

14. Discussion

We have calculated minimum habitat areas for a diverse range of taxa, spanning at one extreme species that are relatively small, mostly sedentary and highly vulnerable to cane toads and, at the other extreme, highly mobile species that are much less likely to be affected by the presence of toads in the landscape. We present this span of results to illustrate the numerous challenges facing the adoption of exclusion as a strategy for reducing the impacts of cane toads in north Australia, and potential responses to those challenges, given the present state of knowledge.

Context and limitations

We do not represent these analyses as management prescriptions for general application across the landscapes of northern Australia. In part this is because the information available on the interactions between toads and many species of conservation interest is too weak to permit such an approach (van Dam et al. 2002). However, we also believe that the search for general prescriptions is misguided. All proposals for protection of native fauna through toad exclusion require detailed individual analysis that takes account of local or regional conditions. Rather than a set of recipes, we consider that the particular value of our contribution is to set out many of the issues that will need to be considered and the parameters to be measured or estimated in performing a rigorous analysis.

A particular limitation of our approach is that we have considered the presence of toads in any numbers to be a serious threat to the persistence of vulnerable species in the landscape. With the possible exception of quolls (M. Oakwood, unpublished data) and some goannas (AJ Griffiths, unpublished; D Holland, unpublished data), our choices of species are based on no quantitative assessment of the impact of cane toad exposure. It is therefore impossible to predict changes in the size and dynamics of populations even over the short term, let alone to demonstrate unacceptable risk of local or regional extinction. There is no consensus regarding the probability of adaptation, through individual (and “cultural” through imitation (Dugatkin 2000)) learning from sublethal interactions with toads, or through selection for improved tolerance of bufotoxins or selection for heritable disinterest in preying on toads. Many note the persistence, albeit at reduced densities, of putatively highly vulnerable species like northern quolls in Queensland (S Garnett, pers. comm.) and goannas in Territory sites (WJ Freeland, unpublished) despite large populations of toads.

When the risks of leaving the putative threat unmanaged are effectively unknown, it is

difficult to do more than approximately rank options for different responses. An optimal approach is unspecifiable. There is a risk that an overenthusiastic response to toads, if it diverts a substantial proportion of the funds that would otherwise be used for demonstrably robust conservation work, will weaken conservation performance.

To illustrate this point, consider the hypothesis that the effect of toads is an initial acute and then chronic reduction of densities rather than the total elimination of local populations. Subsequent fragmentation of habitats at an otherwise relatively benign level might put dispersed populations of "resistant" individuals at great risk. Should available investments be directed at seeking to maintain landscape integrity at very large scales, rather than building expensive localised exclosures of unknown efficacy? How many species will be maintained by expenditure on the functional equivalent of extraordinarily large cages compared with equivalent expenditures on keeping very often marginal land out of frequently economically marginal production (see Holmes 1996).

Making choices

Under circumstances of continued uncertainty, we consider that relatively modest expenditures on exclusion strategies with a high prospect of long-term success, despite a boisterous climate, are to be preferred over more ambitious approaches. This seems to us to suggest use of natural islands under relatively tight quarantine, backed by captive breeding of vulnerable fauna, to be the optimal mid-term strategy, while biological or other effective controls of toad density are sought.

If expenditures on long artificial barriers are at all justified, they are best designed to complement relevant natural barriers. In the case of the cane toad, this means making use of peninsulas with a morphology that permits exclosure of large areas by a relatively short barrier (as illustrated by Cobourg Peninsula). But this conclusion is also contestable. *Bufo marinus* is capable of surviving considerable periods in seawater, and is regularly observed swimming in saline waters in mangrove habitats, even when freshwater flows from local rivers are too low to significantly dilute these waters (AJ Griffiths, unpublished observations). The design of inter-tidal barriers capable of retaining integrity despite high tidal flows, frequent storms and irregular cyclones, deposition of natural and anthropogenic debris and rapid corrosion, remains uncertain. If such a barrier was to be built, it would be desirable to conduct trials to also allocate funds to assess durability and effectiveness of different designs in limiting the likelihood of toads simply swimming or hopping around them.

Operational considerations

The exercise of producing these estimates of extinction probabilities and costs of enclosure has raised a number of important issues regarding the operational choices associated with such a management tool. Among the most significant are:

- (1) The ratio of perimeter to area enclosed decreases with increasing size of enclosures. For example, for a square enclosure, doubling the perimeter increases the area enclosed four-fold. The area enclosed increases rapidly with increased investment in perimeter fencing.
- (2) Conversely, the probability of extinction rises approximately exponentially as the enclosed area - and hence the population protected - decreases. As a consequence, risks of failure increase very rapidly if attempts are made to extract savings from reduced expenditure on a perimeter (Figure 2).
- (3) Dependence on a single population and hence the integrity of the structure that protects it is an inherently high-risk approach. In many areas of favourable cane toad habitat (especially coastal habitats), cyclones or other high intensity storms are frequent. There is a small but measurable risk of catastrophic failure. In regions subject to such storms, following severe events, attention to conservation issues is likely to be accorded lower priority than urban and other infrastructure like utilities, roads, and housing. As a consequence, repair is unlikely during ensuing periods of high rainfall and, presumably, high rates of dispersal of cane toads at all stages of the life cycle. Cane toad invasions of enclosures of substantial size may be effectively irreversible if delays in repair are protracted. Non-estuarine islands of reasonable elevation, and hence low susceptibility to flooding during storm surges of up to several metres above normal tidal limits, are likely to provide much more robust protection in the face of cyclonic conditions.
- (4) Other catastrophic events, such as outbreaks of disease, also threaten single populations. Responses to such risks might include erection of multiple "natural" enclosures or maintaining genetically relevant captive populations, or both. Obviously the cost of individual structures and the increasing perimeter to area ratio with smaller enclosures (Figure 2) will inhibit strategies like subdivision to reduce risk of simultaneous catastrophic failure. The maintenance of captive breeding colonies will in most cases appear to be a considerably lower cost option than multiple enclosures, but captive populations are not immune from risk of disease, destruction in storm or fire. The

desirability of maintaining a number of genetically distinct stocks may also increase the desirability of multiple captive populations.

- (5) A widely applied rule of thumb for determining the size of captive populations needed to maintain genetic integrity (retaining 90% of genetic variance over 100 years) is $475/L$, where L is the generation length. We have applied this rule of thumb in our estimates. However, it should be noted that with close management, especially of family size, this can be approximately halved, so that for quolls the minimum requirement will be about 250, and for large reptiles of the sort we considered, 100 plus (Frankham et al. 2002).
- (6) The most effective conservation strategies that take account of uncertainty and risk of vulnerable fauna will require "hybrid" responses, rather than a search for a single cost- or conservation-optimal design.
- (7) Given high costs of management of the toad threat and finite resourcing for conservation, responses to the issues raised by toads have the potential to constrain other conservation activity. We sought to reflect this additional "cost" by incorporating interest payments in the estimates of the annual cost of the large capital expenditures on structures, which serves to help emphasise the scale of such investments compared with many other conservation programs. However, we have not provided equivalent estimates of the collateral benefits of toad-based investments that secure sites against other threats. For example, good biological "quarantine" systems for islands may return multiple conservation benefits protecting against a wide range of potential threats.
- (8) We have taken no account of the cost of placing barriers to the movement of small mammals, reptiles and amphibians across large parts of the landscape, nor the loss of habitat in wide firebreaks. Risks associated with such issues would need to be assessed case by case and inform judgments about the net benefits of such interventions.

15. Conclusions

This new work on deriving minimum viable population sizes combined with estimates of costs of building relevant exclosures against cane toads has implications that extend beyond the immediate cane toad management problem. Areas required for minimum viable populations of important elements of the north Australian fauna are large and the costs of

excluding threats are accordingly very high. The minimalist goal of avoiding conservation disasters (extinctions) by such interventions is not self-evidently cheaper nor demonstrably more effective than conservation strategies that seek to maintain landscape integrity rather than respond to individual threats. It remains an open question whether a more rational approach to the mid to long term problem of cane toads is to seek to better manage other processes that will exacerbate effects of increased mortality of vulnerable species, especially habitat fragmentation.

To depend on enclosing small spaces - which remain vulnerable and require intense ongoing intervention - is to retreat from the larger issues confronting northern Australia and to avoid the difficult long term questions. It seems reasonable to suggest that under some circumstances, such enclosures may provide a useful adjunct to more comprehensive strategies. However, those comprehensive strategies must address, realistically and preferably quantitatively, the situation that will apply to toads after an achievable biological and other control program. A sober appraisal based on the situation with other species (for example the rabbit) that have been subject to focused attention for decades, backed by resources for control that are unlikely to ever be devoted to species that do not threaten agriculture or human health, is that the pest will remain common in the landscape. Thus the long term strategy must address the interaction of the toad threat with other processes like land clearing and habitat fragmentation, fire management, and other invasive species. A magic bullet for the toad, no matter how expensive and how effective, is only one part of a much larger problem confronting many more elements of the north Australia biota.

Appendix: The candidate species

(i) Canis lupus dingo (dingo)

Dingos remain relatively common in Australia and are found in scattered groups across Southeast Asia. With the exception of Tasmania they were formerly found throughout the entire Australian continent but are now absent from densely settled parts of the south-east and south-west (Menkhorst 2001).

Pressures on the dingo population include habitat loss and culling by humans. They compete with foxes and feral cats for small animal food sources but have shown greater success with large prey, especially in times of drought. The dingo has also benefited from access to stock watering points and the provision of abundant non-native food (Corbett 1995). The greatest current threat to pure populations of dingo appears to be hybridisation due to interbreeding with domestic/wild dogs (Corbett 1995; Menkhorst 2001; Hintze 2002). Dingo populations in both the Borrooloola and the Roper River region have been shown to be adversely affected by the cane toad at least in the short term (Catling et al. 1999). Dingos were ranked among the 10 highest at risk species from the cane toad in Kakadu National Park (van Dam et al. 2002).

Undisturbed by humans, dingos form packs of 3-12 individuals. Dingos are monogamous and cooperative breeders. Packs have distinct male/female hierarchies with only the dominant pair breeding successfully. They breed once per year and average 5 pups per litter. Dominant females will kill the young of other females within the pack. Dingos obtain sexual maturity around 22 months and pair during their 3rd year, often mating for life (Corbett 1995).

Dingos are opportunistic carnivores (Menkhorst 2001), 60% of their diet being mammals, with reptiles and birds making up the remainder (Strahan 1983). Although they eat a diverse range of prey they tend to specialise on abundant species, changing hunting strategy to maximise success (Corbett 1995).

A pack typically remains in the territory of their birth, traveling 10-20km per day. Home ranges vary from 10 to 77 km² depending on the environment. Home ranges are larger in arid regions and smallest in the moist forested mountains of E and SE Australia. Home range is a function of the reliability and regularity of food availability and terrain rather than pack size (Corbett 1995).

(ii) Dasyurus hallucatus (northern quoll)

The northern quoll's range has become increasingly smaller and fragmented. Currently it is

restricted to six main areas, the Harmersley Range and the Kimberly in Western Australia, northern and western parts of the Top End in Northern Territory, northern Cape York, Artherton in the Cairns area and the Carnarvan Range in the Bowen areas, Queensland. Formerly they were found across northern Australia from the northwest cape Western Australia to southeast Queensland (Menkhorst 2001). The northern quoll is considered to be near threatened (Parks and Wildlife Commission NT 2003).

Although the reason for the species decline is not well understood, impacts that degrade the habitat including changes to grazing and fire regimes which remove shelter and increase their vulnerability to predation are likely causes. In combination with increased predator abundance (feral dogs and cats) and road kill, such habitat change may have lead to the broad scale decline of the northern quoll (Oakwood 2000; Department of Environment and Heritage 2004). Recent research in Kakadu has shown northern quoll populations declining at alarming rates prior to cane toad arrival due to unknown factors (van Dam et al. 2002). There is a large amount of anecdotal evidence of local population declines in areas following the introduction of the marine toad (Burnett 1997; Phillips et al. 2003). This species has been assigned the highest priority in the risk assessment of cane toads in Kakadu National Park (van Dam et al. 2002).

Quolls have a naturally short life span, the northern quoll reaching sexual maturity at 11 months in both sexes, most females surviving 2 breeding seasons and reaching a maximum age of 3 years while males rarely survive the breeding season, reaching a maximum age of 14 months (Oakwood 2000). Litters average six young, with around a third lost prior to independence. Whereas most females remain in the area they were born, most males disperse from the natal area by the age of 6-8 months (Strahan 1983).

The northern quoll is an aggressive predator. Diet is varied and may include small mammals, reptiles and insects, as well as figs and other soft fruit (Strahan 1983)

The northern quoll is most common in rocky , sparsely vegetated areas and open woodlands (Department of Environment and Heritage 2004). There is a large difference in the size of reported home ranges for the species. Schmitt et al recorded home ranges between 0.2ha to 3.5ha for both sexes (Schmitt et al. 1989). Oakwood reported the female home range to be 35ha with some overlap of foraging ranges when the density was high (3-4 females/km²), and the male home range to be similar, expanding during the mating season to more than 100ha (Oakwood 2002).

(iii) *Epipipiorhynchus asiaticus* (black necked stork/Jabiru)

The black necked stork is found in north and northeastern Australia from the Pilbara, Western Australia to eastern Queensland and southern New Guinea (del Hoyo et al. 1992). In the past it was found along the coastal strip as far south as the Hunter River, although at present there are few records from New South Wales (Garnett and Crowley 2000). The species global status is least concern (Garnett and Crowley 2000). However, it has shown decline in the southern end of its range and is listed as endangered in New South Wales and rare in Queensland (Dorfman et al. 2001).

Black necked storks are highly susceptible to disturbance and prefer areas little visited by humans. Habitat loss is by far the greatest threat over their distribution range. This includes felling of nest trees, encroachment of agriculture and aquaculture (Birdlife International 2003), and the degradation of wetlands through drainage, invasion of weed species, salinisation and siltation (del Hoyo et al. 1992). Other threats outside Australia include capture for pet trade and zoos, and in Australia and elsewhere, collision with electricity wires and the introduction of the cane toad (Sundar 2003). Although this species is ranked as an uncertain (high) risk in the risk assessment of cane toads in Kakadu National park it is likely to consume native anurans and exhibits foraging behaviour that will probably maximise exposure to the cane toad metamorphlings and possibly adults (van Dam et al. 2002).

The black necked stork rarely occurs in groups being dispersed as single birds or pairs or loose family flocks (Sundar 2003). Larger aggregations may occur when severe drought reduces suitable habitat (Simpson et al. 1999). Outside of the breeding season, flocks of up to 100 birds form (Australian Museum 2003). Pairs remain together for many years and tend to use the same sites repeatedly (Simpson et al. 1999) and are known to use the same nest in successive breeding attempts (Sundar 2003). Clutches of 2-4 eggs are produced and 2 or 3 chicks may be raised successfully to fledging (Simpson et al. 1999). Young birds stay with the adults for a considerable time and do not disperse far (del Hoyo et al. 1992).

Black necked storks are completely carnivorous feeding mainly on fish, but also taking frogs, snakes, turtles, crabs, prawns, molluscs, beetles and arthropods (del Hoyo et al. 1992).

The storks prefer comparatively undisturbed freshwater wetlands (del Hoyo et al. 1992). They forage in river pools, swamps, irrigated crops, dry floodplains and open grassy woodland but are less often found along the coast, occasionally in mangroves and rarely on coastal mudflats (del Hoyo et al. 1992; Simpson et al. 1999; Birdlife International 2003).

There are few data on the size of the home range, but a belief that each pair require a large territory (del Hoyo et al. 1992).

(iv) *Dacelo leachii* (blue winged kookaburra)

The range of the blue winged kookaburra includes Northern Australia and New Guinea. It is found in northeast and northern Queensland, northern Northern Territory and northern Western Australia (Simpson et al. 1999; del Hoyo et al. 2001).

The major threat to the kookaburra is habitat destruction resulting from the clearance of woodland and forest for farming. They are not globally threatened and are fairly common over most of their range (del Hoyo et al. 2001). There is a risk of the cane toad affecting their population as they occupy a broad range of habitats that will more than likely see them encounter the cane toad (van Dam et al. 2002).

The family group consists of up to 8 individuals composed of a pair and its offspring from previous years. The male bird and the auxiliaries (of which a larger number are male) assist in the preparation of the nest, feeding of the breeding female prior to laying, incubation, feeding the chicks and territorial defense. Clutch sizes are up to 5 eggs although generally only 2 chicks survive. A third chick may survive if food is plentiful. In general the kingfishers are quite long-lived, surviving up to 12 years in the wild and greater than 15 years in captivity (del Hoyo et al. 2001). Breeding pairs form long term bonds which are probably life long (Marchant and Higgins 1990).

Their diet consists of mainly invertebrates, small vertebrates (including frogs – need to clarify this in all cases, including discussion of nocturnality etc), small birds, birds eggs and small mammals. In Kakadu it consisted of 59% invertebrates and 41% vertebrates (del Hoyo et al. 2001)

The blue winged kookaburra prefer open tropical and subtropical *Eucalyptus* forests, woodlands (Marchant and Higgins 1990) and paper bark swamps (Simpson et al. 1999) avoiding areas with dense understorey (del Hoyo et al. 2001). In the Northern Territory they are found at a density of 0.08-0.72 birds per hectare (Marchant and Higgins 1990). Their mean territory size is 0.4km² (del Hoyo et al. 2001).

(v) *Aquila audax* (wedge tailed eagle)

The wedge tailed eagle is found throughout mainland Australia, Tasmania and southern New Guinea (Australian Museum 2003). However, the population in Tasmania is considered a

different sub species (del Hoyo et al. 1994). Although the mainland subspecies is widespread and common the Tasmanian race is endangered and has been reduced to 60-80 breeding pairs (del Hoyo et al. 1994).

Supposed impact on domestic stock has given rise to a long history of human persecution. Even now the eagle is subject to illegal shooting and poisoning. Local declines in southern Australia have been attributed to habitat disturbance, especially in heavily settled and farmed areas (del Hoyo et al. 1994; Simpson et al. 1999). Although the eagle may benefit from thinning of tree cover, introduction of the rabbit and access to abundant carrion from road kills etc, intolerance of human activity leads to nest abandonment and therefore threatens breeding success (del Hoyo et al. 1994).

Eagles are sexually mature at 3 years and although they may pair in immature plumage, they seldom breed before adult plumage at 6 years (del Hoyo et al. 1994). They are monogamous and apparently mate for life unless one bird of the pair is killed, after which the survivor will find a new mate (Australian Museum 2003). They lay 1-3 eggs rarely 4, and usually rear only one young per clutch, although in a good year, two chicks may fledge in some nests. They are a fairly long-lived species with records of birds living to 40 years in captivity. Although predominantly carrion eaters, the wedge tailed eagle also takes live prey like rabbits, small macropods, reptiles and birds (del Hoyo et al. 1994). Although there is no direct evidence of wedge tailed eagles taking cane toads in Queensland and the eastern half of the Northern Territory, their documented willingness to prey on other herpatiles (del Hoyo et al. 1994), and the conspicuousness and abundance of the cane toad in their range, suggests that some predator-prey interactions between these two species are highly likely. They may also feed on the carrion of individuals of other species (e.g. goannas) that have been killed by ingesting cane toads.

Wedge tail eagles can live in most terrestrial habitats but avoid areas of dense human population and dense rainforest (del Hoyo et al. 1994). They prefer wooded and forested land and open country (Australian Museum 2003). Established breeding pairs will defend the home range around their nest sites from other eagles but will hunt for food in a larger territory that they do not defend (Australian Museum 2003). Home ranges differ according to the region, breeding pairs in temperate regions occupy from 30-35 km² and in arid lands 3-6 birds may occupy 100km² (Zoological Parks and Gardens Board of Victoria 2003). Other ranges recorded are 28-32km² for the eastern highlands (NSW), 53km² in arid NSW and 32-108km² in arid Western Australia (Sharp et al. 2001). Nesting densities were calculated for western

NSW to be one pair per 3-9km² and in the semi arid zone one pair per 40-48km² (Sharp et al. 2001).

(vi) *Ixobrychus flavicollis* (black bittern)

Black bitterns are found in the Moluccas, New Guinea, Bismarck Archipelago and Australia (del Hoyo et al. 1992). Within Australia they are widely distributed in the near coastal region, from southern New South Wales north to Cape York and along the entire northern coast to the Kimberley region, also in the south western corner of Western Australia (Marchant and Higgins 1990). Although the northern Australian population is apparently secure, declines have occurred along the southern margins of its range (Garnett and Crowley 2000) coinciding with clearing for agriculture and increased salinity of rivers (Marchant and Higgins 1990).

Threats include habitat loss and predation by feral cats on eggs and young. A wide range of activities have affected habitat availability including clearing, grazing and trampling of riparian vegetation and salinisation, siltation and pollution of wetlands and waterbodies (National Parks and Wildlife Service NSW 1999). There are some reports of deaths of this species after ingesting juvenile cane toads and, due to its broad range of habitats it will more than likely encounter cane toads (van Dam et al. 2002).

Usually solitary during the non-breeding season the black bittern can sometimes be found in small colonies. During the breeding season they are seen in pairs (Marchant and Higgins 1990; del Hoyo et al. 1992). They are monogamous and both parents incubate and tend the young until fledging (Marchant and Higgins 1990; del Hoyo et al. 1992). They are generally single-brooded and produce between 3 to 6 eggs, normally 4 (National Parks and Wildlife Service NSW 1999).

The black bittern are nocturnal and generally feed at dusk and at night (Marchant and Higgins 1990). They feed on fish, frogs, molluscs, crustaceans and insects (del Hoyo et al. 1992).

Typically the black bittern is found in areas where permanent water and dense vegetation are present. Preferring densely forested freshwater streams and pools or other wetlands. In Australia it also frequents mangrove and Melaluca swamps, margins of estuaries, lagoons, tidal creeks and mudflats (del Hoyo et al. 1992; National Parks and Wildlife Service NSW 1999; Simpson et al. 1999). Currently there is no available information on the home range of the black bittern

(vii) *Ardeotis australis* (Australian bustard)

The Australian bustard is found in all states but is generally rarer or absent in the south, especially in the southeast. It is also found in southern Papua New Guinea ranging into Irian Jaya (del Hoyo et al. 1996). The Australian population is thought to number at least 100 000 birds with the majority occurring in northern Australia (Birdlife International 2003), where heavy rains reduce access of humans whilst they are breeding (Simpson et al. 1999). Their range has contracted markedly since the first settlement (Marchant and Higgins 1990) and they are considered endangered in New South Wales and Victoria and vulnerable in South Australia (Stanger et al. 1998). Their global status is near threatened (del Hoyo et al. 1996; Garnett and Crowley 2000).

Heavy hunting for food and sport, up to at least 1940 when they were formally protected, greatly affected their distribution. Other factors in their decline include habitat destruction (including intensive agriculture and invasion of pastoral land by woody weeds), and the impact of introduced animals (particularly the fox) (Marchant and Higgins 1990; del Hoyo et al. 1996; Simpson et al. 1999; Birdlife International 2003). Traditional and illegal hunting is still considerable and pesticides have been responsible for local extinctions (Garnett and Crowley 2000). There may be some increase in abundance in response to clearing, but this effect dissipates as agriculture intensifies (Birdlife International 2003).

The Australian bustard is loosely gregarious with single birds or small groups of 2-6 in sight of others at favorable feeding and breeding sites. Non-breeding birds appear sparsely scattered in small groups of 2-10, and much more rarely in flocks of hundreds where food and water are abundant (Marchant and Higgins 1990). They are polygamous and lay 1-2 eggs (del Hoyo et al. 1996; Simpson et al. 1999) and are hatched with a covering of down and open eyes, capable of leaving the nest alone within a few days (Simpson et al. 1999). Only the female incubates and stay with the young (Marchant and Higgins 1990).

Nomadic omnivores, the Australian bustards eat myriapods, arachnids, insects, reptiles, young birds, small rodents, molluscs, shoots, roots, leaves, flower-heads, seeds and berries (Marchant and Higgins 1990; del Hoyo et al. 1996; Simpson et al. 1999), and thus although they may not consume cane toads directly, would likely still compete with them for food. Individuals feed during the day on the ground in open grasslands (Marchant and Higgins 1990).

Australian bustards are generally confined to areas where the upper canopy cover is less than 10% or under 2m high or near areas where grasses are dominant (National Parks and Wildlife Service NSW 1999). They are found mostly in grassland dominated by tussocky forms, also

in sparse low shrubland, savanna, grassy woodland, artificial landscapes such as pastoral land, crops and golf-courses (del Hoyo et al. 1996; Simpson et al. 1999; Garnett and Crowley 2000). The species is highly nomadic and moves in response to rainfall (National Parks and Wildlife Service NSW 1999).

(viii) *Aspidites melanocephalus* (black headed python)

Black headed pythons are found in the northern third of Australia except in the extremely arid regions (Mirtschin and Davis 1992; Barker and Barker 1994; Cogger 2000). Humans, cats dogs and foxes are the main threat to populations

Sexual maturity is obtained in 3 years for females and 18 month in males. Clutch size ranges from 3-18 eggs, (Mirtschin and Davis 1992; Barker and Barker 1994; Torr 2000; Geer 2003), with an average of 12 (G. Bedford, CDU, pers com).

The black headed python is primarily nocturnal and preys mainly on reptiles including a wide variety of lizards and snakes (including venomous species) and occasionally on small mammals and birds (Barker and Barker 1994; Torr 2000). Although there is no direct evidence of predation by black headed pythons upon frogs, they may opportunistically choose to ingest cane toads once they become numerically abundant in the black headed python's habitat. There may also be indirect effects of toads on the python if the presence of toads drives a change in the abundance of small mammals, their primary prey item.

They are most often found in woodlands, open forest and rocky areas but also inhabit grassland and shrubland and are reported from a wide range of other habitats. They spend a considerable time underground, using the burrows of mammals and goannas or occasionally excavating their own burrow (Barker and Barker 1994). Bedford's previous studies on the home range of four other python species measured homeranges between 0.3ha to 18ha. Based on his observations he estimates the black headed python to have a home range likely to be double that of the greatest measured for the other species (G. Bedford, CDU pers com)

(ix) *Acanthophis praelongus* (northern death adder)

The northern death adder is found in the subhumid to humid areas of the Kimberley Ranges, northern Northern Territory, northern Queensland and possibly in southern New Guinea (Storr et al. 1986; Mirtschin and Davis 1992).

Habitat destruction appears to be the most significant factor in the decline of death adders. However they have been observed to disappear from areas shortly after the introduction of the

cane toad (Grigg et al. 1985). The northern death adder has been identified in Phillips study as one of 49 snakes that are at risk from the invasion of the cane toad based on the overlap of their distribution with the toad and their dietary composition. It was shown that they have the ability to ingest a single toad large enough to be fatal (Phillips et al. 2003). This species has also been identified as one of the 10 species of high risk in the risk assessment of cane toads in Kakadu National Park (van Dam et al. 2002).

These snakes are live bearers (Cogger 2000). Litter sizes vary from 13-33 with an average of 23.1 (Webb, Shine and Christian, unpublished data)

Northern death adders are nocturnal ambush feeders that use caudal luring to attract prey (Webb et al. 2002). They eat amphibians, lizards, small mammals and birds (Mirtschin and Davis 1992; Cogger 2000).

They inhabit a range of habitats preferring grasslands, woodlands (wet and dry eucalypt forests), rocky ranges and outcrops (Mirtschin and Davis 1992). There is no information to date regarding the size of their home range.

(x) *Varanus panoptes* (northern sand goanna)

The northern sand goanna is found in the Kimberley and arid western regions of Western Australia and Northern Territory (Cogger 2000).

There is little information on the impact man has on this species. Generally the conservation status of all Australian varanids is sound. The extent of traditional use of the goanna for food varies; they comprise only a small part of the diet of residents of coastal regions but make up a larger proportion of the meat in the diet of desert dwellers. The presence of the cane toad poses a major threat to many northern Australian species of goanna (King and Green 1999). There is some anecdotal evidence that declines have occurred following the appearance of the toad (Burnett 1997; Phillips et al. 2003). Long term sampling of the northern sand goanna in Boorooloola prior to and after the invasion by cane toads showed population decline. Survivors of the initial decline are thought to “seed” a recovering population that doesn’t attack the toad (Freeland unpublished; van Dam et al. 2002). This species was ranked among the 10 highest risk species in the risk assessment of cane toads in Kakadu National park (van Dam et al. 2002).

The northern sand goanna has clutch sizes of 7-13 (Geer 2003). Clutches are buried deep in the soil, especially along the margins of creek beds (King and Green 1999).

This ground dwelling monitor feeds on a variety of prey, largely on insects and small terrestrial vertebrates (Cogger 2000). As they are found mainly in riparian habitats their diet consists of large amounts of aquatic prey (Shine 1986).

The northern sand goanna occurs in a variety of habitats including beaches, beach dune grasslands, grasslands, mangroves, woodland, monsoon forest, open forest and vine forest (Geer 2003). Home range sizes of 3ha have been recorded on the Adelaide river floodplain (T. Madsen, pers com).

(xi) *Varanus indicus* (mangrove monitor)

The Mangrove monitor is found in the rainforest and coastal mangrove habitats of eastern Cape York Peninsula and the islands of the Torres Strait, coastal mangrove forests of Arnhem Land, Northern Territory, New Guinea and other parts of the Indo-Papual Archipelago (Cogger 2000). Within this large distribution there is much variation in size, pattern and scalation (Bennett 1998).

On the Marshall Islands the marine toad proved toxic to the lizard (Bennett 1998), and a decline of the species on Kayangel Atoll was noted following the introduction of the cane toad (Burnett 1997). The mangrove monitor was ranked among the 10 highest risk species in the risk assessment of Kakadu National Park. Although it does not appear to occupy key cane toad habitats it often forages around the back swamps and paleochannels of the floodplain where it will probably be exposed to them (van Dam et al. 2002).

In varanids the clutch size is generally related to body size (King and Green 1999). The clutch size of the mangrove monitor is probably smaller than would be expected for a medium sized lizard. However, observation suggest that when food is abundant that they may reproduce frequently, producing a large number of small clutches of 1-6 eggs (Bennett 1998).

Diet of mangrove monitors consists predominantly of frogs, lizards, crabs, fish, insects and small mammals (King and Green 1999) and also includes birds and their eggs and the eggs and young of turtles and crocodiles (Bennett 1998). Mangrove monitors are always found close to water (Bennett 1998). They are restricted to coastal mangroves in northern Australia and rainforest and coastal mangrove on the eastern Cape York Peninsula and Torres Strait islands (Cogger 2000). Home ranges of this species have been estimated in the Northern Territory to be 0.9ha for females and 0.4ha for males (J. Smith, CDU, pers com}

(xii) *Chlamydosaurus kingii* (frilled neck lizard)

The frilled neck lizard is found in the Kimberley district, Western Australia through the top end of Northern Territory to the Cape York Peninsula, eastern Queensland and southern New Guinea (Cogger 2000).

Lizard numbers in southeastern Queensland have diminished as a result of land clearing, whilst predation by cats and death in fires have resulted in direct losses. There is some anecdotal evidence that decline in numbers has followed the introduction of the cane toad (Phillips et al. 2003).

This lizard has an early maturing and multiple brooded life history strategy. Double clutching has been recorded. However, not all females reproduce in each reproductive season or in consecutive years (Griffiths 1994). Reportings of clutch size varies considerably, ranging from 3 to 23 with a positive correlation between female SVL and clutch size (Bedford et al. 1993; Geer 2003). In captivity this species has lived for at least six years. However, given the large size of the species it is likely that it could live much longer (Greer 2003).

Frilled necks are sit and wait predators that eat insects such as lepidoptera larvae, termites and ants, and more rarely small vertebrates (Shine and Lambeck 1989; Greer 2003), though there is no record of them consuming frogs or tadpoles, and so they may be at low risk from cane toads except indirectly via competition for common food. Primarily arboreal frilled neck lizards and are found in savanna woodlands (Greer 2003) and dry sclerophyll forests (Cogger 2000; Savage 2001). Their home range size differs between sexes and during the wet and dry seasons. Adult male home range size during the dry is recorded as 1.96 ± 0.57 ha ($n=16$) and during the wet 2.53 ha, adult female home range size in the dry is recorded to be 0.634 ± 0.12 ha and during the wet 0.68 ha ($n=7$) (Griffiths 1994).

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