obtained then the chemical could be dispersed widely in water bodies or in baits. The main disadvantages of toxins are that the cost of production is often a limiting factor and their deployment is labour intensive. An added problem is introduced if species-specificity cannot be obtained.

Toxins are currently the main means of controlling vertebrate pests

Nevertheless, the use of toxins is currently the main means of controlling most vertebrate pest species. Generally, however, these toxins are not species-specific. For mammalian pests the list is a long one but the main ones in use are 1080 (sodium fluoracetate) for rabbits, foxes and dogs, cyanide for foxes and dogs, pindone for rabbits, phostoxin (phosgene) for rabbits, zinc phosphide for mice, and various anticoagulants for mice and pigs. Strategies to limit the non-target impacts have been developed for some of them. For the use of 1080 for foxes in eastern Australia, for example, baits are buried to reduce the opportunity for uptake by native species. Unlike most native species, foxes, and dogs

to some extent, will dig these baits up. Another example is the use of free-feeding of oats or carrots on disturbed ground for rabbits prior to the feeding of oats or carrots containing 1080 or Pindone. This strategy tends to attract rabbits in to the poison site and allows a measure of uptake to be calculated prior to the poisoning so that all the poison bait is taken in one night. Another, more recent, strategy is to combine the toxin with compounds that specifically modify the metabolism of the target animal such that smaller doses of toxin can be used.

Few toxins are available for control of amphibians

There are few examples of using toxins to control amphibians and those that are used are non-specific. The skin of frogs is used as an organ for water exchange and is highly permeable. Many compounds can be taken up directly through the skin of amphibians. In Hawaii, the frogs *Eleutherodactylus coqui* and *E. planirostris* have been introduced and create a noise nuisance in built up areas and compete with native species for insect food. Authorities use a 16% aqueous citric acid solution to spray on frogs in shrubs around affected areas. This kills the frogs but leaves the vegetation intact. Phenolic compounds are readily absorbed through the skin of amphibians and Dettol has been used by members of the public to poison toads.

These non-specific compounds are highly effective and, provided they are acceptable under animal welfare regulations, can be used to target individual animals. They are however useless in baits or as additives to water bodies where there is little control over the species that would take them up. What is needed is a cane toad-specific or at least a *Bufo*-specific toxin which could be applied in a bait or to water bodies where cane toad adults or tadpoles are in the presence of valued native species. An enhancement would be their use with attractants where toads could be selectively targeted.

A toxin for cane toads

The discovery of such a toxin could be approached in a number of ways. One would be to screen a range of compounds known to be toxic to vertebrates, against toads and frogs and see if any have differential effects. This is an open-ended and costly approach. Those that were demonstrably more toxic in toads than frogs could be developed to enhance the effect and provide some degree of safety for valued native species. Another approach would be to identify physiological differences between toads and frogs and see if there are any metabolic pathways, such as endocrine systems, that could be targeted with known compounds. Additionally, there may be receptors in toads absent or different enough in frogs to be able to synthesise toxic ligands specific for toads.

Olfactory attractants to enhance toxin uptake

Another possibility is targeted delivery of toxins; for example if we do succeed in finding olfactory attractants, it may be possible to design delivery systems that cause toads to apply contact toxins to themselves, for example by entering amplexus with a bait containing a contact toxin.

Recommendation

Investigate the development of a toxin as specific to cane toads as possible.

Cost: \$350,000/year for 3 years in the first instance with continuation beyond 3 years depending on progress.

4.4 DISSEMINATING AND NON-DISSEMINATING GMOs

Tony Robinson

Because of the difficulties encountered in identifying naturally occurring biocontrol agents for cane toads and the history of failure in discovering natural biocontrol agents for other species (with the curious exception of two agents being found for use in the European rabbit *Oryctolagus cuniculus*) CSIRO has been pursuing the idea of constructing such an agent using molecular biological techniques. This project has been funded at \$500,000 a year over the last three years by the Australian Department of Environment and Heritage from the Natural Heritage Trust with matching funding from CSIRO.

The concept

The concept is based on an observation made in 1965 by US workers where they showed that if bullfrog tadpoles were inoculated with adult haemoglobin, they generated an immune response and either died as they went through metamorphosis or survived and retained larval haemoglobin rather than expressing adult haemoglobin. It is now known that there are a range of proteins that are not expressed in the tadpole stage and only appear during or after metamorphosis. Many of these proteins are essential for adult survival and we reasoned that if you could immunise tadpoles against them, or interfere with them in some other way, it could be the basis of a biocontrol agent.

Progress to date with CSIRO's research

We have repeated the 1965 US work using cane toad tadpoles and in-vitro expressed cane toad β -haemoglobin and have confirmed that the same effect occurs in cane toads except that all our tadpoles survived. They all however retained their larval haemoglobin and the expression of adult haemoglobin was reduced significantly. We have also identified a number of genes in cane toads that are expressed in adults and not in tadpoles and are currently working our way through these genes in an attempt to see if they can compromise metamorphosis.

An ideal way to deliver an immunising dose of a protein to a tadpole would be via a vector virus. It has been shown in a number of viral systems that viruses can deliver antigens to target animals. The advantage with the amphibian system is that those antigens would act very much like a vaccine as there would be no immunological tolerance to the antigen in the tadpole. Nevertheless, there is still a requirement for that virus to be species-specific or at least its affect to be species-specific and so we have devised a number of approaches to address this problem.

We have chosen to use an Australian ranavirus as a vector in the first instance to prove the concept of viral delivery. First we needed to attenuate that virus so that it did not kill tadpoles and that has been achieved for the purposes of the experiment. We have also shown that it is possible to engineer the virus to contain and express foreign genes and we are currently engineering the virus to contain adult cane toad β -haemoglobin. We are expecting that such a virus will be capable of immunising tadpoles against adult haemoglobin.

The need for species-specificity

Ideally, we would like to be able to synthesise a virus that was disseminating as this would fulfill the desire to have on hand a cheap and effective biocontrol agent. To do this we need to ensure we have a species-specific agent. The ranavirus we are currently working with may not allow us to do that. It is not species-specific and needs to be attenuated to both allow us to test antigens in toads but also, if it was to be deployed in the field, to reduce its potential impact on other species. In general, attenuation compromises transmission and reduces the efficacy of the agent. Preliminary experiments however indicate that the engineered vector does not cause death in tadpoles and adults and furthermore adults are protected from subsequent infection with wildtype virus. These results suggest that the current engineered virus is infectious and replicates within its host.

There are two directions that can be taken at this point. We could attenuate or engineer (e.g. insert 'suicide' genes) the ranavirus such that it is totally non-disseminating and rely on species-specificity being obtained through the antigen. We are currently screening our antigens and looking for differences between cane toad and native frog antigens such that we could use only those components of the antigen that are different. We are also looking at devising a RNA interference approach to target the regions in the mRNAs of these antigens that are toad specific. Significant progress has been made in constructing a short interfering RNA (siRNA).

Potential alternative vectors for a GMO biocontrol approach

One benefit of using a ubiquitous virus is that it would effectively vaccinate all susceptible animals against hematopoietic necrosis. However, if this is not acceptable to the public, a second approach is to search for other viruses of cane toads that are capable of being engineered and which do not necessarily kill the toad but which would be species-specific and transmissible. The obvious candidates are the large DNA viruses such as the herpesviruses and adenoviruses. Representatives of both these virus families in other species have been found to be host-specific or have a very limited host-range, particularly the adenoviruses. Examples of both virus groups have been found in the leopard frog, *Rana pipiens*. A targeted search would be needed to see if similar viruses can be found in toads. This would not require the identification of sick animals nor require that the search necessarily be done overseas. The *Rana pipiens* viruses have been completely sequenced and the sequences are available from the publicly accessible DNA databases. This means that a search for such viruses could be conducted using PCR with degenerate primers (high G+C and low G+C) based on a relatively conserved gene such as the DNA polymerase. Another virus family that has been used to create recombinant viruses is the poxvirus family but there are no amphibian isolates available.

Nevertheless, a PCR search could include poxviruses using degenerate primers based on a conserved gene in this family. A similar approach could be used for *Bufo* spp. other than *B. marinus* to identify *Bufo* specific agents that upon cross-infection will cause a lethal disease in cane toads (refer above).

A major external review of the CSIRO project took place in December 2002 and a workshop was held in February 2004 to assess the GM biocontrol approach and to make recommendations for future directions. The ideas expressed above are consistent with the recommendations from those reviews.

Recommendation

The current CSIRO project investigating disseminating/Non-disseminating GMOs be continued for a further 7 years with annual reviews.

Cost: ~\$550,000/year.

4.5 MODELS TO EXPLORE THE ECOLOGICAL AND EVOLUTIONARY FEASIBILITY OF POTENTIAL BIOLOGICAL CONTROL STRATEGIES.

Hamish McCallum

Whichever of the potential control strategies listed above are investigated, an important aspect of exploring their feasibility is to use mathematical models to explore their likely consequences and effectiveness, both in the relatively short-term (ecological time scale) and in the longer term (evolutionary time scale).

The steps necessary in such a modelling program are as follows:

Problem identification

- Identify the control options to be modelled
- Identify questions models must answer
- Identify criteria for evaluating control options.

Model construction

- Construct frameworks for each control option
- Undertake sensitivity analysis and determine data requirements (iterations/refinement: discard inappropriate options).

Data collection and model parameterisation

- Data collation/collection
- Data analysis and parameter estimation.

Model analysis

- Generation of recommendations: i) feasibility; ii) preconditions for success or failure.

These steps will be necessary for any one of the above control strategies, and will need to be repeated iteratively with successively more detailed models as data become available.

The appropriate modelling methodology would depend both on the question being addressed and the stage in the iterative process, but methods would involve deterministic differential equations, stochastic models and spatially-explicit individual based models.

These latter approaches are more “realistic” but at the cost of lower ability to generalise and substantial data requirements. For all but the simplest modelling approaches, the models must be linked to an appropriate program of experimental and field work to estimate the necessary parameters.

Some modelling questions specific to the above research program are listed below. Note that the answers to most of these questions are likely to depend on the environmental conditions in which the toads live. Models are likely to need to be adapted to a number of different environmental conditions:

Bufo specific pathogens

If such an agent is located:

- Given its known pathogenicity and transmissibility to cane toads, what is its likely impact on populations, its likely rate of spread, and in what density cane toad populations might it become established?
- Is it likely to persist in the environment, or require continual reintroduction?

Sterile males and sex of offspring

- Are these approaches feasible?
- How many sterile males would need to be released?
- What level of population suppression is achievable, and over what timescale?

Cane toad specific toxins and attractants

- What is the likely impact of these agents on toad populations in various environments?
- What is the optimal time for use to achieve maximum control?
- Using spatial models, what is the appropriate spatial scale on which control is feasible, and at what spacing (and in what pattern) should bait stations be distributed?
- Again using spatial models, over what spatial scale will attractants need to work in order for them to be effective?

GM biocontrol agents (non-disseminating)

- What is the likely impact of these agents on toad populations in various environments?
- What is the optimal time for release to achieve maximum control?
- Using spatial models, what is the appropriate spatial scale on which control is feasible?

GM biocontrol agents (disseminating)

- Given its known pathogenicity and transmissibility to cane toads, what is its likely impact on populations, its likely rate of spread, and in what density cane toad populations might it become established?
- Is it likely to persist in the environment, or require continual reintroduction?
- Will such an agent persist in competition with wild (non genetically modified) versions of the vector?
- What are the likely consequences of natural selection on both the cane toad and GMO in the medium term? Is rapid development of resistance a possibility.

Recommendation

Modelling should be undertaken to assist with the determination of which of the approaches to long-term control suggested in this report would, if successfully developed, provide an efficient control mechanism. This would probably take up to five years. However, one year should be enough to rule out a method that is unlikely to work. Cost: \$95,000/year for 5 years.

5. CURRENT MANAGEMENT OF CANE TOADS IN AUSTRALIA AND OVERSEAS

5.1 NEW SOUTH WALES (NSW)

Ron Haering

Legislative Framework

National Parks and Wildlife Act (NPW Act) 1974

The Department of Environment and Conservation (DEC) administers the NPW Act under which DEC is responsible for the care, control and management of all national parks, historic sites, nature reserves, Aboriginal areas, state game reserves, state recreation areas and certain regional parks within NSW and for the care and protection of native fauna and flora. The NPW Act also requires the preparation of a plan of management for each reserve managed by DEC. The conservation of wildlife and their habitats is an objective of each plan and this provides a process for the management and control of pest species such as cane toads on DEC lands.

Threatened Species Conservation Act (TSC Act) 1995

Cane toads are not currently listed under this Act as a Key Threatening Process and are therefore not subject to the preparation of a Threat Abatement Plan. The TSC Act enables the preparation of recovery plans for threatened species, populations and ecological communities. An action in a recovery plan may prescribe measures to manage the threat of cane toads on a particular threatened species, endangered population or ecological community.

Rural Lands Protection Act (RLP Act) 1998

There is no prescribed method of control of cane toads and therefore this species cannot be listed as a pest species under the RLP Act, which requires landholders to continually suppress and destroy pest species. The Rural Lands Protection Boards administer and implement the RLP Act.

Non-indigenous Animals Act (NiA Act) 1987

This Act regulates the keeping, movement and import of exotic species into NSW. It classifies animals into categories of pest potential. Cane toads are in the highest category. Keeping is restricted to Statutory Zoos or facilities licensed under the *Exhibited Animals Protection Act 1986* by the Department of Primary Industries (DPI).

Distribution

Most of NSW is free of cane toads. The species has a patchy distribution, predominantly restricted to northern NSW, but extending as far south as Port Macquarie approximately 400 km north of Sydney. Cane toads are established in the Tweed River Valley and extend west of Lismore, approximately 90 km from the NSW coast. They extend further south to Woodburn, with a 50 km gap to a population at Yamba/Angourie on the southern side of the Clarence River close to

Grafton. There is a further gap of 240 km to the Port Macquarie population. The precise westerly range of the species is not exactly known.

Cane toads occur in a number of national parks (NP) and nature reserves (NR), including Nightcap NP, Mebbin NP, Border Ranges NP Yuraygir NP and Lake Innes NR.

Cane toads have been recorded at numerous other locations outside their known range. They include Coffs Harbour, Kempsey, Taree, Wyong, Sydney, Armidale and Dubbo. Most records have been individual toads inadvertently arriving in vegetable boxes, earthworks or nursery supplies.

There are no known records of cane toads on islands in NSW.

Cane Toads are thought to be extending their range in NSW at approximately 3-4 km per year, which is relatively slow when compared to Queensland and Northern Territory. However, their long term distribution in NSW has been modelled to the northern sections of the western slopes of the Great Dividing Range and coastal NSW extending into Victoria (Van Beurden 1981).

In the short to medium-term, there is concern that cane toads may become established between Grafton and Port Macquarie, particularly in areas, such as Hat Head NP and the southern end of Yuraygir NP, which have records of the threatened green and golden bell frog (*Litoria aurea*). Similarly, cane toads may extend as far west as the headwaters of Clarence River, which will greatly enhance their ability to disperse into this catchment area.

Management

The DEC has taken a lead role in the management of cane toads and works cooperatively with the DPI, frog interest groups and the general community. Within DEC, the management of cane toads is coordinated centrally by the Pest Management Unit and in operation by regional staff. The DEC Threatened Species Units may also provide technical assistance and resources, particularly in regard to the implementation of a species recovery plan which may have an action relevant to the management of cane toads. Time and resources directed to the management of cane toads in NSW compete with other important pest issues such as foxes, feral pigs, wild dogs and a multitude of weed species.

The primary objective of management has been to prevent cane toads establishing outside their existing range. In areas with isolated populations of cane toads, such as Yamba and Port Macquarie, further effort has been made to eradicate, or at least control the abundance of local populations.

Management objectives have generally been implemented through the promotion of community education and awareness programs at the state and local level. The intent of these programs is to:

- raise community awareness of the potential impact of cane toads on biodiversity
- increase community ownership of the cane toad issue
- increase community involvement in the control of cane toads in some areas

- enhance the ability of the community to distinguish cane toads from native frog species
- raise community awareness of native frogs and their conservation requirements
- reduce the risk of inadvertent transfer of cane toads in fresh produce and other materials
- respond efficiently to findings of cane toads outside their known range.

In key areas such as Coffs Harbour, Bellingen and Nambucca, which are between Grafton and Port Macquarie, the awareness program included public displays, notices, media releases and the distribution of a cane toad awareness kit to all local councils, plant nurseries, supermarkets, veterinarians, fishing groups and wildlife carer and conservation groups.

Each year in the Grafton area, the DEC has undertaken a number of cane toad ‘round ups’ with the local community. At Yamba in March 2003, the DEC combined with the local Dunecare Group and Golf Club to hold a community cane toad muster, which resulted in the collection of a large number of animals from known hot spots, in and around the local National Park. Similar ‘round ups’ have also occurred in the Port Macquarie and Lismore areas.

The most practical and humane option for killing cane toads in NSW is the use of freezing, when preceded by cooling to 4°C. This method has the endorsement of NSW Animal Welfare Advisory Council (AWAC) where other humane methods of euthanasia are shown to be unacceptable or impossible to use.

The DEC is working to minimise the risk of inadvertent movement of cane toads in fresh produce and building supplies and respond efficiently to sightings of cane toads outside their known range. Codes of Practice are being developed for industry to implement risk management procedures when receiving high risk materials such as soil, turf, pot plants, baled hay, straw and green waste. In Sydney, the DEC and the peak frog interest group FATS (Frog and Tadpole Society), work collaboratively to provide industry groups with education and awareness raising materials and a hot-line contact number should a cane toad be sighted.

Lord Howe Island is a designated World Heritage Area 760 km north of Sydney. A number of NSW and Commonwealth agencies have responsibilities in respect of quarantine arrangements for Lord Howe Island. The island receives cargo fortnightly from a vessel loaded at Yamba Port, Iluka at the mouth of the Clarence River. Cargo loaded onto the vessel can include anything from road base to fresh packed produce, which may be sourced or temporarily stored, in Cane Toad infested areas. The Lord Howe Island Board is working to improve quarantine measures to minimise the risk of cane toads reaching the island.

Future management of Cane Toads in NSW would be enhanced by:

- identifying the nature and degree of potential impacts of cane toads on the most susceptible native fauna, such as Spotted-tail Quolls (*Dasyurus maculatus*), frog-eating snakes, pond breeding frogs (particularly the threatened green and golden bell frog and goannas)
- identifying environmental factors governing the spread of cane toads in NSW

- developing and implementing strategies and methods to limit the ability of cane toads to access suitable breeding sites. This may include appropriately designed fences and dense plantings of vegetation
- developing and implementing (innovative) strategies and methods for local control of cane toads. This may include using attractants such as pheromones to lure cane toads to a central collection point
- liaising with Commonwealth and other state agencies to exchange information and monitor developments in cane toad control strategies. In particular, the Commonwealth funded CSIRO research into biological methods of cane toad control
- monitoring the success of education and awareness strategies
- determine where relevant to management the detailed distribution of cane toads, particularly in regard to DEC estate.

5.2 QUEENSLAND

Frank Keenan

Distribution

From the original introduction of 101 Cane Toads to Gordonvale, near Cairns, toads were bred up and distributed to four sites in Queensland. From there Cane Toads have progressively spread along the Queensland coast and inland as far as Longreach, Roma, St George and Mt Isa and in adjacent areas in New South Wales and Northern Territory (a time series of maps indicating spread is available). Fig. 5.1 indicates the current distribution of cane toads in Queensland. Whilst the rate of expansion of the cane toad population in Queensland appears to have slowed, it may not have reached its final range in this state. How far cane toads will spread if we have a series of wet years like those of the 1970s is a matter for speculation.

The potential range of cane toads in Australia predicted from Climex using the present distribution within Queensland is shown in Fig. 5.2. It may well expand beyond this. No speculation about greenhouse effects has been included.

Cane toads on islands

Queensland has 1165 islands and cays. Cane toads are on most islands with tourist infrastructure and many uninhabited islands including National Parks. For many islands the status is unknown. We cannot guarantee that any Queensland island is currently or will remain free of cane toads.

Cane toad spread

As well as natural expansion across country, cane toads are very effective hitchhikers, establishing small incursions sometimes hundreds of kilometers ahead of the front line. Over the range of the cane toad in Queensland, their distribution is not necessarily continuous. The impact of disease processes and starvation on cane toad populations is not well documented.

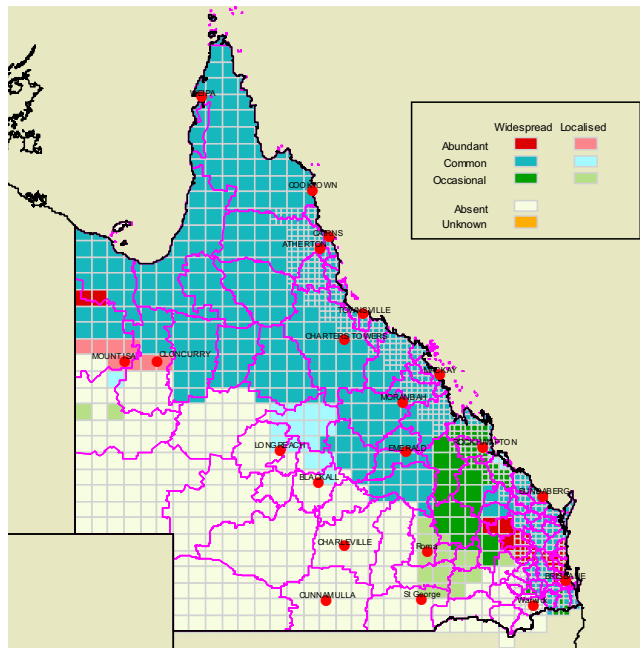


Figure 5.1. The current distribution of cane toads in Queensland

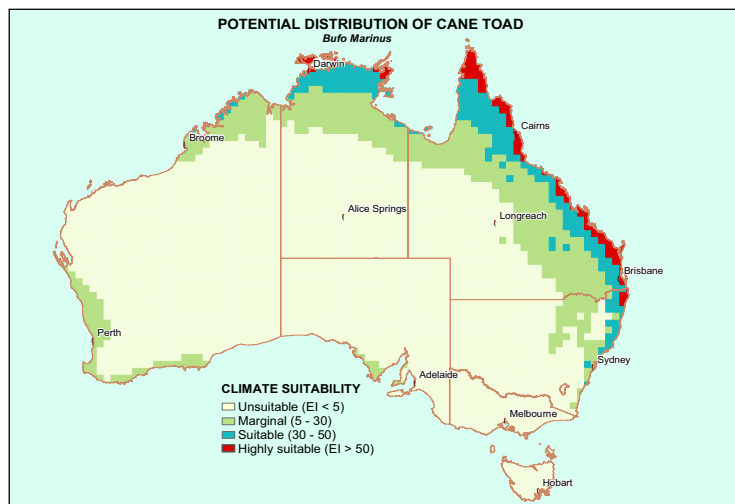


Figure 5.2. Potential Australian distribution predicted from Climex on the basis of the distribution of cane toads in Queensland in 2004

Pest status of *Bufo marinus* in Queensland

All exotic amphibians except *Bufo marinus* are declared as a Class 1 pest under the *Land Protection (Pest and Stock Route Management) Act 2002*. While the pest impacts are recognised, cane toads are widespread and there is currently no practical broad scale control/eradication tool available. Declaration would place a legal

obligation on all landholders (including State land managers) to undertake reasonable control measures on their land. With existing technology, control is considered beyond the resources of Queensland.

Incursion prevention

As well as looking at strategies to prevent incursions of cane toads beyond their current range, we need also to be mindful that there are other invasive exotic amphibians (e.g. *Bufo melanostictus*) which is currently as close as East Timor. AQIS in Cairns have had 12 intercepts of these toads in the past three years.

Management and monitoring of cane toads in Queensland

In Queensland, weed and pest management is administered under the *Land Protection (Pest and Stock Route Management) Act 2002* and the *Land Protection (Pest and Stock Route Management) Regulations 2003*. All exotic amphibians except *Bufo marinus* are declared as class 1 pests. Class 1 pests are subject to eradication within the state.

The reason that *Bufo marinus* is not declared is because they are widespread within the state and there is no practical broad scale control tool available. Declaration of a pest species places a requirement on landholders (including State land managers) and Local Authorities to undertake reasonable steps to control the declared pest on their land.

Local community groups do become involved in “Toad Buster” activities and are encouraged to do so. However, this is not an official activity. The impact of community campaigns against cane toads could increase as better cane toad traps become available.

Data on the distribution and frequency of *Bufo marinus* is now collected as part of Queensland’s Annual Pest Assessment process. Information is mapped on a 0.5 degree grid map and published on the Department of Natural Resources and Mines’ web site. Other *ad hoc* data are collected by the Departments of Natural Resources and Mines and Environment Protection Authority.

5.3 NORTHERN TERRITORY

Robert Taylor and Keith Saalfeld

Research into the impacts of cane toads by the then Northern Territory Parks and Wildlife Commission began around 1983 soon after the arrival of the species into the Territory. However a concerted coordinated management response to the issue didn’t commence in earnest until the funding of a program entitled Island Arks in mid 2003. The various components of this program are outlined below.

Public education

As there is presently no method of broadscale long-term control, a public awareness campaign was designed which focused on living with the toad and minimising its

impact on urban and rural residents. Advertising campaigns have been running for several years in the print media and on radio. An invigorated campaign including television will commence shortly, prior to and coincident with the arrival of the toad front on the rural outskirts of greater Darwin. There are several messages and information being promoted in these campaigns:

- Awareness of the biology of the toad (e.g. its large fecundity, its habitat and sheltering habitats)
- Identification of the cane toad and how to distinguish it from native species. This is required to try to ensure native species are not mistaken for toads and thus killed
- How to try to toad proof the boundary of a property with exclusion fencing
- The impact of toads on pets and need to train dogs to avoid mouthing toads
- How to humanely kill cane toads
- The risk of cane toads hiding in goods taken to islands (see below).

Public involvement

Involvement of the public in cane toad control is being spearheaded by Frogwatch, a community organisation dedicated to raising public awareness and involvement in conservation of frogs. Frogwatch are considering round-up type activities as well as coordination of control activities around important sites such as wetlands in the rural areas surrounding Darwin (e.g. McMinns lagoon). With the success of the trap they have designed for cane toads they now believe that, with appropriate levels of community involvement, they will be able to prevent the entry of cane toads into the urban areas of Darwin and Palmerston. In February 2005 the Northern Territory government announced that \$422,000 would be provided over 18 months to Frogwatch to run a community campaign to combat the toad. Included in this amount are funds for a half-time position to evaluate the benefits of this campaign for biodiversity.

Distribution monitoring

In recent years the location of the cane toad front nearest Darwin has been monitored to assess its current location and rate of movement so that an estimate of when it will reach Darwin can be determined. The location of the front in other areas as it spreads to Western Australia has been monitored by Frogwatch.

Impact assessment

Research was undertaken over many years by Bill Freeland, principally focused on impacts on frogs (Freeland 1984; Freeland 1985; Freeland and Martin 1985; Freeland 1986ab; Freeland *et al.* 1986; Freeland and Kerin 1988, 1991). Work by Watson and Woinarski (2003) and Oakwood (2004) in Kakadu National Park documented the devastating impact of cane toads on northern quolls. Funding has also been provided to Charles Darwin University to document the impacts of toads on two goanna species *Varanus mertensi* and *V. indicus*. There are also extensive impact studies being undertaken at Fogg Dam on a range of groups (e.g. snakes, freshwater turtles and invertebrates) by a team from Sydney University (see Table 2.5).

Surveys of quolls on Vanderlin Island have been conducted several times to assess the impacts of the invasion of this island by cane toads in 2002 associated with major flooding of the Macarthur River.

Translocation

Because of the devastating impacts of cane toads on northern quolls, quolls have been translocated onto two islands, Astell and Pobassoo, off the coast of eastern Arnhem Land (Rankmore *et al.* 2003). Translocation of goannas has not been considered to date as there are presently quite a few islands with various species in the Northern Territory (*Varanus tristis*- 4 islands, *Varanus scalaris*- 7 islands, *Varanus panoptes*- 9 islands, *Varanus mertensi*- 4 islands, *Varanus gouldii*- 6 islands, *Varanus glebopalma*- 6 islands, *Varanus acanthurus*- 13 islands) and because it is possible that populations of these species will recover.

Biosecurity

The Northern Territory is implementing an Island Biosecurity Program that aims to minimise the chance of cane toads being taken to off-shore islands. Actions under this program include:

- Development and implementation of a set of biosecurity protocols for off-shore islands
- Increasing the awareness of Traditional owners of the biodiversity conservation value of their islands
- Assisting Traditional owners in keeping their islands free of cane toads and feral cats
- Raising the awareness of people who visit islands or who are moving to reside on islands of the impact that cane toads and feral cats will have on off-shore islands
- Working with local island communities and industries that are transporting goods and people to islands to prevent the accidental transportation of cane toads to islands.

Biosecurity Protocols

A series of targeted biosecurity protocols are being developed in conjunction with specific industries involved in the movement of people and goods to and from off-shore islands. These protocols will cover issues such as cane toad-proof fencing for storage facilities, trapping programs for storage and loading facilities, inspection of freight and luggage for cane toads, disposal of cane toads, and response to detection of cane toads in freight or luggage. We will also be targeting people and industries that send goods to islands to ensure goods are delivered free of toads to transportation companies.

Protocols are also being developed that will govern response to the detection of cane toads on an island. These protocols will be developed in conjunction with the local communities and provide a detailed response to the detection of cane toads.

Biodiversity conservation awareness

An education campaign is being undertaken to increase awareness of the threat that cane toads pose to islands and the biodiversity values of islands. This education

campaign is being conducted through presentations at schools, local communities, industries involved in the movement of goods and people to islands, etc. The campaign aims to increase awareness of the importance of islands and what protocols exist or are being developed to keep cane toads off islands.

Schools

Actions include:

- talks and displays at schools for all island communities
- provision of information kits to schools including cane toad posters, fact sheets and stickers
- involvement of schools in cane toad lookout activities.

A key component of the schools program has been to stress to children not to transport toads to islands and to report any sighting of toads on an island to local authorities.

Local communities

Actions include:

- public awareness talks and displays for all island communities
- provision of signage for barge landings and boat ramps in appropriate languages for each site
- production of a DVD, TV commercials, radio advertising, posters, fact sheets and stickers. The DVD has been produced for Aboriginal communities and uses Aboriginal actors. It is available in six languages to cover all coastal communities. Around eighty percent of the coastline and nearly all of the Northern Territory's islands are owned by Aboriginal groups.

As with schools, a key component of the local community awareness has been the reporting of any sightings of cane toads on islands to local authorities immediately, and the immediate response required by local communities to a sighting. The capability to eradicate toads on an island is dependant upon the immediacy of detection and response is stressed in all presentations.

Boating and barge industries

Actions include:

- working with local barge companies to develop guidelines/procedures/protocols to prevent accidental transportation of Cane Toads to islands
- provision of signage for barge landings and boat ramps that emphasise need to check loads for Cane Toads prior to movement
- development of industry-specific pamphlets that boating and barge companies can send to clients to ensure that clients are aware that they should ensure cargo does not contain Cane Toads prior to delivery to boating and barge companies for loading.

Barges have been identified as the most likely means by which cane toads could reach more distant off-shore islands in sufficient numbers to establish. Transport in air cargo is not considered a significant risk as it is unlikely that numbers greater than single individuals would be transported, whereas, with barge cargo, it is likely that a number of individuals could be transported simultaneously.

The primary role for barge companies has been identified as keeping cane toads out of cargo after it has been delivered to their loading facilities. To this end, the cane toad-proofing of loading facilities has been identified as a primary objective and funding sought for either cane toad proof storage areas or cane toad proof perimeter fencing. The Tiwi Islands barge company is in the process of building a toad proof fence around their site.

The need for clients to ensure that cargo delivered for shipment is cane toad-free has been identified as a high priority. This is especially the case in light of proposed legislation (see below) which would impose penalties on those responsible for the movement of cane toads into declared cane toad exclusion areas. Some inspection of cargo prior to loading has been identified as a requirement and a number of potential inspection regimes are being investigated.

Building and nursery industries

Both have been identified as a potential primary source of cane toad-infected cargo delivered to barge companies for shipment to off-shore islands. Actions include:

- cooperation with local industries to develop guidelines/procedures/protocols to ensure that cargo delivered for shipment to islands is cane toad free
- development and supply of industry specific posters, pamphlets and other materials to aid in identification of cane toads and the means by which they may be transported (e.g. for nursery industry) buried in soil in pot plants shipped for landscaping).

Both these industries may store cargo for long periods prior to shipment. During this storage phase it is possible that cargo may become infested with cane toads and this infested cargo then transported to the island destination. To prevent this either cane toad proof storage areas need to be built or cargo inspection regimes developed, or both, so that cargo delivered for shipment is cane toad-free.

Legislation

It is proposed to amend the *Territory Parks and Wildlife Conservation Act* to permit the declaration of cane toad exclusion areas. Penalties for the transport of cane toads into a cane toad exclusion area will apply in those cases where reasonable actions have not been taken to implement procedures to detect the presence of toads.

Development of short-term control

Traps are a potentially useful means of reducing the population of toads in small areas and if used with an attractant can act as an early warning of the presence of toads in areas such as toad-free islands. They are also potentially useful inside exclusion fencing around areas such as a barge freight storage facility where traps could pick up toads that had been taken across the fence barrier in freight to be transported to an island if the freight is stored overnight.

We have tested several trap designs presently available and are also running a cane toad trap competition (in conjunction with the CRC for Pest Animal Research). The six short-listed designs (attractants and/or traps) will be tested and the most efficient and effective one awarded prize money and assistance with commercialisation.

Development of long-term control

The Northern Territory government has pledged financial assistance of \$100,000/year for three years to assist with development of a long term control for cane toads. The specific project that this money will go to fund will be determined from priorities determined by the National Cane Toad Taskforce.

Development of Aboriginal land owners capacity for management of islands and awareness raising

Nearly all of the islands off the coast of the Northern Territory are owned by Aborigines. It is thus extremely important, if cane toads are to be kept off islands and if islands are to be used as refuges and translocation sites for species that are heavily impacted by cane toads, that the Aboriginal owners support these goals, are actively engaged in raising awareness of the issue in their communities and involved in the management of important conservation values. Hence, an important part of the government's response to cane toads has involved working with traditional owner groups and supporting the formation of new Aboriginal ranger groups and the involvement of existing ones. These rangers have given talks to schools and generally educated the community about the impacts of cane toads and the risk of them being inadvertently taken to islands. This has included the production of a DVD with Aboriginal actors that will be available in six or more Aboriginal languages. Aboriginal rangers have also been actively involved in projects such as the translocation and subsequent monitoring of quoll populations on islands.

National coordination

The Northern Territory government saw the need for coordination of the response to the cane toad invasion, both in terms of developing agreed priorities for research into short and long-term control, and in terms of the management response to their presence and spread. A recommendation was put to the NRMCC and the National Cane Toad Taskforce was subsequently set up (see section 1).

Status under legislation

The *Territory Parks and Wildlife Conservation Act* allows for the declaration of introduced animals as feral animals. Areas can be declared as Feral Animal Control Areas. In these areas the owner of land can be required to undertake control or eradication of a feral animal. Cane toads have not yet been declared as feral animals in the Northern Territory. The existing legislation is currently under review and changes may include provision for the declaration of Feral Animal Exclusion Areas as outlined above.

5.4 WESTERN AUSTRALIA (WA)

Peter Mawson

Cane toads are currently not established in WA. From time to time individual animals are encountered at widely dispersed locations throughout the state from the Kimberley region in the north to as far south as Perth. All toads encountered to date have arrived

in WA with the direct assistance of humans. Over the past three years, toads (live and dead) have been encountered singly at a number of locations (see Table 5.1).

Table 5.1. History of recent cane toad arrivals in Western Australia reported to authorities.

Date	Location	Status
2002	Broome airport	Desiccated specimen, date of arrival unknown.
2004	Coral Bay	Freshly dead specimen caught up in camping gear used in the Northern Territory a few weeks before.
2004	Kununurra	Mummified specimen, date of arrival unknown.
2004	Kununurra	Live toad captured at quarantine checkpoint.
2005	Perth	Live toad air-freighted to Perth from Queensland in a pair of shoes. Killed on site.

In August 2004 the Federal Minister for the Environment and Heritage wrote to the WA Minister for the Environment seeking WA's cooperation to undertake a Kimberley cane toad program, to be implemented jointly by both governments. The Australian government offered to fund the program on a dollar for dollar basis with the State. The WA government responded favourably and agreed to the establishment of a jointly funded program, but indicated that there was a need to avoid duplication of issues currently being dealt with by the National Cane Toad Taskforce.

In October 2004 the WA Agriculture Protection Board (APB) established a State Cane Toad Management Advisory Committee to develop a management strategy to mitigate the impact of cane toads on the biodiversity and primary production of the State. The committee will have representation made up of government, non-government and community groups including traditional landowners. The committee will review the effectiveness and efficiency of existing strategies to manage cane toads. It is proposed that the Australian government will also have representation on this committee to avoid the need to have two committees addressing the same general issues. In addition a small and technically focused Cane Toad Taskforce will be established to manage operations involving the Departments of Agriculture (DAWA) and Conservation and Land Management (CALM).

In December 2004 the WA Ministers for Agriculture, Forestry and Fisheries and Environment jointly announced that \$600,000 in funding had been made available to fund the development of a strategy to prevent cane toads entering and establishing in WA. As yet there has not been any confirmation of whether the Australian government will match this funding, and if so, in what format the federal contribution would be made. No state appropriations have been allocated for 2005/06 or beyond. The initiative will address four key areas: quarantine and surveillance, implications for biodiversity, research and development, and public awareness.

A number of research proposals have been developed to address deficiencies in our knowledge of the current status of a range of potentially susceptible fauna species prior to the arrival of cane toads in WA. A smaller subset of the proposals has already been successful in attracting funding. Alcoa Australia Ltd has funded a Frog Watch program to be conducted by Drs Dale Roberts (University WA) and Paul Doherty (WA Museum) with the aim of monitoring Kimberley frog communities prior to the

arrival of cane toads. The program will run for 3 years and has received \$80,000 in funding.

Conservation and Land Management (CALM) has applied for funding to carry out fauna surveys on the Kimberley islands to determine what important fauna species they currently support and what species might be affected by cane toads in the event they reach the islands. There are more than 120 islands in the Kimberly region and most are only a short distance from the mainland. This survey would also provide important information on which islands might be suitable sites for translocation of species such as quolls. CALM has also developed a project outline for a full biological survey of the mainland Kimberley region to complement similar surveys conducted in the Nullarbor-Goldfields, Carnarvon Basin, and the Pilbara (under way at present). At present neither of these survey proposals has been successful in attracting the required funding from state government. CALM is also planning to repeat the full survey of the freshwater crocodile populations in Lakes Argyle and Kununurra (last conducted in 1989) to provide a baseline on the status of the population prior to the arrival of cane toads.

Researchers from two WA universities (Dr Graham Thompson, Edith Cowan University) and Prof. Phil Withers (University WA) are preparing an ARC Linkage Grant application entitled “Assessing the impact of the cane toad, *Bufo marinus*, on the terrestrial fauna of the East Kimberley using best-practice terrestrial fauna surveys”. The primary objective of this research project is to monitor the impact that cane toads will have on native vertebrates and ecosystem function in the east Kimberley. CALM has been invited to participate in the application as an industry partner, with that participation being dependent on available funds over the required period. Other industry partners are also being sought. Given the limited funds available in 2004/05 for cane toad research, and no indication of future funding beyond that period this project may provide a good investment strategy.

On 18th February 2005 a meeting was held in Perth that was attended by staff from CALM, the WA Department of Agriculture, the Australian Department for the Environment and Heritage and the Northern Territory Department of Infrastructure, Planning and the Environment. At this meeting discussions were held to progress the Federal Minister’s offer of funding to match any allocation by the WA government towards managing the arrival and impact of cane toads in WA. Discussions also addressed the potential for cooperation between WA and Northern Territory authorities to monitor the approach of the main front of cane toads towards the WA/Northern Territory border, to detect any populations ahead of the front and possibilities for common public awareness-raising for tourists passing into WA from further east. The potential for the Northern Territory to have representation on the executive group overseeing the WA Cane Toad Management Advisory Committee was also canvassed. Final decisions on these and other issues have not been reached.

5.5 INTERNATIONAL

Robert Taylor

Cane Toads have been introduced throughout the world as a control agent for various beetle pests of sugar cane, banana and other cash crops (Lever 2001). They have been

described as "the most introduced amphibian in the world" (Carmichael and Williams 1991). The Invasive Species Specialist Group (www.issg.org/database/species) lists them as being introduced to Hawaii, Puerto Rico, U.S. Virgin Islands, Guam and Northern Mariana Islands, American Samoa, Republic of Palau, much of the Caribbean including Antigua, Barbados, Cuba, Dominica, Grenada and Carriacou Island, Guadeloupe, Grand Cayman Island, Haiti, Dominican Republic, Jamaica (including Cabarita Island), Martinique, Montserrat, Nevis, St. Kitts, St. Lucia, St. Vincent, Bermuda, Egypt, Mauritius, and Diego Garcia of the Chagos Archipelago. In the Pacific Australia, Japan, Papua New Guinea, Philippines, Cook Islands, Micronesia, Fiji Islands, Kiribati, Republic of the Marshall Islands, the Solomon Islands, and Tuvalu. Despite this wide distribution and the impacts on fauna and its annoyance value, there appears to have been little done to control or limit the spread of the species in other parts of the world. The only examples that could be found was from Fiji.

Fiji

A joint initiative between the New Zealand Government, the IUCN Invasive Species Specialist Group (ISSG), and the Global Invasive Species Programme (GISP) entitled Cooperative Islands Initiative is developing a plan to try to eradicate cane toads from Viwa Island in Fiji in order to protect the critically endangered Fijian ground frog, *Platymantis vitianus*. It is believed that competition is occurring between cane toads and the ground frogs. Viwa island is 60 ha and 0.95 kms from the adjoining larger island of Viti Levu. It is estimated the project will cost around \$150,000 over a 6-year period. It is estimated that there are over 25,000 Cane Toads on Viwa. Biosecurity issues will also be considered as boats regularly visit Viwa. This is to try to ensure cane toads are not brought to the island again if eradication is successful.

The use of toxins, capture by hand and trapping are being considered on land. Part of the trapping program may include strategically placed newly constructed ponds ("dry season traps"). The effectiveness of dogs to detect cane toads will be tested. Breeding habitat will also be targeted. Water is a limiting resource on the island. Drinking water is mainly from rainwater collected from roofs. There are three main man-made ponds (in the dry season) that can overflow in the wet season and are ideal breeding locations for cane toads. A proposed solution to the water problem is to provide pipes, gutters and drainage for the villagers. It is proposed to modify areas around water bodies (e.g. fencing) in order to prevent cane toads reaching these areas to breed. The ground frog has no free swimming tadpole stage and hence it will not be harmed by a reduction in free water sources. Ephemeral wetlands will still provide breeding habitat for cane toads in the wet season. Rock pools above the high water mark may also provide breeding habitat and hence targeted collection around the outer margin of the island may be required. Repeated hand collection of eggs and tadpoles by physical removal (dip-netting) will be conducted at remaining ponds. Rotenone, clove oil and other toxins will be trialed against cane toad tadpoles. An initial trial eradication may be conducted on a small uninhabited island with cane toads to monitor for an unforeseen ecological implications. Eradication of *Rattus exulans* is being considered in conjunction with the cane toad eradication.

Florida

After several attempts at deliberate introduction to Florida, cane toads were eventually established after an accidental release by an importer at the Miami International Airport, Dade county, in 1955 (Krakauer, 1968). Florida has never attempted to control cane toads. Although the authorities would prefer that they had not been introduced into Florida, they are at most a minor nuisance. The native southern toad, *Bufo terrestris*, is abundant and widespread throughout Florida. Native predators have evolutionarily dealt with bufotoxin for millennia, so *Bufo marinus* presents no special problems to native predators, which either behaviorally avoid the poison glands or are not affected by the toxins. The fact that native predators readily eat cane toads may in part account for the fact that they are not a major problem in the wild. Cane toads in Florida occur primarily in urban areas and have not widely invaded native habitats. The greatest threat that they present is to naive domestic dogs.

6. RECOMMENDATIONS FOR BEST PRACTICE MANAGEMENT AND PRIORITY RESEARCH

In this final chapter we address the last two requirements of the brief from the Natural Resources Management Ministerial Council:

- Identify any gaps in current approaches
- Assess the costs and benefits of options for priority joint national action.

In previous chapters we have identified a series of research projects that included some that would cover existing gaps in the present approach. Here we prioritise these projects within each of the three areas covered i.e. impact, short-term control and long-term control, and provide a rationale for these prioritisations. These priorities represent the consensus view of the Taskforce. The chapter also outlines what we believe is a best practice management approach within the confines of our presently available knowledge and control technology.

Assessment of the costs and benefits of action, particularly in terms of what research should be pursued is more problematic. Such determinations presume that the probability of success of an approach can be assessed and that the benefits of the introduction of a new approach or the technology to be developed are known *a priori*. Modelling offers an approach to this determination (see section 4.5). However such modelling has not yet been carried out. Cost-benefit analysis is discussed below prior to the presentation of our prioritised recommendations.

6.1 COST-BENEFIT ANALYSIS

Hamish McCallum

It is essential that any management decisions made concerning control of Cane Toads be made using an appropriate cost benefit analysis. Whether the proposed control is small-scale or large-scale, there will obviously be financial costs involved in its implementation. There may also be ecological costs. These might include impacts on non-target species. Successful control likewise will bring benefits and costs both ecological and economic.

The key problem, which is common to most ecological decision making, is that there is substantial uncertainty associated with these costs and benefits. This uncertainty includes both uncertainty about whether or not a given control strategy will be successful (and on what temporal and spatial scale) and also uncertainty, given a particular level of control, on what the economic and ecological consequences for the remainder of the ecosystem will be. In addition, there is the difficulty of relating ecological benefits and costs to economic benefits and costs.

Currently, most environmental managers attempt to synthesise available information and reach a consensus position that balances competing social demands on natural resources. All managers recognize that we have incomplete information and understanding but make decisions without any formal or theoretical support to deal with uncertainty. Recently, a few decisions in renewable natural resource industries

have been supported by population or ecological system models. More commonly, decisions are based on expert judgement. They aim to maximize a benefit (in this context, control of Cane Toads) or minimize a risk (such as the chance of extinction of species such as northern quolls), given constraints such as the available financial resources. Recently, new decision-theoretic tools have been developed that allow managers to deal explicitly with spatial and temporal uncertainty.

In essence, these approaches require estimating, for each possible management action, the probability of each potential outcome, together with the overall cost of each of these outcomes, given the particular management action. In this context, benefits are considered to be "negative costs". Once this has been done, the costs for each outcome are multiplied by the appropriate probabilities, and the management action with the lowest weighted cost (or equivalently the highest benefit) is chosen. It is important to recognise that "do nothing" is just another potential management action and needs to be evaluated alongside other options.

This approach relies on being able to estimate the probability of particular outcomes occurring given that certain management actions are taken. Because we are looking at ecosystem level outcomes (which include a very large number of response variables), this is a difficult problem with the state of current ecological knowledge. However, such an approach is in fact applied by all managers, even if they do not use formal tools either to predict the outcomes or to weigh up alternative management strategies. To employ less ad hoc techniques requires developing ecological models able to predict, with appropriate levels of uncertainty, the consequences of the various management actions. In turn, these ecological models must rest on good experimental data about the impacts of Cane Toads and ecological field studies capable of estimating the various population parameters involved in the ecological models.

6.2 BEST PRACTICE MANAGEMENT

National Cane Toad Taskforce Members

Below we have identified what we believe presently constitutes best practice in relation to the management of the threat from cane toads. This will obviously change over time as our knowledge increases and, hopefully, as better techniques are developed to combat the threat from cane toads.

We believe the highest priority is to try to keep cane toads out of areas where they will not reach naturally (i.e. many of our islands or areas such as south-west Western Australia where climatic barriers exist to movement from the north and east) and areas where they will not reach by natural movement for a long time (i.e. detecting hitch hiker toads well ahead of the front). Involvement of the community in this detection of toads outside their present range is essential and hence education and awareness campaigns and following up on reports is an essential element of this.

Islands

- Identify which islands cane toads are unlikely to reach naturally (due to a low probability of transport in freshwater after flooding or due to distance to the mainland)

- Survey all of the islands large enough to support viable populations of species likely to be impacted by the presence of cane toads
- On the basis of the information above, determine the necessity for, and feasibility of, translocating impacted species that are not adequately conserved on islands.

Island biosecurity

- Undertake an education campaign about the ways in which cane toads can be inadvertently transported to islands for companies sending goods to islands, for individuals visiting islands, for island residents and for people moving to reside on islands
- Advise these individuals and groups on how to minimise the chances of toads being carried in goods they are transporting to islands
- Work with barge companies to quarantine loading and storage facilities from access by cane toads
- Goods that could potentially harbour toads and that are to be transported to islands should be stored in a quarantined storage facility at least overnight and traps and attractants used to draw out any toads sheltering before transporting the goods
- Set up systems to detect the presence of vanguard colonising toads on important cane toad-free islands (e.g. automatic recording devices for calls, traps on islands with residents where these can be serviced regularly)
- Set up response systems and procedures for eradication of vanguard colonising toads
- Engage with island communities so that they understand the threat and are supportive of the objective of remaining toad-free. Fund training programs and ranger programs to assist or run these surveillance campaigns.

Education

- Provide information to members of the public so that they are aware of the threat posed by cane toads. This should be targeted for the audience. Thus issues of importance for traditional indigenous communities will not be identical to those for urban residents
- Experience has shown that the use of visual material on DVD presented in Aboriginal languages by Aboriginal actors is a good way to disseminate information to indigenous communities
- Provide information on protection of pets and the response to poisoning of pets
- Provide information on how to try to exclude toads from living areas
- Provide information on how to distinguish native frogs from cane toads to minimise mistaken killing of native frogs through misidentification
- Provide information on how to kill toads humanely and how to dispose of the bodies
- See also “Island biosecurity” above and “Monitoring and biosecurity on the mainland” below.

Community input and participation

- Community concern has played a large role in awakening political interest in addressing the threat from toads. Government practice now requires consultation

with, and often participation by, the public in determining policy and practice. Hence best practice will include community consultation and/or representation on any committees determining action on cane toad issues. Indigenous participation should be a key objective given the impact of the toad on cultural issues and bush tucker and the predominant ownership of islands by Aboriginals (at least in the Northern Territory)

- Community participation on islands is vital in biosecurity campaigns (see above)
- For areas on the mainland, determine what the objectives are for community participation in different areas
- For “backyard” situations provide information on hand collection, provide effective and humane traps for sale or rent and provide information on disposal
- For toad buster campaigns see “Population reduction” section below.

Communication and coordination

- It is important that the results of research are circulated in a timely manner so that implications for management can be determined and acted upon. It is also important that forums are provided to allow research priorities and results to be discussed and determined
- Similarly with management of cane toads, it is important that opportunities are provided so that operational procedures can be discussed and strategies developed and approaches coordinated
- Communication is also required between the research and management community and with the public at large
- The National Cane Toad Taskforce could potentially spearhead this communication and coordination function, possibly with expanded membership and with two subcommittees, one for research and one for management.

Exclusion areas

- Determine if there are hot spots where the abundance or diversity of impacted species is high
- Determine whether any of these sites will provide viable areas for the long-term maintenance of species and whether any of that subset are able to be cost-effectively protected by exclusion barriers
- Determine whether any other areas with populations of impacted species meet the criteria in the dot point above
- Examine the efficacy of a range of physical exclusion mechanisms.

Population reduction

- Determine whether a primary focus of efforts to reduce population numbers is to assist with biodiversity conservation or for social and/or educative purposes
- If control is undertaken with community involvement for social and/or educative purposes then the exact objectives should be agreed prior to commencement. An assessment should be undertaken of the cost-effectiveness of the program in relation to access provided to people who are not usually reached by community education campaigns and the extent to which the message was understood and awareness raised

- If control is undertaken for biodiversity conservation then either:
 - determination of whether the targeted biodiversity outcomes are achieved should be undertaken as an integral part of the program and continuation of control predicated on biodiversity benefits being shown to accrue; or
 - the level of control required to achieve biodiversity outcomes should be known prior to commencing.

Monitoring and biosecurity on the mainland

- Because of the propensity of cane toads to shelter in goods or vehicles that transport them ahead of the front of the advancing population, new populations can form ahead of the front. Depending on how far ahead of the front these populations are, how fast the front is advancing and how large the population is when discovered, consideration could be given to trying to eradicate such pioneer populations. Judgement on this issue needs to take into account the feasibility and cost of such an eradication and the likelihood that some sort of control method will be developed before the front arrives. If no development of control strategies is likely in the available time frame then no benefit will accrue
- Monitoring for the presence of cane toads far ahead of the front of the expanding cane toad population may allow eradication of founder individuals before they breed. This will involve educating the community on what to look and listen for and having a response team available to follow-up reports
- Education of people about the ways in which cane toads “hitchhike” and increased surveillance at border checkpoints and areas where tourist vehicles congregate at night ahead of the front will reduce establishment of outlier populations
- Monitoring of the location of the front and its speed of movement will allow information to be provided to the public in areas ahead of the front so that they are aware of when cane toads will probably arrive in their area. This information will also allow researches and management officers to better plan their activities (e.g. before and after comparisons for research and erection of exclusion devices for management)
- Dogs trained to detect the presence of cane toads from their smell may be a very useful way to pick up the presence of cane toads where they are expected to occur at low densities. Examples are individuals ahead of the front as outlined above, checking for animals that might have breached an exclusion fence, or animals that might have newly colonised an island (either as a hitchhiker or in floodwaters).

6.3 PRIORITY RESEARCH PROJECTS

National Cane Toad Taskforce Members

The projects listed below are only a small subset of those that would potentially be useful. We have included those we believe are the highest priority at this time. Even though these are all a high priority we have given them a ranking so that if funds available do not match the financial requirements of the complete list then the most urgent ones can be funded first. Projects are grouped under three major areas, impacts, short-term control and long-term control. We have only ranked projects within these major areas. This is because we believe it is important that work be undertaken in parallel in these areas. Thus, work on the development of short-term control needs to be undertaken while the longer term work required for the

development of long-term control methods is being carried out. Similarly, work on impacts such as that outlined for northern quolls can be used to guide management and can possibly be used to help determine a strategic approach to short-term control.

The costs outlined below should be treated as indicative only. They will undoubtedly change with more detailed scoping of individual projects. These costs are also marginal costs and do not include any matching funds by the research provider or overhead costs. Different providers would have different requirements and thus it is not possible to provide full costings. As an estimate, though, the total cost of each project would probably be in the order of double the marginal cost. Values are calculated as at 2004.

Assessment of the impacts of cane toads on biodiversity

The very existence of a National Cane Toad Taskforce and the recent listing of cane toads as a threatening process under the EPBC Act implies that it is already recognised that cane toads are a grave threat to biodiversity. This, however, has only recently been shown conclusively in the case of the northern quoll (Watson and Woinarski 2003; Oakwood 2004). It has to be said that the threat to biodiversity from cane toads, however, is not as great as the threat from some other invasive species such as foxes and cats that have probably led to the extinction and massive decline of many species (Kinnear *et al.* 2002). However, in northern Australia where foxes and rabbits are not present, cane toads probably rank close to feral cats as one of the main threats to biodiversity.

The prioritisation of projects to assess the threat from cane toads (Table 6.1) was carried out in the context of a recent increase in such projects in the Northern Territory where scientists have taken advantage of the situation to document biodiversity prior to the arrival of cane toads. This is particularly the case with the research being carried out by the University of Sydney at Fogg Dam where many years of pre-cane toad population data are available for a variety of groups such as snakes. These projects are now awaiting the imminent arrival of cane toads and hence many projects will be reported on in several years. We do not believe that it is a priority to repeat this work in different jurisdictions. Rather we believe that, wherever possible, we should focus on projects that will improve our ability to manage impacts. The recommended projects also give a higher priority to sorting out issues to do with species presently believed to be impacted. This is not to say that we should not pursue impact research into those groups where impacts are presently undocumented but are considered likely. Thus one project recommended is an assessment of the likelihood of impacts on different groups and species to identify priority targets.

Table 6.1. Impact of cane toads: priority projects and their ranking. 1 is the highest priority.

Project	Priority	Cost
Determine the factors associated with persistence or recovery of northern quoll populations within the range of cane toads in Queensland. (Repeated in short-term control section below).	1	\$200,000 over two years
Investigate impact on threatened invertebrate taxa likely to be impacted (e.g. restricted camaenid snails in Northern Territory and Western Australia). (Repeated in short-term control section below).	2	\$350,000 over 3 years
Investigate the status of populations of impacted species in areas in Queensland that have had cane toads for a long period. Priority groups would be goannas and frog-eating snakes.	3	\$200,000 over two years
Quantify the impact of cane toads on availability of bush tucker for an indigenous community and document any other cultural impacts.	4	\$70,000
Complete the assessment of the likelihood of different groups and species being impacted by cane toads (for those groups not already comprehensively assessed).	5	\$100,000
Add unpublished cane toad reports to the feral species information website of the Invasive Animals CRC (www.feral.org.au)	6	\$15,000

Short-term control

Because control of cane toad populations is problematic, our highest priority is to keep cane toads off islands through biosecurity protocols and surveillance methods for colonisers (Table 6.2). Assessment of the occurrence of impacted species on islands is also a high priority as these populations will become extremely important for these species as a whole in the longer term and will determine the need for management interventions such as translocation to islands. The next highest priority is to determine which areas within the mainland range of the cane toad were the highest value and the easiest logistically to protect (either by exclusion or population reduction). Determining the value of community control programs is also seen as being of equal value as in many situations the person power to undertake control will only be available if the community takes a substantial role in such programs. Knowledge of the level of reduction in cane toad populations that is required to provide biodiversity outcomes is also essential for such programs. If complete removal of toads is required for recovery or protection of impacted species then control may be pointless if programs cannot achieve this outcome. The next priority is given to developing effective and efficient tools for short-term control i.e. traps, attractants and exclosures.

Table 6.2. Short-term control of cane toads: priority projects and their ranking. 1 is the highest priority.

Short-term control approach	Approach Priority	Project	Project priority within each approach	Development cost	On-going cost	Probably of long term success
Island arks and biosecurity	1	<ul style="list-style-type: none"> • Review of the conservation potential of islands in relation to impacted species. • Identification of what types of islands eradication of cane toads could potentially be successfully carried out. Undertake trial eradication on a suitable island • Review the occurrence of toads on islands in Queensland and the Northern Territory and the mechanism for their arrival on these islands. 	1	\$50,000 for desktop study. Millions for field component.	Medium	High
			2	\$350,000 over 3 years		
			3	\$10,000 for “telephone” study. \$200,000+ for field checking of a selection of uninhabited islands		
High priority places for protection	2	<ul style="list-style-type: none"> • Examination of sites where quolls have persisted within the range of the toad. • Examination of the degree of population reduction or exclusion of cane toads required to achieve biodiversity outcomes. • Identification of sites where highly restricted invertebrates occur that may be adversely impacted by toads. • Identification of sites where occurrence of impacted species is high and where toad control is feasible and practical. 	1	\$200,000 over two years	Medium	Medium
			2	\$300,000 over 3 years		
			3	\$350,000 over 3 years		
			4	\$350,000 over 3 years		

Table 6.2 (continued).

Short-term control approach	Approach Priority	Project	Project priority within each approach	Development cost	On-going cost	Probably of long term success
Traps and attractants	2	Evaluate how traps and attractants can be used efficiently in an operational sense and what objectives they are capable of achieving. Examples are: <ul style="list-style-type: none"> • Are traps capable of catching all colonising toads and hence forming a protective barrier? • Can traps be used in conjunction with physical barriers to eliminate problems with leakage of toads across them? • What distance apart should traps be placed to catch all toads or to achieve some acceptable density of toads? • Is it possible to use traps and attractants to reduce toad densities to acceptably low levels in areas selected to serve as refugia for fauna impacted by toads? 	1	\$180,000 (to start)	High	Low (hard to sustain effort)
Community participation	2	Test whether community action can achieve the objective of protection of biodiversity.	1	\$160,000 for several sites	Medium	Low for biodiversity outcomes.
Limiting resources	3	Examination of whether water sources in the dry season are a limiting resource in some areas and whether fencing or trapping of these areas can effect population control.	1	\$180,000 over 2 years	Medium	Good
Exclosure fences	3	Testing some potential designs on a small scale in different situations.	1	\$110,000 over 3 years (plus cost of the fences.	High	Good if design proved, maintenance simple and area large enough for species.

Long-term control

The ranking of projects in terms of priority for long-term control (Table 6.3) took into account what research had been done in the past and the success of that research together with the feasibility of each proposed project based on currently available knowledge and technologies. Other factors taken into consideration were public attitudes to new technologies such as GMOs, concerns around the release of transmissible infectious agents and the need to find a solution at a continental scale as well provide local solutions. Using these criteria, it was agreed that modelling was an overarching priority to guide the direction of proposed approaches to long-term control and it was that this approach could provide such guidance within a year of commencement. The other activity that was given priority was Stage 1 in the search for a cane toad specific pathogen. The other projects, the GMO, toxin and sterile male/daughterless approaches were equally ranked as Priority 2 as all were considered well worth pursuing in parallel. One of these projects, the GMO approach, is already receiving funding through the Natural Heritage Trust. At this early stage it was not possible to judge the probability of the success of the three approaches due to the high level of uncertainty that is inherent in discovery research. It was agreed that in pursuing these approaches, the best way to manage the uncertainty was to review progress on a yearly basis. Stage 2 and Stage 3 in the pathogen search project and Stage 2 in other approaches were ranked as Priority 3 as they are dependent on Stage 1 and could not be commenced until a suitable control agent or toxin was identified.

Table 6.3. Long-term control of cane toads: priority projects and their ranking. 1 is the highest priority.

Long-term control approach	Priority	Project	Project priority within each approach	Project cost (marginal costs only)	On-going cost
Modelling control strategies	1	Modelling alternative strategies to guide direction of research		\$95,000/yr for 5 years	N/A
Pathogens (within or outside natural range of Cane Toad)	2	Stage 1 – Literature review, search criteria, collaborator identification	Progression to Stages 2 and 3 dependent on identification of a suitable candidate in Stage 1	\$37,000 (for first year, less in subsequent years)	N/A
	3	Stage 2 – Characterisation of candidate pathogen		\$242,000/yr	Low
	3	Stage 3 – Registration, release and monitoring		\$1M+ ?	Low
Genetically Modified Organism	2	Stage 1 - Continuation of the current CSIRO project – discovery of target metamorphosis genes and testing in vector viruses	Progression to Stages 2 dependent on identification of a suitable candidate in Stage 1	~\$550,000/yr for further 7 years	Low if disseminating, Production and distribution costs for non-disseminating.
	3	Stage 2 – Registration, release and monitoring		\$1M+ ?	Low

Table 6.3 (continued).

Long-term control approach	Priority	Project	Project priority within each approach	Project cost (marginal costs only)	On-going cost
Toxins	2	Stage 1 - identification and testing of potential toxins	Progression to Stages 2 dependent on identification of a suitable candidate in Stage 1	\$350,000/yr	Production and distribution of the active compound
	3	Stage 2 - Registration		\$500,000+ ?	Low
Sterile male	2	Stage 1 - Production of triploids (sterile male approach). Production of tetraploid individuals (sterile offspring approach). Investigate the sex determining system.		\$250,000/year for three years	\$100,000 /yr for ten years
	3	Stage 2 - Determine viability and libido of triploid and tetraploid individuals, and investigate gonadal development in the polypoid constructs.			
	3	Stage 3 - Field-testing of triploid sterile males (enclosure studies). Field-testing of tetraploid males.			

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