supervising scientist report 164

A preliminary risk assessment of cane toads in Kakadu National Park

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Department of the Environment and Heritage

supervising scientist

national centre for tropical wetland research

This report has been prepared by staff of the Environmental Research Institute of the Supervising Scientist (*eriss*) as part of our commitment to the National Centre for Tropical Wetland Research.

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This report should be cited as follows:

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

The Supervising Scientist is part of Environment Australia, the environmental program of the Commonwealth Department of Environment and Heritage.

Supervising Scientist
Environment Australia
GPO Box 461, Darwin NT 0801 Australia

ISSN 1325-1554

ISBN 0 642 24370 0

e-mail: publications@eriss.erin.gov.au

Internet: http://www.ea.gov.au/ssd/index.html

Printed in Darwin by NTUniprint

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Background and approach

Cane toads (*Bufo marinus*) entered the Northern Territory (NT) in 1980 from Queensland and are rapidly approaching Kakadu National Park (KNP), having recently been reported in the upper Mann River and Snowdrop Creek, approximately 15–30 km to the east of Kakadu National Park. Concern about the invasion of cane toads in Kakadu National Park has been highlighted on a number of occasions, and in 1998 participants at a workshop on the potential impacts and control of cane toads in Kakadu National Park conceded that a strategic approach for assessing and possibly minimising cane toad impacts should be developed. The first stage would be an ecological risk assessment to predict the likely extent of impacts of cane toads in Kakadu National Park and identify key vulnerable habitats and species. This information could be used to develop new monitoring programs and assess existing ones. This assessment is a direct result of Environment Australia's concern about the potential impacts of cane toads in Kakadu National Park.

The wetland risk assessment framework developed by ***eriss*** for the Ramsar Convention was used to predict key habitats and the species most at risk. The majority of the assessment involved identifying the problem, the potential extent and effects of the problem, the risk, and subsequently making recommendations on monitoring. Major information gaps relevant to predicting impacts and developing appropriate monitoring programs were also identified.

The risk assessment was based on information from published and unpublished scientific and anecdotal reports. Information on Kakadu National Park was derived from relevant research projects undertaken in the Park since the early 1980s. A number of relevant Territory and Commonwealth agencies were consulted, as were relevant cane toad, native fauna and/or wildlife management experts from around Australia. Discussions were held with community members in the Borroloola and Mataranka regions to gain an indigenous/cultural perspective of the cane toad issue.

Identification of the problem

Since their introduction to Australia in 1935 to control sugar cane pests in Queensland, cane toads have spread naturally and with human assistance throughout much of Queensland, northern NSW and the Top End of the NT. The cane toad's preference for certain disturbed areas means that areas of degraded natural habitat have probably helped their spread. They eat a wide variety of prey, breed opportunistically, have a far greater fecundity than native anurans, and develop rapidly particularly in warmer waters. They tolerate a broad range of environmental and climatic conditions, can occupy many different habitats and compete for resources with many native species. Most significantly, they possess highly toxic chemical predator defences, with many experimental and anecdotal reports of deaths of native predators that have attempted to consume cane toads.

It is accepted that the cane toad will establish and spread rapidly in Kakadu National Park — a World Heritage area with Ramsar listed wetlands, well known for its spectacular wilderness, nature conservation values, rich diversity of habitats, flora and fauna, and cultural significance. There is serious concern that the World Heritage status of Kakadu National Park could be diminished if any of these attributes were adversely affected by cane toads.

The potential extent of cane toads in Kakadu National Park

Cane toads are likely to colonise almost every habitat type within Kakadu National Park. The saline regions of the coastal plains and deltaic estuarine floodplains will most likely support some cane toads at various times, although they are not likely to use these habitats on a permanent basis. Other less suitable areas include deep open water and/or flowing channel habitats and tidal regions of larger rivers (excluding riparian zones) which extend 70 to 80 km inland during the Dry season. The steady range expansion over the last ten years indicates that most wetland habitats are probably suitable as breeding habitat and also as Dry season refuges.

Patterns of dispersal within Kakadu will probably rely on the transport corridors and the major rivers and creeks. Dispersal rates within a catchment could be up to 100 km y^{-1}. The current location of cane toads would indicate an initial progression down the South Alligator River catchment via its sub-catchments (eg Jim Jim Creek, Deaf Adder Creek). Invasion of other areas of the Park will likely depend on which waterways' headwaters are colonised first (eg Mary River, East Alligator River).

Maximum population densities of various cane toad life stages for limited areas of suitable habitat in Kakadu could be expected to be in the order of: 4000 to 36 000 eggs per metre of shoreline; ~15 to 60 m^{-2} for tadpoles; 2.5 m^{-2} for metamorphlings; and 2000 ha^{-1} for adults, depending on temporal and spatial factors.

The Dry season will see a gradual retreat of many cane toads from seasonally inundated wetlands. The vegetation and cracks in the black soils on the floodplains should offer sheltered, moist habitat during the mid Dry season. In the late Dry season, adult cane toads will congregate near permanent water with adequate shelter. Few cane toads would be present in the drier areas of the tall, open eucalypt forest and woodland habitats of the lowland plains. The first rains of the Wet season will stimulate dispersal and increased breeding activity. With the progression of the Wet season, cane toads will disperse into terrestrial habitats, namely the open forests and woodlands. When large areas of the floodplains are inundated, cane toads will be concentrated on the remaining dry ground, which may make them highly visible to Park visitors.

The potential effects of cane toads on Kakadu National Park

The potential effects of cane toads upon Kakadu National Park are outlined in six sections of this report: effects on predator species; effects on prey species; effects of resource competition; cultural effects; economic effects; and other potential effects.

Predators

The majority of information on cane toad impacts relates to toxic effects on predators. A substantial amount of literature exists on effects on individuals, but little scientific information is available on population effects. The degree of susceptibility of potential cane toad predator species in Kakadu National Park was determined using three criteria:

Definite: documented adverse effects upon populations of this species have been reported in the literature;

Probable: documented in the literature as having eaten cane toads or their early life stages and adverse effects on individuals reported, but not on populations;

Possible: documented in the literature or through expert consultation as eating, or thought likely to eat, native frogs or their early life stages, but effects of eating cane toads unknown.

A total of 151 species or species groups were identified under these criteria, covering a broad taxonomic range including aquatic invertebrates, fish, frogs, lizards, snakes, birds and mammals. Eleven species were considered *definitely* susceptible to cane toads, comprising 5 lizard, 3 snake and 3 mammal species. Sixteen species or species groups were considered *probably* susceptible to cane toads, while 124 species or species groups were considered *possibly* susceptible to cane toads.

Prey

Little information was available on effects of cane toads on prey species. Cane toad tadpoles have been observed preying on the eggs of some native frogs, though they are thought not to be significant predators of native anuran early life stages. Rather, cane toad tadpoles have been observed to feed mainly on cane toad eggs, algae and detritus, as well as scavenging upon dead animals and animal material which they will consume in preference to plant material. Juvenile and adult cane toads are generalist feeders, consuming almost any type of terrestrial animals, with ground-dwelling ants, termites and beetles usually dominating the diet. Some small mammals, birds, reptiles and frogs are consumed in very small numbers. No study has specifically investigated the impact of cane toads on communities of ground dwelling arthropods. One general impact study reported a decline in beetle (Coleoptera) numbers, possibly due to cane toads. It is impossible to determine how many of the undescribed invertebrate species in Kakadu, many of which may be endemic, could be affected by cane toads.

Competition

Little information was available on competition between cane toads and native animals for resources such as food, shelter and breeding sites. The potential for competition between cane toad tadpoles and native frog tadpoles (eg the ornate burrowing frog) appears to exist, although, several reports suggest considerable segregation of breeding sites. Competition between adult cane toads and frogs appears to be minimal, with the pattern of habitat and food exploitation differing markedly. The major factor separating resource use is the cane toad's heavy reliance on ground-dwelling ants, termites and beetles as major food sources. There has been some indication from the Roper River region of the NT of competition effects. In particular, some species of small reptile were found to decline in areas colonised by cane toads. A competition effect was suspected, but not confirmed. Two frog species (the brown tree frog and green tree frog) have possibly been linked to competition-related declines, although the evidence is not strong. It is possible that many other species within Kakadu, including endemic aquatic invertebrates, could be subject to competition by cane toads.

Cultural effects

Concerns for the decline in numbers of bush tucker species such as monitor lizards, snakes and turtles have already been noted by several Aboriginal communities in the NT. This decline is likely to have very significant impacts upon Aboriginal communities within Kakadu. Some traditional ceremonies in the Borroloola region have been altered to request the spirits to return these foods, and in some cases, totem species (eg freshwater crocodile). From experience elsewhere in the NT, it appears that Aboriginal people, by necessity, eventually grow accustomed to the presence of cane toads, although this does not necessarily diminish the underlying concerns of these people. Areas of human habitation in Kakadu including the township of Jabiru, Aboriginal communities, Ranger stations, tourist accommodation and camping grounds are expected to have high densities of cane toads. This will impact on outdoor recreational activities and, in some areas, increase the likelihood of pets being poisoned from mouthing or ingesting cane toads.

Economic effects

Cane toads are unlikely to have an adverse impact on the general economy and tourism income of Kakadu National Park. The reactions to cane toads in the NT have ranged from disinterest to dismay. International tourists do not recognise toads as an invasive species, while visitors from Queensland are well accustomed to toads. However, tourists from other states express deep concern about cane toads, especially in World Heritage sites such as Kakadu. Tour operators in Kakadu share a similar concern. However, the major attributes of Kakadu continue to attract tourists, and are likely to overshadow any concerns about adverse economic impacts of cane toads.

Cane toads do have an economic value as dissecting specimens for research and education purposes, and as a supply for medicinal and leather products. Such industries exist in Queensland and will probably become established in the NT once cane toads are present in sufficient numbers.

Other potential effects

Another potential effect is the contamination of water supplies with rotting toad carcasses and the subsequent release of the toxins. There have been many reports of the poisoning of pets and poultry from drinking contaminated water. Experimental water-borne exposure of the toxin to various organisms has resulted in toxicity, but generally only at high concentrations.

The issue of potential impacts of cane toads on granivorous prey insects and resultant repercussions on Kakadu's native plants has been raised, although this is highly speculative. There is evidence, for example, that high densities of harvester ants can significantly reduce the density of speargrass (*Sorghum intrans*). In terms of plant-animal interactions, it is possible that subtle ecological changes could occur amongst other biota, and other flow-on effects.

Feral cats and pigs have been known to die from mouthing or ingesting cane toads. These animals cause damage to the native fauna and landscape of Kakadu, and any decline in their numbers would be considered a benefit. The reduction in numbers of predators such as varanids (goannas) and snakes could be of benefit to the several species of ground-dwelling/nesting birds in Kakadu, in addition to crocodiles and turtles whose eggs are preyed upon by other large reptiles.

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.

Identification of the risk

The data on cane toad effects, distribution and densities are mostly inconclusive and/or show great variability. In addition, information on distributions and abundance of Kakadu animal species are deficient. Nevertheless, it is still possible to identify key habitats and also prioritise particular species based on the likelihood that they will be at greater risk from cane toads than other species, and their importance to the ecological and/or cultural values of Kakadu.

Identification of key habitats

Aquatic stages

In Kakadu, cane toads will breed in both temporary and permanent waterbodies and so their aquatic stages will be found in a variety of aquatic habitats. They will concentrate their breeding activity during the wetter periods, although they are also known to breed during the Dry season. During the Wet season, when many of the major wetland habitats are inundated, cane toad breeding may be concentrated in the wetland habitats associated with the open forests and woodlands of the lowland plains.

Terrestrial stages

As the Dry season progresses, cane toads will move progressively from sites of temporary water to permanent water. The floodplains and sheltered habitats on the margins of floodplains and temporary or shallow billabongs will provide ideal cane toad habitat during the early to mid Dry season. The late Dry season will see high densities of cane toads near permanent water or moisture, including permanent billabongs and patches of monsoon rainforest.

The Wet season will probably see the highest numbers of cane toad metamorphlings, mainly around the moist margins of the waterbodies they emerged from. Wet season inundation of the major wetland habitats will see the majority of adult cane toads dispersing into the woodlands and open forests of the lowland plains. The vegetation within the woodlands will provide suitable shelter for cane toads during the Wet season.

Identification of species at risk

Predators

The initial susceptibility ranking of each of the 151 predator species identified as being *definitely*, *probably* or *possibly* susceptible to cane toads was further refined to a ranking of risk using exposure (ie available habitat overlap, feeding ecology, behaviour) and ecological/cultural importance status information. Four risk categories — *likely*, *possible*, *uncertain* and *unlikely* — were defined, being adapted from the original susceptibility criteria. Within these categories, different priorities were assigned.

The original 151 predator species were allocated a risk ranking accordingly. Ten species were considered *likely* to be at risk of experiencing population level effects, with the northern quoll being assigned the highest priority. The 9 remaining species including 5 lizards, 3 snakes, and one mammal were assigned high priority. Twelve species or species groups were considered to be at *possible* risk of experiencing population level effects, although none were listed as endangered or vulnerable, or thought to be notable (rare, or have restricted range, outstanding taxonomic interest, or uncertain or declining status) or flagship (ecological/cultural importance to Kakadu) species. Thus, all species were assigned moderate priority status. Represented in this category were two groups of aquatic invertebrates, 3 frogs, one lizard, 3 snakes, freshwater crocodile and 2 birds. Due to a lack of information, the risk of population level effects was considered to be *uncertain* for 98 species or species groups, although 21 of these were assigned high priority. These species include 3 fish, 3 frogs, 6 lizards, one snake, 4 birds and 4 mammals. The remaining species in this risk category were assigned moderate priority. These include two groups of invertebrates, 4 fish, 17 frogs, 9 snakes, 42 birds and 3 mammals. A total of 31 species were considered *unlikely* to be at risk of experiencing population level effects (based on relevant ecological, feeding or behavioural information) and were assigned low priority. These included 11 fish, 18 birds and 2 mammals.

Prey

Quantitative data on impacts to prey species are scant, and very little can be concluded about the species or species groups at risk. Cane toads occasionally consume small vertebrates, but populations of these are not likely to be at risk. There is little doubt that termites, beetles and ants will be heavily exploited by cane toads in Kakadu. Due to the potentially high cane toad densities, and an individual cane toad's ability to consume up to hundreds of prey items in one night, ground-dwelling arthropods are at greatest risk. The potential impact of cane toads on endemic invertebrates is unknown. The only species known to suffer long-term population decline or extinction from the impact of cane toads is a tapeworm found in the intestines of a snake.

Competitors

The available experimental information suggests that some native frog tadpoles (eg *L. ornatus*) may be at risk through competition with cane toad tadpoles. However, observations suggest that native frogs rarely share breeding habitats with cane toads. Although adult native frogs do not appear to compete with cane toads, the potential risk to native tadpoles represents a risk to native frog populations. Some of the smaller insectivorous reptile species of Kakadu may be at risk from competition for food resources by cane toads, but nothing more can be concluded.

Cultural, socio-economic and other risks

The major impacts on Aboriginal communities within Kakadu National Park will be a decline in some traditional foods and, in some situations, the alteration of ceremonies following declines of food and totem species. Aboriginal people elsewhere in the NT have accepted the presence of cane toads but still express concern regarding the impacts. Aboriginal communities within Kakadu may also become accustomed to cane toads albeit most likely sharing the same concerns. Cane toads will congregate in areas of human habitation within Kakadu, and will be of nuisance value in these places, and will also represent a risk to domestic and semi-domestic dogs.[1]

Tourism, the major economic activity of Kakadu, is not at risk from the presence of cane toads, and visitor numbers will not decrease as a result. With predicted high numbers in Kakadu, there may be an opportunity to harvest them for commercial benefit.

Other potential effects of cane toads have been hypothesised, including the contamination of water supplies, secondary effects on vegetation communities, the spread of human diseases, and the substance abuse of cane toad toxin. Details of these potential effects and hence the risks posed by them are essentially unknown.

Uncertainty and information gaps

This assessment has highlighted that there are major information gaps contributing to a large degree of uncertainty about the potential extent and impacts of cane toads in Kakadu. These include: uncertainty about densities of cane toads in Kakadu, effects of fire and burning regimes, degree of land/habitat disturbance, and the extent to which the Arnhem Land escarpment and plateau will act as a barrier and/or be colonised; the lack of quantitative data on the impacts on animal populations, particularly in the long-term, quantitative data on Kakadu fauna populations and distributions as well as dietary information; incomplete knowledge of Kakadu's invertebrate fauna, many being undescribed and possibly endemic;

[1] No domestic cats are allowed to be kept in the Park.

unknown response and susceptibility of most Kakadu fish species; unknown competitive interactions with native frogs; unknown chemoreceptive response in snakes and their ability to detect cane toad toxins; conflicting and unclear information on freshwater turtles; insufficient information on conservation listed species; the lack of experimental or anecdotal evidence regarding effects on bats; and impacts to as yet unidentified endemic species.

Recommendations for additional surveys and monitoring

Priority habitats for monitoring

Seven major habitat types were identified for future monitoring: floodplain communities; swamp communities; monsoon forest; riparian communities; woodland and open forest communities; springs, soaks and waterholes; and escarpment/plateau pools.

Priority species for monitoring

The species of most concern, and therefore a priority for monitoring, include the northern quoll, sandstone antechinus, red-cheeked dunnart, brush-tailed phascogale, dingo, all of the varanid lizards, northern death adder, king brown snake, western brown snake, ghost bat, black-necked stork, comb-crested jacana, Oenpelli python and freshwater crocodile. These are based on their risk rating, notability or listing as vulnerable, and also importance to Aboriginal people.

Given that many species assigned to risk category 3 were done so due to a lack of information about effects of cane toads, it is possible that further information could result in the re-prioritisation of some species.

Although risks to prey species are unknown, beetles, termites and ants should be considered for inclusion in monitoring programs.

Monitoring the possible effects of competition between cane toads and native aquatic invertebrates and vertebrates should be given high priority, particularly in escarpment/plateau pools where endemic species are known to exist. Similarly, monitoring for competitive effects between adult cane toads and insectivorous reptiles should also have high priority.

Priorities for addressing information gaps

A number of information gaps require addressing before more confident estimates of risks can be derived. Monitoring programs assessing the effects of cane toads upon Kakadu species will allow greater understanding of the risks. There is a need for appropriate baseline data, not just for cane toads but to monitor and assess other management issues that will arise in the future (eg other invasive species, fire and tourism). In addition, surveys should be conducted to identify and map the distribution of the endemic species of Kakadu, particularly in the escarpment and sandstone regions. All survey and/or monitoring programs should concurrently measure cane toad abundances and habitat preferences. Other information gaps that could be addressed but are less of a priority, include the effects of fire on cane toads and the lack of information for particular species or species groups (eg freshwater turtles, red goshawk).

Evaluation of past and present monitoring programs

As it may be several years before all of Kakadu is occupied by cane toads (eg some escarpment/plateau habitats), it is possible that some new monitoring programs may have sufficient time to accumulate pre-cane toad (ie baseline) data. It is highly unlikely that new monitoring programs will have time to provide similar data for many floodplain and lowland habitats. Data from major past and present monitoring programs within Kakadu may provide an alternative, noting that they were developed with objectives other than cane toad impacts in mind.

Broad scale surveys

The two major fauna surveys of the last 20 years provided information on abundances, distribution and habitat preferences of birds, mammals, reptiles and amphibians in a range of habitats similar to those identified in this report. The information from these surveys is not appropriate to use as current baseline. However, the established sites provide the opportunity for re-sampling before cane toads arrive. Not all habitat types were included in these surveys.

A proposed representative re-sampling of the Stage 3 Wildlife Survey, which is hoped to be undertaken next Dry season could possibly provide one season of pre-cane toad data.

Ongoing monitoring programs

The only major ongoing fauna monitoring programs in Kakadu National Park are those associated with assessing potential environmental impact downstream of ERA Ranger Mine and the Jabiluka lease area. Monitoring programs are being conducted by ***eriss*** and ERA/EWL Sciences (Energy Resources of Australia Ltd/Earth Water Life Sciences).

Aquatic macroinvertebrates are monitored at sites in the Magela Creek system (since 1988) and a number of control sites elsewhere in the Park. Sites from other areas have also been monitored regularly in the past (ie upper South Alligator River and Baroalba, Nourlangie and Gulungul Creeks). Though these studies were not designed for detecting cane toad impacts, inferences would be enhanced if cane toad invasion/distribution was monitored. Billabongs sampled in the Magela and Nourlangie Creek systems may provide information on (potentially vulnerable) freshwater snails.

Fish communities in the Magela, Nourlangie and upper East Alligator systems have been monitored annually since 1994, and data exist for fish migration patterns in Magela Creek from 1985 to 1996.

'Whole-ecosystem' monitoring by ERA/EWLS has also been conducted at sites in Swift, Magela and Nourlangie Creek systems. Zooplankton, macroinvertebrates, fish, frogs, reptiles, bushbirds, waterbirds and mammals were surveyed in 1994/95 and again in 2000/01.

Other surveys or monitoring programs

Other past programs may also contribute to background information, including surveys of waterbirds on the Magela and Nourlangie floodplains. It has been proposed to re-survey the original Magela floodplain sites, in order to update/add to the existing information on birds.

Information from the CSIRO Kapalga fire study from the late 1980s to the mid 1990s will provide a useful basis for detecting and assessing impacts once cane toads arrive there. Mammals, reptiles and insects were sampled originally and were re-sampled for small mammals in 1999.

It will be very difficult to obtain adequate baseline data for a cane toad impact monitoring program. While the ongoing programs will be of some use, they are not necessarily targeted at the priority species identified in this report.

Risk management and reduction

Given the outcomes of the assessment, some relevant issues can be discussed that may assist Park managers in developing a risk management strategy.

Parks Australia North has already been active with regards to management of cane toad issues, having initiated a cane toad identification training program and rapid response strategy to manage human assisted incursions of cane toads. Additionally, frog recording stations have been established at four sites in Kakadu (and more are planned). Baseline data have been collected for the past two Wet seasons.

Very little will be able to be done to reduce cane toad numbers in Kakadu. Particular measures may prove effective in localised areas (eg townships, caravan parks), but efforts would need to be ongoing. Management of areas damaged by feral pigs may help reduce the densities of cane toads in pig-affected areas. Chemical and biological control methods are insufficiently developed at this stage.

It is recommended that Parks Australia North manage the invasion of cane toads initially by i) ensuring that monitoring efforts are underway to assess the impacts of cane toads upon the natural and cultural values of Kakadu, and ii) investigating measures by which cane toads can be managed on a localised basis.

The preliminary risk assessment provides a starting point from which Parks Australia North can determine the monitoring requirements for fauna. In addition, it provides an overview of the potential cultural and socio-economic impacts, which could be studied in greater detail by appropriate experts.

Acknowledgments

This assessment would not have been possible without the generous assistance of many people. We thank Arthur Johnston (***eriss***), Peter Cochrane (Parks Australia), and Peter Wellings and Terry Bailey (Parks Australia North) for their support for and patience towards the outcomes of the project. For valuable advice on cane toads, Kakadu and other National Parks, and diets of native species, our thanks go to: Ross Alford (James Cook University), Laurie Corbett (Earth Water Life Sciences), John DeKoning, John Papple, Scott Bailey, John Woinarski and Bill Freeland (Parks & Wildlife Commission of the Northern Territory), Tony Griffiths (Northern Territory University), Rick Shine and Eric Dorfman (University of Sydney), Mike Tyler (University of Adelaide), Bill Daw (Roper River Land Care), Brian Pascal (Territory Manor — Mataranka), Colin O'Keefe (Queensland National Parks) and others listed on page 5. Thanks to Kathy Wilson (PA), Beryl Smith and Ryan Barrawe (PA/Jawoyn Traditional Owners for southern Kakadu) and Jacqui Rovis-Hermann (***eriss***) for their help and advice on the Katherine/Borroloola Region field trip. Members of the Borroloola, Burunga and Beswick communities for their time and patience describing 'life with toads'. Thanks to Ben Bayliss and John Lowry (***eriss***) for support with graphics and Chris Humphrey (***eriss***) for providing information on endemic aquatic invertebrates. For valuable comments on the final manuscript, thanks go to Bill Freeland, Ross Alford, John Woinarski, Peter Whitehead (Key Centre for Tropical Wildlife Management, Northern Territory University (NTU)), Chris Humphrey and Ann Webb (SSD).

Finally, this project was jointly funded by ***eriss*** and Parks Australia North.

List of abbreviations

ANPWS	Australian National Parks and Wildlife Service
ERAES	Energy Resources of Australia Environmental Sciences
eriss	Environmental Research Institute of the Supervising Scientist
EWLS	Earth Water Life Sciences
JCU	James Cook University
KNP	Kakadu National Park
KNPBM	Kakadu National Park Board of Management
NLC	Northern Land Council
NT	Northern Territory
NTU	Northern Territory University
PAN	Parks Australia North
PWCNT	Parks and Wildlife Commission of the Northern Territory
SIL	Snout–ischium length
SVL	Snout–vent length

Update

Spread of cane toads

Since this assessment was completed in September 2000 (and circulated for extensive peer review), cane toads were first reported in Kakadu National Park in January 2001. They have been found in the upper reaches of the South Alligator drainage where it adjoins the Katherine River drainage. On the 18th of August 2001 one large toad was found at the top of Jim Jim Falls and on the 31st of October 2001 an additional 4 large toads were found and cane toad tadpoles were discovered in a waterhole. Other toads were also heard calling in the area. Earlier in the year, 5 toads were found at the bottom of Jim Jim falls, but these were thought to have 'hitch-hiked', as none were found in the surrounding area. In November 2001 they were found upstream in the East Alligator River. In February 2002 cane toads were approximately 5km east of the Mary River Ranger Station. Surveys on the 14th of January 2002 confirmed that cane toads had arrived at the Kambolgie Creek camp ground, with 18 toads sighted on the Gunlom road between the Yurmikmik Trail car park and Kambolgie Creek.

Parks Australia North is contributing to a web site 'Northern Australian Frogs Database System' http://www.frogwatch.org.au recently established by FrogWatch that will provide updated information about the biology of cane toads and their spread through northern Australia.

Education and awareness

The cane toad identification training program and rapid response strategy outlined in section 4 was conducted jointly by KNP and ***eriss*** staff during November and December 2000, with numerous informal presentations and discussions held at locations throughout the Park. KNP staff, Energy Resources of Australia staff, tourist operators and the general public were briefed on cane toad impacts and the identification of cane toads, including the eggs and tadpoles. Posters, bulletins and items in local media articles and tourism newsletters were, and continue to be, part of the education and awareness program. A cane toad information 'flip book' being prepared for Aboriginal communities is also nearing completion. KNP staff have been trained to search for early cane toad incursions, and Park Rangers continue to monitor the spread of toads.

Monitoring

A number of monitoring programs have continued or have been initiated in the past 12 months that may provide valuable baseline (pre cane toad) data upon which to assess future impacts:

- The 'whole–ecosystem' monitoring in Magela Creek and Nourlangie Creek (Sandy and Buba billabongs) systems (see section 3.4.2) was repeated in 2000–2001.
- The aquatic macroinvertebrate and fish monitoring programs conducted by ***eriss*** are continuing on an annual basis (see section 3.4.2). Fish communities of Gulungul Creek were also examined in 2001, after an early monitoring period that extended from 1979 to 1990 and in which fish from 10 sites were surveyed on a monthly basis.

- The frog recording stations (see section 4) continue to be used to collect data on the relative abundance of native frog species, with two additional towers installed during 2001. The program will continue to 2002 after which funding support will be reviewed. This form of monitoring remains expensive and reliant on external expertise.
- Terrestrial fauna (small mammals, birds, reptiles and frogs) surveys were undertaken at around 260 quadrats in the southern half of the Park between January and November 2001, and at least some of these will be repeated in 2002. This employs baseline data from identical and comparable surveys conducted 5–10 years ago. (Tropical Savannas CRC, Parks and Wildlife Commission of the Northern Territory, and KNP staff).
- In 2001, radio tracking of the spotted tree monitor (*Varanus scalaris*) and the black-headed monitor (*V. tristis*) to examine habitat use, diet and territorial behaviour was carried out in the Koongarra Saddle region of Kakadu. (Professor Sam Sweet, University of California, Santa Barbara).
- Trapping and radio tracking of quolls was initiated in 2001 and will continue through 2002. Progress of the study beyond 2002 will be dependent on funding. (Dr Meri Oakwood, University of New England, NSW).

1 Introduction

1.1 Background

Territory and Commonwealth agencies have been aware of the impending arrival of the cane toad (*Bufo marinus*) to Kakadu National Park (KNP) and the Top End in general for a number of years (Jacklyn 1992, ANPWS/KNPBM 1991, 1998). Cane toads entered the Northern Territory (NT) in 1980 (Freeland & Martin 1985), and their presence has since been confirmed in western Arnhem Land, as far north as the headwaters of the Mann River system (J De Koning PWCNT pers comm), and to the south at Beswick (M Shepherd, NLC, pers comm), the headwaters of the King River, east of Katherine (*NT News* 21 June 2000) and the south-east of Nitmiluk National Park (J De Koning, PWCNT, pers comm). From this it is apparent that cane toads are rapidly approaching Kakadu National Park. Concerns about cane toads invading Kakadu have been raised on a number of occasions (ANPWS/KNPBM 1991, 1998, Jacklyn 1992, Roeger & Russell-Smith 1995, Storrs & Finlayson 1997). However, there has been little action to implement research and/or monitoring to predict, assess and if possible implement actions to minimise the impacts of cane toads on the natural ecosystems and cultural values of Kakadu.

In 1998, a workshop on the potential impacts and control of cane toads in Kakadu (ERAES 1998) again brought the issue to the fore. Although funding opportunities were considered scarce, there was consensus that a strategic approach for assessing and possibly minimising cane toad impacts should be developed. It was proposed that the initial step in any such approach should be a predictive ecological risk assessment to identify key species and habitats at risk, from which new monitoring programs could be developed and the relevance of existing monitoring programs assessed. Recently, Environment Australia acknowledged that the full extent of the impact of the arrival of the cane toad in Kakadu is unknown and should be assessed (Environment Australia 1999). This assessment was initiated as a direct result of these concerns.

1.2 Aim

The major aims of the ecological risk assessment were:

- To predict the likely extent of impacts of cane toads in Kakadu;
- To use this information to identify key vulnerable species and habitats that could form the basis of a comprehensive monitoring program.

1.3 Approach

1.3.1 Wetland risk assessment framework

eriss has developed a wetland risk assessment framework (van Dam et al 1999) based on established ecological risk assessment approaches (van Leeuwen 1995, US EPA 1998). The methodology, which has been adopted by the Ramsar Convention on Wetlands (Resolution VII.10), consists of six major steps:

- identification of the problem;
- identification of the (potential) effects;

- identification of the (potential) extent of the problem;
- identification of the risk;
- risk management and reduction;
- monitoring (fig 1) (van Dam et al 1999).

This risk assessment encompassed the first four steps of the framework in order to provide recommendations for monitoring, and also provide a basis upon which Parks Australia North could determine management actions. It was essentially a desktop and liaison exercise directed at collating, analysing, and making predictions based on all relevant information on cane toads in Australia and on the Kakadu environment. In addition to identifying key species at risk, it also served to identify the major information gaps, particularly in terms of the development of an appropriate monitoring program.

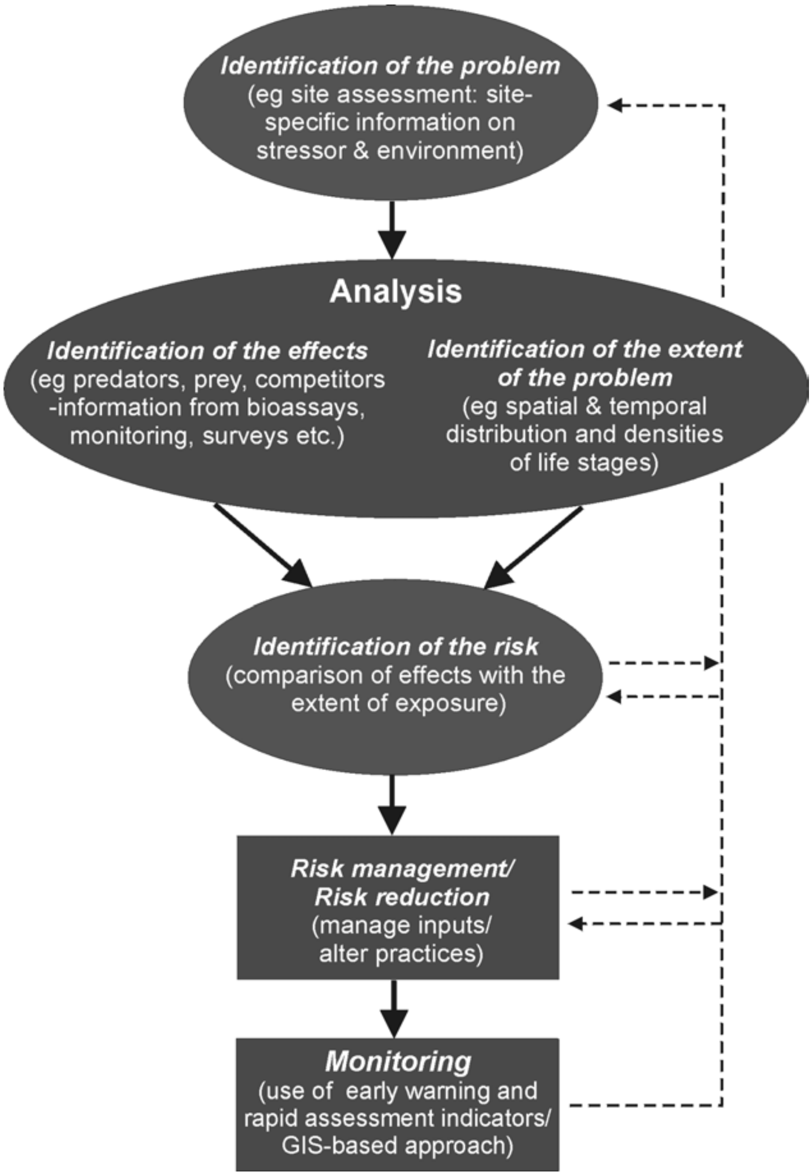

Figure 1 Model for wetland risk assessment (updated from van Dam et al 1999)

1.3.2 Information sources

Literature review

Both published and unpublished reports or data were sourced and obtained through a comprehensive literature review. Further relevant publications were then identified and obtained from within these sources.

In the 1980s and early 1990s, a number of comprehensive reviews of cane toad life history and potential impacts in Australia were published. Rather than re-evaluate all the specific publications and other reports incorporated in the reviews, this assessment utilised the reviews as the foundation of the information base, and built upon the foundation by evaluating the relevant literature since 1990. In some cases, earlier information was sourced in order to verify or obtain further specific information.

Information on Kakadu was obtained by searching and identifying the relevant research projects undertaken in the Park, and their associated outcomes since the early 1980s.

Liaison with government, universities and industry

Territory and Commonwealth agencies previously involved in cane toad research were also contacted where necessary to obtain relevant information and seek advice. These included Parks Australia North, CSIRO Division of Wildlife and Ecology, Parks and Wildlife Commission of the Northern Territory, Earth, Water Life Sciences (EWL Sciences; formerly ERAES), Northern Territory Tourist Commission, Northern Land Council, and Katherine Region Tourist Association. Relevant cane toad, native fauna and/or wildlife management experts consulted during the compilation of this report included:

Associate Professor Ross Alford, James Cook University

Dr Laurie Corbett, Earth, Water Life Sciences

Mr John De Koning, Parks & Wildlife Commission of the Northern Territory

Dr Bill Freeland, Parks & Wildlife Commission of the Northern Territory

Dr John Woinarski, Parks & Wildlife Commission of the Northern Territory

Mr Anthony Griffiths, Northern Territory University

Professor Gordon Grigg, University of Queensland

Mr Ian Morris, Noonamah, NT

Mr Greg Miles, Parks Australia North

Professor Rick Shine, University of Sydney

Professor Michael Tyler, University of Adelaide

Dr Peter Whitehead, Key Centre for Tropical Wildlife Management, Northern Territory University

Liaison with local communities

In order to understand community perceptions of cane toads, ***eriss*** and Parks Australia North held discussions with local Aboriginal people affected or soon to be affected by cane toads. Discussions were held in Borroloola, where cane toads have now existed for approximately 10 years, and in the Mataranka region (ie Barunga, Beswick), where cane toads only arrived in the first few months of 2000. The Borroloola meeting provided information on perceived impacts of cane toads, and a general understanding of how local Aboriginal communities had adapted to their presence. The Mataranka meetings helped to understand the types of issues local communities in and around Kakadu were concerned about, and also to disseminate general information on the cane toad.

2 The risk assessment

2.1 Identification of the problem

2.1.1 Cane toads — overview of natural history

Bufo marinus — more commonly known as the marine toad or cane toad — and its relatives are considered to be one of the older or more structurally primitive groups of broad skulled toads (Martin 1972). A fossil toad from the La Venta fauna of the late Miocene of Colombia (Estes & Wassersug 1963) is indistinguishable from modern *B. marinus* from northern South America. It was discovered in a floodplain deposit, which might suggest that *B. marinus* has always preferred more open habitats (Zug & Zug 1979).

Toads of the genus *Bufo* of the family Bufonidae have a natural worldwide distribution including the Americas, Africa and Eurasia. Areas described as having no native species of *Bufo* include Madagascar, Australia and its associated islands and New Guinea (Cogger 1992, Tyler 1975, Zug et al 1975). Cane toads have a natural range in Central and tropical South America extending from approximately 27° N latitude in southern Texas and western Mexico to 10° S latitude in central Brazil (Zug & Zug 1979).

Once a toad has reached approximately 50 mm SVL (snout to vent length) it may be recognised by certain characters: a heavy-bodied, short legged appearance with its maximum width being nearly three-quarters of its body length (fig 2). The head is broad with a truncate snout and bony ridges (cranial crest) on the periphery. Behind the head are a pair of large protuberant parotoid glands. The skin is exceptionally warty, and in juveniles of both sexes and mature females, the colouration is usually a dusky brown with a mottled dorsal pattern and a beige mid-dorsal stripe often present. Adult males are generally a more uniform cinnamon brown colour (Tyler 1975, Zug & Zug 1979).

The cane toad is one of the largest toads in the world, with females being recorded at 230 mm SVL and 1.25 kilograms in weight. No studies that assess cane toad longevity under natural conditions are known. However, toads kept in captivity have survived to nearly 16 years of age (Pemberton 1949, Tyler 1975).

The cane toad has a typical amphibian life cycle of egg–tadpole–juvenile–adult–egg. Egg numbers vary considerably with the size and age of the female (van Beurden 1980), and have been reported to number between approximately 4000 to 36 000 per adult (Mungomery 1936, Straughan 1966, Zug & Zug 1979). However, cane toad tadpoles are aggressive predators of cane toad eggs and often consume over 99% of eggs laid (Hearnden 1991).

Cane toads are said to be opportunistic breeders and are capable of breeding throughout the year (Beebe 1927, Stuart 1935, Duellman 1978, Mungomery 1935b), although in any given area, bioclimatic factors may determine the frequency and duration of breeding. For example, in subtropical areas, breeding is limited to the warmer months of the year (Krakauer 1968, Straughan 1966) and is generally stimulated by rain (Alcala 1955, Wingate 1965, Hardy & McDiarmid 1969, Crump 1974, Pippet 1975).

Figure 2 An adult cane toad

The Top End of the Northern Territory, including Kakadu National Park, has ideal bioclimatic conditions for prolonged cane toad breeding (Jacklyn 1992, and see sections 2.2.2 and 2.2.3). However, most breeding will occur during the wetter periods of the year, from December to June, depending on the size and length of the Wet season (Alford et al 1995, Freeland 2000).

Under NT conditions, newly-laid eggs have been reported to develop into tadpoles in around 3 days, with development through to complete metamorphosis taking approximately 22 days during the Wet season (Hearnden 1991). Newly metamorphosed toads are usually diurnal, but can also be active at night, with their activity governed mainly by moisture, temperature and wind resulting in a habitat restriction of no more than 10 m from the vicinity of water (van Beurden 1978, Freeland & Kerin 1991, James 1994). Adult toads are essentially nocturnal with peaks in activity occurring between 2100 to 0100 hours and 0500 to 0700 hours (van Beurden 1978).

There have been a number of studies done on the physiological tolerances of toads at all life stages. The thermal tolerances of the embryonic and larval stages have been detailed by Floyd (1983a). For embryos at the time of spawning, temperatures outside of 18°C and 34°C are fatal. Larval stage temperature tolerance depends on the thermal history and the stage of development, and up to the final stage of metamorphosis the range minimum is about 7°C to 15°C and the range maximum is about 38°C to 43.5°C (Floyd 1983b). For adult toads, critical temperatures are reported to be about 6°C to 12°C for the range minimum and 30.5°C to 42.5°C for the range maximum, again being dependent on thermal history (Stuart 1951, Krakauer 1970, Brattstrom & Lawrence 1962, Brattstrom 1968, Johnson 1972, McManus & Nellis 1975). For the larval stage of cane toads the rate of death due to desiccation is fast when compared to other anuran species (Valerio 1971). Adults are able to withstand the loss of up to 52.6% their body water (Krakauer 1970).

Cane toads have been reported to eat almost anything they are able to catch which is small enough to be swallowed (Easteal & Floyd 1986, Tyler 1975, van Beurden 1980). Of the approximately 2500 species of anurans in the world, it is one of only two that are truly omnivorous (Tyler 1975). Based on considerable numbers of studies on stomach content analysis (see section 2.3.2), the majority of the diet consists of insects and within this group there is generally a predominance of beetles and ants. Smaller quantities of crabs, spiders, centipedes, millipedes, scorpions, worms and molluscs may also be present, even vertebrates such as frogs, small mammals, lizards and snakes occasionally appear in the diet. Cane toads have also been observed consuming rotting fruit and vegetable matter found on refuse piles, as well as pet food (Alexander 1964, Ormsby 1955) and human faeces. Quantities of plant material have also been recorded in toad stomachs. It is thought that the diet of cane toads may reflect the available food within their location, though this has not been proven (Freeland 1984).

In both the native and introduced ranges, all of the literature on cane toad habitat report a preference for more open, disturbed or human modified habitats and usually close to water such as flood prone river banks, cleared forests, savannas, parklands, paddocks, dams and roadsides. In Australia, cane toads have been reported in every vegetation zone except for high altitudes, very arid areas and dense rainforest (Covacevich & Archer 1975). Jacklyn (1992) stated that toad densities should be higher in urban areas such as Darwin, and in open woodland areas such as Kakadu stage 3 and lower in the more densely vegetated areas such as Kakadu stage 1. Opinion is divided as to whether cane toads will thrive in the wetlands of the Top End. They would appear to be good tadpole habitat, but wetlands in Venezuela and the Everglades of Florida, for example, do not have high densities of toads (M Hero, pers comm, Krakauer 1968). As cane toads cannot tolerate extended periods of immersion, only the margins of the extensively flooded areas will be available to their terrestrial stages.

Like other species of *Bufo*, cane toads have a large pair of parotoid glands that can secrete or even squirt jets of a combination of highly toxic substances that act as a defense mechanism. Even the egg and tadpole stages may be toxic or at least unpalatable to both aquatic and terrestrial predators (Crossland 1992, 1997, Crossland & Alford 1998, Lawler & Hero 1997, Licht 1968). The toxin, a mixture of bufotoxins, bufogenins and possible other substances, is capable of killing a wide variety of animals including reptiles, birds and small mammals (Covacevich & Archer 1975), dogs and cats (Knowles 1964, Rabor 1952) and even humans (Licht 1967, Rabor 1952). On the other hand, some species are able to consume cane toads, either because they are immune to the toxin or they avoid eating the toxic skin and glands.

2.1.2 History of cane toad invasion in Australia

In the 1930s, entomologists were searching for control techniques to combat a number of insect pest infestations of considerable severity and economic magnitude. With the information available to them and in particular the absence of skilled herpetologists available for comment, they had no reason not to regard the cane toad as a cheap and effective method of control (Tyler 1975).

After favourable reports that the toad had successfully controlled sugar cane pests following its introduction into Puerto Rico (Dexter 1932) and other areas including much of the Caribbean and western Pacific, it was decided to introduce toads into Australia to control the greyback cane beetle (*Dermolepida albohirtum*) and the Frenchi beetle (*Lepidiota frenchi)* (Mungomery 1935a, 1936).

On 22 June 1935, 101 toads were introduced from Hawaii to Gordonvale, near Cairns in Queensland, and were maintained and bred at the Meringa Sugar Experiment Station

(Mungomery 1935b, 1936). Once progeny became available, they were transported to all major sugar cane growing districts in the state. By 1937, toads had been liberated in Mossman, Babinda, Ingham, Bambaroo, Giru, Ayr, Mackay, Bundaberg and Isis districts (Mungomery 1937). From these initial introductions, the populations soon began a geographic expansion, both along the coast and inland. The mode of dispersal was primarily natural or short distance movements with the assistance of humans (Easteal et al 1985, Sabath et al 1981).

The impetus behind the introduction of the cane toad into Australia was mainly from the sugar industry and, at the time, there was protest and controversy surrounding the introduction. Much of this came from natural history societies and individual naturalists (Froggatt 1936, Kinghorn 1938). This controversy has persisted (Freeland 1984). It was argued that the cane toad would have an adverse affect on the native fauna by out-competing other species for food and shelter, and by killing predators with its toxic chemical defenses. There was also speculation about the cane toad's ability to control the beetles, as there was no evidence from Australia to support this (Kinghorn 1938, Richardson 1941). In the years that followed, it became apparent that the cane toad was ineffective in maintaining control of the target pests in Australia largely due to the differing habits and specific habitats of predator and prey (Covacevich & Archer 1975, Richardson 1941).

In 1935 the Federal Government imposed a ban on further distribution of cane toads (Bell 1936a) pending more detailed data on their 'behaviour' under Australian conditions. Following intervention from the Queensland authorities who presented the Federal Health Department with data on diet analyses that were apparently adequate to provide the reassurances that had been sought, the ban was lifted in October 1936 (Bell 1936b, Tyler 1975).

Over the years there have been a number of reports of accidental and deliberate introductions of cane toads to areas outside of its initial distribution in Queensland (Covacevich & Archer 1975, Easteal et al 1985, Sabath et al 1981, Tyler 1975, van Beurden 1980). Three of the documented accidental releases occurred when specimens intended for laboratory use escaped in Darwin in 1974, Perth in 1974 and Sydney in 1978. Tyler (1975) detailed the accounts of the Darwin and Perth releases, attributing the unsuccessful establishment of populations to the cooperation and enthusiasm of the media, general public and officers of the relevant authorities. The specimens in Sydney also failed to establish a population (van Beurden, pers obs, in van Beurden 1981).

Some reported introductions (deliberate or accidental) where populations became established include Byron Bay in northern New South Wales (van Beurden & Grigg 1980), south-west Cape York, Fraser Island (Covacevich & Archer 1975), James Creek (north-west of Burketown) (Freeland & Martin 1985) in Queensland, and Groote Eylandt in the NT (W Freeland, pers comm, in Easteal et al 1985). In view of the number of isolates and releases that have been documented, human-aided spread is common, though often unsuccessful in marginal habitats. Even after all the reports on the adverse effects of cane toads, keen gardeners and nurserymen in New South Wales thought nothing of introducing cane toads to their gardens from nearby populations (van Beurden 1980).

2.1.3 Kakadu National Park — overview of habitats and fauna

Kakadu National Park is well known for its spectacular wilderness and nature conservation values (ANPWS/DEST 1991, Finlayson & Von Oertzen 1996). Kakadu is 20 000 km^2 in size and is located in the Alligator Rivers Region (the name 'Alligator Rivers Region' is derived from the network of rivers that form the main hydrological components of the area — fig 3).

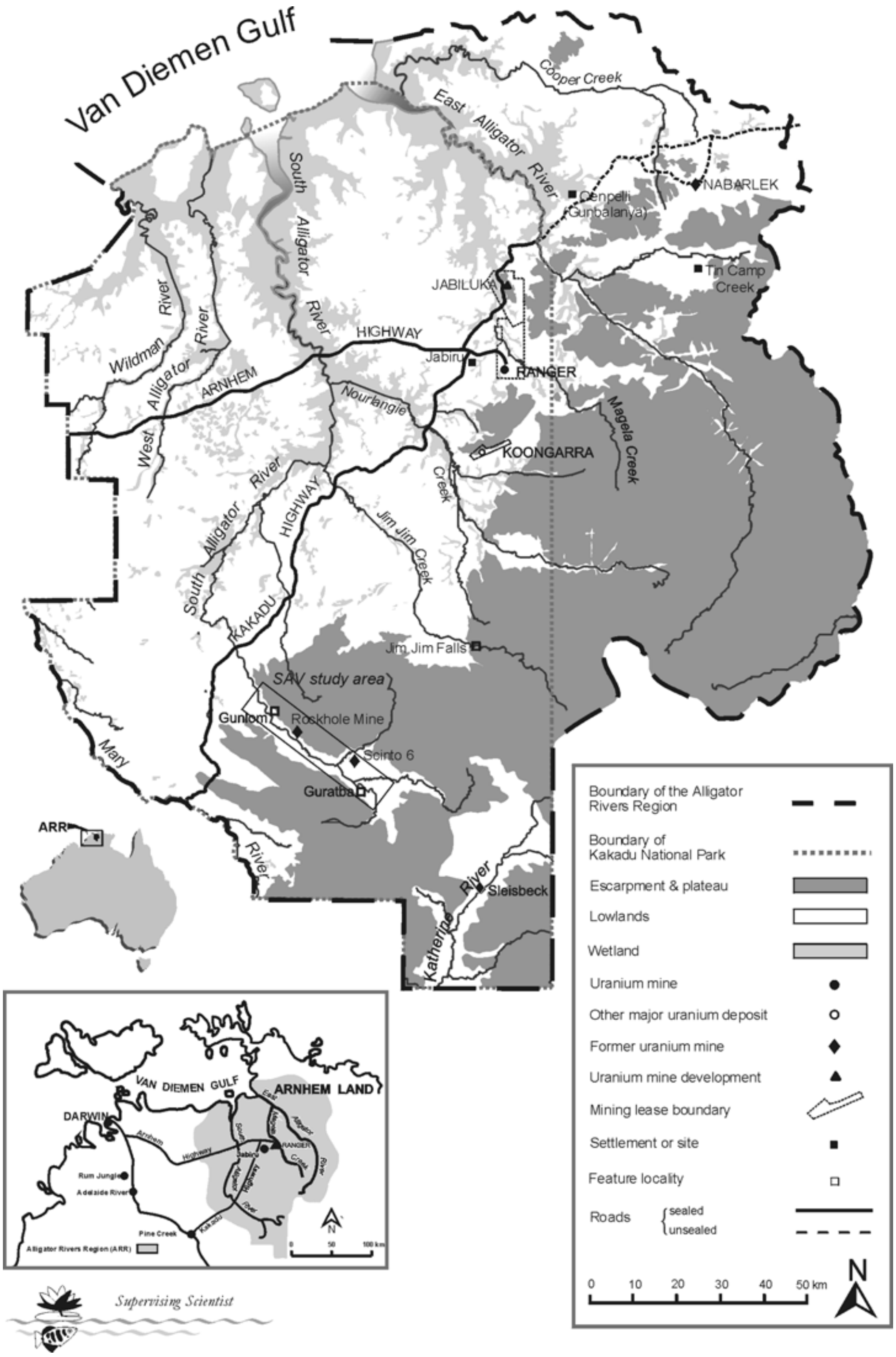

Figure 3 The Kakadu region

The Park extends southwards for over 250 km from Van Diemen Gulf in the north through large tidal estuaries, floodplains and lowlands to source areas at the head of the river catchments in the deeply dissected 'sandstone country' of the Arnhem Land Plateau.

In recent times Kakadu has been modified by pastoral, mining and tourist activities, as well as the introduction of exotic flora and fauna (Finlayson & Von Oertzen 1996). However, the geographic diversity, together with the wide climatic and hydrological gradients across Kakadu, creates a rich diversity of habitats (Braithwaite & Werner 1987). Not surprisingly, this diversity is reflected in the variety of plants and animals associated with the Park and, as a result, Kakadu is considered to be the most floristically and faunistically diverse area of monsoonal Australia (Lazarides et al 1988). For example, approximately 1874 species of plants (Brennan 1996), 184 species of spiders, some 296 species of crustacea, over 10 000 species of insects, 59 fish species, 25 species of amphibia, 128 reptile species, 289 species of birds and 64 mammal species are known to occur in the region (Press et al 1995). The Park's biodiversity along with its cultural heritage contributes to its status as a World Heritage Site and its recognition internationally by the Ramsar Convention as a site containing wetlands of international importance. Over the past 20 years tourism has boomed, with visitor numbers currently exceeding well over 200 000 per annum (Parks Australia 1999).

In general terms, there are five major landforms (also referred to as morphologic provinces or physiographic units) in Kakadu, each supporting a wide range of terrestrial and aquatic habitats:

- Coastal plains (containing estuaries, intertidal flats and chenier ridges);
- Floodplains (containing estuarine and alluvial plains);
- Lowland plains (dominated by eucalypt woodlands);
- Sandstone plateau (comprising the Arnhem Land escarpment complex and its outliers);
- The southern hills and basins.

A comprehensive description of the habitats, let alone the fauna of Kakadu is not within the scope of this assessment, however, a brief description of each major landform in Kakadu and the fauna typically associated with each is provided next.

2.1.3.1 Coastal plains

The coastal plains (intertidal wetlands) of Kakadu occupy approximately 127 450 ha (Bayliss et al 1997), comprising around 6.5% of the total Park area. The landform concerned, in places 4–5 km wide, lies within a macrotidal monsoonal environment driven by powerful physical and climatic forces that alter its characteristics over several scales in time and space (Davie 1985, Woodroffe et al 1985). Within the coastal plain region, the estuaries (tidal rivers where there is a mixing of salt and freshwater) and intertidal flats (themselves 16 400 ha in extent, Bayliss et al 1997) provide a niche for a wide array of plants and animals that are largely adapted to living in oxygen-deficient saline mud (Parks Australia 1999).

In common with the situation elsewhere in Kakadu, the nature and extent of the estuaries and intertidal flats vary considerably from one season to another. During the Dry season sea water is able to penetrate up the major rivers to a distance of approximately 100 km from the coast and hypersaline conditions develop on the intertidal flats. In contrast, both environments become freshwater dominated in the Wet season when floodwaters force the headwaters of the estuaries coastward and inundate the intertidal flats.

Mangrove communities are strongly zoned along the intertidal topographic gradient and occupy approximately 7200 ha of Kakadu (Bayliss et al 1997). They form relatively narrow bands along the coast and along tidally-influenced creeks and river banks.

Other habitats in the coastal plain region that can be defined in vegetation as well as elevational terms are (a) the discontinuous chenier ridges (up to 25–60 m wide) that occur inland of the mangrove zone and (b) the coastal dunes. The latter commonly support a coastal form of monsoon rain forest, stands of black wattle and, on unconsolidated beach sands immediately above the high water mark, narrow bands of foredune vegetation (eg *Spinifex, Ipomoea*).

The dominant habitats in the coastal plain region are:

- Mangrove communities;
- Samphire/saline mudflats (landward of the mangrove zone);
- Freshwater springs (on coast);
- Sedgeland (on chenier ridges);
- Coastal dunes, comprising both:
  - Mixed grassland/forbland (on foredunes);
  - Lowland monsoon rain forest (semi-deciduous);
- Nearshore reefs;
- Seagrass meadows;
- Non-vegetated (barren) wetlands, comprising:
  - Intertidal mudflats (seaward of the mangrove zone);
  - Clay pans;
  - Beaches.

The invertebrate fauna of the coastal plain region comprises 59 species of molluscs (especially numerous mud/mangrove dwelling species) and approximately 36 species of crustacea (Hegerl et al 1982). Sixteen species of prawns, dominated by sergestids (*Acetes* sp) and a penaeid (*Atypopenaeus formosus*), occur in the East Alligator estuary (Davis & May 1989). The insect fauna of the coastal plain region includes at least 83 species and there are 60 different species of spiders (Hegerl et al 1982).

The vertebrate fauna of the coastal plain region of Kakadu comprises 85 species of fish including many marine vagrants such as salt pan sole, tailed sole, mudskipper, barramundi, nursery fish, scat, thread-fin salmon, salmon-tailed catfish, pop eyed mullet, brown river stingray, mangrove jack, bull shark and river sawfish (Hegerl et al 1982, Griffin 1985). Davis and May (1989) list 52 species of fish in the East Alligator estuary, with sciaenids (*Johnius* spp.) and gobies the most abundant species.

According to Hegerl et al (1979), frogs are rarely observed in estuarine areas. However, 16 species of reptiles, including estuarine crocodiles, Stoke's sea-snake, white-bellied mangrove snake, bockadam, mangrove monitor, sea turtles (loggerhead, olive ridley, green, flatback, pacific) and two species of file snakes, are known to occur (Braithwaite et al 1991). Very few geckoes and skinks occur in mangrove areas (Hegerl et al 1979).

Morton and Brennan (1983) reported that at least 75 species of birds occur in the coastal plain region of Kakadu. These include numerous waders (the seasonal populations are not large according to Bayliss et al 1997), osprey, great egret, plumed egret, little egret, mangrove heron, pied heron, reef heron, brahminy kite, mangrove kingfisher and white-bellied sea eagle. Orange-footed scrub fowl and jabiru are commonly found near mangroves (Morris 1996) as well as notable species such as great-billed heron, large-tailed nightjar and collared kingfisher (Bayliss et al 1997, Parks Australia 1999). Notable species included those considered to be rare, or have restricted range, outstanding taxonomic interest, or uncertain or declining status (Woinarski et al 1989). Nankeen (rufous) night herons are known to utilise areas supporting monsoon forest on the coast as rookeries (Miles 1988).

Excluding marine mammals, such as dugong and short-beaked river dolphin, only four native mammal species are associated with the coastal plain region of Kakadu. These include northern brush-tailed possum, black fruit bat, water rat and false water rat. The false water rat (*Xeromys myoides*) is listed as vulnerable in the *Environmental Protection and Biodiversity Conservation (EPBC) Act* 1999. Feral cats are said to be numerous in mangrove areas (Morris 1996).

2.1.3.2 Floodplains

The 'floodplains' of Kakadu occupy approximately 193 850 ha or around 10% of the Park area (Bayliss et al 1997). They are underlain by nutrient-rich sediments (commonly known as black cracking clays) and experience an abundance of water in the Wet season and are an area of prolific plant and animal life. The floodplains in the lower reaches of the major river systems of Kakadu (referred to below as deltaic–estuarine 'blacksoil' plains) differ from those in the upper reaches (the alluvial plains) — they are underlain by slightly different surface sediments and set at slightly different elevations. Deltaic-estuarine plains are by far the most extensive (Woodroffe et al 1995).

The range of habitats found in each of the floodplain types are as follows:

Deltaic estuarine (blacksoil/organic clay) plains, containing:

- Salt mudflats;
- Mangrove/mangal creeks;
- Sedgeland (robust sedge meadows);
- Mixed grassland/sedgeland (in paleochannels);
- Back swamps and ill-drained depressions.

Alluvial (sandy/clayey sand) plains, containing:

- Grassland;
- Mixed grassland/woodland;
- Swamp communities of various types such as:
    - Reed swamp;
    - *Melaleuca* (paperbark) swamp;
    - *Nelumbo* (lotus lily) swamp;
- Lowland (sub-coastal) monsoon rainforest, on seasonally dry floodplain margins and around perennial springs;
- Riparian communities, both woody and non-woody;
- Channel habitats of various types such as:
    - Open water (linear permanent lagoons);
    - Perennial streams;
    - Seasonal feeder streams;
    - Springs;
    - Sandy creekbeds;
    - Soaks and waterholes;
- Off-channel habitats, including:
    - Backflow billabongs (or backwater swamps);
    - Paleochannels (cut-off meanders).

The large number of subtly different habitats that collectively make up the floodplains of Kakadu together with the large spatial extent of the floodplains mean that the fauna of the area is not only diverse, but also abundant. From the point of view of invertebrates, the species associated with the sub-coastal monsoon forests appear to be relatively well known. For example, Kikkawa and Monteith (1980) and Friend (1985) suggest that at least 120 species of spiders and 210 species of certain insect groups including 36 butterfly, 81 beetle, 32 Hemiptera, 17 Diptera, 15 Psocoptera and 29 grasshopper species are associated with this specific type of floodplain habitat (Press et al 1995). From the point of view of macrocrustacea, the floodplains of Kakadu are known to support species such as cherabin crayfish (*Macrobrachium* sp.), freshwater yabbie/crayfish (*Cherax* sp.) and freshwater crabs (*Holthuisana* sp.) (Morris 1996).

Numerous freshwater species of fish occur, prominent amongst which are saratoga, archer fish, longtom, empire gudgeon, chequered rainbow fish, flat head goby, mouth almighty, eel tailed catfish and freshwater herring (Bishop et al 2001). None are endemic to the region or listed under the EPBC Act (1999), although a potential candidate (listed as notable by Roeger & Russell Smith 1995), is the sharp-nosed grunter. At least 24 species of amphibia occur (Tyler & Cappo 1983, Braithwaite et al 1991), including the northern dwarf tree frog, *Litoria bicolor* (a specialised swamp dweller). There are no endemics or notable species (Roeger & Russell Smith 1995). Most are semi-aquatic or terrestrial with widespread occurrence in a range of habitat types.

Although 22 species of aquatic or semi-aquatic reptiles are associated with the floodplains of Kakadu (Braithwaite et al 1991), none are considered to be rare or endangered (Roeger & Russell-Smith 1995). The reptile fauna includes saltwater and freshwater crocodiles, freshwater turtles (pig-nosed, snapping, northern long-necked, short-necked), Macleay's water snake, Arafura file snake, water python, common tree snake, death adder, king brown snake, freshwater snake, slaty grey snake and Merten's water monitor (Miles 1988, Morris 1996). Of these, the saltwater crocodile and pig-nosed turtle are listed as notable species by Roeger & Russell Smith (1995).

Due to the spectacular aggregations of magpie geese (over a million birds) and ducks in the late Dry season, birds are an extremely important faunal component of the floodplains of Kakadu. None are endemic to the region or listed under the EPBC Act of 1999, but potential candidates (listed as notable by Roeger & Russell-Smith 1995) are magpie goose, burdekin duck, wandering whistling duck, yellow chat and grass owl. Both the latter species are restricted in Kakadu to the floodplains. The subspecies of yellow chat (*Epthianura crocea tunneyi*) occurring here is now recognised as endangered (Garnett & Crowley 2000). Typical floodplain species include green pygmy goose, purple swamp hen, white faced heron, jabiru, Australian pelican, forest kingfisher, azure kingfisher, little kingfisher, Australasian grebe, barking owl, rufous owl, bustard, masked plover, royal spoonbill, glossy ibis, red kneed dotterel, black fronted plover, darter, cormorant (little pied & little black), comb-crested jacana, brolga, and (in the Dry season) Australian pratincole (Miles 1988, Morris 1996). Amongst the 65 species of birds known to use the monsoon forest component of Kakadu's floodplains as their primary habitat (Kikkawa & Monteith 1980), the white-browed robin is the only one solely restricted to this habitat, and is listed as notable by Roeger & Russell-Smith (1995).

The floodplains of Kakadu are characterised by mammal species such as dingo, dusky rat, common planigale (a carnivorous marsupial mouse), delicate mouse, and water rat (Braithwaite et al 1991, Woinarski 2000). None of the mammal species known to use the monsoon forest component of the floodplains are restricted to it, but many species use it at some time in the year. A higher than normal dependency on monsoon forest is evident in species such as *Melomys burtoni* (rodent) and 4 species of bats, one of which, *Macroglossus minimus*, is listed as notable by Roeger & Russell-Smith (1995).

2.1.3.3 Lowland plains

The dry, gently undulating lowlands (or peneplains) of Kakadu comprise nearly 16 000 km^2, or 80% of the Park (Parks Australia 1999). The soils are shallow, infertile and often overlie extensive sheets of laterite and deeply weathered rocks. In common with the major landforms elsewhere in Kakadu, the lowlands are heavily influenced by seasonal factors (such as long waterless periods followed by periods of abundant rainfall) and, as a result, a complex mosaic of vegetation communities has developed in response to local differences in slope, soil and flooding regime (edaphic factors). The vegetation in the ground layer of the woodlands that cover Kakadu is dominated by tall grasses and is extraordinarily diverse in terms of plant and animal species.

The dominant habitats of the lowlands are:

- Tall open eucalypt forest (on better drained soils);
- Open eucalypt woodland (on slightly heavier, less well-drained soils);
- Mixed shrubland.

Scattered throughout these habitats are wetlands comprising:

- Heathlands (in poorly drained depressions);
- Perennial streams;
- Seasonal feeder streams;
- Springs and waterholes;
- Sandy creekbeds;
- Seepage zones and soaks.

Of all the landforms in Kakadu the lowlands are the richest in plants and animals. Compared with a similar area of wetland in the Park there are eight times the mean number of lizards, four times the mean number of mammals and twice as many frogs in the lowlands (Braithwaite 1985). The areas most rich in species are around seepage zones, but otherwise all species are widely distributed. According to Humphrey (1999) the high seasonality and vagility of the species associated with the lowlands has mitigated against endemism and accounts for the widely dispersed nature of the biota.

Apart from the considerable amount of data that are available about ants and termites in Kakadu (Andersen 1997), the invertebrate fauna of the lowlands appears to be poorly understood. However, with over 100 species of ants per ha in the lowland areas of Kakadu, the tall open eucalypt forest habitat contains the highest ant diversity in the world (Braithwaite & Werner 1987).

The vertebrate fauna of the lowlands includes numerous frogs and reptiles. Examples of frogs include red eyed tree frog, golf ball frog, green tree frog, northern bull frog and ornate burrowing frog (Miles 1988, Morris 1996). The area is frequented by snakes such as the king brown snake, olive python, children's python, black-headed python, carpet python, file snake, death adder, northern small eyed snake, brown tree snake, orange-naped snake, northern bandy bandy, half girdled snake, whip snake and western brown snake (Miles 1988, Morris 1996). Various monitor lizards, such as the sand goannas (*Varanus gouldii* and *V. panoptes*), spotted tree monitor (*V. scalaris*) and black headed monitor (*V. tristis*), dragon lizards and skinks, such as the frilled lizard, chameleon dragon, two-lined dragon, blue tongue skink, firetailed skink and Burton's legless lizard, as well as geckoes (eg velvet gecko and spiny tailed gecko) are all characteristic of the area (Miles 1988, Press et al 1995, Morris 1996).

The bird species found in the lowlands of Kakadu typically include carrion-eating varieties (such as the whistling kite and black kite), 15 nectar-eating species, 24 seed-eating species and 50 insect feeders (Braithwaite 1985). Other species commonly associated with the area appear to be barking owl, bush stone curlew, common koel, brown falcon, brown goshawk, crested hawk, blue-winged kookaburra, pied butcher bird, partridge pigeon, owlet nightjar, spotted nightjar, pheasant coucal, sulphur-crested cockatoo, little corella, chestnut-backed button quail and bustard.

Mammals recorded in the lowlands of Kakadu typically include agile wallaby, antilopine wallaroo, sugar-glider, brush-tailed possum and various marsupial carnivores, including the northern quoll, brush-tailed phascogale and fawn antechinus, black footed tree rat, brush-tailed rabbit rat, pale field rat and both species of fruit bats (Miles 1988, Morris 1996).

2.1.3.4 Sandstone plateau

The Arnhem Land plateau (composed chiefly of quartz and sandstone) is a harsh environment. It is exposed and extremely hot for much of the year, soil (shallow coarse sands) is scarce, plant cover is sparse and protection from insolation is generally lacking. Water drains away quickly with the result that, in the Dry season, the fauna of the region relies heavily on the small waterholes, springs and pools that remain in rock fissures, gullies or on the floor of the forested gorges. The rock platforms of the 'stone country', as it is called, are dissected by a network of deep gorges on the floor of which tall monsoon forest has developed. The dense shade, lower temperature and moisture of the forests aid the survival of all associated species.

There are a large number of endemic species in the sandstone region (Miles 1988, Morris 1996). This is presumably a consequence of the isolation and antiquity of the plateau region as well as the higher plant diversity and productivity associated with rocky areas. Amongst aquatic biota, the macrocrustacean groups, the isopods (family Amphisopodidae, genus *Eophreatoicus*) and prawns and shrimps (families Atyidae and Palaemonidae) that occur in the sandstone escarpment and plateau country of Arnhem Land display a high degree of endemism and species diversity (Bruce 1993, Bruce & Short 1993, G Wilson (Australian Museum), C Humphrey (***eriss***) & J Short (Qld Museum) unpublished data).

Up to 20 species of *Eophreatoicus* have so far been distinguished (though undescribed), with greatest diversity being in the north-west portion of the Kakadu/Arnhem Land sandstone plateau. To date, isopods have been found in springs and seeps of the King, East Alligator, South Alligator and Katherine rivers and/or their tributaries.

Two new palaemonid genera (Australia has only four genera) occur only in the sandstone escarpment and plateau country of Kakadu and Arnhem Land. Two species of the palaemonid shrimp, *Leptopalaemon*, are recognised; one unidentified species occurs in a tributary of Magela Creek while *Leptopalaemon gagadjui* (Bruce & Short 1993) is more widespread, occurring in stone country portions of the South Alligator, East Alligator, Katherine and Mann Rivers and/or their tributaries. Two species of the palaemonid shrimp, *Kakaducaris*, are recognised; both are extremely restricted in distribution and occur in upland, fish-free habitats. One undescribed species occurs in a few small tributaries of the East and South

Alligator Rivers, while *Kakaducaris glabra* (Bruce 1993) occurs in a small tributary of the South Alligator River.

A new (undescribed) species of atyid shrimp, representing a new genus, is known from a small spring at the base of the Mount Brockman outlier, in the upper catchment of Nourlangie Creek.

At least one species of freshwater crab, *Holthuisana* sp. (family Sundathelphusidae), is known to be a stone country endemic (J Short pers comm), being found in a tributary of Koolpin Creek (South Alligator River) and in the upper Katherine River and some tributaries.

The array of habitats that are found in the sandstone country include:

- Low, open eucalyptus woodland;
- Low shrubland (in sandy outwash areas);
- Closed monsoon rainforest (a wet form — associated with springs and seepages; a dry form — associated with boulder strewn scree slopes; and a depauperate form — associated with sandy ravines);
- Heathland (on shallow sandy soils);
- Dry spinifex (*Triodia*) grassland;
- Spongy (*Micraira*) grassland — in the Wet season;
- Ephemeral pools on rock platforms ('wet rockland');
- Perennial streams;
- Seasonal feeder streams;
- Springs, soaks and waterholes (mainchannel waterbodies); and
- Plunge pools (below waterfalls).

Between them, these habitats support some of the most highly valued and unusual fauna in Kakadu. For example, the terrestrial invertebrate fauna is known to comprise 184 species of spiders and 475 species of insects (including Leichhardt's grasshopper, 147 Coleoptera, 42 Hemiptera, 24 Diptera, 24 Psocoptera, 41 Lepidoptera and 31 Proctotrupoid species) (Kikkawa & Monteith 1980). The isopods, prawns and shrimps (macrocrustacea) also display a high degree of endemism and species diversity (Humphrey 1999).

The vertebrate fauna of the sandstone region, especially of the monsoon rainforests, includes less species of mammals, reptiles and frogs than some of the lowland habitats (Braithwaite et al 1991, Press et al 1995). Two endemic frog species (*Litoria personata* and *Uperoleia arenicola*) occur in the sandstone region (Braithwaite & Werner 1987). In all, only 8 species of amphibia are said to be associated with the monsoon rainforests of the sandstone region (Kikkawa & Monteith 1980), but many other species occur in other sandstone environments.

None of the freshwater fish species present in the sandstone region are endemic to the area or listed under the EPBC Act (1999). However, the region acts as a core area for potential candidates for listing, such as Mariana's hardyhead, exquisite rainbow fish, Midgley's grunter, and sharp-nose grunter (Roeger & Russell Smith 1995). Characteristic species of stream headwaters include black-striped rainbow fish, Gertrude's blue-eye and a number of terapontid species (Humphrey & Dostine 1994).

Although not particularly diverse, the reptile fauna of the sandstone region is highly distinctive. Apart from species such as ring-tailed dragon, long-tailed rock monitor, ridgetailed monitor, skink (*Egernia arnhemensis*), brown tree snake and carpet snake, species such as the Oenpelli python, *Gehyra pamela*, *Oedura gemmata*, and *Ctenotus coggeri* are all endemic (Braithwaite & Werner 1987). Kikkawa and Monteith (1980) consider 16 of the reptile species found in the sandstone region are closely associated with the monsoon rainforest component.

The monsoon rainforests of the sandstone region are a key habitat for frugivorous avifauna (eg the endemic banded fruit dove, rose-crowned fruit dove and Torres Strait pigeon). They are also important to birds such as Pacific baza (crested hawk), grey goshawk, large-tailed nightjar, little kingfisher, white-browed robin, channel-billed cuckoo, koel, rufous owl and yellow oriole. The sandstone friar-bird and the white-throated grass wren are endemic to the sandstone region monsoon rainforests (Miles 1988, Morris 1996).

The mammals of the sandstone country also comprise several regionally-restricted species such as black wallaroo, short-eared rock wallaby, little rock wallaby (nabarlek), sandstone antechinus, rock ringtail possum and large rock rat.

2.1.3.5 Southern hills and basins

Due to its heterogeneous geology, the southern hills and basins is a large region in the south of Kakadu of very marked environmental complexity (Woinarski & Braithwaite 1991). The area comprises a series of long, low, stony hills, rugged strike ridges of volcanic origin, granites and intervening valleys. Much of the landform has an extensive cover of pebbles and small stones. The dominant habitats include:

- Open eucalypt woodland;
- Low closed forest;
- Shrubland (open and closed components);
- Hummock grassland;
- Rivers and streams;
- Monsoon forest;
- Floodplains (or alluvial flats) comprising:
  - Sedgeland;
  - Grassland;
- Billabongs (in the Dry season);
- Sand springs (in the upper reaches of South Alligator).

The southern hills and basins is a region of Kakadu that is particularly rich in rare and endangered species (Woinarski et al 1989, Woinarski & Braithwaite 1991). Little is known about the invertebrate fauna. However, the vertebrate fauna comprises many freshwater fish species (such as saratoga, glass perchlet, rainbow fish, archer fish and sleepy cod), 24 frog species (two of which, carpenter frog and *L. personata*, are notable with respect to conservation) and 96 species of reptiles (Woinarski & Braithwaite 1991). Ten of the reptile species are classified as notable (eg northern knob-tailed gecko, jewelled velvet gecko, giant cave gecko, chameleon dragon, rock monitor, Oenpelli python and *Varanus primordius* (Roeger & Russell Smith 1995). The reptile fauna also includes freshwater crocodiles, Spalding's skink and freshwater turtles (northern long necked, pig-nosed and saw-shelled) (Miles 1988).

The birds of the southern hills and basins consist of 198 species, 8 of which are classified as notable (Roeger & Russell Smith 1995). These include the Gouldian finch, hooded parrot, white-throated grass wren, flock pigeon, partridge pigeon, banded fruit dove, rufous owl and red goshawk.

Native mammals are exceptionally diverse and abundant in the region. In fact, with 59 mammal species known to be present (14 of which are notable with respect to conservation), no other area in north-west Australia is known to be higher in terms of mammal diversity than the southern hills and basins of Kakadu (Woinarski & Braithwaite 1991). Many species (eg Calaby's mouse, Kakadu dunnart, short-tailed mouse) are restricted and considered rare and endangered (Roeger & Russell Smith 1995).

2.1.3.6 Conclusions regarding types and distribution of habitats, species richness and species-habitat associations in Kakadu National Park

Terrestrial habitats, mainly in the form of tall open eucalypt forest, comprise 80% (approximately 16 000 km^2) of Kakadu. Known as the lowlands landform they are the richest habitats in the Park in terms of plant and animal species. Within all five major landforms of Kakadu there is a wide variety of wetland habitats. By definition, these habitats comprise land where an excess of water is the dominant factor determining the nature of soil development and the types of plant and animal communities living at the soil surface (Cowardin et al 1977). The most extensive of these (covering approximately 2000 km^2) are the floodplain habitats of the Alligator Rivers Region.

The diversity of macroinvertebrates of freshwater environments in Kakadu is considered high (Outridge 1987), although no assessment of their conservation status in the Park as a whole is possible. Most assessments appear to have focused on escarpment pools, backflow billabongs and creek channel habitats on the Magela Creek. Hence, only in this particular river system are the dynamics of benthic macroinvertebrate communities in the streams, riffles and billabongs well known (Humphrey & Dostine 1994, Humphrey 1999).

The conservation status of the following invertebrate phyla could not be evaluated because of the lack of any data: Cnidaria, Platyhelminths, Polyzoa, Annelida, Arachnida (except for spiders) and Tardigrada.

Due to the low soil fertility of the lowlands of Kakadu, insects are pre-eminent amongst animals in their relationship with plants (Andersen & Braithwaite 1996). The lowlands support a diverse community of invertebrate herbivores (particularly termites and grasshoppers) that in turn support a rich fauna of vertebrate insectivores (particularly small birds and lizards).

Most of the data on the vertebrate fauna of Kakadu consists of species lists and information on their general biology (Woinarski & Braithwaite 1991). Generally speaking, information about the spatial and temporal distribution patterns of the vertebrate fauna is limited but, where known, is primarily related to moisture and nutrient gradients. Additionally, patterns of animal habitat distribution are influenced by fire intensity and frequency (Braithwaite et al 1991).

While many species occur throughout Kakadu they do not necessarily occur in all parts at all times (Braithwaite & Werner 1987). For example, wetland-dependent species move from one wetland to another seeking preferred habitat conditions. Similarly, many open forest species (eg flies) migrate to monsoon forests as a Dry season refuge (Kikkawa & Monteith 1980).

Feeding ecology is well known for certain types of waterbirds (eg cormorants, black winged stilt, whiskered tern and darter, Dostine & Morton 1988a,b, 1989), fish (Bishop et al 2001), aquatic/semi-aquatic reptiles (Shine 1986a,b) and frogs (Tyler & Cappo 1983).

In summary, of all the landforms in Kakadu the lowlands are the richest in plants and animals. The sandstone country is exceptionally important because of the large number of endemic species present in the area. Similarly, the southern hills and basins is a region of Kakadu that is particularly rich in rare and endangered species.

2.1.4 Conceptual model

A conceptual model, based on historical information on cane toad behaviour and ecology, and the ecological, cultural and socio-economic attributes of Kakadu National Park, is shown in table 1. This formed the basis of the risk assessment.

2.2 The potential extent of cane toads in Kakadu National Park

2.2.1 Distribution and range expansion

This section deals with the current and potential distribution of the cane toad in the NT, densities of natural populations and some factors influencing their distribution and density. Habitat and other environmental preferences are the main determinants of cane toad distribution and these are discussed in further detail in section 2.2.2.

2.2.1.1 Current distribution and invasion rates in NT

Cane toads moved into the NT during the 1982–83 Wet season, by following the Nicholson River drainage system (Freeland & Martin 1985). However, Jacklyn (1992) reported independent sightings of cane toads in the NT on the upper Nicholson River in 1980. The rate of spread of cane toads through the Gulf of Carpentaria lowlands and within NT up to 1999 has remained relatively constant, at around 27 km per year (Freeland & Martin 1985, Freeland 2000). This rate has been substantially greater than that recorded in northern New South Wales (<10 km per year; van Beurden & Grigg 1980, Freeland & Martin 1985). Freeland and Martin (1985) speculated that the different invasion rates may have been a consequence of a lack of topographic barriers to toad dispersal, and/or due to the tropical climate of the Gulf area being more suitable.

By 1995, the cane toad had invaded downstream areas of the Roper River catchment and was spreading upstream (Catling et al 1998). By October 1999, the cane toad had colonised almost the entire Roper River catchment and much of eastern Arnhem Land (Freeland 2000). In early January 2000, the cane toads arrived at Elsey National Park and Mataranka (S Bailey, PWCNT, pers comm) and since then have been reported at the outstations of Beswick and Barunga, in the Waterhouse River catchment (a sub-catchment of the Roper River), approximately 70 km south-south-east of the south east boundary of Kakadu National Park (fig 4). In late July 2000, cane toads were found to be present in Snowdrop Creek, an upper tributary of the Katherine River, about 15 km east of the Kakadu boundary, and were also reported to be in the headwaters of the Mann River, and in the south-east corner of Nitmiluk National Park (J De Koning, PWCNT, pers comm; fig 4). These recent reports of the current distribution of cane toads have indicated a much greater than average rate of dispersal during in the last (1999–2000) Wet season. Given that the Katherine River flows through the south-east corner of Kakadu only about 15 km downstream of its confluence with Snowdrop Creek, it is possible that cane toads are already present in Kakadu, in the Katherine River, although a recent search in the region did not reveal any cane toads (T Bailey, Parks Australia North, pers comm).

Table 1 Matrix of potentially adverse environmental impacts associated with the introduced cane toad (*Bufo marinus*) in Kakadu National Park

Environmental attribute at risk	Life history stages			
	Egg	*Larva (Tadpole)*	*Metamorphling/ Juvenile*	*Adult*
Predators				
Freshwater invertebrates	*	*		
Fish	*	*		
Amphibia	*	*	*	*
Reptiles		*	*	*
Birds			*	*
Mammals			*	*
Prey				
Phytoplankton		*		
Annelida			*	*
Mollusca			*	*
Arthropoda			*	*
Insecta			*	*
Chordata			*	*
Competitors				
Amphibia		*	*	*
Insect-eating birds			*	*
Insect-eating lizards			*	*
Cultural values				
Decline in bush tucker			*	*
Decline in totem species			*	*
Contamination of sacred sites	*	*	*	*
Impact on religious ceremonies	*	*	*	*
World Heritage values				
Rare and threatened species			*	*
Endemic species		*	*	*
Aesthetic			*	*
Human health				
Spread of disease in communities			*	*
Spread of human parasites			*	*
Poisoning (possible mortality)	*		*	*
Contamination of water supplies/bodies				
Drinking water	*	*	*	*
Springs/waterholes	*	*	*	*
Nearshore islands				
Depauperation of resident fauna	*	*	*	*
Significant vegetation types				
Annual grasses			*	*

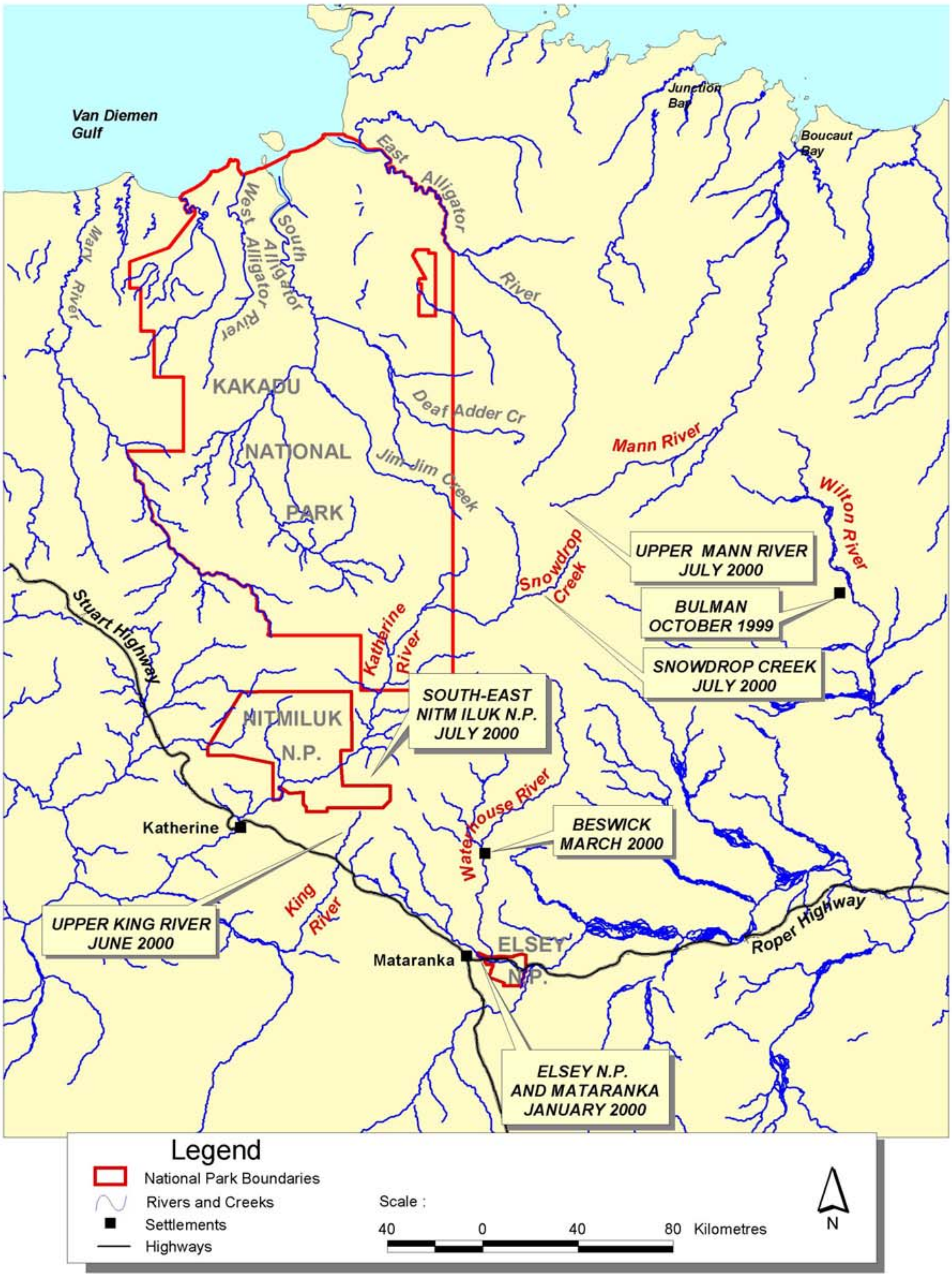

Figure 4 The documented current west north-west range of cane toads in the Top End. (Roads, drainage and locality information reproduced with the permission of the Australian Surveying and Land Information Group (AUSLIG), Canberra, www.auslig.gov.au)

2.2.1.2 Potential distribution

The potential distribution of the cane toad in Australia is still unclear because its geographical range is still expanding, however, several investigators have predicted the potential distribution and arrived at varying conclusions. Van Beurden (1981) predicted range expansion into coastal New South Wales and the northern sections of the western slopes of the Great Dividing Range, coastal Victoria and eastern South Australia, the south and north coasts of Western Australia, and the north coast of Tasmania and NT. Floyd (1983a) arrived at a more conservative estimate, predicting occupation of the whole of Cape York Peninsula, the north of the NT west to the Kimberley Plateau in Western Australia, and down the east coast as far as Wollongong. Recently, a more detailed modelling exercise indicated that the cane toad could permanently inhabit the wet coastal areas of the eastern and northern parts of the continent at least as far south as Port Macquarie in the east, and Broome in the west (Sutherst et al 1995).

Much of the Top End of the NT will be colonised by cane toads (Freeland & Martin 1985, ERAES 1998, Freeland 2000). Freeland and Martin (1985) predicted that at the current rate of spread, and based on following the coast, cane toads will have colonised the northern portion of the Northern Territory, by the year 2020. If they move to Darwin via the coast, Darwin plus the floodplains of the major rivers to the east of it will support large populations of cane toads by 2027. Based on migration up the Roper and Katherine Rivers, cane toads will arrive in Darwin by about 2020, assuming they travel at the same rate along rivers as they do across river systems. Human-assisted dispersal is likely to result in a far greater rate of colonisation (Freeland & Martin 1985). Jacklyn (1992) predicted that cane toads, by colonising and rapidly spreading down the Katherine and Daly River systems would most likely reach Litchfield National Park and Darwin before reaching Kakadu, which is protected by the south-east Arnhem Land escarpment. However, given the current north-western most range of cane toads (ie in the Katherine and Mann River catchments), they will almost certainly reach Kakadu before Litchfield and Darwin.

Colonisation of cane toads within catchments has been shown to be far greater than between catchments. For example, intra-catchment invasion rates have been reported at over 100 km per year, compared with 27 km per year for overall, long-term invasion in NT (Freeland & Martin 1985, Jacklyn 1992). Given the current distribution of cane toads near the eastern-south-eastern boundary of Kakadu, it is likely that the cane toad will first enter Kakadu via the Katherine River, subsequently moving into the adjacent upper South Alligator River catchment (fig 4). In addition, cane toads may soon enter Kakadu via Jim Jim Creek and/or Deaf Adder Creek (J De Koning, PWCNT, pers comm; fig 4). Once in the South Alligator River catchment, the spread of cane toads downstream to the northern coastal regions of Kakadu could occur within a matter of two Wet seasons. The potential extent of cane toads within Kakadu is discussed in section 2.2.3, following consideration of their preferred habitats and environmental conditions in section 2.2.2.

2.2.1.3 Densities

Numerous studies have assessed cane toad densities in relation to invasion and habitats. Cane toad density has been reported to vary according to time of the year, climatic variability, habitat type, degree of land disturbance, time since colonisation and density-dependent effects (Freeland 1986, Cohen & Alford 1993, Alford et al 1995, Lampo & Bayliss 1996, Lampo & De Leo 1998, Freeland 2000). Lampo and De Leo (1998) concluded that juvenile and adult survival, not egg or larval survival, were the major determinants of cane toad densities in Australia.

Information on the densities of the terrestrial stages of cane toads relates only to densities adjacent to bodies of water, which is certain to be the maximum density. Very little is known about densities of cane toads in general open forest or other habitats away from water. However, because cane toads are susceptible to desiccation (Schwarzkopf & Alford 1996), these densities are likely to be always lower, and possibly zero in the Dry season. Similarly, the distribution of tadpoles and metamorphlings is very patchy, and tadpoles also display a strong aggregative behaviour. Thus, density data for all cane toad life stages usually apply only to relatively small components of the environment.

Cane toad populations introduced into Australia have attained densities much higher than those reported in native habitats (Lampo & De Leo 1998). Density estimates for various native range habitats, including riparian forest, arid, semi-arid, savanna and urban, were an order of magnitude lower than density estimates for Australian populations (Lampo & Bayliss 1996). However, population densities in Australia also vary markedly, and thus, it is difficult to estimate long-term population patterns based on short-term density estimates (Lampo & Bayliss 1996). Freeland (1986a) found that mean population density increased from 536 ha^{-1} for a 1–2 yr old population (Westmoreland and Burketown), to 1173 ha^{-1} for a 19 yr old population (Normanton), but decreased to 82 ha^{-1} for a 47 yr old population (Townsville). However, further density estimates for Townsville between 1987 and 1992 indicated that the cane toad population fluctuates markedly, with both low and high densities (~1000–2000 ha^{-1}) being recorded within and between years (Alford et al 1995). Catling et al (1998) reported cane toad densities to increase from zero to just over 1000 ha^{-1} in a NT billabong from November 1995 to May 1997 (~18 months), while density estimates in another billabong where cane toads had occurred for at least 5 to 7 years ranged from 10 to approximately 300 ha^{-1}. Thus, cane toad numbers increase rapidly following colonisation (Freeland 1986a), but there has been some evidence of post-colonisation declines, thought to be due to factors such as depletion of food resources, or a response to predators, pathogens or parasites (Easteal & Floyd 1983, Freeland 1986a, Catling et al 1998). However, at this stage there is no direct evidence of post-colonisation declines in density in the NT (Freeland 2000).

Little attention has been paid to the comparison of cane toad densities in undisturbed and disturbed habitats in Australia. However, in other countries cane toads have been observed to reach higher densities in disturbed areas (Zug et al 1975, Zug & Zug 1979, Freeland 2000). Population densities are high in urban areas or areas of human habitation and rapidly decrease in less disturbed habitats (Zug et al 1975).

In addition, rain forest, swamps and rivers have apparently acted as dispersal barriers (Zug et al 1975). In Australia, during the Dry season, the highest densities occur in habitats near to water, while during the Wet season, populations disperse into other habitats (Alford et al 1995). This is discussed further in section 2.2.2. Population numbers in Queensland have been reported to increase after a good Wet season (ERAES 1998).

Densities of cane toad tadpoles and metamorphlings have also been reported in Australia (Cohen & Alford 1993, Alford et al 1995, Freeland 2000). Alford et al (1995) found mean tadpole densities at Calvert Hills Station in the NT and Townsville to vary between 15 m^{-2} to 61 m^{-2} (~ 0.11/L to 0.45/L). Hearnden (1991) reported much higher peak tadpole densities, in the order of 600-800 m^{-2} (~ 4.4/L to 5.9/L), but these estimates were based on organism-weighted ratios, and only serve to highlight the strong aggregative behaviour and patchy distribution of cane toad tadpoles. Mean densities of metamorphlings (newly emerged; 9–29 mm snout-ischium length [SIL]) have been estimated at 2.1–2.6 m^{-2} within one metre of a waterbody, and 0.6–0.8 m^{-2} at two to five metres from water (Cohen & Alford 1993). As newly metamorphosed toads spend almost their first few weeks close to water (Boomsma &

Arntzen 1985), these represent density estimates for the most preferred habitats. Metamorphling densities away from the moist margins of waterbodies would be very close to zero except after rain (Freeland & Kerin 1991, James 1994; also see section 2.2.2.3)

2.2.1.4 Methods of dispersal and factors affecting dispersal

Cane toads can disperse by natural or human-related means. Natural rates of spread are generally slower than human-related spread. Natural dispersal of cane toads is facilitated by a range of means, including transport of eggs and tadpoles by flood waters, transport of eggs and early tadpoles in the plumage of waterbirds, and rafting by adults during floods (van Beurden 1979). Human-related spread includes the accidental or deliberate introduction of cane toads to a previously uncolonised area (Tyler 1975, van Beurden 1979, Sabath et al 1981, Freeland & Martin 1985, Easteal & Floyd 1986). Natural dispersal of cane toads can be facilitated by human activity, such as land clearing, roads acting as movement corridors for toads, and the construction of farm dams (Straughan 1966, Seabrook & Dettman 1996, Freeland 2000).

The gradual spread of the cane toad from sites of introduction suggests that active, long distance transportation by humans has not been a major mode of dispersal (Sabath et al 1981). However, it has been acknowledged that modern transport clearly has the capacity to hasten the cane toad's colonisation of Australia (Freeland & Martin 1985). It seems likely that the isolated population of cane toads reported north-west of Burketown in 1980 was established with human assistance (Freeland & Martin 1985). It is this population that has moved into the NT. Isolated introductions of cane toads to the Darwin region have been reported on a number of occasions, although they were contained in all cases.

Roads and other vehicle tracks have been shown to provide an efficient dispersal mechanism for cane toads, as they provide corridors of open, level ground devoid of vegetation, along which toads concentrate their activity (Seabrook & Dettmann 1996). It is evident that roads influence the direction (and distance) that cane toads travel and facilitate the colonisation of new areas and of natural habitats intersected by roads and vehicle tracks (Seabrook & Dettmann 1996). Seabrook and Dettman (1996) found far fewer cane toads in rainforest and wet sclerophyll forest than on the roads that went through them. Land clearance for agricultural/pastoral and associated activities also appears to have helped the spread of cane toads (ERAES 1998). In addition, cane toads may benefit from cattle hoof prints, pig-rooting holes and hollows beneath or within fallen trees as small depressions and fallen trees provide cover and protection from desiccation (ERAES 1998).

Topographic/geographic barriers are known to influence the dispersal of cane toads. Dispersal of toads has been slower in mountainous regions than in the lowlands (Zug & Zug 1979, Easteal & Floyd 1986). Barriers in the form of waterfalls are also likely to restrict, but not preclude, the movement of cane toads. In addition, relative rates of dispersal are also likely to depend on the density of surrounding vegetation (Seabrook & Dettmann 1996).

Other factors affecting the dispersal of cane toads include the availability of suitable shelter and water/moisture (van Beurden 1981, Alford et al 1995, ERAES 1998), and these are discussed in further detail in section 2.2.3. Minimum temperature and rainfall tolerances are not likely to be a limiting factor in the dispersal of cane toads in northern Australia (Sabath et al 1981).

2.2.2 Preferred habitats and environmental/bioclimatic conditions

An understanding of the types of habitats and environmental/bioclimatic conditions preferred by cane toads is essential in predicting their potential extent in Kakadu. Habitats and environmental conditions are discussed together here as they are interrelated and often difficult to separate.

2.2.2.1 Embryos

Cane toad embryo habitats equate to the breeding sites of adult cane toads (see section 2.2.2.4). Briefly, cane toad eggs are laid in long gelatinous strings, in a range of aquatic habitats, including permanent or temporary waterbodies, and slow running or standing water, and are usually attached to aquatic vegetation or surfaces such as sticks or rocks (Easteal & Floyd 1986, Freeland 2000). Embryo development and survival are dependent on particular environmental/bioclimatic conditions. Cane toad embryos emerge as hatchlings within 2–3 days following egg deposition, depending on temperature (van Beurden 1979, Floyd 1983a, Freeland 2000).

Cane toad embryos have successfully developed into tadpoles in 15% seawater (ie 5‰ salinity) and 0.6% NaCl (6‰ salinity), indicating some tolerance to saline conditions (Takano & Iijima 1937, Ely 1944). Covacevich & Archer (1975) noted an instance of adult cane toads in amplexus and a string of freshly laid eggs in the salt water of Rainbow Beach in south-east Queensland, as well as cane toad eggs, tadpoles, and newly metamorphosed young on a tidal flat at Amos Bay, 30 km south of Cooktown (Covacevich & Archer 1975).

2.2.2.2 Tadpoles

As with embryos, tadpole habitats are largely pre-determined by the preferred breeding habitats of adult cane toads (section 2.2.2.4/1). There are particular conditions within habitats that are more suited to tadpole survival than others. These are discussed further below.

Salinity and temperature are two factors that affect the survival potential of cane toad tadpoles. Schultze-Westrum (1970) has reported the ability of cane toads in New Guinea to breed in brackish water and to survive water temperatures of 40°C in the larval stage. The thermal tolerance limits of cane toad tadpoles are considered to be around 8–45°C (Crossland 1997), although their optimal range would presumably be significantly narrower than this, as is the case for adults (Freeland 1984). Tadpoles have been successfully raised in water of 5–6‰ salinity (Takano & Iijima 1937, Ely 1944). At 7‰ salinity, Ely (1944) found that some hatchlings emerged and reached 2–3 mm. in length, but all died within 3 days. Thus, around 6‰ salinity can be considered the upper tolerance limit for successful development of cane toad tadpoles. Cane toad tadpoles have been observed in hot, shallow, slightly brackish pools on a tidal flat at Amos Bay, 30 km south of Cooktown (Covacevich & Archer 1975). Unfortunately, the salinity of these pools was not reported. Takano & Iijima (1937) also successfully raised eggs and tadpoles in water with pH values of between 4 and 9, further indicating their broad environmental tolerances.

Cane toad tadpoles exhibit diurnal behaviour, being most active and feeding during the day, and less active at night (Zug & Zug 1979). It has been observed that they undergo colour transformation, from black during the day to mottled pale brown (similar to the substrate) at night. This may reflect the relative advantages of maximising heat absorption during the day and then reverting to cryptic coloration at night (Evans et al 1996). Cane toad tadpoles also form dense congregations or schools numbering hundreds of individuals (Freeland 2000).

Preferred habitats of cane toad tadpoles within certain types of waterbodies have been described to some extent. In rivers and streams, cane toad tadpoles are most common in shallow, lentic areas (Evans et al 1996). In the NT, Freeland (pers comm) found that cane toad tadpoles were commonly found in both temporary and permanent waterbodies. However, cane toad tadpoles were uncommon in aquatic habitats with clay or silt substrates, whereas many native anuran tadpoles were positively associated with such habitats (unpublished, as cited in Freeland 2000). Cane toad tadpoles also appear to be more common in waters of high transparency and light penetration, and this could be due to a greater abundance of algae (as a food resource, Evans et al 1996) and/or the higher water temperatures (facilitating larval development, Floyd 1983a, Hearnden 1991). As cane toad tadpoles approach metamorphosis, their swimming ability decreases and they aggregate in the shallow margins of the waterbody, awaiting full metamorphosis (Easteal & Floyd 1986, Crossland 1997).

2.2.2.3 Metamorphlings

Metamorphosis of *Bufo* tadpoles is more rapid than most native toads, but the newly-emerged metamorphlings are small and physiologically underdeveloped (Pough & Kamel 1984, Freeland & Kerin 1991, Cohen & Alford 1993). Their small size makes them susceptible to evaporative water and heat loss and, as a result, newly-metamorphosed cane toads congregate and remain around the moist margins of waterbodies (Freeland & Kerin 1991, Cohen & Alford 1993). In addition, the physiological constraints of cane toad metamorphlings determine the environmental conditions in which they are most active. Activity is promoted by warm temperatures, moist substrates and conditions that allow for evaporative cooling (ie windy) (Freeland & Kerin 1991). As a result, cane toad metamorphlings are usually active during the day, although they can be active at night under certain environmental conditions (eg dry conditions; Freeland & Kerin 1991, James 1994).

Cohen and Alford (1993) found that metamorphlings were restricted to within 5 m of the water's edge, with over 95% of the smallest (9–12 mm SIL) metamorphlings occurring within 1 m of the water's edge, and larger metamorphlings (19–29 mm SIL) up to 5 m from the water's edge. Interestingly, the effect did not differ between the wet and Dry season. These findings were reported for riverine habitats similar to many of those found in Kakadu (ie characterised by gently sloping banks vegetated by *Melaleuca* and *Pandanus,* surrounded by dry open *Eucalyptus* woodland). Thus, most metamorphlings will be restricted to the aquatic habitats they emerged from, unless it rains (eg during the Wet season), and other waterbodies can be accessed (Freeland & Kerin 1991, James 1994).

The capacity for cane toads to move away from water is greatly influenced by body size. Larger toads can be active in cool, dry, shady, or windy night-time conditions that inhibit activity of smaller toads (Freeland & Kerin 1991). As a result, they are able to disperse into drier habitats away from water. However, an increase in body size also reduces the relative capacity for evaporative cooling and thus restricts activity under hot windy conditions (Freeland & Kerin 1991). Thus, as cane toads develop into juveniles (30–70 mm SVL), their activity pattern changes to one of nocturnal and diurnal depending on size and the environmental conditions (Freeland & Kerin 1991, James 1994).

Cane toad metamorphlings experience high mortality due to the conditions of the physical environment, predation and competition (Freeland & Kerin 1991). Preferred environmental conditions for metamorphling growth and survival include sufficient moisture (ie substrata with ~20% moisture wet/weight), vegetation cover (which provides both shelter and food resources), and lower population densities (James 1994, Alford et al 1995). These factors interact with the availability of suitable retreat/shelter sites, such as vegetation litter, fallen trees, cattle hoof prints and even pig rooting holes (Alford et al 1995, ERAES 1998).

Little is known of the salinity tolerances of metamorphling and juvenile cane toads. However, they have been observed being active on tidal flats (Covacevich & Archer 1975).

2.2.2.4 Adults

General

Adult cane toads are nocturnal, terrestrial and ground-dwelling in nature (van Beurden 1978, Easteal & Floyd 1986), and require regular access to moisture (van Beurden, 1980, Freeland & Kerin 1988). They are reported to be most active soon after dusk (Zug & Zug 1979, Easteal & Floyd 1986), with major activity peaks occuring in the late evening between 2100 and 0100 hours, and also in the early morning from 0500 to 0700 hours (van Beurden 1978).

In Australia, cane toads have been reported in every type of habitat except at high altitude and in very arid areas (Covacevich & Archer 1975). Much of the information on habitat preferences indicates that adult cane toads reach their highest densities in open, disturbed habitats, close to available water, such as floodprone river banks, areas cleared of vegetation (eg grazed paddocks, farm dams, roadsides), villages or communities (eg household lawns, parklands, golf courses, roadsides) and other open areas (eg burnt habitats) (Zug & Zug 1979, van Beurden, 1980, Freeland 1984, Easteal & Floyd 1986). Such habitat use has also been reported from overseas studies (Krakauer 1968, Zug et al 1975, Zug & Zug 1979).

Adult cane toads will also occur in many undisturbed habitats including grasslands, savannas and rainforests, although densities in areas with closed tree canopies may be lower than open areas (van Beurden 1979, Seabrook & Dettmann 1996, ERAES 1998). Heavy ground-level vegetation may also reduce cane toad density by restricting movement and ability to sight prey (van Beurden 1979, Zug & Zug 1979, Seabrook & Dettmann 1996). However, dense ground-level vegetation will not exclude cane toads, and may actually benefit them during dry periods by reducing desiccation (ERAES 1998).

According to Straughan (1966), all habitats in Queensland, from the dense, wet rain forests adjacent to the coast to the dry savanna woodlands of the ‘cattle country’, have been successfully colonised by cane toads. Van Beurden and Grigg (1980) reported that adult cane toads were present in Queensland in coastal bog, leprionia swamp, teatree swamp, sheoak swamp, shallow brackish lagoon, heath, dry sclerophyll, wet sclerophyll and rain forest habitats, although sightings in the latter two were rare. No individuals were recorded in areas of dense mangrove habitat (van Beurden & Grigg 1980). Seabrook (1993) also found very few cane toads in wet sclerophyll and paperbark swamp. Other researchers have also commented that cane toads are either absent or only present in very low numbers in dense tropical rainforest (Zug et al 1975, van Beurden 1978, Freeland 1984, Seabrook 1993, Seabrook & Dettmann 1996), and that unbroken forest can and does act as a dispersal barrier (Zug & Zug 1979, Seabrook & Dettmann 1996). R Alford (JCU, pers comm, 2001), recently stated that although cane toads are often in low densities in large, unbroken areas of rainforest, they can reach relatively high densities in small patches or gallery forests, simply because such habitats provide moist refugia from the drier savannas that surround them, and in which the toads forage. Radio-tracking of cane toads at Heathlands Reserve on Cape York Peninsula, confirmed that cane toads regularly used the gallery forests that occur along the creeks (R Alford, JCU, pers comm). Van Beurden (1980) found that the percentage of land cleared and the proximity of fresh water proved to be the strongest correlates of cane toad numbers, with the two variables accounting for 60% of the variability of toad numbers. Further evidence for cane toads’ dependence on freshwater is provided by Freeland (2000) who reported that adult cane toads, where possible, visit freshwater at least once every three days.

Freeland (1984) reported few differences between the kinds of habitats used by cane toads in the Americas (the original distribution of cane toads) and in countries where the cane toad has been introduced. Zug and Zug (1979) summarised the types of habitats the cane toad inhabits in its native range (table 2), highlighting the broad environmental tolerance range of the species. For the NT, it has been reported that cane toads are most abundant in areas of little or no grass, herb or shrub cover (Freeland 2000). In addition, abundance varies according to substrate — highest on soils of fine texture, intermediate on sand and lowest on rocky substrates (Freeland 2000).

Table 2 Selected examples of habitats occupied by cane toad populations in other parts of the world (habitat descriptors unchanged from original sources)*

Habitat	Locality	Source**
sandy beach	Mexico	Hardy & McDiarmid 1969
along streams	"	"
clearings in cloud forest	"	Martin 1958
tropical scrub forest	"	Duellman 1961
quasi-rainforest	"	Duellman 1965
broad-leafed forest	"	"
dense scrub forest	"	"
coconut grove		"
rainforest	Guatemala	Duellman 1963
grasslands	"	Stuart 1950
aquatic-riparian	"	"
open broad-leaf forest	"	"
true savanna	"	"
tropical moist forest	Honduras	Meyer & Wilson 1971
tropical dry forest	"	"
tropical arid forest	"	"
subtropical wet forest	"	"
subtropical moist forest	"	"
subtropical dry forest	"	"
tropical rain forest	Guyana	Beebe 1925
open cleared areas	Trinidad	Kenny 1969

* After Zug & Zug (1979); ** See Zug & Zug (1979) for reference details.

Adult cane toads can withstand saline conditions for varying periods, and appear to have a tolerance of, rather than a preference for, salt or brackish water (Easteal & Floyd 1986). There are accounts of adult cane toads in salt or brackish water, including swimming at sea in Bermuda and in the brackish water of an estuary in Mexico, on tidal mudflats in Jamaica, and on tidal flats, frontal dunes of ocean beaches, and the inland border of coastal mangroves in Australia (Neill 1958, Covacevich & Archer 1975, Easteal & Floyd 1986). In the NT, traditional land owners have observed adult cane toads swimming in McArthur Estuary, and thus colonising Kangaroo Island, at the mouth of the Carrington and McArthur Rivers (Begg et al 2000). The pH of a waterbody also appears not to restrict the presence of adult cane toads. Straughan (1966) and Covacevich and Archer (1975) reported that areas of coastal wallum (*Melaleuca quinquenervia* woodland with poorly drained and very infertile soils) in south-east Queensland (Cooloola), which are characterised by very acid waters, supported large populations of toads.

Breeding sites

In the NT, both male and female cane toads remain in reproductive condition throughout the year (Freeland 2000), although breeding activity is usually concentrated in the wetter periods (ie December–June; Alford et al 1995). In both the cane toad's native range and in Australia, reproduction occurs in a wide variety of wetland habitats (Freeland 1984), including lotic (flowing — rivers and streams) and lentic (standing — lagoons, lakes, dams and ponds) permanent waterbodies, temporary waterbodies and even brackish water (Ely1944, Neill 1958, Covacevich & Archer 1975, Evans et al 1996, Freeland 2000). However, certain preferences do exist.

Evans et al (1996) investigated the factors influencing choice of breeding site by the cane toad in its native range (ie Venezuela). The majority of results can most likely be extrapolated to Australia and in particular Kakadu National Park. Lentic waterbodies, particularly those isolated (either seasonally or permanently) from a river or stream, appeared to be preferred as breeding sites to lotic waterbodies (Evans et al 1996). In addition, breeding appeared to be preferred in temporary rather than permanent waterbodies, although Freeland (2000) did not report such a preference for cane toads in the NT.

There are a range of other factors that also appear to influence the choice of breeding site. Evans et al (1996) found that breeding sites had clearer water of slightly higher pH, shallower waterbody margins, more algae, less vegetation on the bank, were more highly disturbed, and had a shallower maximum depth, in comparison to non-breeding sites. Preferred breeding sites usually possessed some, but not all of these characteristics (Evans et al 1996). It is important to recognise that while some of the environmental variables are likely to be causally related to breeding site choice, other variables may simply be correlated with these or other (not measured) habitat variables (Evans et al 1996). However, those factors that were identified by Evans et al (1996) as being statistically important in explaining the choice of breeding site are briefly described below.

Water transparency — Cane toads demonstrate a strong preference for clear water, with the proportion of waterbodies used for breeding dropping markedly as transparency decreases. Of all waterbodies classed as clear, 50% showed evidence of breeding. High water transparency will promote the growth of filamentous algae — a major food source for cane toad tadpoles (Evans et al 1996).

Temporary waterbodies — Cane toads have a strong preference for using temporary waterbodies for breeding. Evidence of breeding was found in 48% of temporary waterbodies and in only 16% of permanent waterbodies. Temporary waterbodies tend to have shallower maximum depths and margins, resulting in higher water temperatures than permanent waterbodies, thus maximising growth rate of cane toad tadpoles (Evans et al 1996). Straughan (1966) also found that shallow waterbodies were preferred as cane toad breeding sites.

Vegetation density — Cane toads prefer to breed in waterbodies with no surrounding vegetation (Evans et al 1996). Use of waterbodies declines rapidly with increase in surrounding vegetation. Dense surrounding vegetation might increase sunlight exposure to the waterbody, thus limiting algal growth and lowering water temperature. Both of these factors will limit the growth rate of cane toad tadpoles. Cane toads have also been reported to prefer breeding in waterbodies with less surrounding vegetation elsewhere in their native range (Zug & Zug 1979) and in Australia (W Seabrook unpublished data, as cited in Evans et al 1996).

Although the above environmental factors do appear to influence choice of breeding site, the cane toad can still be considered a habitat generalist, having the ability to breed in waterbodies with a wide range of characteristics throughout a large range of habitat types (Evans et al 1996). This remarkable adaptability as far as breeding sites is concerned contrasts sharply with the habits of many species of native frogs which are highly selective in their choice of breeding sites (Covacevich & Archer 1975). Factors that have been found not to influence the choice of cane toad breeding site include waterbody size, aquatic plant cover, water chemistry parameters (except pH), substrate type (eg sand, mud or rock) (Straughan 1966, Evans et al 1996) and salinity (Covacevich & Archer 1975).

Shelter sites

Adult cane toads are primarily nocturnal and use daytime shelter or retreat sites to lessen water loss and reduce heat gain (Cohen & Alford 1996, Schwarzkopf & Alford 1996). This is vital during the Dry season as the availability of water decreases (Cohen & Alford 1996). Cane toads use a variety of diurnal shelter types including: burrows constructed by other animals, natural cavities under rocks, logs and dried vegetation, ‘forms’ (ie above-ground constructions) constructed by the toads themselves and shady open patches of ground (Schwarzkopf & Alford 1996). Similar shelter types have been reported for other *Bufo* species in South America (Zug & Zug 1979). In addition, Cohen and Alford (1996) reported wet grass to be an effective shelter site for cane toads, although Freeland (2000) reported that in the NT, cane toads are most abundant in areas of little or no grass, herb or shrub cover. Man-made habitats also provide a range of shelter types, including drainpipes, reticulated gardens and debris (Covacevich & Archer 1975, van Beurden, 1980, Freeland, 1984, Freeland 2000).

Schwarzkopf and Alford (1996) found the pattern of retreat use by cane toads was seasonal. During dry periods, toads preferred burrows and natural cavities or forms constructed near streams; during the Wet season they preferred forms at a distance from permanent water. Shelter site choice was less discriminatory during intermediate, moderately wet periods, with toads using burrows and forms near and far from streams with equal frequency (Schwarzkopf & Alford 1996). This seasonal pattern of shelter use by toads is consistent with their need to minimise evaporative water loss (Schwarzkopf & Alford 1996). Cane toads regularly spend up to three days in shelter sites, emerging to rehydrate at permanent waterbodies or on earth damp with dew[2] (Schwarzkopf & Alford 1996). Although cane toads can withstand over 50% body water loss (Krakauer 1970), Schwarzkopf and Alford (1996) observed that they used shelters that provided more protection from desiccation than was strictly physiologically necessary. Thus, cane toads are able to withstand considerably more water stress than they typically do, at least in the wet/dry tropical environment (Schwarzkopf & Alford 1996).

Cane toads have been observed to aggregate in shelter sites — an activity thought to reduce the effective surface area:volume ratio and further minimise evaporative water loss (Cohen & Alford 1996). They regularly return to the same shelter sites, particularly burrows (Cohen & Alford 1996), especially during the Dry season (Schwarzkopf & Alford 1996).

Soil moisture is a major factor influencing selection of shelter sites, and cane toads clearly favour areas and shelters with moist soil (Cohen & Alford 1996). In addition, relative humidity and ambient shelter site temperatures influence site selection (Malvin & Wood 1991). Cohen and Alford (1996) found that when soil moisture was higher, cane toads favoured shelters with higher soil temperatures. Environmental temperature may also influence shelter site selection — during the Dry season, on days when protection from high

2 Cane toads are able to absorb moisture through their skin from the soil, water or atmosphere (Freeland 1984).

daily temperatures is required, cane toads appear to favour burrows (Schwarzkopf & Alford 1996). Burrows may also provide protection from predators (Schwarzkopf & Alford 1996).

In summary, shelter site selection is almost always related to the need to minimise water loss and/or reduce heat gain. Cane toads show a marked preference for burrows or natural cavities close to permanent water during the Dry season, while preferring above-ground forms further from permanent water during the Wet season. During the transitional periods between the wet and the dry, site selection is less discriminatory. Cane toads often aggregate in groups in shelter sites and also regularly return to the same site, particularly during the Dry season. Cohen and Alford (1996) suggested that availability of shelter sites with adequate combinations of thermal and hydric characteristics that are close enough to water for regular rehydration may be a limiting factor for cane toads during the Dry season.

Seasonal distribution

During the Dry season, the highest densities of adult cane toads are in habitats near to water (Alford et al 1995, Freeland 2000), although this will most likely also be affected by certain habitat preferences (eg preference for more open- than densely-vegetated habitats). Alford et al (1995) noted that activity near water was affected by total rainfall in the month before sampling — the proportion of adults active near water decreased as rainfall increased in the Dry season. However, as the associated surface water dries out, cane toads retreat and concentrate around permanent water again. Freeland (2000) reported that reproduction can also occur following rainfall during the Dry season. Thus, it is likely that breeding activity will commence during the transition from Dry to Wet season (ie usually October–November) when the first rain storms arrive.

During the Wet season, adult cane toads disperse widely, following gradients of resource availability or searching for reproductive habitat (Alford et al 1995). Females appear to move greater distances and visit waterbodies less frequently than males (Alford et al 1995). The proportion of males active near water increases with increasing rainfall in the Wet season, probably reflecting increased reproductive activity (Alford et al 1995).

Cane toads are unable to effectively regulate their water uptake therefore cannot survive extended periods of inundation or exposure to flooded areas (ERAES 1998). Thus, during the Wet season, they need access to elevated (non-flooded) areas for survival (ERAES 1998). This information is based on experience in the Florida Everglades where toads live on small (dry) islands within the Everglades (ERAES 1998).

2.2.3 Summary of potential extent in Kakadu National Park

If they are not already in the south-east corner of the Park (ie in the Katherine River), cane toads are likely to move into Kakadu National Park during the next Wet season, through natural dispersal within and across catchments of the major rivers and creeks surrounding the east south-east boundary.

Other potential scenarios for cane toads to enter Kakadu include:

- ‘hitch-hikers’ in vehicles, caravans or removal containers;
- natural dispersal along transport corridors, most likely the Arnhem and Kakadu Highways;
- a combination of the above two scenarios;

Parks Australia North is currently implementing a rapid response strategy to control ‘hitch-hiking’ cane toads. It is hoped that this will prevent the establishment of long-term cane toad populations from transported individuals. Such introductions have previously been successfully controlled elsewhere (Tyler 1975). The most likely mode of entry of large numbers of cane toads into Kakadu will be via natural dispersal within and across the Katherine River catchment, into the upper South Alligator River or Jim Jim Creek catchments, and possibly further north, into Deaf Adder Creek. Another major entry point is likely to be the Kakadu Highway along which cane toads will disperse into the Park.

Once in Kakadu, it is highly likely that the cane toads' pattern of dispersal will rely on the transport corridors and the major rivers and creeks (shown in fig 5).

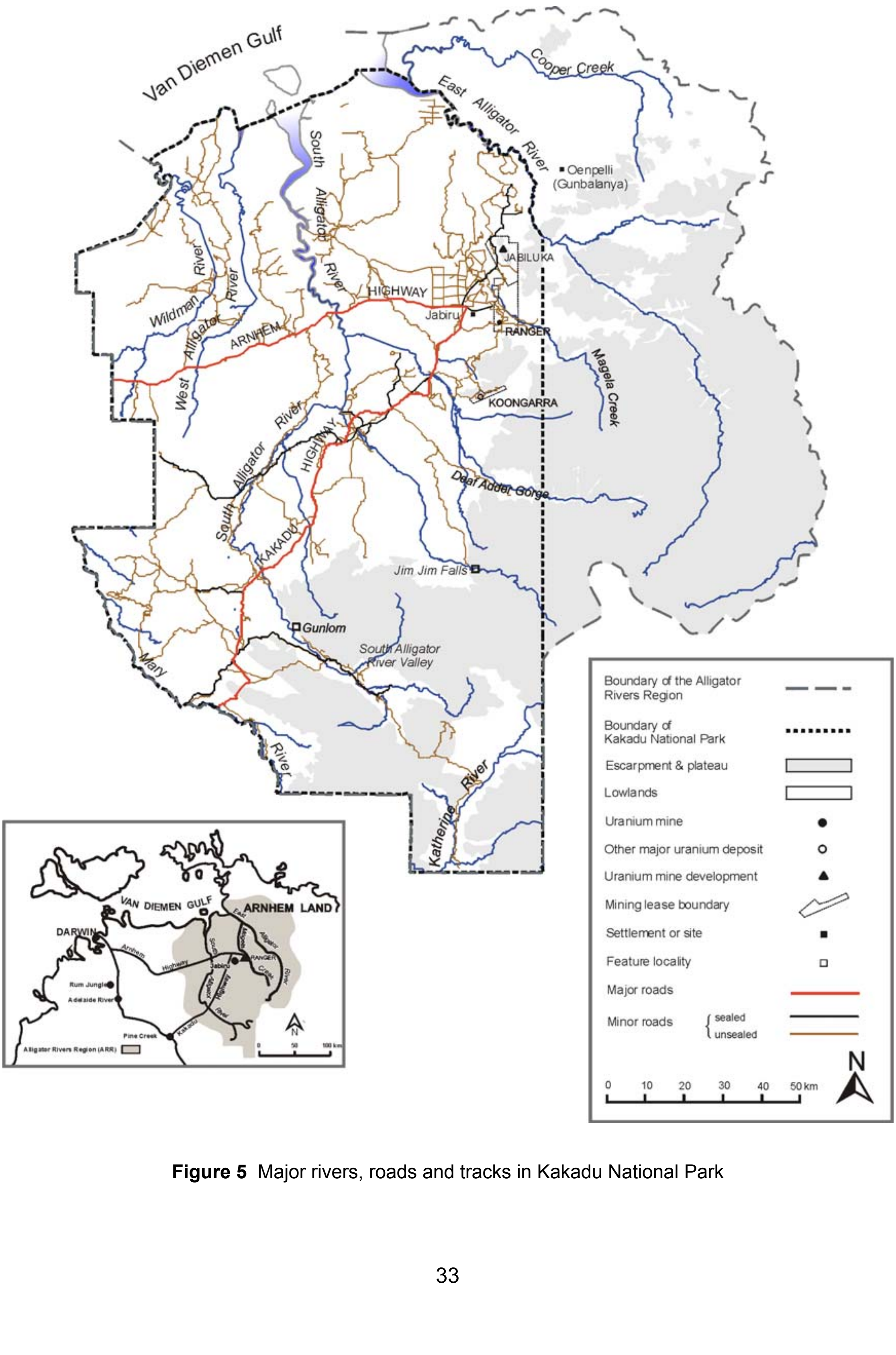

Figure 5 Major rivers, roads and tracks in Kakadu National Park

Given the current location of cane toads, this would indicate an initial progression down the South Alligator catchment and several of its associated sub-catchments (eg Jim Jim Creek, Deaf Adder Creek). In addition, dispersal via the Kakadu Highway will result in cane toads colonising the Mary River catchment, and subsequently the south-western and western areas of Kakadu. Given these scenarios, it is likely that the north-west (ie West Alligator catchment) and possibly north-east (ie Magela/East Alligator catchment) sectors of Kakadu will be the last to be colonised. However, cane toads may enter the upper East Alligator River catchment (via dispersal from the upper Mann River) in the next Wet season, resulting in earlier than anticipated colonisation of the north-east corner of Kakadu. It is difficult to predict time-frames for these events, but cane toad dispersal rates within a catchment could be up to 100 km y^{-1}. Another unknown at this stage is the ability of cane toads to negotiate escarpment (ie rocky) country. It is suspected that the rocky and inhospitable escarpment terrain and some areas of the Arnhem Land plateau will act as a dispersal barrier to cane toads, though not exclude them (B Freeland, pers comm, R Alford, pers comm). Monitoring the movements of cane toads as they approach the western Arnhem Land escarpment will provide valuable information on this aspect. The cane toads' apparently successful negotiation of the Arnhem Land plateau to date may have been facilitated by large sections of flat, easily-negotiable terrain as well as the disturbance of wetland habitats by buffalo.

Given the available information, the following cane toad population densities in Kakadu could be expected:

- egg densities in some parts of waterbodies could be in the order of 4000–36 000 per metre of shoreline;
- maximum tadpole densities in waterbodies are likely to be between ~15 and 60 m^{-2} (but strong aggregative behaviour means that tadpoles will only cover a small area of the waterbody);
- maximum metamorphling densities along the moist margins of some waterbodies could be in the order of 2.5 m^{-2} (see below for further discussion of habitats);
- maximum adult densities adjacent to some waterbodies could be in the order of 2000 ha^{-1}, but are likely to fluctuate markedly due to temporal and spatial factors such as Wet versus Dry season, initial versus long-term colonisation, vegetation type, natural versus human-modified/disturbed habitats.

Jacklyn (1992) speculated whether toads would thrive in the wetland areas of the Top End. The steady west and north-westward range expansion of cane toads over the last ten years indicates that many of the wetland habitats are indeed ideal, probably as breeding habitat and also Dry season refuges. Given the available information, it appears likely that cane toads will colonise almost every habitat in Kakadu, although the extent of colonisation may vary greatly among habitats.

In order to refine the estimate of the potential extent of cane toads in Kakadu, it is probably most appropriate to identify habitats of least concern. These appear to be the saline regions of the coastal plains and deltaic estuarine floodplains, incorporating the intertidal mudflats, beaches, mangrove communities, samphire/saline mudflats, clay pans, tidal creeks, sedgeland and coastal dunes. These habitats comprise approximately 10% of the total area of Kakadu. While cane toads are likely to occur in most of the saline habitats at various times, they will probably not use them as permanent habitat, given the large amount of preferred freshwater wetlands inland. In addition, populations are not likely to be large, since eggs and tadpoles are unlikely to survive in water with a salinity greater than 6‰. Dry season conditions may be too extreme (ie hot and dry with little shelter) for cane toads to spend much time in these habitats, while during the Wet season, they are often inundated with water.

Other areas that may not represent suitable habitat for cane toads include deep, open water channel habitats and the tidal regions of the larger rivers. These habitats do not provide suitable conditions for cane toad eggs or tadpoles and are unlikely to harbour these life stages. Similarly, the tidal reaches of the South Alligator and East Alligator Rivers, which extend up to 70 to 80 km inland during the Dry season (limit of 5–6‰ salinity; Chappell & Ward 1985), are not likely to represent major cane toad habitat. However, it should be noted that the riparian zones of many of these deep, open water, and/or tidal reach habitats (excluding saline riparian zones) are likely be suitable for cane toads. Again, while cane toads, or their eggs, tadpoles or metamorphlings, might be present in these habitats at various times and in varying abundance, it is thought that tidally-influenced channels will not represent a major habitat type.

As the Dry season progresses, there is likely to be a gradual retreat of cane toads from seasonally inundated wetlands (such as paleochannels on the floodplains), the moist and sheltered habitats on the margins of the floodplains (eg *Melaleuca* forests bordering floodplains), seasonal creeks and their associated temporary pools, and *Melaleuca* swamps. Grasslands and sedgelands on the floodplains will also provide sheltered, moist habitat during the mid Dry season, but may become too dry and hot late in the Dry season. Cracks in the black soils of the floodplains will also provide shelter and moisture as the Dry season progresses. During the late Dry season, adult cane toads will congregate at sites on or adjacent to permanent water that also offer adequate shelter. These will include the riparian zones around channel habitats such as in-stream billabongs and plunge pools, off-channel habitats such as back-flow billabongs, springs, *Melaleuca* swamps, patches of monsoon and sandstone rainforest, and possibly seepage zones and soaks. Margins of waterbodies that have been disturbed by feral pigs will provide ideal shelter sites (ie burrows) for cane toads. During this time of year there will most likely be few cane toads in the terrestrial habitats such as the tall, open eucalypt forests and woodlands of the lowland plains, except where moisture is present.

The first rains of the Wet season, usually around November will probably stimulate dispersal and increased breeding activity that may continue through the Wet season. Reproduction will most likely occur in standing water habitats or in sheltered areas of flowing water habitats, including pools in rocks and creek beds appearing after the early Wet season rains. During the Wet season, development time from egg stage to metamorphling can be as short as 25 days (Hearnden 1991). Therefore cane toads will be able to take advantage of the temporary pools of water from initial rains. Thus, eggs, tadpoles and metamorphlings will become more numerous early in the Wet season.

As the Wet season progresses and intensifies, many of the riparian and other wetland habitats, including the *Melaleuca* swamps, floodplains and off-channel billabongs, become inundated and cane toads are likely to disperse into the terrestrial habitats, such as the open eucalypt forests and woodlands, or remain on the margins of the inundated areas. The annual Wet season growth of spear grasses (*Sorghum* spp.) and other ground cover vegetation, while possibly restricting dispersal to some extent, will provide ideal shelter sites for cane toads. Reproduction will probably occur in the seasonal streams and waterholes scattered throughout these habitats. Prior to inundation, the floodplains may also provide ideal habitat, with the new growth of floodplain vegetation providing suitable shelter and food resources.

The effect of fire and the burning regime on cane toad dispersal and habitats is largely unknown. Several references allude to fire aiding dispersal of cane toads (Covacevich &

Archer 1975, ERAES 1998) — presumably by eliminating dense undergrowth. However, fire also reduces shelter sites. Dry season burning of floodplain and some other habitats in Kakadu may make them unsuitable Dry season habitats for cane toads by reducing available shelter sites, but the barest, most burnt ground cover occurs during the late Dry season when cane toads are least likely to disperse.

Inundation of wetland habitats in Kakadu during the Wet season, particularly January to March, may also provide a barrier to dispersal. However, major rivers and associated inundated floodplains and swamps will not prevent dispersal, just slow the process during the wettest times of the year (ie the monsoonal periods).

2.3 The potential effects of cane toads in Kakadu National Park

2.3.1 Effects on predator species

The toxicity of the cane toad has been a major cause for concern since its introduction into Australia. Many native frogs produce mild toxins that aid in defense against predators, but the potency of cane toad toxin renders it lethal to most frog-eating vertebrates and others that might inadvertently ingest it (van Beurden 1980).

The extent of the effect that cane toads have on predator populations in the long term remains controversial. Researchers agree there is a dearth of published information on this topic, but there are differing opinions about the long-term adverse effect of cane toads on predator populations. It is generally acknowledged that a variety of predators will die from mouthing or ingesting toads, but whether or not this causes long-term population decline of the predator remains unclear. There are no conclusive studies to substantiate whether cane toads have an adverse long-term effect on populations of any Australian species of predator (Freeland 1990). Burnett (1997) argued that because of ethical and logistic limitations to field experimentation on cane toad predator impacts, lack of observational experiments and the limitations of correlative science when dealing with data obtained by other than experimental means, populations of predatory species may continue to decline or go extinct while managers continue to wait for conclusive quantitative data that may be unattainable anyway.

Studies that have suggested cane toads may have had an effect on species populations (rather than just individuals) have generally used museum records as a basis for determining possible impact of cane toads (Covacevich 1974, Shine & Covacevich 1983). This is not an adequate basis for determining whether or not the cane toad has had an effect on the population density of a species. An apparent decline in the rates of museum registration of cane toad-susceptible species relative to similar rates for a non-susceptible species cannot distinguish between the possible effects of the cane toad, and possible effects of land clearance and land use changes over the period of registration (Shine & Covacevich 1983).

There are a number of species potentially capable of feeding on cane toads without adverse effects. These species are mentioned in the relevant sections here but are not included in the tables of potentially susceptible species. Some appear relatively immune to the cane toad's toxin, while others feed on cane toads from the ventral (underneath) surface or eat just the non-toxic parts, thus avoiding the major concentrations of toxin (Freeland 1990)

Tables 3 to 9 list known and potential cane toad predator species found in Kakadu National Park that are known to be, or may be, susceptible to cane toad toxin. In addition, the tables provide summary information on species status and their preferred or major habitats, where available. The EPBC Act (1999) was used to identify species listed as 'endangered' or 'vulnerable'.

Notable mammal, bird, reptile and amphibian species were identified from Woinarski et al (1989) and Roeger and Russell-Smith (1995), while notable fish species were identified from Larson and Martin (1990) and Bishop et al (2001). Notable species included those considered to be rare, or have restricted range, outstanding taxonomic interest, or uncertain or declining status (Woinarski et al 1989). For the birds, species considered rare by Dorfman (1997) were also included as notable. In addition, flagship species were identified based on their perceived ecological/cultural importance to Kakadu. Many of the species listed have been included based on available dietary information relating to consumption of native anuran eggs, tadpoles and frogs. There is insufficient information to say that these potential toad consumers *will* be adversely affected if they *do* eat cane toads. The tables are based on information from both anecdotal and experimental sources, details of which are outlined in the source references.

The criteria used for assessing the susceptibility of predators were:

Definite: documented adverse effects upon populations of this species have been reported in the literature;

Probable: documented in the literature as having eaten cane toads or their early life stages and adverse effects on individuals reported, but not on populations;

Possible: documented in the literature or through expert consultation as eating, or thought likely to eat, native frogs or their early life stages, but effects of eating cane toads unknown.

2.3.1.1 Invertebrates

Relatively little attention has been paid to invertebrate predators, most of which are found in aquatic environments. The early life stages of cane toads are toxic or at least unpalatable to certain predators (Voris & Bacon 1966, Licht 1967, 1968, Wassersug 1971, Kruse & Stone 1984, Lawler & Hero 1997, Crossland 1997). However, little is known of the toxicity of these stages to native Australian aquatic invertebrate predators. Because cane toads utilise both temporary and permanent waterbodies for breeding (Crossland & Alford 1998, Freeland 2000), it is likely that many aquatic invertebrate predators in Kakadu will be exposed to the early life stages of cane toads.

The effects of cane toad eggs, hatchlings and tadpoles on some native aquatic invertebrate predators have been investigated or discussed by Crossland (1997) and Crossland and Alford (1998). Crossland and Alford (1998) found that cane toad eggs, hatchlings and/or tadpoles are toxic to native snails, water beetle larvae (Dytiscidae), backswimmers (Notonectidae) and leeches (Hirudinea), with individuals of these taxa dying after consuming cane toads (table 3).

Table 3 Predatory groups of aquatic invertebrates in Kakadu National Park, potentially susceptible to cane toads

Species		**Degree of susceptibility**			**Status**
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*	
water beetles	*Cybister* spp., *Hydaticus* spp.			*	common
backswimmers	*Anisops* spp.			*	common
leeches	Phylum: Annelida (worms) Class: Hirudinea		*		common
snails	*Austropeplea lessoni*		*		common

Source: Crossland 1997, Crossland & Alford 1998

Only the mortality of the snails (100%) and leeches (60%) was considered significant, with the other taxa exhibiting intraspecific variation in their susceptibility to cane toads. Genera of the Dytiscidae and Notonectidae tested are represented in Kakadu, and the snail (*Austropeplea lessoni*) is dominant on the floodplains in both deep and shallow waters (C Humphrey, ***eriss***, pers comm). At least eleven gastropod species are found in Kakadu and most are widespread and abundant in lentic parts of the systems (Humphrey & Dostine 1994). It is unknown if the particular species of leech (*Goddardobdella elegans*) tested is found in Kakadu.

Other aquatic invertebrate predators tested, including water scorpions (Nepidae), giant water bugs (Belastomatidae), dragonflies (Odonata), freshwater prawn, crab and crayfish (Decapoda), either consumed cane toad eggs or tadpoles without apparent ill effect, or killed cane toads but consumed none or only a small portion of the carcass. Some water beetles and crustaceans (eg freshwater prawns, crabs and crayfish) can be maintained on a diet of cane toad eggs and tadpoles for at least 4 weeks without apparent ill effect, during which time they consume large numbers, suggesting that they may be potential predators of cane toads in nature (Crossland, unpubl. data).

Some terrestrial invertebrates are also successful cane toad predators. Martin and Freeland (unpubl. data) observed a centipede preying on a 60 mm sub-adult cane toad without apparent ill effects. Large wolf spiders and ants, in enclosure experiments, have been observed to prey on cane toad metamorphlings with no ill effects (van Beurden 1980).

Endemic invertebrates located in escarpment streams may predate upon cane toad eggs or tadpoles. These include freshwater prawns and shrimps, crabs and isopods. Given that freshwater prawns and crabs (*Holthuisana* spp.; which is represented in Kakadu) appear to be able to successfully consume cane toad eggs and/or hatchlings and tadpoles, the endemic species are not considered susceptible, although little is known about the isopods.

2.3.1.2 Vertebrates

Fish

Fish species that have been investigated as cane toad predators and occur within Kakadu include the purple-spotted gudgeon (*Mogurnda mogurnda*), empire gudgeon (*Hypseleotris compressa*), eel-tailed catfish (*Neosilurus hyrtlii*), glassfish (*Ambassis agrammus*), fly-specked hardyhead (*Craterocephalus stercusmuscarum*), rainbow fish (*Melanotaenia splendida australis*), banded grunter (*Amniataba percoides*), spangled grunter (*Leiopotherapon unicolor*), sleepy cod (*Oxyleleotris lineolata*), mouth almighty (*Glossamia aprion*), barramundi (*Lates calcarifer*) and sooty grunter (*Hephaestus fuliginosus*) (Pearse 1980, Crossland 1997, Hearnden 1991, Lawler & Hero 1997, Crossland & Alford 1998). Studies have found that most fish either ignore cane toad early life stages or taste and rejected them without apparent ill effects (Crossland & Alford 1998, Hearnden 1991, Pearse 1980, Voris & Bacon 1966). However, cane toads have been found to be toxic to the fly-specked hardyhead (Crossland & Alford 1998), the banded grunter, the spangled grunter (Hearnden 1991) and the purple-spotted gudgeon (Pearse 1980) in the instances where these species attempted to consume or consumed cane toad eggs and/or tadpoles.

Fishes probably avoid cane toad early life stages because they can detect their noxiousness (Lawler & Hero 1997, Licht 1968, Voris & Bacon 1966, Crossland 1997). Barramundi and sooty grunters have been observed to attack tadpoles but spit them out almost immediately, displaying signs of distress by vigorously opening and closing their mouths and shaking their heads from side to side for up to a minute (Crossland 1997). Results from Lawler and Hero

(1997) suggested an ontogenetic shift in the palatability of cane toad tadpoles to barramundi, the later stages being less palatable.

Fish species that are known to eat native anuran early life stages, and therefore may eat cane toads include the tarpon, saratoga, fork-tailed catfish (*Arius* spp.), banded grunter, spangled grunter, common archerfish (*Toxotes chatareus*) and sleepy cod (table 4) (Bishop et al 2001, Pancontinental 1981, Tyler & Crook 1987). The fork-tailed catfish species identified as eating native frogs is the salmon catfish *Arius leptaspis*. There are two other species of fork-tailed catfish in Kakadu and both have similar diets to *A. leptaspis*, and are likely to eat native frogs.

Table 4 Predatory fish species in Kakadu National Park, potentially susceptible to cane toads

Species		**Degree of susceptibility**			**Status**	**Habitats***
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
tarpon	*Megalops cyprinoides*			*		F,L,H
saratoga	*Scleropages jardinii*			*		F,L,H
salmon catfish	*Arius leptapis*			*		F,L,H
blue catfish	*Arius graeffei*			*		F,L,H
Midgley's catfish	*Arius midgleyi*			*		L
long tom	*Strongylura krefftii*			*		F,L,H
fly-specked hardyhead	*Craterocephalus stercusmuscarum*		*			F,L,H
banded grunter	*Amniataba percoides*		*			F,L,H
coal grunter	*Hephaestus carbo*			*	notable	H
spangled grunter	*Leiopotherapon unicolor*		*			F,L,H
primitive archerfish	*Toxotes lorentzi*			*	notable[1]	L,H
common archerfish	*Toxotes chatareus*			*		F,L,H
golden goby	*Glossogobius aureus*			*		F
flathead goby	*Glossogobius giuris*			*		F,L,H
square-blotch goby	*Glossogobius* sp.			*	notable	L,H
dwarf gudgeon	*Oxyeleotris nullipora*			*		F
black-banded gudgeon	*Oxyeleotris selheimi*			*		F
purple-spotted gudgeon	*Mogurnda mogurnda*		*			L,H

Source: Pearse 1980, Crossland & Alford 1998, Crossland 1997, Pancontinental 1981, Bishop et al 2001, Tyler & Crook 1987, Larson & Martin 1990

* Habitats — F: Floodplain, L: Lowlands, H: Headwaters (from Pidgeon, unpubl. Data, in Press et al 1995).

1 May be common in some escarpment waterbodies but has patchy distribution outside of and within KNP and generally is not often seen.

The primitive archerfish (*Toxotes lorentzi*) and the coal grunter (*Hephaestus carbo*) have relatively restricted distributions and are rarely seen in Kakadu. The primitive archerfish has the same feeding habits as the common archerfish, and the coal grunter is primarily carnivorous, therefore, both species could possibly eat native frogs or their early life stages. Other species such as the longtom (*Strongylura krefftii*) and some members of the Eleotrididae (gobies and gudgeons) (table 4) include vertebrates in their diets and may eat native frogs or their early life stages and therefore could potentially eat cane toads. However, no information is available on native frogs in the diet of these species, their ability to detect and avoid cane toad toxin, or their susceptibility if they *do* ingest cane toads. Although known or thought to eat native frog eggs and tadpoles (Bishop et al 2001), one of the eleotrids, the sleepy cod, and the mouth almighty have been observed in laboratory trials not to consume cane toad eggs and tadpoles (Hearnden 1991). Members of the eel-tailed catfish, rainbowfish and glassfish eat mainly aquatic insects and their larvae, small crustaceans, algae and detritus, and would be unlikely to attempt to eat cane toad eggs or tadpoles. The remaining fish species of Kakadu are mainly herbivores/detritivores.

Amphibians

Crossland (1997) and Crossland and Alford (1998) have investigated or discussed the effects of cane toad eggs, hatchlings and tadpoles on some native species of tadpoles. Of the 8 species tested, the northern dwarf tree frog (*Litoria bicolor*), desert tree frog (*L. rubella*), and ornate burrowing frog (*Limnodynastes ornatus*) are present in Kakadu. After consumption of cane toad eggs, *L. bicolor* experienced 100% mortality, *L. rubella* 30% and *L. ornatus* 90%. Consumption of cane toad hatchlings resulted in 10% mortality for *L. ornatus*. *L. rubella* did not consume cane toad hatchlings, and *L. bicolor* was not tested. No native frog tadpoles attempted consumption of live cane toad tadpoles. However, dead cane toad tadpoles were consumed, resulting in 80% mortality for *L. bicolor*, and 90% mortality for *L. ornatus*. *L. rubella* did not consume any. The fact that very few *L. rubella* ate very few cane toad eggs, hatchlings or tadpoles suggests that either they have a greater ability than other native tadpoles to detect the noxiousness of cane toads, or, *L. rubella* tadpoles do not normally eat anuran early life stages (Crossland 1997).

Behavioural responses suggest that native frog tadpoles are unable to detect the toxicity of cane toad eggs. The tadpoles showed no avoidance response when they came into contact with cane toad eggs. Rather, they persisted in grazing on egg strings until they had penetrated the gelatinous string and consumed the fertilised eggs inside, after which they always died (Crossland 1997). It should be noted that the major predator of cane toad eggs and tadpoles is the cane toad tadpole itself (Hearnden 1991).

Other Kakadu frog species whose tadpoles are known or thought to eat native frog eggs and/or tadpoles, and therefore, might eat cane toad eggs and tadpoles, include the giant frog (*Cyclorana australis*), green tree frog (*Litoria caerulea*), Dahl's aquatic frog (*Litoria dahlii*), Roth's (brown) tree frog (*Litoria rothii*), and the marbled frog (*Limnodynastes convexiusculus*) (Catling et al 1998, Tyler & Cappo 1983). In addition, it is thought that tadpoles of almost all of the other native frog species found in Kakadu will consume frog eggs and/or tadpoles if they co-exist (M Tyler & R Alford pers comms). The native frog species susceptible or potentially susceptible to cane toads are listed in table 5.

Reptiles

Lizards

There is no conclusive scientific evidence that lizard populations have declined due to cane toads, but there is strong anecdotal evidence to suggest that some populations have been adversely affected (Burnett 1997, Covacevich & Archer 1975, Dryden 1965, van Beurden 1980, Easteal et al 1985). There is also anecdotal and experimental evidence that some varanid species die after mouthing cane toads (Covacevich & Archer 1975, Freeland 1990, Speare & McDonald, unpubl. data, 'Cane toads on Lizard Island' 1988, Stammer 1981).

Burnett (1997) attempted a risk assessment of varanid species based on responses to a questionnaire completed by naturalists who were present in certain areas prior to and after the arrival of cane toads. He assigned a cane toad susceptibility score based on: 1) whether the predator shares habitat closely with cane toads; 2) the predator is known to eat frogs and if toad related predator population declines were recorded; 3) what percentage of the predators' distributions lie within the potential distribution of cane toads in Australia. Of the 21 varanids assessed, 11 occur in Kakadu. Burnett (1997) placed 5 of these species in a high risk category, 5 in moderate risk and one in low risk. The criteria for these risk categories are different from the susceptibility criteria used in this assessment and have been adapted accordingly (table 6).

Table 5 Predatory frog species in Kakadu National Park, potentially susceptible to cane toads

Species		**Degree of susceptibility**			**Status**	**Habitats***
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
marbled frog	*Limnodynastes convexiusculus*			*		F,M,S,S/F, MF,W,OF,Es
ornate burrowing frog	*Limnodynastes ornatus*		*			F,S/F,MF,W, OF,Es
giant frog	*Cyclorana australis*			*		F,S,S/F,MF, W,OF,Es
long-footed frog	*Cyclorana longipes*			*		F,S/F,MF,W/ OF,Es
northern dwarf tree frog	*Litoria bicolor*		*			F,M,S,S/F, MF,W,OF
green tree frog	*Litoria caerulea*			*		F,S/F,MF,W, OF,Es
Dahl's aquatic frog	*Litoria dahlii*			*		F,S,S/F,MF, Es
Roth's (brown) tree frog	*Litoria rothii*			*		F,S,S/F,MF, W,OF,Es
desert tree frog	*Litoria rubella*		*			F,S,S/F,MF, W,OF,Es
Copland's rock frog	*Litoria coplandi*			*		Es
Peter's frog	*Litoria inermis*			*		F,S,S/F,MF, W,OF
pale frog	*Litoria pallida*			*		F,S/F,MF,W, OF,Es
Rockhole frog	*Litoria meiriana*			*		Es
javelin frog	*Litoria microbelos*			*		No information
rocket frog	*Litoria nasuta*			*		F,S,S/F,MF, W, OF,Es
masked rock frog	*Litoria personata*			*	Notable	Es
Tornier's frog	*Litoria tornieri*			*		F,S/F,MF,W, OF,Es
watjulum frog	*Litoria wotjulumensis*			*		F,S/F,OF,Es
carpenter frog	*Megistolotes lignarius*			*	Notable	Es
northern spadefoot toad	*Notaden melanoscaphus*			*		W,OF
bilingual froglet	*Ranidella bilingua*			*		F,S,S/F,MF W,OF,Es
northern Territory frog	*Sphenophryne adelphi*			*		Es
Jabiru toadlet	*Uperoleia arenicola*			*	Notable	Es
floodplain toadlet	*Uperoleia inundata*			*		F,S/F,W,OF, Es

Source: Catling et al 1998, Crossland 1997, Crossland & Alford 1998, M Tyler pers comm, Tyler & Cappo 1983

* Habitats — F: Freshwater, M: Estuarine mangroves, S: Sedgelands, S/F: Sedgeland/forest ecotone, MF: Lowland monsoon forest, W: Woodland, OF: open forest, PF: Paperbark forest, Es: Escarpment (adapted from Braithwaite et al 1991, Woinarski & Braithwaite 1991).

Table 6 Predatory lizard species in Kakadu National Park, potentially susceptible to cane toads

Species		Degree of susceptibility			Status	Habitats*
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
rock monitor	*Varanus baritji*			*	notable	MF, Es
Kimberley rock monitor	*Varanus glauerti*			*		No information
long-tailed rock monitor	*Varanus glebopalma*			*		Es
Gould's or sand goanna	*Varanus gouldii*	*				S,S/F,W,OF
mangrove monitor	*Varanus indicus*	*				M
Merten's water monitor	*Varanus mertensi*	*				F,MF,W
Mitchell's water monitor	*Varanus mitchelli*			*		S/F,OF,PF, Es
northern sand goanna	*Varanus panoptes*	*				S,S/F,W,OF, PF
–	*Varanus primordius*			*	notable	W,OF,Es
spotted tree monitor	*Varanus scalaris*	*				S/F,MF,W, OF,Es
black-headed monitor	*Varanus tristis*			*		W,OF,Es
blue-tongued lizard	*Tiliqua scincoides*		*			S/F,MF,W, OF

Source: Burnett 1997, Covacevich & Archer 1975, Dryden 1965, Freeland 1990, Speare & McDonald unpubl. data, 'Cane toads on Lizard Island' 1988, van Beurden 1978, van Beurden 1980, Catling et al 1998, Stammer 1981, Easteal et al 1985, Seabrook 1991, Shine 1986a, Tyler & Crook 1987, Roeger & Russell Smith 1995.

* Habitats — F: Freshwater, M: Estuarine mangroves, S: Sedgelands, S/F: Sedgeland/forest ecotone, MF: Lowland monsoon forest, W: Woodland, OF: open forest, PF: Paperbark forest, Es: Escarpment (adapted from Braithwaite et al 1991, Woinarski & Braithwaite 1991, Roeger & Russell Smith 1995).

The Conservation Commission of the Northern Territory (CCNT), now Parks and Wildlife Commission of the Northern Territory (PWCNT), has conducted feeding experiments to investigate the basis of the apparent survival of large species of varanid lizards in areas invaded by the cane toad. With no experience of cane toads, two species of varanid from Darwin both attacked the toads provided. One initially survived an encounter with a small toad, but both ultimately died within about 20 minutes of mouthing larger toads. In contrast, 'toad wary' varanids from Queensland and the Borroloola region did not attempt to attack the toads. These results suggest that either large varanids are capable of learning to avoid eating cane toads, or that the invasion of areas by cane toads leads to selection against varanids that attempt to eat cane toads (Freeland 1990).

In 1989 the CCNT began a long-term study in the Borroloola area to make some assessment of the impact of cane toads on populations of Gould's goanna and the northern sand goanna (Freeland 1990). Using the assistance of an Aboriginal woman and her two trained 'goanna dogs' they were able to sample goannas prior to and after invasion by cane toads, and obtain a relative index of varanid abundance:mean search time to locate a large varanid. Their data suggested that (a) when cane toads invade an area they kill many goannas, (b) the goanna populations then decline, (c) some goannas survive the invasion, (d) goannas surviving the invasion do not attack cane toads, and (e), over the long term, goanna populations recover. Although the extent of the recovery of goanna populations has not been determined, observations around Townsville suggest that recovery leads to the re-establishment of large populations (Freeland 1990).

In the Roper River region of the NT, Catling et al (1998) found indications that some reptile species may have been adversely affected by cane toads, with abundance and species diversity being lower at the 'toad area' than at the 'invasion area' and 'no toad area'. This applied mainly to the small reptiles that were thought unlikely to ingest cane toads, thus it may have been a resource competition effect (see section 2.3.3). There were many species in the region that may ingest cane toads, that were not affected. Catling et al (1998) concede that the results are inconclusive due to small sample sizes and/or the possibility of significant covariates being a part of a significant area/year/season interaction. The study area was beyond the limit of distribution of some large reptile fauna that may be significantly affected by cane toads, such as the northern sand goanna. Large varanids were low in numbers in all three study areas, and all records except one were of small (<1 m) varanids (Catling et al 1998).

None of the dragon lizards (agamids) are considered to be potential consumers of cane toads and unlikely to be susceptible as predators (Rick Shine, pers comm). The frillneck lizard, although achieving a reasonable size, has been found to have a diet consisting entirely of invertebrates (Griffiths & Christian 1996). However, after several years of cane toad colonisation at Lawn Hill National Park (LHNP), rangers reported removing cane toads from the mouths of frillneck lizards that frequented the camping area (C O'Keefe, LHNP Ranger, 1985–1996, pers comm). The lizards were distressed but not dead; and over the next few years their presence in the camping area gradually diminished to the point where none could be found. It is possible that this shift in the normal prey of the frillneck lizards was induced by a lack of available invertebrate prey which resulted from consumption by cane toads, or simply due to the abundance of a potential new food source (ie cane toads). Potential shifts in prey preference due to cane toads were also noted by Dr Laurie Corbett (EWL Sciences) in his response to our enquiries on the diets of the native fauna.

Snakes

There is much anecdotal evidence to suggest that cane toads have been responsible for individual mortality and declines in population numbers of elapid snakes (van Beurden 1980, Easteal et al 1985, Covacevich & Archer 1975, Shine & Covacevich 1983, Mirtschin & Davis 1982, Covacevich 1974, Seabrook 1991). These reports include species of black snake, brown snake and death adders. Mortality from attempted consumption of cane toads has also been reported for the colubrid snakes, the slaty-grey snake (Cameron & Cogger 1993, Covacevich & Archer 1975, S Burnett, unpubl. data), the brown tree snake (Cameron & Cogger 1993, Covacevich & Archer 1975) and the carpet python (Covacevich & Couper 1992, R Speare, unpubl. data).

The slaty-grey snake is claimed to be a 'pugnacious eater of frogs' (Miles 1988). Other Kakadu snake species that include frogs in their diet and therefore may potentially consume cane toads, but for which there is no information of effects, are included in table 7 (Rick Shine, pers comm, Catling et al 1998).

Madsen and Shine (1994) found that Dahl's aquatic frog (*Litoria dahlii*) was highly toxic to most of the snake species with which it is sympatric. Seven species of snake including children's python, water python, green tree snake, slaty-grey snake, keelback snake, northern death adder and black whip snake were force fed *L. dahlii*. All but the keelback snake (*Tropidonophis mairii*) died after ingesting frogs constituting at least 20% of the predators mass. They noted that other than the keelback snake, these snake species do not eat *L. dahlii* in the wild and these snakes may be better able to deal with the invasion of cane toads than has been generally supposed.

Table 7 Predatory snake species in Kakadu National Park, potentially susceptible to cane toads

Species		Degree of susceptibility			Status	Habitats*
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
black-headed python	*Aspidites melanocephalus*			*		S/F
Children's python	*Liasis childreni*			*		W,PF,Es
water python	*Liasis fuscus*			*		F,M,S,S/F, MF
olive python	*Liasis olivaceus*			*		S,S/F,MF,W, OF
carpet python	*Morelia spilota*		*			S/F,MF
Oenpelli python	*Morelia oenpelliensis*			*	notable	Es
brown tree snake	*Boiga irregularis*		*			S/F,MF,OF, PF,Es
Macleay's water snake	*Enhydris polyepis*			*		M,S
slaty-grey snake	*Stegonotus cucullatus*		*			S,S/F,MF,Es
northern death adder	*Acanthophis praelongus*	*				S,S/F,OF,Es
black whip snake	*Demansia vestigiata*			*		S,S/F,W,OF
olive whip snake	*Demansia olivacea*			*		W,OF
-	*Demansia papuensis*			*		no information
king brown snake	*Pseudechis australis*	*				S/F,MF,OF,Es
western brown snake	*Pseudonaja nuchalis*	*				S,OF
northern small-eyed snake	*Rhinoplocephalus pallidiceps*			*		S/F,W

Source: Covacevich & Archer 1975, Shine & Covacevich 1983, Cameron & Cogger 1993, Covacevich & Couper 1992, Catling et al 1998, Speare, unpubl. data, Mirtschin & Davis 1982, S. Burnett, unpubl. data, Easteal et al 1985, Seabrook 1991, van Beurden 1980, Miles 1988, Morris 1996, Roeger & Russell-Smith 1995.

* Habitats — F: Freshwater, M: Estuarine mangroves, S: Sedgelands, S/F: Sedgeland/forest ecotone, MF: Lowland monsoon forest, W: Woodland, OF: open forest, PF: Paperbark forest, Es: Escarpment (adapted from Braithwaite et al 1991, Woinarski & Braithwaite 1991).

It is interesting to note that Covacevich and Archer (1975) reported the common or green tree snake (*Dendralaphis punctulatus*) as showing no ill effects after ingesting cane toad tadpoles and young. Madsen and Shine (1994) force fed this species with the toxic *L. dahlii* at a ratio of 12% of the snake's body mass, with no ill effects. When force fed with *L. dahlii* at a ratio of 21% of the snake's body mass, the snake died. Therefore, this and the other snake species mentioned may be able to consume either a number of small cane toads or a lesser number of larger toads.

Other than the keelback snake, the feeding habits of these species suggests they may be able to identify frogs by chemoreception before seizing them. The keelback snake appears to rely on vision rather than chemoreception and this may pose a strong selective advantage for individuals capable of tolerating a wide array of anuran toxins (Madsen & Shine 1994). This species is a frog eating specialist (Morris 1996). It is not only immune to cane toad toxin, it thrives in captivity on cane toads and utilises them regularly as a food source (Covacevich & Archer 1975).

The snakes that were susceptible to *L. dahlii* when force-fed have been considered as *possibly* susceptible below, but their apparent ability to recognise and reject toxic prey items has implications when determining relative risks and is further considered in section 2.4.

The diet of the Oenpelli python is thought to consist entirely of warm-blooded animals (G Miles, Parks Australia North, pers comm). However, related species such as the carpet python have been reported as dying from attempted consumption of cane toads (Covacevich & Couper 1992, R Speare, unpubl. data), and thus, the Oenpelli python may be susceptible. The diet of the Arafuran filesnake (*Acrochordus arafurae*), which is common in Kakadu, has been well studied (Shine 1986b, Houston & Shine 1993) and consists entirely of fish. It is not considered susceptible to cane toads.

Crocodiles

Covacevich and Archer (1975) reported that the saltwater crocodile (*Crocodylus porosus*) could both mouth and ingest cane toads with apparent impunity. Members of the Borroloola community in the NT reported a small saltwater crocodile found dead on Ngukurr River (Roper catchment) with a cane toad in its stomach. There have been unsubstantiated reports to the PWCNT of deaths among freshwater crocodiles (*Crocodylus johnstoni*) possibly from the mouthing/ingestion of cane toads, and members of the Borroloola, and Beswick communities reported an increase in the number of small freshwater crocodiles found dead (Begg et al 2000). This contrasts with reports of *C. johnstoni* actively hunting and ingesting cane toads (K. McDonald, pers comm, cited in Freeland 1990).

Records of freshwater crocodiles from a cane toad related fauna study in the Borroloola region (Catling et al 1998) indicated that cane toads had no effect on freshwater crocodile populations (counts changed little within areas over four surveys). However, there are numerous convincing anecdotal reports of freshwater crocodiles dying following cane toad consumption, the most recent of these from the upper Mann River in September 2000 (C Humphrey ***eriss***, pers comm), Elsey National Park in October 2000 (S Bailey, PWCNT, pers comm) and Nitmiluk National Park (B Bayliss, ***eriss***, pers comm). Based on the information outlined here, the freshwater crocodile (*C. johnstoni*) was considered *probably* susceptible to cane toads.

The CCNT has also conducted feeding experiments on *C. johnstoni* to determine their susceptibility to cane toad toxin and preference for eating cane toads. When force fed, all 6 crocodiles used in the experiment died within about 3 hours. However, when 12 crocodiles were placed in an enclosure with 12 cane toads for a week, all of the crocodiles survived and were in good condition despite 7 of the toads being killed and the majority of the cane toad carcasses consumed. It is thought that the habit of shredding and thus washing the toad prior to ingestion may dilute or remove the toxin, or that the crocodile's gastric secretions may neutralise the toxin. There has been no report of declining populations of *C. johnstoni* from Queensland. Surveys carried out under the NT Crocodile Management Program are sufficient to predict any major decline should they occur (Freeland 1990).

Turtles

Anecdotal and experimental evidence suggests that none of the three species of turtle known to ingest cane toads are adversely affected. Covacevich and Archer (1975) report a long-necked turtle (*Chelodina* sp.) observed feeding on a dead cane toad and showing no apparent ill effects. Crossland and Alford (1998) tested the saw-shelled turtle (*Elseya latisturnum*) and Krefft's river turtle (*Emydura krefftii*) with cane toad tadpoles and although many tadpoles were consumed, the turtles seemed unaffected. Hamley and Georges (1985) also found the saw-shelled turtle to be a successful predator of the cane toad.

In contrast to the above reports, there are unsubstantiated reports from Aboriginal communities on Groote Eylandt and around Borroloola that cane toads have killed 'goanna, blue-tongue, long-necked turtle, geese and everything' (Evans 1999). Similarly, community members from Beswick and Burunga, south of Katherine, include barramundi and long- and short-necked turtles in their list of species affected by toads (Begg et al 2000). In another observational report, seven turtles (short and long-necked) were found dead in a recreational dam near Mataranka. The previous night, residents had killed dozens of cane toads around the dam and left them by the water's edge. The next morning, many of the cane toad carcasses had been consumed and there were a number of dead turtles. Dead turtles had not been found in the dam prior to the invasion of cane toads (B Pascal, Manager, Territory Manor, pers comm). Given the extreme nature of this occurrence (ie the turtles were killed by an unnatural rapid consumption of large quantities of toads), the fact that the turtle species were not fully identified, and the contradictory experimental evidence, we did not identify turtles as being susceptible to cane toads. However, it is acknowledged that much uncertainty exists and more information needs to be sought.

The pig-nosed turtle (*Carettochelys insculpta*) feeds mainly on fruits, flowers, seeds and aquatic vegetation, however, fish and mammal remains have been found in the stomachs of pig-nosed turtles presumably consumed as carrion which may be an important component of the diet (Georges & Kennett 1989, Georges et al 1989). Cane toads could possibly be consumed as carrion. However, no anuran remains have been recorded in the diet of pig-nosed turtles (Georges & Kennett 1989).

Birds

Dorfman (1997) compiled a list of bird species within Kakadu that could be potentially under threat from cane toads once they arrived. The level of threat was scored qualitatively from 0 to 4, based on the following criteria: 'known or suspected consumption of native tadpoles; known or suspected consumption of native frogs; propensity to forage in areas where cane toads or their tadpoles are likely to be; the birds themselves are rare within Kakadu'. Data on food were acquired from Barker and Vestjens (1989) and foraging habitat from Marchant and Higgins (1990). Based on this assessment, Dorfman (1997) considered at least 76 of the local bird species could be potentially under threat from cane toads. This list has been used for the current assessment, but refined taking into account documented information on the responses of particular bird species to cane toads (table 8). Catling et al (1998) listed additional species that they believed may be potential consumers of cane toads (table 8).

A few bird species are known to eat cane toads without apparent ill effects. Some may be immune to cane toad toxin, while other species eat only the non toxic parts of the toad — a technique these species use on native frogs. These species include the koel, black kite, tawny frogmouth (although a report of sick individuals has been received; B Pascal, Manager, Territory Manor, pers comm), bush thick-knee and Australian bustard (Covacevich & Archer 1975, Mitchell et al 1995, Freeland 1987). Ibis (species unknown) and white-faced herons have been observed feeding unharmed on cane toad metamorphs in NSW (Seabrook 1991).

Covacevich and Archer (1975) reported deaths of individual crows (*Corvus* sp.) and kookaburras (*Dacelo novaeguineae*) after mouthing cane toads. However, they also report consumption by these species of young toads or road-killed toads with no apparent ill effects. Van Beurden (1980) also reports deaths of kookaburras, the little bittern (*Ixobrychus minutus*) and the black bittern (*Ixobrychus flavicollis*) after ingesting juvenile cane toads. Although crows and kookaburras are reported to successfully eat cane toads, — the lack of effect possibly being related to the amount of toxin ingested — they have been included in table 8 based on the reports of individual mortality.

The black-necked stork (or jabiru) and the comb-crested jacana are known or thought likely to consume native anurans (E Dorfman, pers comm, 2000). Both are considered to be flagship species of Kakadu National Park, and any decline in their numbers would be taken very seriously.

Table 8 Predatory bird species in Kakadu National Park, potentially susceptible to cane toads

Species		Degree of susceptibility			Status	Habitats*
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
pacific black duck	*Anas superciliosa*			*		FP,RF
Australasian grebe	*Tachybaptus novaehollandiae*			*		FP,RF
hoary-headed grebe	*Poliocephalus poliocephalus*			*		FP,RF
darter	*Anhinga melanogaster*			*		M,FP,RF
pied cormorant	*Phalacrocorax varius*			*		C,M,FP,RF
little pied cormorant	*Phalacrocorax melanoleucos*			*		C,M,FP,RF
little black cormorant	*Phalacrocorax sulcirostris*			*		C,FP,RF
great cormorant	*Phalacrocorax carbo*			*		FP
Australian pelican	*Pelecanus conspicillatus*			*		FP,RF
white-faced heron	*Egretta novaehollandiae*			*		FP,RF
little egret	*Egretta garzetta*			*		FP
pacific heron	*Ardea pacifica*			*		FP,RF
great-billed heron	*Ardea sumatrana*			*	notable	M,FP,RF
pied heron	*Ardea picata*			*		FP,RF
great egret	*Ardea alba*			*		FP,RF
intermediate egret	*Ardea intermedia*			*		FP,RF
striated heron	*Butorides striatus*			*		C,M
rufous night heron	*Nycticorax caledonicus*			*		M,FP,RF,MF
black bittern	*Ixobrychus flavicollis*		*			M,FP,RF,MF
glossy ibis	*Plegadis falcinellus*			*		FP,RF
Australian white Ibis	*Threskiornis molucca*			*		C,M,FP,RF
straw-necked ibis	*Threskiornis spinicollis*			*		FP,RF,W/OF
sacred ibis	*Threskiornis aetheopica*			*		C,M,FP,RF
royal spoonbill	*Platelea regia*			*		M,FP,RF
black-necked stork	*Ephippiorhynchus asiaticus*			*	flagship	M,FP,RF
pacific baza	*Aviceda subcristata*			*		FP,RF,MF, W/OF
black-shouldered kite	*Elanus axillaris*			*		M,FP,RF, W/OF
letter-winged kite	*Elanus scriptus*			*		FP
square-tailed kite	*Lophoictinia isura*			*	notable	W/OF,Es
black-breasted buzzard	*Hamirostra melanosternon*			*		FP,RF,W/OF, Es
whistling kite	*Haliastur sphenurus*			*		Th
brahminy kite	*Haliastur indus*			*		C,M,RF,MF
spotted harrier	*Circus assimilis*			*		FP
swamp harrier	*Circus approximans*			*		FP,RF
brown goshawk	*Accipiter fasciatus*			*		RF,W/OF, MF,Es

Species		Degree of susceptibility			Status	Habitats*
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
wedge-tailed eagle	*Aquila audax*			*		FP,W/OF,Es
little eagle	*Hieraaetus morphnoides*			*		C,FP,W/OF
brown falcon	*Falco berigora*			*		FP,RF,W/OF, Es
nankeen kestrel	*Falco cenchroides*			*		FP,W/OF
brolga	*Grus rubicunda*			*		FP,RF,W/OF
buff-banded rail	*Gallirallus philippensis*			*		FP
bush hen	*Amaurornis olivaceus*			*		FP
white-browed crake	*Porzana cinerea*			*		C,FP,RF
Eurasian coot	*Fulica atra*			*		FP
Comb-crested jacana	*Irediparra gallinacea*			*	flagship	FP,RF
beach thick-knee	*Esacus neglectus*			*		C
masked lapwing	*Vanellus miles*			*		FP,RF
silver gull	*Larus novaehollandiae*			*		C
gull-billed tern	*Sterna nilotica*			*		C,FP,RF
whiskered tern	*Chlidonias hybridus*			*		C,FP,RF
white-winged black tern	*Chlidonias leucopterus*			*		C,FP,RF
pheasant coucal	*Centropus phasianinus*			*		RF,W/OF
barking owl	*Ninox connivens*			*		RF,W/OF, MF,Es
boobook owl	*Ninox novaeseelandiae*			*		RF,W/OF, MF,Es
barn owl	*Tyto alba*			*		FP,RF,W/OF
spotted nightjar	*Eurostopodus argus*			*		FP,RF,W/OF, Es
blue-winged kookaburra	*Dacelo leachii*		*			M,RF,W/OF, MF,Es
red-backed kingfisher	*Todiramphus pyrrhopygia*			*		FP,RF,W/OF
sacred kingfisher	*Todiramphus sanctus*			*		Th
collared kingfisher	*Todiramphus chloris*			*	notable	M
dollarbird	*Eurystomus orientalis*			*		RP,W/OF,Es
grey shrike-thrush	*Colluricincla harmonica*			*		RF,W/OF,Es
magpie lark	*Grallina cyanoleuca*			*		FP,RF,W/OF
pied butcherbird	*Cracticus nigrogularis*			*		RF,W/OF
crow	*Corvus orru*			*		Th
great bowerbird	*Chlamydera nuchalis*			*		RF,W/OF, MF,Es

Source: Dorfman 1997, Covacevich & Archer 1975, Mitchell et al 1995, Catling et al 1998, Dostine & Morton 1988, 1989, Recher & Holmes 1982, van Beurden 1980, Freeland 1987, Seabrook 1991, Cassels 1970, Lavery 1969, Goodacre 1947, Roeger & Russell-Smith 1995.

Habitats — C: Coastal mudflats and beaches, M: Mangroves, FP: Open floodplains/grasslands, RF: Riparian and fringing forest, W/OF: Woodlands and open forests, MF: Monsoon forest, Es: Escarpment and plateau, Th: Throughout (adapted from Barnett 1980, Morton & Brennan 1983).

Mammals

A number of researchers have considered the potentially adverse impact of cane toads on quoll (native cat) populations — specifically northern quolls (*Dasyurus hallucatus*) (Braithwaite & Griffiths 1994) and spotted-tailed quolls (*D. maculatus*) in southeastern and northeastern Queensland (Covacevich & Archer 1975, Watt 1993, Burnett 1993). The risk assessment used by Burnett (1997) for varanid lizards also included information on four species of quoll. He reported anecdotal evidence of apparent declines in quoll populations within a matter of months after cane toad colonisation of areas in northern Queensland. Of the four species in question, the northern quoll (which also occurs in Kakadu) was placed in the highest risk category.

Catling et al (1998), in their surveys in the Borroloola region, identified another four species of small native mammal that may eat cane toads, three of which are found in Kakadu. These are the long-tailed planigale (*Planigale ingrami*), common planigale (*P. maculata*) and northern brown bandicoot (*Isoodon macrourus*) (table 9). Other mammal species known or thought to eat native anurans are listed in table 9. Recent research in Kakadu has indicated that populations of some small mammals such as the northern quoll and northern bandicoot are declining at an alarming rate, due to unknown factors (Woinarski 2000). If this is the case, the presence of cane toads may exacerbate this decline. It is unknown whether the declines are local, restricted to the Kapalga study area, or widespread across Kakadu National Park.

Table 9 Predatory mammal species in Kakadu National Park, potentially susceptible to cane toads

Species		**Degree of susceptibility**			**Status**	**Habitats***
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*		
northern quoll	*Dasyurus hallucatus*	*			notable	RF,W/OF,Es
brush-tailed phascogale	*Phascogale tapoatafa pirata*			*	notable	W/OF
long-tailed planigale	*Planigale ingrami*			*		FP,W/OF
common planigale	*Planigale maculata*			*		FP,RF,W/OF, MF,Es
sandstone antechinus	*Pseudantechinus bilarni*			*	notable	Es
red-cheeked dunnart	*Sminthopsis virginiae*			*	notable	W/OF
northern brown bandicoot	*Isoodon macrourus*			*		FP,W/OF
ghost bat	*Macroderma gigas*			*	vulnerable	Es
dingo	*Canis familiaris dingo*	*				Th
feral cat	*Felis catus*	*				Th
feral pig	*Sus scrofa*		*			C,FP,RF,W/OF,MF

Source: Begg et al 2000, Braithwaite & Griffiths 1994, Covacevich & Archer 1975, Burnett 1997, Catling et al 1998, ANPWS/DEST 1991, van Beurden 1980.

Habitats –C: Coastal mudflats and beaches, M: Mangroves, FP: Open floodplains/grasslands, RF: Riparian and fringing forest, W/OF: Woodlands and open forests, MF: Monsoon forest, Es: Escarpment and plateau, Th: Throughout (adapted from Morton & Brennan 1983, Strahan 1983).

There are reports of domestic dogs and cats dying or becoming ill after mouthing or ingesting cane toads (Knowles 1964, Rabor 1952, van Beurden 1980). The dingo is considered a potential consumer of cane toads. In surveys in the Borroloola region, the dingo was one of only a few species whose populations were considered to be adversely affected by cane toads (Catling et al 1998). Feral cats are present in Kakadu and it is possible that they may be affected in a similar manner to domestic cats (see section 2.3.6.4). Feral pigs may also ingest cane toads (Catling et al 1998). Members of the community of Borroloola reported the death of a large semi-domestic pig that was seen trying to eat a cane toad (Begg et al 2000).

The water rat (*Hydromys chrysogaster*) has been reported to successfully consume cane toads by eating only the non-toxic parts (Frauca 1974, Covacevich & Archer 1975). It has been suggested that this behaviour is likely to be an extension of existing behaviour towards a new prey species, as many Australian native frogs also have toxic skin secretions (R Alford, pers comm, 2000). In fact, native frogs of several species, including green tree frogs, and striped burrowing frogs, have been dealt with similarly by predators (R Alford, pers comm, 2000).

Kakadu is home to a great diversity of bat species. The ghost bat, a notable species, is thought to eat native frogs (ANPWS/DEST 1991) and therefore may eat cane toads. Other bat species may eat native frogs and potentially cane toads, however, no information is available.

2.3.2 Effects on prey species

Potential effects of cane toads on their prey can be categorised into those food items consumed by cane toad tadpoles (ie aquatic stages) and by cane toad metamorphlings, juveniles and adults (ie terrestrial stages).

2.3.2.1 Tadpoles

Very few studies have assessed the effects of cane toad tadpoles on prey species. Cane toad tadpole diet is thought to consist primarily of detritus, algae and other suspended organic material (Easteal & Floyd 1986, Crump 1989). Hearnden (1991) found that cane toad tadpoles regularly preyed upon cane toad eggs and, to a lesser extent, on cane toad hatchlings (ie the stage between egg and tadpole). The presence of older cane toad cohorts resulted in a decrease in cumulative survival from egg to metamorphosis from 4% to 0.1% under field conditions (Hearnden 1991). Interestingly, the reduction in the densities of cane toad egg and hatchlings as a result of predation by cane toad tadpoles only served to facilitate growth and metamorphosis of the survivors (Hearnden 1991, Alford et al 1995).

Recently, Crossland (1998) investigated predation by cane toad tadpoles and found that they were not significant predators of native frog eggs, hatchlings or tadpoles. In contrast, tadpoles of some native frogs (particularly *Limnodynastes ornatus*, ornate burrowing frog) were often found to prey upon eggs and hatchlings of the same species and/or other native frog species. The study indicated that tadpoles of native frogs, particularly *L. ornatus*, were likely to have a greater impact on the survival of early life stages of native frogs than were cane toad tadpoles, noting, however, that this could be potentially offset by the naturally higher densities of cane toad tadpoles (Crossland 1998).

Impacts of cane toad tadpoles on freshwater algal assemblages and potential secondary (cascade) effects on other primary consumers do not appear to have been assessed. This would be of more concern in small, isolated and/or temporary pools.

2.3.2.2 Metamorphlings, juveniles and adults

Cane toads are generalist feeders and consume a wide variety of prey (Freeland 1984). Almost all terrestrial phyla are represented in toad stomach content analyses. By far the major type of prey items consumed are arthropods. Ants, termites and beetles are usually eaten in the greatest numbers (Freeland 1984, 1990). It has been proposed that the diet of a toad may simply reflect the relative abundance of prey species within its location, though this has not been proven (Freeland 1984).

Tyler (1975) described three categories of studies undertaken on cane toad diet, expressing caution about their interpretation: i) a large number of short notes reporting isolated stomach contents usually of an unusual nature; ii) short-term, detailed analyses of the stomach contents of large numbers of toads at different localities; and iii) monitoring studies examining responses when high densities of cane toads exhausted local insect food sources. The first category often attracts the most attention but can be the least accurate in reflecting normal diet. For example, reports of cane toads eating larger animals such as mice, rats, birds, lizards, small snakes and frogs are quite common in the literature (Rabor 1952, Tyler 1975, van Beurden 1980, Freeland 1984, Easteal & Floyd 1986). Freeland and Kerin (1988) and Freeland et al (1986b), examined over 550 cane toad stomachs and found the remains of native frogs in only 3 stomachs. Although this frequency of predation on frogs is low, Freeland and Kerin (1988) speculated that cane toad populations of 5000 ha^{-1} could be expected to have a major impact on the native frog community. However, no such effect was evident in the extent of population recovery of native anurans following experimental reduction (Freeland & Kerin 1988).

For all frogs and toads, the primary stimulus that triggers a feeding response is prey movement (Tyler 1975, Freeland 1984). For cane toads, Ingle and McKinley (1978) demonstrated that black objects are more likely to elicit prey catching behaviour than white objects of a similar size, and the same applies to objects that are elongated along the axis of movement. Cane toads also respond to auditory stimuli, having been observed homing in to feed on native amphibians that were calling from an urban cement pool in Panama (Jaeger 1976). Cane toads have also learnt to seek out and eat non-motile food items, such as domestic pet food, discarded meat and vegetable matter, even human faeces, thus providing further dietary options (Tyler 1975, Freeland 2000, Alexander 1964, Ormsby 1955). This behaviour of learning to locate and return to abundant food sources has also been observed by Waterhouse (1974): cane toads repeatedly returned to cattle droppings (to feed on dung beetles), the ground beneath streetlights (Brattstrom 1962) and termite burrows (Fellows 1969).

Dietary preferences between cane toad metamorphlings/juveniles and adults are somewhat different. Van Beurden (1978) analysed the stomach contents of 30 juvenile cane toads captured on a grassy sand substrate and 30 captured on a leaf litter substrate. The stomach contents of juveniles from the grassy sand substrate comprised about 20% mites, 25% collembolans, 25% aphids, and 8–10% each of chironomids and ants. Stomach contents of those from the leaf litter substrate comprised 70% mites and about 17% ants. Thus, the diets of metamorphlings and juveniles are generally dominated by smaller invertebrates such as mites, collembolans, aphids, chironomids and small ants (van Beurden 1978, Freeland 1984, 1990). It is thought that such organisms might be too small to elicit feeding response from adult toads (Freeland 1984).

A number of studies have assessed the diets of adult cane toads to varying degrees (Bailey 1976, Beebe 1925, Begg et al 2000, Cade & Rice 1980, Clarke 1974, Cohen & Williams 1992, Dexter 1932, Duellman 1978, Fellows 1969, Freeland et al 1986a,b, Goodacre 1947, Grant 1948, Hinkley 1963, Illingworth 1941, Krakauer 1968, Leonard 1933, Lever 1937a, 1938b, 1939a, 1944, 1945, Mungomery 1936, 1937, Noble 1918, Pippet 1975, Richardson 1941, Simmonds 1957, van Beurden 1978, 1980, Van Tets & Vestjens 1973, Weber 1938, Werren 1993, Wolcott 1937, Zug et al 1975, Zug & Zug 1979). A summary of a number of these studies is presented below (also refer to Niven & Stewart 1982 for a further summary).

Zug and Zug (1979) reported the stomach contents of cane toads in their native range. Although limited numbers of stomachs were analysed, it was clear that the major dietary items were beetles (Coleoptera) and ants (Hymenoptera). Mungomery (1936) also reported millipedes as being major dietary items of cane toads in Puerto Rico. Stomach contents of 476 cane toads from a savanna site in Papua New Guinea comprised primarily termites (Isoptera; 40% of total dietary items), ants (33%) and beetles (8%) (Zug et al 1975). Van Beurden (1980) reported the stomach contents of 100 adult cane toads in New South Wales. Beetles and ants were the major dietary items, constituting 35% and 52% of the stomach contents, respectively, with both types being found in almost all of the stomachs analysed. Werren (1993) found that beetles and ants were the most common prey types of cane toads sampled from rainforest sites in north-eastern Queensland. Finally, Begg et al (2000) examined the stomach contents of 12 cane toads from the NT (three from Borroloola and nine from Elsey National Park). Although varying from specimen to specimen, the major dietary items were beetles (~13 species, both large and small), termites (176 in total), ants (137) and bugs (Hemiptera). In every case vegetative material (speargrass seeds, leaves, stems) and small pebbles and sand formed a surprisingly large proportion of the stomach contents. Thus, the major dietary items of cane toads are very similar throughout their distribution, with major differences probably being due to temporal (ie seasonal) and spatial differences in the invertebrate assemblages.

There have been no studies on the impact of cane toads on communities of ground dwelling arthropods. However, Catling et al (1998) did find that reductions in beetle populations were associated with the presence of cane toads. Apart from this study, the absence of data prevents any assessment of the impact of cane toads on their prey communities in Australia or the Neotropics. Observations that long established cane toad populations exist at far lower densities than can be found in recently invaded areas (Freeland 1986a) neither support nor negate the possibility that the lower densities are a result of declines in food availability following invasion (Freeland et al 1986a,b).

Jacklyn (1992) reported that entomologists from the Wet Tropics Management Agency were concerned that large numbers of cane toads that had moved into the rainforests of north Queensland were having an effect on the diverse and little-known insect fauna of the region. However, our attempts to obtain further information on this issue from the Wet Tropics Management Agency were unsuccessful.

The invertebrate fauna of Kakadu is diverse, but only a few groups are well understood (Andersen 1990). It is estimated that over 10 000 insect species occur in the Park (Press et al 1995) and many of these are undescribed. Some of these could well be endemic to Kakadu. To what extent this diversity will be lost because of the cane toads before it is described is impossible to predict. However, due to the selective feeding habits of cane toads and their habit of returning to abundant food sources (Waterhouse 1974), beetles, ants and termites are considered to be groups of ground dwelling insects that may be most affected.

The only species known to suffer long-term population decline or extinction from the impact of cane toads is a tapeworm found in the intestines of a snake (Freeland 1994). The tapeworm rapidly declines in number following cane toad invasion, and remains so, or possibly becomes extinct. The cane toad consumes most of the intermediate stages of the parasite, which are in consequence not transmitted to the host snake.

2.3.3 Effects of resource competition

Cane toads may affect their predators, prey and parasites directly, but they may also affect animals indirectly by depriving them of resources such as food, shelter and breeding sites. Experience in Queensland suggests that cane toads will consume virtually all terrestrial invertebrates within a few hundred metres of waterbodies that serve as toad refugia during the

Dry season. It is therefore likely that they will have a strong adverse effect on other taxa that use these habitats as refugia (R Alford pers comm). Similar to the debate about the effects on populations of cane toad predators, there are often differing opinions and conclusions surrounding the effects of competition for resources between cane toads and native species. As highlighted below, the results of studies on competition are sometimes inconclusive and conflicting.

2.3.3.1 Overseas case studies

In Dumaguete City in the Philippines, Rabor (1952) noted declines in the populations of four native anuran species following the introduction of cane toads. The native species retained their former abundance only in areas where cane toads had not penetrated, and it was concluded that these population declines were the result of competition with cane toads (Rabor 1952). However, Alcala (1957) observed that many native anurans were abundant in their usual habitats (ie non-urban areas) in the Philippines, despite the presence of cane toads. He concluded that cane toads did not compete with native frogs of the Philippines.

In Papua New Guinea, it was observed that increases in cane toad populations in savanna habitat coincided with declines in native reptile populations, including several species of gecko, skink and other terrestrial species that sheltered under logs and rocks (Schultze-Westrum 1970). Following the invasion of cane toads, the numbers of such native species declined and cane toads became the dominant animal found under logs and rocks, suggesting that competition for shelter was a major factor (Schultze-Westrum 1970). Zug et al (1975) concluded that adult cane toads were unlikely to compete with native savanna anuran species in Papua New Guinea due to differences in the 'habits and habitats' of cane toads and native frogs — the native species being either arboreal or closely associated with water. They also stated that although competition may exist between the tadpoles, habitat alterations by humans were more likely to create unsuitable spawning sites for native frogs.

Pernetta and Goldman (1976) concluded that cane toads did not compete with either of the two endemic frog species of Fiji because (1) cane toads mainly occurred in open areas while native frogs were found in forest habitat, (2) cane toads never climb, and therefore feed at a different level in the habitat, and (3) cane toads are larger than the native frogs and would therefore eat larger insects.

2.3.3.2 Australian case studies

As with overseas case studies, many previous Australian case studies focused on the competitive impact of adult cane toads on native anuran fauna. Cassels (1966) warned that cane toads were 'ousting' native Australian frogs but did not provide any data to support the claim. Covacevich and Archer (1975) attributed reductions in populations of some native frogs to competition for, and dominance of, breeding grounds by cane toads. However, they conceded that habitat alteration also may have adversely affected native frog populations. Covacevich and Archer (1975) also reported that it was common to find only cane toads when searching for reptiles and small mammals in some areas of eastern Queensland. Whether or not this remains the case is difficult to establish.

Many residents in New South Wales have reported a decline in numbers of the green tree frog (*L. caerulea*) since the arrival of the cane toad (van Beurden 1978, Seabrook 1991). This species is ecologically quite similar to the cane toad in having a breeding season restricted to the warmer months of the year and mainly feeding in cleared areas. Therefore, competition for breeding sites and food may exist (van Beurden 1978).

Results of a study of competition between cane toad tadpoles and native anuran larvae from the Darling Downs area of southern Queensland, while not conclusive, suggested there was evidence that cane toad tadpoles can affect the growth of native anuran tadpoles under some circumstances (Williamson 1999). Three of the four species examined showed a reduced growth rate in the presence of cane toads. The mechanism of the competition between the species was not examined, although it may have been due to exploitation or interference competition (Williamson 1999). Data on pond use by cane toads indicated that most native anuran species are found in a high proportion of sites that do not contain cane toads. Therefore, although high densities of cane toad tadpoles occur at some sites, tadpole populations of native anuran species may not be affected greatly because they use a larger number of breeding sites than cane toads and are therefore likely to escape subsequent interactions (Williamson 1999).

Crossland (1997) found that cane toad tadpoles can have a significant impact on tadpole communities of the ornate burrowing frog (*Limnodynastes ornatus*) via competitive effects. The intensity and outcome of these competitive interactions in natural waterbodies will vary depending on: 1) the degree to which cane toad and *L. ornatus* tadpoles compete, 2) the timing of arrival of *L. ornatus* to ponds relative to cane toads, 3) the ability of *L. ornatus* to avoid consuming cane toads, and 4) the size of *L. ornatus* tadpoles already present in a waterbody when cane toads breed. In general, the responses of *L. ornatus* tadpoles to different times of introduction of cane toads were consistent with size-specific competition. *L. ornatus* tadpoles performed better (increased survival and increased mass at tail resorption) when cane toads tadpoles were added late to ponds, and performed worse (nil survival) when cane toad tadpoles preceded them into ponds, compared with when both species were added to ponds simultaneously. Since cane toad tadpoles are not significant predators of *L. ornatus* early life stages, this impact was attributed to competitive exclusion by early cane toad tadpoles. In natural waterbodies, cane toad tadpoles may occur at much higher densities than used in this experiment (ie localised cane toad tadpole aggregations of up to 800 m^{-2}; Hearnden 1991). At such densities, one would expect survival of late breeding *L. ornatus* in ponds that already contain cane toad tadpoles to be nil. Cane toads have a greater fecundity than most north Australian frogs (Pengilley 1981, ERAES 1998) and cane toad tadpoles collect in large aggregations (Wassersug 1971, Freeland 2000). Both these factors may confer competitive superiority over native frogs (Freeland 1984).

Little is known about competition between cane toad tadpoles and other aquatic organisms that share similar feeding habits and diets. A range of aquatic vertebrates and invertebrates feed on algae, detritus and suspended organic matter, including the known endemic invertebrates restricted to the escarpment gorges (C Humphrey pers comm). High densities of cane toad tadpoles in isolated pools could out-compete native aquatic vertebrates and invertebrates for food resources.

Freeland and Kerin (1988) examined competitive interactions between cane toads and native frogs around waterholes in the Gulf of Carpentaria. Three of these species, the pale frog (*Litoria pallida*), Roth's (brown) tree frog (*L. rothii*) and the desert tree frog (*L. rubella*) are found in Kakadu. Cane toads had no observable impact on the patterns of habitat and food use by the native species of frog, or on the species compositions, equitabilities and population sizes of native frog communities active during the Dry season. Cane toads also had no influence on recovery following experimental reduction of native frog population sizes, with the recovery being associated with recruitment rather than being purely a result of immigration.

The pattern of habitat and food exploitation exhibited by cane toads differed from those exhibited by native frog species. Also, differences in the pattern of resource use between cane toads and the native frog species were of the same order as differences among the natives. Thus, it is predictable that (if resources are limiting, and inter-specific competition is a force in structuring these communities) invasion by cane toads is unlikely to result in any major impact on the native species studied (or at least no greater impact than the native species exert on each other) (Freeland & Kerin 1988). The major factor separating the resource use of the cane toad from those of the native species was the cane toad's heavy reliance on ants and termites as major food sources. The absence of any apparently significant impact of the cane toad on the native frog fauna was interpreted as a product of the unusual food habits of the toad, together with non-equilibrium frog communities resulting from the highly erratic climate of the region (Freeland 1990).

It could be hypothesised that the cane toad is more likely to have an adverse impact on larger sized native frog species such as the giant frog (*Cyclorana australis*) and the marbled frog (*Limnodynastes convexiusculus*). While this may be possible, aestivation during the Dry season effectively removes these species from competition during the period of the year when resources are most likely to be limiting (eg Janzen 1973). Abundant food and increased vegetation cover at the beginning of the Wet season, a time of reduced cane toad and native frog densities, may reduce competition for food and shelter during the Wet season (Freeland & Kerin 1988).

In a two year study in the Roper River region of the NT, Catling et al (1998) found three species whose numbers (based on presence/absence records only) were possibly affected by the presence of cane toads. These were the dingo, brown tree frog and Gilbert's lash-tail dragon. The dingo is a potential predator of cane toads. However, the latter two species are both arboreal, and thought not to eat cane toads nor (at least as adults) be eaten by them. The effect was thought to be short term only as all three species were present in reasonable numbers in an area with 7 years of cane toad colonisation. Catling et al (1998) also found that abundance and species diversity of most reptiles were lower at the sites inhabited by cane toads for around 7 years compared with the recently invaded site and site with no cane toads. They considered this may have been an indication of a long-term effect on the reptile fauna, particularly the small reptiles, and that it appeared to be an indirect effect because those species were considered not to ingest cane toads. It is possible that both of these scenarios were due to competition for resources, though this cannot be proven. Some depletion of food resources may have occurred as beetle numbers appeared to be adversely affected by the number of cane toads, though the results were highly variable. Despite these observed effects, the study concluded that there was little evidence that cane toads have a significant adverse effect on the diversity and abundance of many of the native fauna examined. Results were often confounded by small sample sizes, and the fact that the interactions between area, year and season may have been the cause of some perceived effects.

Competition for food between cane toads and other insectivores, namely birds, has not been investigated, and nothing can be concluded.

Table 10 lists species found in Kakadu that may be potentially susceptible to competition with cane toads, based on existing literature. It should be noted that the list is not likely to fully represent the total species that may compete with cane toads for resources (eg potential competition for food with escarpment endemic invertebrates). The table includes information from both anecdotal and experimental sources, details of which are outlined in the source references.

Table 10 Species in Kakadu National Park potentially susceptible to competition with cane toads

Species		**Degree of susceptibility**			**Status**
Common name	*Scientific name*	*Definite*	*Probable*	*Possible*	
Gilbert's lash-tail dragon	*Lophognathus gilberti*	*			common
ornate burrowing frog	*Limnodynastes ornatus*		*		common
green tree frog	*Litoria caerulea*			*	common
Roth's (brown) tree frog	*Litoria rothii*	*			common

Source: van Beurden 1978, 1980, Seabrook 1991, Crossland 1997, Catling et al 1998.

The criteria used for assessing the susceptibility of competitors are as follows:

Definite: documented adverse effects to populations of this species have been reported in the literature;

Probable: documented as being adversely affected and effects on individuals reported, but not on populations; or limited anecdotal observations of population declines in the literature;

Possible: suspected competition noted in the literature.

2.3.4 Cultural effects

This section can only claim to provide an overview of potential cultural effects of cane toads in Kakadu National Park. A more detailed study would need to be undertaken to further tease out the issues outlined below. Unless otherwise stated, the information presented below was based on information obtained during the joint ***eriss***/PAN field trip to the Katherine/Mataranka and Borroloola regions (Begg et al 2000). It seems certain that for a period of 4–5 years certain species of goannas and snakes are likely to be adversely affected when cane toads arrive in Kakadu National Park (see section 2.3.1 above). With this being the case, their decline will, in turn, adversely affect Aboriginal communities that are semi-dependent on the availability of such species as a food supply. Furthermore, should a decline in species of particular importance occur, then a change in some of the cultural ceremonies and dances performed by Aboriginal communities in Kakadu National Park seems predictable, as occurred following cane toad invasion in the Borroloola area. Ceremonies were changed to ask the spirits to return to the local Aboriginal people the foods and totem species (eg freshwater crocodile) lost due to the cane toad invasion. However, it is important to note that with the subsequent return/recovery of some of those species (in particular goannas and snakes), it was expected that the ceremonies would revert to their original form.

During a workshop on indigenous use of wetlands in northern Australia, Evans (1999) noted that cane toads on Groote Eylandt and around Borroloola killed 'goanna, blue-tongue, long-necked turtle, geese and everything', highlighting the generally negative image of the cane toad within the indigenous community. At the same forum, Lindner (1999) raised concerns about the potential ecological and cultural impacts of cane toads to Kakadu National Park. However, in outlining priorities for research support, Whitehead and Storrs (1999) did not identify the cane toad as a major research priority because the majority of Aboriginal participants in the workshop did not raise research as an issue.

From a cultural perspective the loss of bush tucker, the mortality of species of religious or cultural significance and the despoiliation of waterholes and springs that are regarded as sacred sites, are regarded as the primary ways in which cane toads will affect the lives of Aboriginal people living in Kakadu National Park.

The township of Jabiru, with its mowed lawns, sprinkler systems, shaded gardens, swimming pools, playing fields, golf course, sewage treatment ponds, street lighting and network of internal roads, will offer a wide selection of ideal habitats and refuges for cane toads. Other areas of human habitation in Kakadu, including Aboriginal communities, Ranger stations, tourist accommodation, caravan parks and camping grounds (eg Mudginberri, Cooinda, Aurora Frontier Lodge and Muirella Park), are also expected to have high densities of cane toads. The impacts will be on outdoor recreational activities, particularly those conducted at night; in some areas, there will be a high risk of household pets (dogs) being poisoned. The invasion of people's homes and other buildings, particularly amenities blocks, will become commonplace. The impact of cane toads on the utilisation of day use areas (picnic grounds) is not expected to be as severe.

2.3.5 Economic effects

It is debatable whether the presence of cane toads in Kakadu will impact adversely on the income that is currently derived from tourism by Parks Australia North and private tour operators.

In spite of the presence of large numbers of cane toads, the numbers of tourists visiting National Parks in Queensland have not declined (R Pidgeon, ***eriss*** pers comm). Depending on the origins of the tourists concerned, the reactions of visitors to the presence of cane toads in areas such as Elsey National Park have ranged from disinterest to dismay (S Bailey, PWCNT, pers comm). For example, overseas tourists do not recognise the animal as being alien; visitors from Queensland have (by now) grown accustomed to the presence of cane toads in natural areas, but visitors from the southern states of Australia express deep concern about the prospect of cane toads, especially in an area such as Kakadu, because of its status as a World Heritage Site. Tour operators in Kakadu share a similar view (I Morris, pers comm).

In conclusion, it is predicted that, while everything possible should be done to control the future influx and numbers of cane toads in Kakadu, the presence of cane toads *per se* will not diminish the flows of money that are presently being generated from tourism in Kakadu. It is predicted that with or without cane toads, the major attributes of Kakadu National Park (eg its aesthetic, cultural and biodiversity values) that currently attract tourists to the area will continue to do so in the future and, in the process, overshadow any concerns about cane toads impacting adversely on economics in the Park.

For a long time it has been known that cane toads can be easily and efficiently cultured (Mungomery 1935b). However, data on the economic value of cane toad farming, laboratory supply and leather industries similar to those that have become established in Queensland are not publicly available (Freeland 1984). Despite this the mere existence of Australian companies with names such as Bufo Products Pty Ltd, Circadian Pharmaceuticals (Leitch et al 2000) and Marino Leather Exports Pty Ltd (pers comm), simply suggests that whether one is referring to parotid venom secretions, tanned skins or cane toads themselves as a commodity, when placed in the right hands, there is money to be made from their availability.

The opportunity to make cane toads commercially useful and to enhance the export potential of cane toad-derived medicinal products to markets in China has already been identified by Leitch et al (2000). Not surprisingly, potential projects of this nature also raise the possibility of exporting the edible parts of cane toads (in the form of the back legs, duly skinned) to countries such as France, and Asia.

2.3.6 Other potential effects

2.3.6.1 Contamination of water by cane toad toxin

The contamination of water by cane toad toxin has been noted on a number of occasions. During periods of breeding activity, larval and adult cane toads are frequently found dead in spawning ponds. They release toxin into the water, and the parotoid glands of adults are generally covered with the exuded viscous white toxin. In surveys and personal interviews, many people have reported poisoning of pets and poultry due to contamination of drinking water (van Beurden 1980), and some consider boreholes and water troughs as sources of drinking water that could be particularly vulnerable to contamination by cane toad toxin (K Boland, Tropical Water Solutions, pers comm) and large numbers of rotting toad carcasses (Freeland 1984).

Aquatic snails (*Physastra*) have been reported to die within 24 hours in the presence of toad toxin at a concentration of 350 mg/L (van Beurden 1980). Concentrations of 1 mg/L toad toxin had no effect on either mosquito fish (*Gambusia affinis*) or rocket frog (*Litoria nasuta*) tadpoles, although above 400 mg/L, these species died in less than 10 minutes (van Beurden 1980). The possible release and effects of cane toad toxin in the water column was investigated by Crossland (1997). Possible release of toxins via predation was simulated by cutting cane toad tadpoles into small pieces. *L. ornatus* tadpoles showed no ill effects when exposed to, but unable to consume, shredded cane toad tadpoles (Crossland 1997).

The major issue concerning contamination of water supplies is probably the rate at which the active substances within the cane toad toxin are broken down. The toxin is highly heat stable; it is still active after boiling for 15 minutes (van Beurden 1980). Thus, it will not be subject to breakdown due to high water temperatures in the late Dry season. Crossland (1997) found that cane toad tadpoles that had been dead for <24 h were generally toxic to snails and some native frog tadpoles when consumed, but cane toad tadpoles dead for 24–96 h were no longer toxic, suggesting the active components had been broken down, or released and diluted in the water. It was speculated that the toxins may break down even faster under natural conditions where they would be exposed to ultraviolet light and undergo photolysis (Crossland 1997).

2.3.6.2 Botanical effects

Although somewhat speculative at this stage, one interpretation of the information available about the role played by ants and termites in Kakadu ecosystems (Andersen & Lonsdale 1990, Andersen 1991), and in particular that of harvester ants (Andrew 1986), is that in the event of cane toads consuming vast numbers of granivorous insects in the Park, there could be botanical repercussions.

Seed harvesting (ie seed predation) by ants occurs throughout Australia and, almost universally, harvester ants are the most important post-dispersal granivores (Andersen 1991). Small mammals (eg rodents) and birds (eg finches) perform the same role but, because of the significant number and diversity of harvester ants (18 species in Kakadu), this particular group is known to eat a wide variety of plant seeds. One of the species involved (*Meranoplus* sp.) specialises on speargrass (*Sorghum intrans).* Speargrass is the dominant annual grass in Kakadu and modelling of *Sorghum* population dynamics suggests that high densities of harvester ants can have a significant impact on plant density (Andersen & Braithwaite 1996).

It is difficult to predict how cane toad predation on harvester ants, for example, might affect these relationships. However, in terms of plant-animal interactions, it seems probable that a variety of subtle ecological changes (such as altered regeneration and recruitment patterns or density of certain plant assemblages) could occur. Furthermore, if extensive/dominant vegetation types such as annual grasses are affected in the process, it is certain that the cascade effects amongst other biota would be significant.

2.3.6.3 Human health effects

In several parts of the world, such as Panama for example, cane toads have been found feeding on human faeces (Marinkelle & Willems 1964) and, as a result, to be carrying human strains of *Salmonella,* a genus of bacillus that commonly causes severe gastroenteritis, typhoid and septicaemia (Kourany et al 1970). Because cane toads harbour the *Salmonella* bacteria, transmission may also occur through handling of the animals.

In the light of this information, as well as data concerning the dissemination of the eggs of human parasites through the spread of cane toad faeces, Freeland (1984) has rightly pointed out that where modern sanitation practices are lacking, the presence of large numbers of cane toads could well represent a health hazard. The parasites mentioned that are disseminated in cane toad faeces include *Ascaris lumbricoides* (a tapeworm), *Trichuris trichuria, Schistosoma mansoni* (intestinal bilharzia), *Uncinaria* (dog hookworm) and the strong likelihood of human hookworm.

Little is known about the potential side effects and toxicity to humans associated with the use of cane toad toxin and skin use (Leitch et al 2000). In countries such as China, the primary medicinal use of cane toad skin extract and toxin is for the management of cardiovascular disorders. However, incidences of intoxication clinically similar to cardiac glycoside poisoning have been reported (Leitch et al 2000).

It seems reasonable to suggest that substance abuse (as documented in the video, *Cane Toads — An Unnatural History*, ABC 1987) could also be practised in the NT. In fact, the cane toad toxin is listed as a dangerous drug under Schedule 2 of the *Drug Misuse Act* in Queensland (ABC 1987). When cane toad toxin is extracted from the parotid glands and dried and smoked in a hand-rolled cigarette, the therapeutic/hallucinogenic effects are said to be sufficiently rewarding for the substance to become habit forming, as it has done in countries such as Fiji (S Choy, Qld DNR, pers comm). Furthermore, due to the long period of time that cane toads have been living in Queensland, there is anecdotal evidence to suggest that similar habits have been adopted by a number of people living in Cairns (S Choy, pers comm).

2.3.6.4 Beneficial effects

There is good reason to believe that not all of the ecological impacts of cane toads on the fauna of Kakadu are, of necessity, going to be adverse.

Attention has already been drawn, for example, to the possibility of feral cats and pigs succumbing as a result of eating cane toads (section 2.3.1.2). There is one report of feral cats declining in numbers, possibly due to cane toads (van Beurden 1980). This outcome could be considered beneficial to much of the smaller native Kakadu fauna. Although feral buffalo have been removed from the floodplains of Kakadu, feral pigs have been difficult to control in certain types of terrain. They continue to cause widespread damage on and around the edges of wetlands, facilitating erosion and the establishment of weed species (Storrs & Finlayson 1997). Any reduction in the present numbers of feral animals would be of obvious benefit to the Park from a conservation perspective.

Ground-nesting birds are also expected to benefit as a direct result of the expected cane toad-induced reduction in the numbers of varanids (J Childs, pers comm) and feral cats. The partridge pigeon (*Geophaps smithii*) is one such species — with its range having been gradually reduced, any improvement in its breeding success would be regarded as highly advantageous. Examples of other ground-nesting birds that would benefit from reduced egg predation by goannas include the three species of quails (*Coturnix* spp.) that are known to inhabit the Park, bush thick-knee (*Burhinus magnirostris*), great bowerbird (*Chlamydera nuchalis*) and the orange-footed scrubfowl (*Megapodius reinwardt*), the latter species being renown particularly for its mound-building nesting habits.

Due to the egg-eating/nest-robbing habits of goannas, it also seems feasible that a short-term decline in the goanna population of Kakadu could reduce the current level of predation on crocodile eggs. With both freshwater and saltwater crocodiles being protected species, an outcome of this nature would clearly be beneficial to both.

2.4 Identification of the risks

2.4.1 Comparison of potential effects and extent

The two integral components of risk are *effects* and *extent* (or *exposure*) (van Dam et al 1999) (see fig 1). A species may be susceptible to cane toad toxin, but if the cane toad does not constitute part of its diet, or if very few individuals of the species ever encounter cane toads (eg arboreal species), then the risk to the overall population is negligible. The above two sections have attempted to define the potential extent of cane toads in Kakadu and the species groups that are most susceptible. From these, it is evident that a comparison of cane toad effects and extent cannot provide a simple and/or quantitative estimate of risks to species of Kakadu. Data on cane toad effects are mostly inconclusive and unquantified, while data on cane toad distribution and densities highlight great variability and uncertainty. In addition, despite the large body of biological data on Kakadu, information on species abundances and distributions are deficient (see section 2.5). Nevertheless, it is still possible to identify key habitats and also prioritise particular species based on 1) a likelihood that they will be at greater risk from cane toads than other species, and 2) their importance to the ecological and/or cultural values of Kakadu.

2.4.2 Identification of key habitats

Section 2.2 highlighted that cane toads tend to be habitat generalists. Nevertheless, given their dependence on moisture, it was also evident that cane toads prefer particular habitats at particular times of the year. The following summary outlines what are considered to be the key habitats for the major cane toad life stages.

2.4.2.1 Aquatic stages

Cane toads will breed in both temporary and permanent water and thus, their aquatic stages will be found in a variety of aquatic habitats. However, it is most likely that cane toad eggs and tadpoles will be concentrated in shallow lentic areas of water. This includes temporary pools of water and also sheltered, littoral zones of creeks and billabongs. Although cane toads will concentrate their breeding activity during the wetter periods (eg November–June), they are also known to breed during the Dry season. Thus, during this period, but particularly during the late Dry season–early Wet season, with the onset of the first rains, cane toad eggs and tadpoles will probably be present in waterbodies that act as important Dry season refuges. During the Wet season, when many of the major wetland habitats (eg the floodplains, *Melaleuca* swamps, lowland monsoon rainforests, other riparian habitats, and larger creek channel habitats) are inundated, cane toad breeding, and therefore eggs and tadpoles, may be concentrated in the wetland habitats associated with the open forests and woodlands of the lowland plains (eg heathlands, perennial streams, seasonal feeder streams, springs and waterholes and seepage zones and soaks).

2.4.2.2 Terrestrial stages

Dry season

As the Dry season progresses, cane toads will progressively move from sites of temporary water to permanent water. Habitats such as paleochannels on the floodplains (grasslands/sedgelands), the moist, sheltered habitats on the margins of floodplains and temporary or shallow billabongs (eg *Melaleuca* forests bordering floodplains, or as described by Braithwaite et al (1991), the sedgeland/forest ecotone), and seasonal creeks and their associated temporary pools will provide ideal cane toad habitat during the early to mid Dry season. Colonisation by cane toads in all the above habitats will be facilitated by the disturbance created by feral pigs, which brings moisture to the soil surface and produces cavities and burrows that make ideal Dry season shelter sites.

During the late Dry season, areas around permanent water will represent the key cane toad habitats. These include riparian zones around channel habitats such as in-stream billabongs and plunge pools (eg *Melaleuca* forests), any permanent off-channel aquatic habitats, springs, patches of lowland monsoon forest, sandstone monsoon rainforest, and possibly seepage zones and soaks. Feral pig disturbance will again promote the colonisation of cane toads in these habitats. As mentioned above, most of these habitats act as Dry season refuges for a wide range of aquatic and terrestrial wildlife. Finally, areas of human habitation will also be focal habitats for cane toads in Kakadu during the Dry season, where there is continual access to moisture.

Wet season

The Wet season is the period of greatest reproduction, so it will probably see the highest numbers of cane toad metamorphlings. These individuals will generally remain around the moist margins (ie within 5 m) of the waterbodies they emerged from (ie shallow, lentic areas of water) or of nearby waterbodies. Given the inundation of many of the major wetland habitats during the Wet season, the majority of adult cane toads will most likely disperse into the woodlands and open forests of the lowland plains, which comprise about 80% of the area of Kakadu. As described above, the variety of wetlands associated with these habitats will probably be focus points for breeding. The annual grasses and vegetation debris (eg logs) within the woodlands and open forests will provide suitable shelter for cane toads during the Wet season.

2.4.3 Identification of species at risk

2.4.3.1 Predators

Section 2.3 identified 151 predator species or species groups within Kakadu National Park that were considered susceptible or potentially susceptible to cane toads. This included 11 species considered *definitely* susceptible to cane toads (refer to section 2.3.1 for susceptibility criteria), 16 species or species groups considered *probably* susceptible to cane toads, and 124 species or species groups considered *possibly* susceptible to cane toads. While this ranking provides some indication of risk, it does not consider the extent to which the species may actually be exposed to cane toads (ie habitat/niche overlap, behaviour) or the ecological/cultural importance of the species. Thus, the risk of cane toads causing population level effects to predator species was assigned a ranking as outlined in table 11. Habitat information for the Kakadu species was compared with the key habitats identified for cane toads. Where it was clear that no or very little habitat overlap would occur, the species was assigned a lower risk. Similarly, where available, relevant information on feeding ecology or behaviour was also used to determine whether a species should be assigned a higher or lower risk. Within the risk categories, priorities were also assigned, based on whether the species was listed or considered endangered, vulnerable, notable or flagship (see table 11).

Table 11 Criteria for determining risk categories and level of priority for predatory species susceptible or potentially susceptible to cane toads

Risk category	Priority	Criteria
1. Likely *Population level effects likely*	Highest	Endangered, vulnerable, notable or flagship species considered *definitely* susceptible to cane toads, regardless of relevant habitat information.
	High	As above, but for species not listed as notable or flagship.
2. Possible *Individual mortalities probable, population level effects unknown but possible*	High	Endangered, vulnerable, notable or flagship species considered *probably* susceptible to cane toads, unless relevant habitat/ecological information suggests they are at less risk.
	Moderate	As above, but for species not listed as notable or flagship. Species considered *possibly* susceptible to cane toads, where relevant habitat/ecological information suggest they are at greater risk.
3. Uncertain *May or may not eat cane toads, with effects on individuals or populations unknown*	High	Endangered, vulnerable, notable or flagship species considered *possibly* susceptible to cane toads, unless relevant habitat/ecological information suggests they are at less risk.
	Moderate	As above, but for species or species groups not listed as notable or flagship. Species considered *probably* susceptible to cane toads, where relevant habitat/ecological information suggests they are at less risk.
4. Unlikely *Effects on individuals or populations are unlikely*	Low	Species considered *possibly* susceptible to cane toads, where relevant habitat/ecological information suggests they are at less risk.

The risks of cane toads to predator species, and their associated priority status are shown in table 12.

Risk category 1 — Likely risk

One species in the highest risk category, the northern quoll, is listed as notable and should be given the highest priority for attention (table 12).

The 9 remaining species in the highest risk category should be given high priority. These species included 5 lizards (all varanids), 3 snakes (all elapids) and one mammal (dingo). The feral cat, considered *definitely* susceptible, was excluded from the table because it is a non-native and not a priority for monitoring or assessment of cane toad impacts. Any impacts on feral cat populations will be seen as a beneficial effect to Kakadu. From published habitat information, the mangrove monitor (varanid lizard) does not appear to occupy key cane toad habitats. However, recent observations indicate that this species often forages around the back swamps and paleochannels on the floodplains (A Griffiths, NTU, pers comm), and so will probably be exposed to cane toads.

Table 12 Risk ranking and priority status for Kakadu National Park species susceptible or potentially susceptible to cane toads

Risk category	1. (Likely)		2. (Possible*)	3. (Uncertain)				4. (Unlikely)
Priority	**Highest**	**High**	**Moderate**	**High**	**Moderate**			**Low**
Species	Northern quoll	Gould's goanna Mangrove monitor Merten's water monitor Northern sand goanna Spotted tree monitor Northern death adder King brown snake Western brown snake Dingo	Leeches (? spp.) Snails (≥11 spp.) Ornate burrowing frog Northern dwarf treefrog Desert tree frog Blue-tongued lizard Carpet python Brown tree snake Slaty-grey snake Freshwater crocodile Black bittern Blue-winged kookaburra	Coal grunter Primitive archerfish Square-blotch goby Masked rock frog Carpenter frog Jabiru toadlet Rock monitor *Varanus primordius* Kimberley rock monitor Long-tailed rock monitor Mitchell's water monitor Black-headed monitor Oenpelli python Great billed heron Black-necked stork (jabiru) Comb-crested jacana Square-tailed kite Ghost-bat Sandstone antechinus Red-cheeked dunnart Brush-tailed phascogale	Water beetles (? spp.) Backswimmers (? spp.) Fly-specked hardyhead Purple-spotted gudgeon Banded grunter Spangled grunter Marbled frog Giant frog Long-footed frog Green tree frog Dahl's aquatic frog Roth's (brown) tree frog Copland's rock frog Peter's frog Pale frog Rockhole frog Javelin frog Rocket frog Tornier's frog Northern spade-foot toad Bilingual froglet Northern Territory frog Floodplain toadlet Black-headed python Children's python Water python	Olive python Macleay's water snake Black whip snake Olive whip snake *Demansia papuensis* Northern small-eyed snake Pied cormorant Little pied cormorant Little black cormorant Great cormorant Australian pelican Little egret Pacific heron Pied heron Great egret Intermediate egret Rufous night heron Royal spoonbill Pacific baza Black-shouldered kite Letter-winged kite Black-breasted buzzard Brahminy kite Spotted harrier Swamp harrier Brown goshawk	Wedge-tailed eagle Little eagle Brown falcon Nankeen kestrel Brolga Buff-banded rail Bush hen White-browed crake Eurasian coot Masked lapwing Gull-billed tern Whiskered tern White-winged black tern Pheasant coucal Spotted nightjar Red-backed kingfisher Sacred kingfisher Dollarbird Grey shrike-thrush Magpie lark Pied butcherbird Great bowerbird Long-tailed planigale Common planigale Northern brown bandicoot	Tarpon Saratoga Salmon catfish Blue catfish Midgley's catfish Longtom Common archerfish Golden goby Flathead goby Dwarf gudgeon Black-banded gudgeon Pacific black duck Australasian grebe Hoary-headed grebe Darter White-faced heron Glossy ibis Australian white ibis Straw-necked ibis Sacred ibis Whistling kite Barking owl Boobook owl Barn owl Crow Striated heron Beach thick-knee Silver gull Collared kingfisher Feral cat Feral pig

* No species in Risk Category 2 were assigned High priority (ie there were no listed, notable or flagship species).

Risk category 2 — Possible risk

Of the 12 species or species groups in the second risk category, none are listed as endangered or vulnerable, or thought to be notable or flagship species. Thus, all species were assigned moderate priority status.

Represented in this category are two groups of aquatic invertebrates, 3 frogs, one lizard, 3 snakes, freshwater crocodile and 2 birds. Little can be said of the leeches and snails other than they appear to readily predate on and are highly sensitive to cane toad eggs or tadpoles (Crossland & Alford 1998), and species found in cane toad breeding habitats may be at risk. Tadpoles of the ornate burrowing frog, northern dwarf tree frog and Dahl's aquatic frog readily consumed cane toad eggs or sometimes hatchlings, with death usually resulting (Crossland & Alford 1998). All three species appear to share similar breeding habitats and periods with the cane toad (Tyler & Crook 1987). However, it has been reported that native frog and cane toad tadpoles co-occur far less frequently than would occur by chance (Freeland 2000, Williamson 1999). The carpet python, slaty-grey snake and brown tree snake also appear to share similar habitats to the cane toad (eg sedgelands/floodplains, floodplain margins, monsoon forests) and are therefore likely to encounter them. Although there is evidence to suggest that at least one of these species avoids consuming the highly toxic native frog, *L. dahlii* (Madsen & Shine 1994), there is no evidence to date of snakes avoiding cane toads. Consequently, all three snake species were retained at their current risk ranking. The reports of freshwater crocodile deaths in relation to cane toads are sufficient to suggest that individuals will die when cane toads arrive. However, there is no evidence to suggest major declines in populations. The black bittern and the blue-winged kookaburra also occupy a broad range of habitats that will more than likely see them encounter cane toads. Some kookaburras have been reported to successfully eat juvenile cane toads or carrion —however, the reports of kookaburra deaths are sufficient for this species to be retained in this risk category.

Risk category 3 — Uncertain risk

Of the 98 species or species groups in the third risk category, 21 were assigned as high priority. Seventeen are listed as either vulnerable or notable, or considered flagship species. These species include 3 fish, 3 frogs, 2 reptiles, one snake, 4 birds and 4 mammals. One of the mammals, the ghost bat, is listed as notable (Roeger & Russell-Smith 1995). The black-necked stork and comb-crested jacana are considered flagship species in Kakadu, while the remainder are considered notable under the criteria outlined in section 2.3.1. In addition to being a flagship species, the black-necked stork exhibits foraging behaviour that will probably maximise exposure to cane toad metamorphlings and possibly adults. Given the well documented susceptibility of varanid lizards to cane toads, all the varanids within this risk category (two of which are notable) have also been assigned as high priority. Habitat information for the varanids suggests significant overlap with key cane toad habitats, although the long-tailed rock monitor appears to be restricted to the escarpment, while no habitat information was found for the Kimberley rock monitor. Like the long-tailed rock monitor, all three notable frog species are generally only found in escarpment habitats. While overall densities of cane toads may be lower in the escarpment country, Dry season congregation around the small, isolated, permanent waterholes in the gorges will probably result in high localised densities. Finally, although the Oenpelli python is thought not to eat amphibians, it is a sufficiently important species to warrant high priority.

The majority of species (77) in this risk category have been assigned as moderate priority. These include two groups of invertebrates, 4 fish, 17 frogs, 9 snakes, 42 birds and 3 mammals. Differential mortality of water beetles (Dytiscidae) and backswimmers (Notonectidae) following consumption of cane toad aquatic life stages was found not to be statistically significant (Crossland & Alford 1998). The fly-specked hardyhead, purple-spotted gudgeon, banded grunter and spangled grunter are the only four fish species reported to die following ingestion of cane toad eggs or tadpoles (Crossland & Alford 1998, Pearce 1980). However, even these studies reported that the majority of individuals did not eat cane toad eggs or tadpoles, indicating that while some individuals may die, populations are probably not at risk. Consequently, these two fish species were assigned a risk rating of three, with moderate priority. The frog species were included based on information that their tadpoles have been observed or are thought to eat native frog tadpoles and carrion (Tyler & Cappo 1983, M Tyler pers comm). However, no effects of cane toads (ie eggs or tadpoles) to these species have been reported. According to M Tyler (pers comm), the frog species will share similar breeding habitats with cane toads, although this may not necessarily be the case, as outlined above (Freeland 2000, Williamson 1999). Apart from the Oenpelli python, all the snake species in this risk category were assigned moderate priority. Although there is good evidence to show that many snake species are capable of detecting and avoiding toxic native anurans (Madsen & Shine 1994), there is none to suggest they will have the ability to detect the cane toad toxins. Thus, the snake species were not assigned a lower priority. Two thirds of the bird species identified as being *possibly* susceptible to cane toads were assigned moderate priority. In some cases, there was information suggesting bird species may be at less risk, in which case they were assigned low priority (see below). The three mammal species were included based on observations and knowledge of relevant native fauna experts about their dietary habits.

Risk category 4 — Unlikely risk

All of the 31 species listed in this category were assigned a low priority status based on relevant ecological, feeding or behavioural information. These included 11 fish, 18 birds and 2 mammals. As outlined above, although cane toad eggs and tadpoles are known to be toxic to fish, all fish species that have been tested have generally avoided eating cane toad eggs and/or tadpoles. This behaviour appears to spread across a range of taxa, suggesting that the ability to detect the noxiousness is widespread. Consequently, with the exception of the fish species listed as notable, all fish species identified as *possibly* susceptible to cane toads were assigned a low priority. Bird species were assigned a low priority for various reasons. A number of birds, including grebe, white-faced heron, ibis, whistling kite, owl and crow have previously been reported to feed successfully on cane toad tadpoles (Covacevich & Archer 1975, Seabrook 1991). The darter feeds underwater in open, deeper water habitats, where cane toad tadpoles are not likely to be found. Supporting this, Dostine and Morton (1988) found no native anuran remains in the stomachs of darters collected from the Magela floodplain. The striated heron, beach thick-knee and silver gull are generally only found in coastal and/or mangrove habitats, where cane toads are not expected to be present in high numbers. The collared kingfisher, although listed as notable, is also generally only found in mangrove habitats, and probably not likely to be substantially exposed to cane toads. The introduced cat and pig, being pest species, were considered to be of low priority for research or monitoring purposes, although any impacts would probably be of interest to Park management.

2.4.3.2 Prey

Quantitative data on impacts to prey species are scant, and very little can be concluded about the species or species groups at risk. Cane toads are known to consume large quantities of invertebrates and at times small vertebrates. Given the infrequent reports of vertebrates in cane toad stomach contents, populations of small vertebrate species are not likely to be at risk. Termites (>50 species; Press et al 1995), beetles and ants (>300 species; Press et al 1995) appear to be the most likely food candidates for cane toads in Kakadu, and may be at risk, particularly considering the ability of cane toads to return to places of high food abundance (eg termite mounds, ant nests). In particular, beetle numbers have been reported to decline following cane toad colonisation (Catling et al 1998).

2.4.3.3 Competitors

Only three studies have directly examined competitive effects of cane toads in Australia, all focusing on native frog species. The information suggests that some native frog tadpoles may be at risk through competition with cane toad tadpoles (eg *L. ornatus*). However, this will be determined by several factors, most notably the extent to which breeding habitats are shared, and also the succession of anuran early life stages in the waterbody (ie early colonisers will perform better). Nothing is known of the effects, and therefore risks of competition from cane toad tadpoles to other aquatic organisms, including endemic aquatic invertebrates.

Observations by Freeland (2000) suggest that native frogs in the south-eastern Top End rarely share breeding habitats with cane toads, a finding supported by observations from southern Queensland (Williamson 1999). Based on one experimental study conducted in the natural environment, adult native frogs do not appear to suffer from competition with cane toads, and for the purposes of this assessment, they are considered not to be at risk. However, the potential risk to native tadpoles represents a risk to native frog populations, depending on factors such as normal recruitment strategies and existing competition between native tadpoles.

Insectivorous reptiles may be at risk from competition for food resources by cane toads. Declines in the abundance of small reptiles have been reported following invasion of cane toads in the Roper River system, with competition for food being suggested as the most probable cause (Catling et al 1998). Therefore, the small reptile fauna of Kakadu may be at risk from competition with cane toads, but little more can be concluded.

2.4.4 Cultural, socio-economic and other risks

Based on information from areas previously colonised by cane toads, Aboriginal communities within Kakadu will be affected by cane toads. The major risk will be to traditional foods, most notably goanna and possibly some snake species, although declines in numbers may not be permanent. In some situations, ceremonies may be altered following declines of species of particular importance. Aboriginal people from Borroloola had accepted the toads' presence; while noting some effects to their lives, they saw no need to introduce control measures. Cane toads will congregate in areas of human habitation within Kakadu, including Jabiru, Cooinda, Kakadu Ranger stations, Aboriginal communities (eg Mudginberri, Patonga) and camping areas. Cane toads will be of nuisance value in these places and will also represent a risk to domestic and semi-domestic dogs.

Tourism, the major economic activity of Kakadu, is not at risk from the presence of cane toads. Some tourists will no doubt express dismay and concern over the presence of cane toads in Kakadu, however, the numbers of tourists visiting the Park will not decrease as a direct result of the toads' presence. If cane toads reach their predicted high numbers in Kakadu, there may be an opportunity to harvest them for commercial benefit.

A range of other potential effects of cane toads have been hypothesised, although in most cases little information was available (section 2.3.6). Consequently, the risks of contamination of water supplies, secondary effects on vegetation communities (via a reduction in ant and termite species that play an important role), the spread of human diseases, and the substance abuse of cane toad toxin are essentially unknown. Contamination of water supplies may only represent a risk in small quantities of water, and only for short periods of time, as the cane toad toxin is likely to be broken down rapidly under natural conditions.

2.5 Uncertainty and information gaps

Despite the large body of literature on cane toads and Kakadu National Park, this assessment has highlighted that there are major information gaps contributing to a large degree of uncertainty about the prediction of impacts of cane toads to Kakadu.

2.5.1 Extent of cane toads in Kakadu National Park

2.5.1.1 Density of cane toads in Kakadu National Park

Density estimates of cane toads and their early life stages have generally been derived from regions with different environmental conditions from Kakadu National Park. In comparison with the Gulf country and many other areas of Queensland, circumstances in Kakadu such as different species and community structure of predators and prey, higher rainfall, higher minimum temperatures, higher humidity, and greater and more persistent areas of available water, make it difficult to hypothesise on cane toad densities within Kakadu. In addition, little information exists on temporal (seasonal and annual) and spatial variations in cane toad densities, other than they fluctuate greatly.

2.5.1.2 Effects of fire

The effects of fire on cane toad populations has not been investigated. Cane toads have been observed moving away from the front of fires and have been seen in recently burnt areas. The short-term effect of fire would be the removal of some available shelter for the toads, however, this would also apply to native species and competition for the remaining shelter could become crucial to the survival of some species. It has been shown elsewhere that the cane toad is a superior competitor for shelter where they are often the only animal found under rocks, logs and in crevices. If the long term effect of frequent uncontrolled burning removes tree cover and leads to more grassland, this would ultimately benefit cane toads, being known to prefer more open, disturbed areas. However, the fire regime in Kakadu is more controlled than most other regions colonised by cane toads. It remains to be determined if fire will be beneficial or deleterious to cane toad dispersal and/or population densities in Kakadu.

2.5.1.3 Degree of land disturbance

In addition to better managed fire regimes, Kakadu now has less land disturbance than many areas previously colonised by cane toads. The removal of feral water buffalo from Kakadu has seen considerable vegetation regeneration of floodplains, fringing forests and even creekbanks and isolated waterholes of the lowland areas. Feral pigs continue to do much damage, though not as widespread as the damage caused by the buffalo. The strict land use management in Kakadu means that other than mining activity or specific park use, areas are not usually cleared or disturbed. In contrast to this, the Gulf country through which the toads have travelled over the past few decades supports large pastoral properties where cattle and buffalo roam free and land conservation measures are minimal or non-existent. It is unknown what effect the nature of the Kakadu landscape will have on cane toad densities and progress. Evidence from the literature would suggest lower densities and slower progress for less disturbed areas such as Kakadu National Park.

2.5.1.4 The escarpment as a barrier

Cane toads are reported not to prefer rocky areas and it has been suggested that the Arnhem Land escarpment may present a barrier to cane toads, at least slowing their progress into the Park. Once cane toads are in the headwaters of the major Kakadu waterways (ie above the escarpment), it could be assumed that their spread into the lower reaches will be rapid with the assistance of Wet season flooding. Although it is thought that the heavily dissected nature of the western Arnhem Land escarpment will slow the rate of cane toad colonisation of this habitat, it is conceded that toads will eventually occupy much of this area due to the availability of water throughout the Dry season. It is uncertain to what extent this colonisation will occur, whether all escarpment areas will be accessible, and what cane toad densities can be sustained in this so called 'unpreferred' habitat.

2.5.2 Effects of cane toads in Kakadu National Park

2.5.2.1 General cane toad impacts

Despite the great body of knowledge that exists on the general biology and ecology of the cane toad in Australia, there have been very few quantitative studies to investigate its impact on Australian native vertebrate and invertebrate fauna. In contrast, there is substantial anecdotal evidence to suggest that cane toads do impact adversely on the native fauna. Anecdotal and experimental evidence are in agreement that a number of species, or at least individuals of species, will die from mouthing, ingesting or being force fed cane toads. However, such data are missing for most species, and predicting risks based on inter-species/genera extrapolation carries much uncertainty.

Information gathered for this risk assessment suggests that a number of factors may determine whether or not a predator actually dies. These include the amount of toxin ingested relative to body mass, consumption of 'fresh' versus 'old' cane toad carcasses, inter-toad variability in the potency of the toxin, the ability of the predator to regurgitate or remove the toad from the mouth, and the physical condition of the predator. These factors may explain apparent conflicting reports of the responses of individuals of a given species to cane toads (eg kookaburras, crows, turtles, snakes), although no causal link has been demonstrated. Tolerance to small amounts of toxin relative to body mass has been demonstrated for several species of frog-eating snake in relation to the toxic native frog, *L. dahlii*. Consumption of frogs at about 10% of snake body mass proved safe, but became fatal at about 20% of body mass. A greater understanding of the above variables would allow a more confident estimate of risk in many cases.

The greatest uncertainty, and the cause for most concern, is the long-term impact of the cane toad on populations of animals. Few studies have addressed this issue and they remain inconclusive, having not accounted for factors such as habitat alteration, changes in land use practices and seasonal variation, which are generally acknowledged as being significant variables in the population structure and distribution of many native Australian species. The vast majority of the literature on cane toad impacts relates to toxicity to predators, although evidence of population declines is mostly anecdotal. The diet of cane toads has been well documented, but virtually nothing is known about the impact of cane toads on populations/communities of prey species anywhere in Australia, and it is not possible to make confident judgements about risks. Resource competition is another area requiring greater investigation. Anecdotal reports indicate declines of species that neither eat nor are eaten by cane toads; these declines may therefore occur as a result of competition, even if the reports are in fact accurate. The only studies investigating this issue have been the competitive interactions between native frogs (including their early life stages) and cane toads. These information gaps contribute greatly to the uncertainty surrounding the preliminary risk assessment.

2.5.2.2 Effects on Kakadu National Park species

The lack of information on cane toad impacts has direct relevance to Kakadu National Park. The Park has many species whose relationship to cane toads has not been investigated — also the environmental and climatic conditions in general differ from those in the regions where the impacts of cane toads have been examined. Fortunately, Kakadu has limited habitat alteration, and land use practices and management are generally constant and well established. Thus, the monitoring of the impacts of cane toads in Kakadu may prove easier and more meaningful than has been attempted elsewhere in Australia (though see section 3). However, sufficient information on most Kakadu species is also lacking.

Species population, distribution and habitat information

Though there is good species inventory data for Kakadu (ie species richness), very few studies have provided quantitative data on species populations and distributions, particularly on an ongoing basis. Useful abundance and habitat information for various species was collected for a number of studies, including the Kakadu Fauna Survey (Braithwaite 1985), the Stage 3 Kakadu National Park Wildlife Survey (Woinarski et al 1989), programs undertaken in the Magela Creek catchment and other sites as part of monitoring for ERA Ranger Mine and Jabiluka (refer to review of this research by Gardner et al, in press), and the Kapalga fire study (for example, Braithwaite RW (1996), Biodiversity and fire in the savanna landscape). Some habitat data exist for many species, although there is little information on seasonal variations in habitat preferences. Data on species abundance and distribution, as well as species richness, are essential for strengthening any predictions on the effects of an invasive species on native fauna populations.

Dietary information

Predatory species considered *possibly* susceptible to cane toads were those that were known or thought likely to eat native frogs (or their early life stages) and therefore could potentially eat cane toads. The two assumptions — that a *known* frog eater would eat cane toads and, more particularly, that a *potential* frog eater would eat cane toads — carry a large degree of uncertainty. However, given the scope of this assessment, these uncertainties are acceptable in that the major purpose was to identify and prioritise species that might be at risk. Given the uncertainty of the above assumptions, the species in question were assigned the lowest risk rating and in most cases, moderate to low priority.

Another issue related to the diets of predators is that of prey switching. Species were not considered in this assessment if they were known or thought not to eat native frogs or their early life stages. However, there is little information on whether the presence of cane toads can alter patterns of prey selection amongst predators. For example, frillneck lizards are known to be solely insectivorous in areas where cane toads do not exist, yet have been observed attempting to consume cane toads in areas where they do exist (ie Lawn Hill National Park). Such prey switching may be due to a depletion of the usual food resources of the species, or possibly a response to extremely high abundances of a new potential food source. Regardless, it is not possible to predict whether species that do not normally eat frogs will attempt to consume cane toads, and even if they do, whether their populations will be at risk.

Invertebrates

Only a few of the invertebrate groups of Kakadu are well understood and much work remains to be done to identify the many unknown or undescribed species. In overviewing the habitats and fauna of Kakadu (section 2.1.3), absence of any information was noted for a number of invertebrate groups, including Cnidaria, Platyhelminths, Polyzoa, Annelida, Arachnida (except for spiders) and Tardigrada. Most data for other invertebrate groups consist only of species numbers and some habitat information (see Press et al 1995), although aquatic macroinvertebrates have been more extensively studied in areas associated with mining activities (eg Magela Creek). Insects in particular have fundamental roles in ecosystem structure and function. Compared with savannas elsewhere in the world, the mammalian fauna of Kakadu is relatively impoverished and insects assume a number of ecological roles played by vertebrates elsewhere (Press et al 1995). No studies have directly investigated the impacts of cane toads on invertebrate populations. This lack of information and the dearth of knowledge of the Kakadu invertebrate fauna raises many uncertainties about the impacts of cane toads.

Fish

Many fish species have been observed to either ignore or reject cane toads and their early life stages if swallowed. Some of these have showed no effects, whilst others have shown signs of distress but have not died. Other species have died as a result of eating or attempting to eat cane toads. There is no information on how or why some species can detect cane toad toxin, why some species taste and reject them successfully, and why some individuals are unsuccessful. Given the evidence that most species tested appear to be able to detect the toxicity of cane toad eggs and/or tadpoles, most fish species were assigned a low priority in the risk assessment. However, most fish species found in Kakadu have not been assessed for their responses to the presence of cane toads, and again extrapolating across genera, let alone higher orders (eg families) carried some uncertainty.

Frogs

Only one study has investigated the competitive relationships between cane toads and adult native frogs (4 species), the conclusion being that these species of native frogs did not alter their Dry season patterns of habitat and/or food utilisation following invasion by cane toads. This study was conducted in the Gulf of Carpentaria region of the NT and north-western Queensland. The lack of data presents uncertainty for competitive relationships between a large number of Kakadu frog species in a different environment from that of the study. As with many aspects of research into the impacts of cane toads, it is a case of just one study being the only available quantitative information.

Snakes

Due to the toxicity of the native frog, *Litoria dahlii*, it has been hypothesised that some species of snake in Kakadu may be pre-adapted to avoiding cane toads by detecting their noxiousness via chemoreception. As cane toads are the only amphibian in Australia whose chemical defense is based on bufogenins and bufotoxins, these snake species may not be able detect cane toad toxin and may attempt to eat cane toads. The distribution of *L. dahlii* (ie across the Kimberleys, the Top End of the NT and across to the western Cape York Peninsular) overlaps with relatively recent areas of cane toad colonisation. No attempt has been made to investigate the response of snake species whose distribution currently overlaps that of *L. dahlii*, to cane toads, although reported deaths of snakes indicate they are susceptible and unable to detect the cane toad toxins. However, species with chemoreceptive abilities to detect toxins of native species may have a superior ability to 'learn' to recognise cane toad toxins.

Freshwater turtles

There was substantial conflicting information on the effects of cane toads to freshwater turtles. In addition, interpretation of reports was made more difficult by a lack of knowledge of the particular species reputedly affected. Retaining consistency in the approach of the risk assessment meant that turtles were not included as being susceptible or potentially at risk from cane toads. It is clear that impacts of cane toads to freshwater turtles need to be better understood.

Red goshawk

The red goshawk is listed as vulnerable under the EPBC Act of 1999 and only several breeding pairs have been observed in Kakadu, which is an important conservation area for this species. It is unknown if the red goshawk eats native frogs, or if it will attempt to eat cane toads, and it is unknown if this species is affected by cane toad toxin. Some species 'learn' to eat the non-toxic parts of cane toads, however, the red goshawk may lack the population numbers for this to be a suitable population survival strategy.

Bats

There is no literature or anecdotal evidence regarding the impact of cane toads on bats. There are 28 species of bat in Kakadu, and only the ghost bat, which is listed as notable, has been identified as eating native frogs. The remaining species are considered to be insectivorous or nectivorous. Bats are important pollinators of many eucalypts and paperbarks, and disperse certain monsoon forest fruits. More information on bats would not only be of use for decreasing the uncertainty in the risk assessment, but also as a general knowledge base for Parks Australia North.

Endemic species

The dearth of information on endemic species, including the unknown or undescribed invertebrate species, has previously been highlighted. Some of these species may be at risk as predators of, or more likely from competition by cane toad tadpoles, but no information is available. There may be endemic species of invertebrates that are still unknown to science, particularly in the escarpment areas of Kakadu. These species may be susceptible to cane toads, and small isolated populations could conceivably disappear before even being identified.

3 Recommendations for monitoring

One of the aims of the fourth Kakadu National Park Plan of Management (ANPWS/KNPBM 1998) in relation to research, surveys and monitoring is 'to identify things that are changing, both in the short term and in the long term, in the Park environment'.

The objective of this section is to provide advice and recommendations on monitoring requirements for assessing the impacts of cane toads, and also to evaluate the applicability of previous or ongoing monitoring programs for providing baseline data. Given the faster than expected movement of cane toads in the last one or two Wet seasons, and their arrival in Kakadu National Park in the 2000–2001 Wet season, the ability to determine a baseline from previous and/or ongoing monitoring programs has become critical.

3.1 Priority habitats for monitoring

The geographic diversity of Kakadu National Park creates a rich diversity of wetland and terrestrial habitats, many of which will be ideal as cane toad habitat. It is recommended that a range of carefully selected monitoring sites are established to cover each of the following habitats, although it is acknowledged that this will depend to some extent on the species being monitored:

- Floodplain communities (grassland, sedgeland, mixed grassland/sedgeland)
- Swamp communities (reed swamp, melaleuca (paperbark) swamp, Nelumbo swamp)
- Monsoon forest (lowland and sandstone varieties)
- Riparian communities, including the sheltered floodplain margins
- Woodland and open forest communities
- Springs, soaks and waterholes
- Escarpment pools

3.2 Priority species for monitoring

Priority species for monitoring should be based on the risks and priorities assigned in section 2.4.3 and specifically for predators, in table 12. Programs for monitoring cane toad impacts should also monitor cane toad abundance, density and possibly distribution. It is recognised that the most reliable information exists for effects on predators, and some care needs to be taken that the monitoring of species at risk from prey and competition effects is not overlooked. The following general recommendations are suggested.

3.2.1 Predators

Referring to table 12, all species assigned to *risk category 1* should be priority species for monitoring. In addition, species assigned to *risk category 2* should be seriously considered for monitoring. Most species assigned to *risk category 3 — high priority* should also be considered for monitoring.

Of particular importance are the northern quoll and some other small mammals (sandstone antechinus, red-cheeked dunnart, brush-tailed phascogale), dingo, all the varanid lizards, the northern death adder, king brown snake and western brown snake, the ghost bat (being listed as notable), black-necked stork and comb-crested jacana (being flagship species), Oenpelli python, and freshwater crocodile. These are based on their risk rating, notability or listing as vulnerable, and also importance to Aboriginal people.

Species assigned to *risk category 3 — moderate priority* are not considered priority species for monitoring. However, most species were assigned to *risk category 3 — moderate priority* due to a lack of information about effects of cane toads. Thus, the risk is considered to be unknown rather than low, and further specific information on these species may result in their re-prioritisation. Species assigned to *risk category 4* are considered to be at less risk due to relevant information regarding their preferred habitats and/or feeding behaviour and ecology.

3.2.2 Prey

Although the risks to prey species are unknown, any monitoring for prey effects should focus on beetles (Coleoptera), termites (Isoptera) and ants (Hymenoptera: Formicidae).

3.2.3 Competition

Competitive effects between cane toad tadpoles and native aquatic invertebrates and vertebrates (including native tadpoles) may be an important issue and should be investigated. This is of particular importance in isolated escarpment pools, where many endemic species are known to exist (Humphrey unpublished data, Miles 1988, Morris 1996).

In the event of significant competition between cane toad tadpoles and native tadpoles, monitoring of adult native frogs would determine whether effects were being felt at the population level.

Insectivorous reptiles may be at risk from competition with cane toads for food resources, and are considered a high priority for monitoring effects of competition. This is due to the diverse reptile fauna of Kakadu being one of its most noteworthy attributes.

3.3 Priorities for addressing information gaps

A number of major information gaps can be addressed through specific monitoring programs or surveys. They are prioritised below.

1. The lack of information on effects to predatory species, and in particular potential cane toad prey and competitor species in Kakadu, makes it very difficult to predict risks. Monitoring programs developed to assess such effects in Kakadu (see section 3.2) will contribute greatly to understanding the true risks of cane toads.

2. There is a need for appropriate baseline information on native fauna, assuming it can be gathered prior to the arrival of cane toads (also see section 3.4). Whether directly related to cane toads or not, distributional and inventory data are urgently required to ensure that the Park has a sound information base for future monitoring. Continuous long-term monitoring of the major habitats in the Park is needed to provide reliable data from which to assess changes in the conservation status of each habitat, develop guidelines for management and help in the design of conservation research programs. The methods and techniques used must be repeatable and streamlined so that valid comparisons can be made.

3. Related to the above point, greater knowledge of the number and type of endemic species within Kakadu is required. In particular, the escarpment and sandstone regions are thought to harbour many more unknown invertebrate species that may be endemic and may be susceptible to cane toads.

4. Concurrent monitoring of cane toads as part of monitoring programs assessing their impacts will provide further information about the spatial and temporal variations exhibited with regards to densities and habitat preferences, including current uncertainties about cane toads in the escarpment country.
5. An issue that may be considered important to Kakadu management is the effect of fire on cane toad density, distribution and dispersal. Fire is a major forcing factor on the landscape and biology of Kakadu, and an understanding of its effect on cane toads may be useful for determining management options.
6. Other information gaps that were identified related to specific uncertainties regarding fish, frogs, snakes, freshwater turtles, the red goshawk and bats. Of these, further information about the diet and risk to the red goshawk (due to its vulnerable listing), and the ability of snakes (and other animals — eg varanid lizards, fish) to learn to detect the noxiousness of cane toads and avoid eating them, would fill useful gaps in the information base.

3.4 Evaluation of past and present monitoring programs

Given the likelihood that cane toads will disperse throughout much of the Park over the next two Wet seasons, it is highly unlikely that new monitoring programs will provide sufficient pre-cane toad (ie baseline) data. Therefore, it is necessary to evaluate some of the major past and present monitoring programs within Kakadu in terms of their ability to provide such a baseline, and perhaps even to detect effects, noting that the programs were developed with objectives other than cane toad impacts in mind. In addition, monitoring and survey programs undertaken in the early to mid 1980s may still have been influenced by the effects of feral buffalo, or at least the large scale ecological changes that occurred following their rapid removal (Storrs & Finlayson 1997), and may be of little use.

3.4.1 Broad scale surveys

It is appropriate to first discuss the utility of large scale programs that assessed many fauna types in a range of habitats. The two major fauna surveys of the last 20 years were the Kakadu Fauna Survey (Braithwaite 1985) and the Stage 3 Kakadu National Park Wildlife Survey (Woinarski et al 1989). Nothing of their magnitude has been undertaken since. Both surveys provided information on abundances, distribution and habitat preferences of birds, mammals reptiles and amphibians in a range of habitats similar to those identified in this report. Braithwaite (1985) surveyed 30 sites in woodland and forest habitats, not surveying sedgelands (ie floodplains), paperbark, margin or mangrove habitats. This was a logistical decision, based on time and resource constraints, and the fact that the woodland and forest habitats comprised over 55% of the study area. Woinarski et al (1989) surveyed 10 sites in a greater range of habitats, including woodland, open forest, monsoon forest (lowland and sandstone), paperbark forest, and others. The information from these surveys is not appropriate to use as current baseline, however, the established sites provide the opportunity for re-sampling before cane toads arrive. This may allow some estimate of a monitoring baseline, although the ability to detect inferences would still be low.

Parks Australia North has already commenced preliminary discussions regarding a representative re-sampling of the Stage 3 Wildlife Survey. At best, one season of pre-cane toad data could be collected. However, the aim is to establish an ongoing flora/fauna survey program in conjunction with the current program assessing the impact of fire on flora, not just designed for assessing cane toad impacts.

3.4.2 Ongoing monitoring programs

The only major ongoing fauna monitoring programs in Kakadu National Park are those associated with assessing potential environmental impact downstream of ERA Ranger Mine and the Jabiluka lease area. Monitoring programs are being conducted by ***eriss*** and ERA/EWL Sciences.

Aquatic macroinvertebrates have been and continue to be monitored at sites in the Magela Creek system and a number of control sites elsewhere, with regards to assessing potential environmental impacts downstream of uranium mining operations (Humphrey & Pidgeon 2001). Stream sites in Magela Creek have been sampled since 1988, while three sites in the upper South Alligator River were sampled in the period 1987–2000 (C Humphrey pers comm July 2000). In the last 5 years, further (control) sites have been sampled in Baroalba, Nourlangie and Gulungul Creeks (Humphrey & Pidgeon 2001). However, the design is possibly not suitable for detecting cane toad impacts, but inferences would be enhanced if cane toad invasion/distribution was monitored (C Humphrey pers comm July 2000). In addition, billabongs sampled in the Magela and Nourlangie Creek systems from 1995–1996 will provide information on the potentially sensitive snails.

Similarly, fish monitoring programs are currently in place in the Magela Creek system. Fish communities in shallow or backflow billabongs in the Magela, Nourlangie and upper East Alligator systems have been monitored annually since 1994, although some gaps exist. In addition, data exist for fish migration patterns at one point in Magela Creek from 1985 to 1996 (Boyden & Pidgeon 1996) — representing one of the longest (semi) continuous data sets for Kakadu. It is possible that these studies may be able to detect cane toad effects, particularly in Magela Creek.

'Whole-ecosystem' monitoring has also been conducted in the Swift Creek, Magela Creek and Nourlangie Creek (Sandy and Buba billabongs) systems (Corbett 1997, Corbett 1999). A wide range of fauna was surveyed including zooplankton, macroinvertebrates, fish, frogs, reptiles, bushbirds, waterbirds and mammals. Whole-ecosystem monitoring in Swift Creek catchment is currently on hold, although further monitoring may occur around the location of the proposed haul road (L Corbett pers comm August 2000). However, another full 'whole-ecosystem' monitoring program that continued the earlier program commenced in the dry-wet transition of 2000. It is anticipated the program will provide pre-cane toad baseline data for the sites sampled (ie on Magela and Nourlangie systems).

3.4.3 Other surveys or monitoring programs

Some other past programs may serve as useful background information upon which a baseline could be established. Most notably, surveys of waterbirds were carried out in the early 1980s at a number of sites, including the Magela and Nourlangie floodplains (Morton et al 1991) and again in the early 1990s, on the Magela floodplain only (Dostine & Skeat 1993). A proposal has recently been drafted to re-survey the sites of Morton et al (1991) in order to update and add to the existing information on birds, particularly for the Magela floodplain (E Dorfman, unpublished information). The focus of this proposal is on the flagship black-necked stork (jabiru), but would include other waterbirds.

The CSIRO Division of Wildlife and Ecology undertook a large monitoring program assessing the effects of fire on vegetation and fauna (mammals, reptiles and insects) at the Kapalga Research Station in the lower South Alligator river catchment from the mid 1980s to the early 1990s (Russell-Smith 1995). The information from this area is likely to be able to contribute to a baseline when cane toads arrive there. In addition, the sites were re-sampled for small mammals in 1999 (Woinarski 2000), and this information can probably also contribute to a baseline for small mammals in the region.

In summary, it will be very difficult to obtain adequate baseline data for a cane toad impact monitoring program. While the ongoing programs will be of some use, they are not necessarily targeted at the priority species identified in this report.

4 Risk management and reduction

It is not within the scope of this preliminary risk assessment to develop a risk management and reduction strategy. However, given the outcomes of the assessment, some relevant issues can be discussed that may assist Park managers in developing a strategy.

Parks Australia North has already initiated several programs in relation to monitoring cane toads and their impacts. A cane toad identification training program and rapid response strategy are being developed to manage incursions of cane toads through 'hitch-hiking' in vehicles. This is the first step in delaying the establishment in at least the more populated or developed parts of Kakadu. However, given the 'natural' arrival of the cane toads over the next two Wet seasons, such a program will not be effective for very long.

Several frog recording stations have been established in Kakadu as an extension of Professor Gordon Grigg's Roper River system monitoring program. Recording towers have been erected at four sites, all of which are situated between Jabiru, the Arnhem Highway–South Alligator River crossing and Nourlangie Rock (Grigg 1999). Baseline data (with some gaps) have been collected for the past two Wet seasons. Two further recording stations will be established in 2001 (T Bailey pers comm March 2000, Grigg 1999).

Very little will be able to be done to reduce cane toad numbers in Kakadu. Particular measures may prove effective in localised areas (eg townships, caravan parks), but efforts would need to be sustained.

Seabrook and Dettmann (1996) have suggested that land managers need to assess the potential of existing and proposed vehicle access routes in natural habitat areas for facilitating invasions of cane toads into these areas. They considered this to be especially important in areas with high nature conservation value where invasive species such as cane toads have the potential to have adverse effects on wildlife. However, the rivers and roads/tracks network within Kakadu already covers the majority of the Park, making such measures irrelevant.

Physical barriers can be constructed around facilities such as swimming pools by adding a 0.5 m high layer of fine mesh to the bottom of peripheral fencing. Similar precautions can also be taken around potential man-made cane toad breeding sites such as sewage treatment ponds. Thus, construction of physical barriers is successful for specific purposes (eg around swimming pools), but these may not necessarily be the direct responsibility of Park management.

Given that juvenile survival is enhanced in cattle tracks (ERAES 1998), it is highly probable that areas disturbed by pig rooting will provide similar benefits. Management of feral pig damage, whether through more intensive control efforts, or physically minimising the damage, may help reduce the densities of cane toads in pig-affected areas. Manipulating cane toads by habitat alteration may reduce densities, but it will not exclude them from an area (ERAES 1998). Habitat alteration within Kakadu would most likely require careful consideration given the value of many existing habitats.

To date, chemical (eg pheromones and attractants) and biological (eg pathogens) control methods have not been developed. The greatest potential appears to be the development of attractants or even deterrents through natural product research, but funding limitations mean that such control methods are still many years from being an option.

It appears as if the most appropriate way for Parks Australia North to manage the invasion of cane toads is to i) ensure that efforts are underway that will allow inferences to be made about the impacts of cane toads on the values of Kakadu, and ii) investigate measures by which cane toads can be managed on a localised basis, particularly around areas considered to be of high importance.

The preliminary risk assessment provides a starting point from which Parks Australia North can determine the monitoring requirements for fauna. In addition, it provides an overview of the potential cultural and socio-economic impacts, which could be studied in greater detail by appropriate experts.

5 References

ABC (Australian Broadcasting Corporation) 1987. *Cane toads — An unnatural history*. Film Australia Video, Film Australia Ltd, Sydney.

Alcala AC 1955. Notes on the eggs and egg-laying of some amphibians on Negros Island, Philippines. *Silliman Journal* 2, 103−106.

Alcala AC 1957. Philippine notes on the ecology of the giant marine toad, *Silliman Journal* 4, 90−96.

Alexander JR 1964. Observations of the feeding behaviour of *Bufo marinus* (Linne), *Herpetologica* 20, 255−259.

Alford RA, Cohen MP, Crossland MR Hearnden MN & Schwarzkopf L 1995. Population biology of *Bufo marinus* in northern Australia. In *Wetland research in the wet-dry tropics of Australia*. Workshop, Jabiru NT 22–24 March 1995, ed Finlayson CM, Supervising Scientist Report 101, Supervising Scientist, Canberra, 173–181.

Andersen AN & Braithwaite RW 1996. Plant–animal interactions. In *Landscape and vegetation ecology of the Kakadu Region, northern Australia*, eds Finlayson CM & von Oertzen I, Geobotany Series 23, Kluwer Academic Publishers, Dordrecht, The Netherlands, 137–154.

Andersen AN & Lonsdale WM 1990. Herbivory by insects in Australian tropical savannas: a review. *Journal of Biogeography* 17, 433–444.

Andersen AN 1990. The insect fauna of Kakadu National Park, with particular reference to stage 3, Draft submission to the RAC inquiry.

Andersen AN 1991. Seed harvesting by ants in Australia. In *Ant-plant interactions*, eds CR Huxley & DF Cutler, Linnean Society of London, Oxford University Press, New York, 493–503.

Andersen AN 1997. Measuring invertebrate biodiversity: Surrogates of ant species richness in the Australian seasonal tropics. *Memoirs of the Museum of Victoria* 56(2), 335–359.

Andrew MH 1986. Granivory of the annual grass *Sorghum intrans* by the harvester ant *Meranoplus* sp. in tropical Australia. *Biotropica* 18, 344–399.

ANPWS (Australian National Parks and Wildlife Service)/DEST (Department of the Environment, Sport & Territories) 1991. Nomination of Kakadu National Park by the Government of Australia for inscription in the World Heritage List.

ANPWS (Australian National Parks and Wildlife Service)/KNPBM (Kakadu National Park Board of Management) 1991. *Kakadu National Park: Plan of management*. Australian National Parks and Wildlife Service, Canberra.

ANPWS (Australian National Parks and Wildlife Service)/KNPBM (Kakadu National Park Board of Management) 1998. *Kakadu National Park: Plan of management*. Australian National Parks and Wildlife Service, Canberra.

Bailey P 1976. Food of the marine toad, *Bufo marinus*, and six species of skink in a caxao plantation in New Britain, Papua New Guinea, *Australian Wildlife Research* 3, 185−188.

Barker RD & Vestjens WJM 1989. *The food of Australian birds. I. Non-passerines.* Melbourne University Press, Melbourne.

Barnett L 1980. *A checklist of the birds of Kakadu National Park and the Alligator Rivers Region of the Northern Territory*. Australian National Parks and Wildlife Service, Canberra.

Bayliss B, Brennan K, Eliot I, Finlayson CM, Hall R, House T, Pidgeon R, Walden D & Waterman P 1997. *Vulnerability assessment of predicted climate change and sea level rise in the Alligator Rivers Region, Northern Territory Australia*. Supervising Scientist Report 123, Supervising Scientist, Canberra.

Beebe W 1927. Studies of a tropical jungle: one quarter of a square mile of jungle at Kartabo, British Guiana. *Zoologica* 6, 121−139.

Begg G, Walden D & Rovis-Hermann 2000. Report on the joint ***eriss***/PAN cane toad risk assessment field trip to the Katherine/Mataranka and Borroloola regions. Unpublished report. Supervising Scientist, Darwin.

Bell AF 1936a. Giant American toad. *Cane Growers Quarterly Bulletin* 3, 133.

Bell AF 1936b. Removal of a ban on release of giant toads. *Cane Growers Quarterly Bulletin* 3, 48.

Bishop KA, Allen SA, Pollard DA & Cook MG 2001. *Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory: Autecology*. Supervising Scientist Report 145, Supervising Scientist, Darwin.

Boomsma JJ & Arntzen JW 1985. Abundance, growth and feeding of Natterjack toads (*Bufo calamita*) in a 4-year old artificial habitat. *Journal of Applied Ecology* 22, 395–405.

Boyden J & Pidgeon RWJ 1996. Listing of data on fish migration in Magela and Nourlangie Creeks for the period 1985 to 1996. Internal report 220, Supervising Scientist, Canberra. Unpublished paper.

Braithwaite R & Griffiths A 1994. Demographic variation and range contraction in the northern quoll *Dasyurus hallucatus* (Marsupialia: Dasyuridae), *Wildlife Research* 21, 203−17.

Braithwaite RW & Werner PA 1987. The biological value of Kakadu National Park. Search 18(6), 296–301.

Braithwaite RW 1996. Biodiversity and fire in the savanna landscape. In *Biodiversity and savanna ecosystem processes: A global perspective*, eds OT Solbrig, E Medina & JF Sliva, Springer-Verlag, Berlin, 121−140.

Braithwaite RW (ed) 1985. *The Kakadu Fauna Survey: An ecological survey of Kakadu National Park*. Report to ANPWS, Canberra.

Braithwaite RW, Friend GR & Wombey JC 1991. Reptiles and amphibia. In *Monsoonal Australia: Landscape, ecology and man in the northern lowlands*, eds CD Haynes, MG Ridpath & MAJ Williams, AA Balkema, Rotterdam, Netherlands, 109–124.

Brattsrom BH 1962. Homing in on the giant toad, *Bufo marinus*. *Herpetologica* 18, 176−180.

Brattstrom BH & Lawrence P 1962. The rate of thermal acclamation in anuran amphibians. *Physiological Zoology* 35, 148−156.

Brattstrom BH 1968. Thermal acclamation in anuran amphibians as a function of latitude and altitude. *Comparative Biochemistry and Physiology* 24, 93−111.

Brennan K 1996. *An annotated checklist of the vascular plants of the Alligator Rivers Region, Northern Territory, Australia*. Supervising Scientist Report 109, Supervising Scientist, Canberra.

Bruce AJ & Short JW 1993. *Leptopalaemon gagadjui* gen. nov., a new freshwater palaemonid shrimp from Arnhem Land, and a re-evaluation of *Palaemontes holthuisi* Strenth, with a designation of a new genus, *Calathaemon*. *Hydrobiologia* 257, 73–94.

Bruce AJ 1993. *Kakaducaris glabra* gen. nov., sp. nov., a new freshwater shrimp from the Kakadu National Park, Northern Territory, Australia, Crustacea: Decapoda: Paleamonidae with the designation of a new subfamily Kakaducaridinae. *Hydrobiologia* 268, 27–44.

Burnett S 1993. The conservation status of the tiger quoll *Dasyurus hallucatus gracilis* in north Queensland. Unpublished report to Queensland Department of Environment and Heritage, Brisbane.

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

Cade WH & Rice R 1980. Field crickets (Orthoptera: gyryllidae) as prey of the toad *Bufo marinus*. *Canadian Entomology* 112, 335–336.

Cameron EE & Cogger HG 1993. *The herpetofauna of the Weipa region, Cape York Peninsula*. Technical Report 7, The Australian Museum, Sydney.

Cane toads on Lizard Island, *Newsletter of the Lizard Island Research Station, Great Barrier Reef* (1998) 14, 11.

Cassels AJ 1966. Disembowelled toads near water. *North Queensland Naturalist* 34, 6.

Cassels M 1970. Another predator of the cane toad (*Bufo marinus*). *North Queensland Naturalist* 34, 6.

Catling PC, Hertog AL Burt RJ Wombey JC & Forrester RI 1998. *The short-term effect of cane toads on native fauna in the Northern Territory*. final report, February 1998, CSIRO Wildlife and Ecology, Canberra.

Chappell J & Ward P 1985. Seasonal tidal and freshwater chemistry of the South Alligator and Daly Rivers. In *Coasts and tidal wetlands of the Australian monsoon region*, eds KN Bardsley, JDS Davie & CD Woodroffe, Mangrove Monograph 1, Australian National University, North Australia Research Unit, Darwin, 97–108.

Cogger HG 1992. *Reptiles and amphibians of Australia*. 5th edn, AH & AW Reed, Sydney.

Cohen M & Williams SE 1992. General ecology of the cane toad, *Bufo marinus*, and examination of direct effects on native frog choruses at Heathlands, Cape York Peninsula. In *Cape York Peninsula Scientific Expedition Report*, Vol 2, Royal Geographic Society of Queensland Inc, Brisbane, 243−245.

Cohen MP & Alford RA 1993. Growth, survival and activity patterns of recently metamorphosed *Bufo marinus*, *Wildlife Research* 20, 1−13.

Cohen MP & Alford RA 1996. Factors affecting diurnal shelter use by the cane toad, *Bufo marinus*. *Herpetologica* 52(2), 172−181.

Corbett L 1997. Environmental monitoring at Ranger mine: A 'whole-ecosystem' approach. In *Proceedings of the 22nd Annual Minerals Council of Australia Environmental Workshop*, Adelaide, 1997, Minerals Council of Australia, Dickson ACT, 240–254.

Corbett L 1999. Jabiluka baseline surveys: Terrestrial, arboreal and volant vertebrates; and terrestrial invertebrates. Final report for ERA Ranger Mine, Energy Resources of Australia Environmental Services Pty Ltd, Unpublished paper.

Covacevich J & Archer M 1975. The distribution of the cane toad, *Bufo marinus*, in Australia and its effects on indigenous vertebrates. *Memoirs of the Queensland Museum* 17, 305−310.

Covacevich J & Couper PJ 1992. The carpet python *Morelia spilota* (Lacepede), another unsuccessful predator of the cane toad, *Bufo marinus* (Linnaeus), in Australia. *Greater Cincinnati Herpetological Society Contributions in Herpetology* 1992, 57–59.

Covacevich J 1974. An unusual aggregation of snakes following major flooding in the Ipswich-Brisbane area, south-eastern Queensland. *Herpetofauna* 7, 21−24.

Cowardin LM, Carter V, Golet FC & Laroe ET 1977. Classification of wetlands and deep-water habitats of the United States (An operational draft). US Fish and Wildlife Service, Washington DC.

Crossland MR & Alford RA 1998. Evaluation of the toxicity of eggs, hatchlings and tadpoles of the introduced toad *Bufo marinus* (Anura: Bufonidae) to native Australian aquatic predators. *Australian Journal of Ecology* 23, 129−137.

Crossland MR 1992. The effects of cane toad (*Bufo marinus*) eggs on potential aquatic predators. In *Cape York Peninsula Scientific Expedition Report*. Vol 2, Royal Geographic Society of Queensland Inc, Brisbane, 267–270.

Crossland MR 1997. Impact of the eggs, hatchlings and tadpoles of the introduced cane toad, *Bufo marinus* (Anura: Bufonidae) on native aquatic fauna in Northern Queensland, Australia. PhD Thesis, James Cook University, Townsville.

Crossland MR 1998. A comparison of cane toad and native tadpoles as predators of native anuran eggs, hatchlings and larvae. *Wildlife Research* 25, 373−381.

Crump ML 1974. *Reproductive strategies in a tropical anuran community*. Miscellaneous Publications of the University of Kansas Museum of Natural History, No 61, University of Kansas, Lawrence, Kansas.

Crump ML 1989. Life history consequences of feeding versus non-feeding in a facultatively non-feeding toad larva. *Oecologia* 78, 486–489.

Davie JDS. 1985. The mangrove vegetation of the South Alligator River, northern Australia. In *Coasts and tidal wetlands of the Australian monsoon region,* A collection of papers presented at a conference held in Darwin, 4–11 November 1984, eds KN Bardsley, JDS Davie & CD Woodroffe, Australian National University, North Australia Research Unit, Darwin, 133−152.

Davis TLO & May JL 1989. On a collection of fish and prawns from the East Alligator Estuary, KNP, Australia. *The Beagle* (Records of the NT Museum of Arts and Sciences) 6(1), 157–161.

Dexter RR 1932. The food habits of the imported toad, *Bufo marinus*, in the sugar cane sections of Puerto Rico. Bulletin 74, *Proceedings of the Fourth Congress of the International Society of Sugar Cane Technologists*, San Juan, 1−6.

Dorfman E 1997. Possible threats to birds from cane toads in Kakadu National Park (unpublished list supplied to Parks Australia).

Dostine P & Skeat A 1993. OSS/ANPWS waterbird population and habitat monitoring project. Revised May 1993. Internal report 111, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Dostine PL & Morton SR 1988a. Notes on the food and feeding habits of cormorants on a tropical floodplain. *Emu* 88, 263−266.

Dostine PL & Morton SR 1988b. Food of the darter *Anhinga melanogaster*, in the Alligator Rivers Region, Northern Territory. *Emu* 89, 53−54.

Dostine PL & Morton SR 1989a. Feeding ecology of the whiskered tern, *Chlidonias hybrida*, in the Alligator Rivers Region, Northern Territory, *Australian Wildlife Research* 16, 549−562.

Dostine PL & Morton SR 1989b. Food of the black-winged stilt *Himantopus himantopus*, in the Alligator Rivers Region, Northern Territory. *Emu* 89, 250−253.

Dryden GL 1965. The food and feeding habits of *Varanus indicus* on Guam. *Micronesia* 2, 73−76.

Duellman WE 1978. *The biology of an equatorial herpetofauna in Amazonian Equador*. Miscellaneous Publications of the University of Kansas Museum of Natural History No 65, University of Kansas, Lawrence, Kansas.

Easteal S & Floyd RB 1986. The cane toad — an amphibian weed. In *The ecology of exotic animals and plants: Some Australian case histories*, ed RL Kitching, John Wiley & Sons, Brisbane, 26–42.

Easteal S, van Beurden EK, Floyd RB & Sabath MD 1985. Continuing geographical spread of *Bufo marinus* in Australia: Range expansion between 1974 and 1980, *Journal of Herpetology* 19, 185–188.

Ely CA 1944. Development of *Bufo marinus* larvae in dilute sea water. *Copeia* 1944, 256.

Environment Australia 1999. Australia’s Kakadu. Response by the Government of Australia to the UNESCO World Heritage Commission regarding Kakadu National Park.

ERAES (Energy Resources of Australia Environmental Services) 1998. *Cane Toad Workshop: Report of Proceedings*. Jabiru, 8 September 1998, Energy Resources of Australia Ltd.

Estes R & Wassersug R 1963. A Miocene toad from Columbia, South America. *Breviora* 193, 1–13.

Evans M, Yaber C & Hero J 1996. Factors influencing choice of breeding site by *Bufo marinus* in its natural habitat. *Copeia* 4, 904–912.

Evans S 1999. Fisheries issues in the Borroloola region. In *Wise use of wetlands in northern Australia: Indigenous use*, eds P Whitehead, M Storrs, M McKaige, R Kennett & M Douglas, Centre for Tropical Wetlands Management & Centre for Indigenous Natural and Cultural Resource Management, Northern Territory University, Darwin NT, 16.

Fellows AG 1969. Toads and termites. *Victorian Naturalist* 86, 136.

Finlayson CM & von Oertzen I 1996. The Kakadu region. In *Landscape and vegetation ecology of the Kakadu Region, northern Australia*, eds CM Finlayson & I von Oertzen, Geobotany Series 23, Kluwer Academic, Dordrecht, 1–15

Floyd RB & Benbow RF 1983. Nocturnal activity of a population of cane toads, *Bufo marinus*. *Koolewong* 13, 12–14.

Floyd RB 1983a. Thermal physiology of *Bufo marinus* embryos and larvae: The ecological significance of laboratory observations. PhD thesis, Griffith University, Brisbane, Queensland.

Floyd RB 1983b. Ontogenetic change in the temperature tolerance of larval *Bufo marinus* (Anura:Bufonidae). *Comparative Biochemistry and Physiology* 75a(2), 267–271.

Frauca H 1974. Crows, channel-bill cuckoos and cane toads. *Australian Birdlife* 1, 112−144.

Freeland WJ 1984. *Cane toads: A review of their biology and impact on Australia*. Technical report 19, Parks and Wildlife Unit, Conservation Commission of the Northern Territory, Darwin NT.

Freeland WJ 1985. The need to control cane toads. *Search* 16(7–8), 211–215.

Freeland WJ 1986a. Populations of cane toad, *Bufo marinus*, in relation to time since colonisation. *Australian Wildlife Research* 13, 321–329.

Freeland WJ 1986b. Invasion north, successful conquest by the cane toad. *Australian Natural History* 22(2), 69–72.

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

Freeland WJ 1990. Effects of the cane toad *Bufo marinus* on native Australian wildlife: A review of past and current research. CCNT, Darwin NT, unpublished report.

Freeland WJ 1994. Parasites, pathogens and the impact of introduced organisms on the balance of nature in Australia. In *Conservation biology in Australia and Oceania*, eds C Moritz & J Kikkawa, Surrey Beatty & Sons, Sydney, 171–180.

Freeland WJ 2000. Untitled. Unpublished report to Parks & Wildlife Commission of the Northern Territory (PWCNT).

Freeland WJ & Kerin SH 1988. Within habitat relationships between invading *Bufo marinus* and Australian species of frog during the tropical dry season. *Australian Wildlife Research* 15, 293–305.

Freeland WJ & Kerin SH 1991. Ontogenetic alteration of activity and habitat selection by *Bufo marinus*. *Australian Wildlife Research* 18, 431–443.

Freeland WJ & Martin KC 1985. The rate of expansion by *Bufo marinus* in northern Australia, 1980–1984. *Australian Wildlife Research* 12, 555–559.

Freeland WJ, Delvinquier BLJ & Bonnin B 1986a. Decline of cane toad, *Bufo marinus*, populations: Status of urban toads. *Australian Wildlife Research* 13, 597–601.

Freeland WJ, Delvinquier BLJ & Bonnin B 1986b. Food and parasitism of the cane toad, *Bufo marinus*, in relation to time since colonisation. *Australian Wildlife Research* 13, 489–499.

Friend G 1980. Diversity of terrestrial vertebrates and orthopterans in wetland habitats of the South Alligator River Region. Paper presented at Workshop ‘The status and management of tropical wetlands', Darwin, 18–21 August 1980, organised by ANPWS and CSIRO Division of Wildlife Research.

Froggatt WW 1936. The introduction of the great Mexican toad, *Bufo marinus,* into Australia. *Australian Naturalist* 9, 163–164.

Gardner S, Finlayson CM & Pidgeon R (eds) In press. *Description and literature review of the flora and vertebrate fauna of Magela Creek, Alligator Rivers Region, Northern Australia*. Supervising Scientist Report, Supervising Scientist, Darwin.

Garnett ST & Crowley GM 2000. *The action plan for Australian birds 2000*. Environment Australia, Canberra.

Georges A & Kennett R 1989. Dry-season distribution and ecology of the Warradjan *Carettochelys insculpta* (Chelonia: Carettochelydidae) in Kakadu National Park, northern Australia. *Australian Wildlife Research* 16, 323–335.

Georges A, Choquenot D, Coventry AJ & Wellings P 1989. Some observations of the pig-nosed turtle *Carettochelys insculpta* (Testudinata: Carettochelydidae) in northern Australia. *Northern Territory Naturalist* 11, 8–11.

Goodacre WA 1947. The giant toad (*Bufo marinus*) an enemy of bees. *Agriculture Gazette* NSW 58, 374–375.

Grant C 1948. Selection between armed and unarmed arthropods as food by various animals. *Journal of Entomological Zoology* 40, 66.

Griffin R 1985. The importance of mangrove/coastal wetland to three commercial fisheries in the Northern Territory; particularly for barramundi (*Lates calcarifer*). In *Coasts and tidal wetlands of the Australian monsoon region*, a collection of papers presented at a conference held in Darwin , 4–11 November 1984, eds KN Bardsley, JDS Davie & CD Woodroffe, Mangrove Monograph no 1, Australian National University North Australia Research Unit, Darwin, 277–283.

Griffith AD & Christian KA 1996. Diet and habitat use of frillneck lizards in a seasonal tropical environment. *Oecologia* 106, 39–48.

Grigg G 1999. Impact of cane toads on native frogs, Kakadu National Park — baseline study. Final report for Phase 1, September 20.

Hamley J & Georges 1985. The Australian snapping tortoise *Elseya latisternum*: A successful predator on the introduced cane toad? *Australian Zoology* 21, 607–610.

Hardy LM & Mc Diarmid RW 1969. The amphibians and reptiles of Sinaloa, Mexico. *Miscellaneous Publications of the University of Kansas Museum of Natural History* 18, 39–252.

Hearnden MN 1991. Reproductive and larval ecology of *Bufo marinus* (Anura: Bufonidae). PhD thesis, James Cook University of North Queensland, Townsville.

Hegerl EJ, Claridge GF, Davie PJF, Outridge PM , Shanco P & Stock EC. 1982. The Kakadu National Park mangrove forests and tidal marshes, Volume 4: Preliminary results of field studies. Australian Littoral Society, Unpublished report to ANPWS, Brisbane.

Hegerl EJ, Davie PJF, Claridge GF & Elliott AG 1979. The Kakadu National Park mangrove forests and tidal marshes, Volume 1: A review of the literature and field reconnaissance. Unpublished report to ANPWS, Canberra.

Hinkley AD 1963. Diet of the giant toad, *Bufo Marinus* (L.) in Fiji. *Herpetologica* 18, 253–259.

Houston D & Shine R 1993. Sexual dimorphism and niche divergence: Feeding habits of the Arafura filesnake. *Journal of Animal Ecology* 62, 737–748.

Humphrey C & Pidgeon R 2001. Instigating an environmental monitoring program to assess potential impacts upon streams associated with the Ranger and Jabiluka mine sites. A report to the Alligator Rivers Region Technical Committee, November 2001 (Unpublished)

Humphrey CL & Dostine PL 1994. Development of biological monitoring programs to detect mining-waste impacts upon aquatic ecosystems of the Alligator Rivers Region, Northern Territory, Australia. *Mitteilungen Internationalis Vereinigung Limnologiae* 24, 293–314.

Humphrey CL 1999. Potential effects of the Jabiluka Mine upon the biodiversity of Kakadu National Park. In *Response to the ICSU review of the Supervising Scientist's report to the World Heritage Committee*, Supervising Scientist, Darwin, 1–61. (unpublished)

Illingworth JF 1941. Feeding habits of *Bufo Marinus*. *Proceedings of the Hawaiian Entomological Society* 11(1), 51.

Ingle D & McKinley D 1978. Effects of stimulus configuration on solicited prey catching by the marine toad *Bufo marinus*. *Animal Behaviour* 26, 885–891.

Jacklyn P 1992. The status of cane toads in the Northern Territory: Final report for the ECNT, November 1992 (includes report of workshop on cane toad research, CSIRO Division of Wildlife and Ecology, Gungahlin, 28 September – 2 October 1992).

Jaeger RG 1976. A possible prey-all window in anuran auditory perception, *Copeia* 1976, 833–834.

James D 1994. Ecological determinants of survival, dispersal and growth in newly metamorphosed *Bufo marinus*. Honours thesis, James Cook University, Townsville Queensland.

Janzen DH 1973. Sweep samples of tropical foliage insects: Effects of seasons, vegetation types, elevation, time of day, and insularity. *Ecology* 54, 687–708.

Johnson CR 1972. Thermal relations and daily variation in the thermal tolerance in *Bufo marinus*. *Journal of Herpetology* 6, 35–38.

Kikkawa J & Monteith GB. 1980. Animal ecology of monsoon forests of the Kakadu region, Northern Territory. University of Queensland. Unpublished consultancy report to ANPWS, Canberra.

Kinghorn JR 1938. The giant toad, *Bufo marinus*, in Australia. *Australian Museum Magazine* 6, 410–411.

Knowles RP 1964. The poisonous toad and the canine. *Veterinary Medicine* 59, 83–42.

Kourany M, Myers CW & Schneider CR 1970. Panamanian amphibians and reptiles as carriers of Salmonella. *American Journal of Tropical Medical Hygeine* 19, 632–638.

Krakauer T 1968. The ecology of the neotropical toad, *Bufo marinus*, in south Florida. *Herpetologica* 24(3), 214–221.

Krakauer T 1970. Tolerance limits of the toad *Bufo marinus,* in south Florida, *Comparative Biochemistry and Physiology* 33, 15–26.

Kruse KC & Stone BM 1984. Largemouth bass (*Micropterus salmoides*) learn to avoid feeding on toad (*Bufo*) tadpoles. *Animal Behaviour* 32, 1035–9.

Lampo M & Bayliss P 1996. Density estimates of cane toads from native populations based on mark-recapture data. *Wildlife Research* 23, 305–315.

Lampo M & De Leo G 1998. The invasion ecology of the toad *Bufo marinus*: From South America to Australia. *Ecological Applications* 8(2), 388–396.

Larson HK & Martin KC 1990. *Freshwater fishes of the Northern Territory*. Northern Territory Museum handbook no 1, Northern Territory Museum of Arts and Sciences, Darwin, NT.

Lavery HJ 1969. Collisions between aircraft and birds at Townsville, Queensland. *Queensland Journal of Agriculture and Animal science* 26, 447–455.

Lawler KL & Hero J 1997. Palatability of *Bufo marinus* tadpoles to a predatory fish decreases with development. *Wildlife Research* 24, 327–334.

Lazarides M, Craven LA, Dunlop CR, Adams LG & Byrnes 1988. *A checklist of the flora of Kakadu National Park and environs, Northern Territory, Australia*. Occasional paper no 15, Australian National Parks & Wildlife Service, Canberra.

Leitch IM, Lim TH & Boura ALA 2000. *Novel drugs from toad skins*. RIRDC Publication 00/17, Rural Industries Research & Development Corporation, ACT.

Leonard MD 1933. Notes on the giant toad, *Bufo Marinus* (L.) in Puerto Rico. *Journal of Economic Entomology* 26, 67–72.

Lever RJAW 1937a. The giant toad. *Fiji Agricultural Journal* 8, 36.

Lever RJAW 1938b. The giant toad — distribution, diet and development. *Fiji Agricultural Journal* 1937, 9–28.

Lever RJAW 1939. Additional notes on diet of the giant toad. *Fiji Agricultural Journal* 10, 20.

Lever RJAW 1944. Food of the giant toad. *Fiji Agricultural Journal* 15, 28.

Lever RJAW 1945. The giant toad in the Solomon Islands. *Fiji Agricultural Journal* 16, 88.

Licht LE & Low B 1968. Cardiac response of snakes after ingestion of toad parotoid venom. *Copeia* 1968(3), 547–551.

Licht LE 1967. Death following possible ingestion of toad eggs. *Toxicon* 5, 141–142.

Licht LE 1968. Unpalatability and toxicity of toad eggs, *Herpetologica* 24(2), 93–98.

Lindner G 1999. Contemporary indigenous utilisation and management of wetland resources in Kakadu National Park, monsoonal northern Australia. In *Wise use of wetlands in northern Australia: Indigenous use*, eds P Whitehead, M Storrs, M McKaige, R Kennett & M Douglas, Centre for Tropical Wetlands Management & Centre for Indigenous Natural and Cultural Resource Management, Northern Territory University, Darwin, 27–36.

Madsen T & Shine R 1994. Toxicity of a tropical Australian frog, *Litoria dahlii*, to sympatric snakes. *Wildlife Research* 21, 21–5.

Malvin MG & Wood SC 1991. Behavioural thermoregulation of the toad, *Bufo marinus*: Effects of air humidity. *Journal of experimental Zoology* 258, 322–326.

Marchant S & Higgins PJ 1990. *Handbook of Australian, New Zealand and Antarctic birds. Vol 1: Ratites to ducks*. Oxford University Press, Oxford.

Marinkelle CJ & Willems NJ. 1964. The toad *Bufo marinus* as a potential mechanical vector of eggs of *Ascaris lumbricoides*. *Journal of Parasitology* 50, 427–428.

Martin RF 1972. Evidence of osteology. In *Evolution in the Genus Bufo*, ed WF Blair, University of Texas Press, Austin, 37–70.

McManus JJ & Nellis DW 1975. The critical thermal maximum of the marine toad, *Bufo marinus*. *Caribbean Journal of Science* 15, 67–70.

Miles G 1988. *Wildlife of Kakadu and the Top End of the Northern Territory*. *Australia*. Barker Souvenirs, Alice Springs NT.

Mirtschin PJ & Davis R 1982. *Dangerous snakes of Australia*. Rigby, Adelaide.

Mitchell D, Jones A & Hero J-M 1995. Predation on the cane toad (*Bufo marinus*) by the black kite (*Milvus nigrans*). *Memoirs of the Queensland Museum* 38, 512.

Morris I 1996. *Kakadu National Park Australia*. Steve Parish Publishing, Bowen Hills, Qld.

Morton SR & Brennan KG 1983. Birds of the wetlands and riparian forests in the Alligator Rivers Region. In *Environmental protection in the Alligator Rivers region*. Scientific workshop held at Jabiru, NT 17–20 May 1983, Supervising Scientist for the Alligator Rivers Region, Jabiru NT, 42.1–42.23.

Morton SR & Brennan KG 1991. Birds. In *Monsoonal Australia: Landscape, ecology and man in the northern lowlands*, eds CD Haynes, MG Ridpath & MAJ Williams, AA Balkema, Rotterdam, Netherlands, 133–149.

Morton SR, Brennan KG & Armstrong MD 1991. Distribution and abundance of waterbirds in the Alligator Rivers Region, Northern Territory. Open File Record 86, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Mungomery RW 1935a. The giant American toad (*Bufo marinus*). *Cane Growers Quarterly Bulletin* 3, 21–27.

Mungomery RW 1935b. A short note on the breeding of *Bufo marinus* in captivity. *International Society of Sugar Cane Technologists* 1935, 589.

Mungomery RW 1936. A survey of the feeding habits of the giant toad (*Bufo marinus*) and notes on its progress since introduction to Queensland. *Proceedings of the Queensland Society of Sugar Cane Technologists* 1936, 63–74.

Mungomery RW 1937. The present situation regarding the giant American toad in Queensland. *Cane Growers Quarterly Bulletin* 12.

Neill WT 1958. The occurrence of amphibians and reptiles in saltwater areas, and a bibliography. *Bulletin of Marine Science Gulf and Caribbean* 8, 1–97.

Niven BS & Stewart MG 1982. *The precise environment of some well known animals*. *VII*: *the cane toad* (*Bufo marinus*). AES working paper 3/82, School of Australian Environmental Studies, Griffith University, Brisbane.

Noble GK 1918. The amphibian collected by the American Museum Expedition to Nicaragua in 1916. *Bulletin of the American Museum of Natural History* 83, 311–347.

Ormsby AI 1955. Notes on the giant toad *Bufo marinus*. Proceedings of the Royal Zoological Society 6(1), 54–55.

Outridge PM 1987. Possible causes of high species diversity in tropical Australian freshwater macrobenthic communities. *Hydrobiologia* 150, 95−107.

Pancontinental 1981. *A review of Jabiluka environmental studies*. Pancontinental Mining Ltd, Sydney.

Parks Australia 1999. *Kakadu tour operators handbook*. Commonwealth of Australia, Canberra.

Pearse BW 1980. Effects of feeding on *Bufo marinus* by native and exotic fishes. Report to AES, Griffith University, Brisbane, Qld.

Pemberton CE 1949. Longevity of the tropical American toad *Bufo marinus* L. *Science* 110, 512.

Pengilly R 1981. Observations on the cane toad (*Bufo marinus*) in the southern Gulf Country, Queensland, Internal report, CCNT.

Pernetta J & Goldman B 1976. Botaniviti: The elusive Fijian frog. *Australian Natural History* 18(12), 435–437.

Pippet JR 1975. The marine toad, *Bufo marinus*, in Papua New Guinea. *Papua New Guinea Agriculture Journal* 26, 23–30.

Pough FH & Kamel S 1984. Post-metamorphic change in activity metabolism of anurans in relation to life history. *Oecologia* 65, 138–144.

Press A, Brock J & Andersen A 1995. Fauna. In *Kakadu: Natural and cultural heritage management*, eds A Press, D Lea, A Webb & A Graham, Australian Nature Conservation Agency & North Australia Research Unit ANU, Darwin, 167–216.

Rabor DS 1952. Preliminary notes on the giant toad *Bufo marinus* (Linne) in the Philippine Islands. *Copeia* 1952(4), 281–282.

Recher HR & Holmes RT 1982. *The foraging behaviour of herons and egrets on the Magela Creek flood plain, Northern Territory.* Technical memorandum 4, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Richardson CL 1941. The stomach contents of giant toads. In *Cane Pests Board Conference: Record of Minutes and Meetings*, Brisbane, 45–49.

Roeger L & Russell-Smith J 1995. *Developing an endangered species program for Kakadu National Park: Key issues 1995–2002*. ANCA, Canberra.

Russell-Smith J 1995. Fire management. In *Kakadu: Natural and cultural heritage management*, eds A Press, D Lea, A Webb & A Graham, Australian Nature Conservation Agency & North Australia Research Unit ANU, Darwin, 217–237

Sabath MD, Boughton WC & Easteal S 1981. Expansion of the range of the introduced toad *Bufo marinus* in Australia from 1935 to 1974. *Copeia* 1981(3), 676–680.

Schultz-Westrum TG 1970. Conservation in Papua and New Guinea. Final report on the 1970 World Wildlife Fund Mission.

Schwarzkopf L & Alford RA 1996. Desiccation and shelter-site use in tropical amphibians: comparing toads with physical models. *Functional Ecology* 10, 193–200.

Seabrook W 1991. Range expansion of the introduced cane toad *Bufo marinus* in New South Wales. *Australian Zoologist* 27(3&4), 57–62.

Seabrook W 1993. Habitat use of the cane toad *Bufo marinus*: Implications for assessment of impact and control strategies. PhD Thesis, University of Sydney, NSW.

Seabrook WA & Dettmann EB 1996. Roads as activity corridors for cane toads in Australia, *Journal of Wildlife Management* 60(2), 363–368.

Shine R & Covacevich J 1983. Ecology of highly venomous snakes of the Australian genus O*xyuranus*. *Journal of Herpetology* 17, 60–69.

Shine R 1986a. *Diets and abundances of aquatic and semi-aquatic reptiles in Alligator Rivers Region.* Technical memorandum 16, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Shine R 1986b. Ecology of a low-energy specialist: Food habits and reproductive biology of the Arafura Filesnake (Acrochordidae). *Copeia* 2, 424–437.

Simmonds HW 1957. The giant toad *Bufo marinus* in fiji. *Fiji Agricultural Journal* 28, 77.

Stammer D 1981. Some notes on the cane toad (*Bufo marinus*). *Australian Journal of Herpetology* 1(2), 61.

Storrs MJ & Finlayson CM 1997. *Overview of the conservation status of wetlands of the Northern Territory*. Supervising Scientist Report 116, Supervising Scientist, Canberra.

Strahan R (ed) 1983. *The complete book of Australian mammals*. The Australian Museum, Angus & Robertson, Sydney.

Straughan IR 1966. The natural history of the cane toad in Queensland. *Australian Natural History* 15, 230–232.

Stuart LC 1935. A contribution to a knowledge of the herpetology of a portion of the savanna region of central Peten, Guatemala. *Miscellaneous Publications of the Museum of Zoology, University of Michigan* 29, 1–56.

Stuart LC 1951. The distributional implications of temperature tolerances and haemoglobin values in the toads *Bufo marinus* (Linneus) and *Bufo bocourti* (Brocchi). *Copeia* 1951, 220–229.

Sutherst RW, Floyd RB & Maywald GF 1995. The potential geographical distribution of the cane toad, *Bufo marinus* L. in Australia. *Conservation Biology* 9(6), 294–299.

Takano S & Iijima K 1937. Studies on the life history and habits of *Bufo marinus* in Formosa. Part 1: The relationship between growth of the tadpole and the quality of the breeding water. *Taiwan Government Sugar Experiment Station Report Japan* 4, 1937.

Tyler MJ & Cappo M 1983. Diet and feeding habits of frogs of the Magela Creek system. Open file record 10, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Tyler MJ & Crook GA 1987. *Frogs of the Magela Creek system.* Technical memorandum 19, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Tyler MJ 1975. The cane toad *Bufo marinus*: An historical account and modern assessment. The Vermin and Noxious Weeds Destruction Board Victoria and the Agriculture Protection Board, Western Australia.

US EPA 1998. *Guidelines for ecological risk assessment*. EPA/630/R-95/002F. Risk Assessment Forum, Washington, DC.

Valerio CE 1971. The ability of some tropical tadpoles to survive without water. *Copeia* 1971, 364–365.

van Beurden EK & Grigg GC 1980. An isolated and expanding population of the introduced toad *Bufo marinus* in New South Wales. *Australian Wildlife Research* 7, 305–310.

van Beurden EK 1978. Report on the results of stage 1 of an ecological and physiological study of the Queensland cane toad, *Bufo marinus*. Report to ANPWS, Canberra.

van Beurden EK 1979. Report on the results of stage 2 of an ecological and physiological study of the Queensland cane toad, *Bufo marinus*. Report to ANPWS, Canberra.

van Beurden EK 1980. Report on the results of stage 3 of an ecological and physiological study of the Queensland cane toad, *Bufo marinus*. Report to ANPWS, Canberra.

van Beurden EK 1981. Bioclimatic limits to the spread of *Bufo marinus* in Australia: A baseline, *Proceedings of the Ecological Society of Australia* 2, 143–149.

van Dam RA, Finlayson CM, & Humphrey CL 1999. Wetland risk assessment: A framework and methods for predicting and assessing change in ecological character. In *Techniques for enhanced wetland inventory and monitoring*, eds CM Finlayson & AB Spier, Supervising Scientist Report 147, Supervising Scientist, Canberra, 83–118.

van Leeuwen CJ 1995. General Introduction. In *Risk assessment of chemicals: An introduction*, eds CJ van Leeuwen & JLM Hermens, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1–17.

Van Tets GF & Vestjens WJM 1973. *Birds and their food at Mackay Airport*. Queensland Division of Wildlife Research Memoir No 8, CSIRO, Canberra.

Voris HK & Bacon JP Jr. 1966. Differential predation on tadpoles. *Copeia* 1966, 594–598.

Wassersug R 1971. On the comparative palatability of some dry-season tadpoles from Costa Rica. *American Midland Naturalist.* 86, 101−109.

Waterhouse DF 1974. The biological control of dung. *Scientific American* 230, 101−109.

Watt A-M 1993. Conservation status and draft management plan for *Dasyurus maculatus* and *Dasyurus hallucatus* in southern Queensland. Unpublished report to Queensland Department of Environment and Heritage, Brisbane.

Weber NA 1938. The food of the giant toad, *Bufo Marinus* (L.) in Trinidad and British Guiana with special reference to ants. *Annals of the Entomological Society of America* 31, 499–503.

Werren GL 1993. Size and diet of *Bufo marinus* in rainforest of north eastern Queensland. *Memoirs of the Queensland Museum* 34(1), 240.

Whitehead P & Storrs M 1999. Synthesis and outcomes. In *Wise use of wetlands in northern Australia: Indigenous use*, eds P Whitehead, M Storrs, M McKaige, R Kennett & M Douglas, Centre for Tropical Wetlands Management & Centre for Indigenous Natural and Cultural Resource Management, Northern Territory University, Darwin, 60–65.

Williamson I 1999. Competition between the larvae of the introduced cane toad *Bufo marinus* (Anura: Bufonidae) and native anurans from the Darling Downs area of southern Queensland. *Australian Journal of Ecology* 24, 636–643.

Wingate DB 1965. Terrestrial herpetofauna of Bermuda. *Herpetologica* 21, 202–218.

Woinarski JCZ & Braithwaite RW 1991. The terrestrial vertebrate fauna and vegetation of the Kakadu Conservation Zone. Unpublished report CSIRO Wildlife and Ecology prepared for Resource Assessment Committee.

Woinarski JCZ 2000. Population trends of small mammals at Kapalga. Unpublished report to Kakadu Research Advisory Committee, 17 February.

Woinarski JCZ, Gambold N, Menkhorst K & Braithwaite RW. 1989. Wildlife of Kakadu Stage III. Final report to ANPWS. Unpublished report, CSIRO Tropical Ecosystem Research Centre.

Wolcott GW 1937. What the giant Surinam toad, *Bufo Marinus* (L.) is eating now in Puerto Rico. *University of Puerto Rico Journal of Agriculture* 21(1), 79–84.

Woodroffe CD, Chappell JMA, Thom BG & Wallensky E. 1985. Geomorphology of the South Alligator Tidal River and Plains, NT. In *Coasts and tidal wetlands of the Australian monsoon region*. eds KN Bardsley, JDS Davie & CD Woodroffe, Mangrove Monograph 1, Australian National University, North Australia Research Unit, Darwin, 3–16.

Zug GR & Zug PB 1979. The marine toad, *Bufo marinus*: A natural history resume of native populations. *Smithsonian Contributions to Zoology* 284, 1–54.

Zug GR, Lindgren E & Pippet JR 1975. Distribution and ecology of the marine toad, *Bufo marinus*, in Papua New Guinea. *Pacific Science* 29, 31–50.