NATIONAL RECOVERY PLAN FOR THE

NORTHERN QUOLL

Dasyurus hallucatus

Photo – Craig Ward

Australian Government

Department of Environment and Conservation

Our environment, our future

Northern Territory Government

Queensland Government

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Note: This recovery plan sets out the actions necessary to stop the decline of, and support the recovery of, the listed threatened species or ecological community. The Australian Government is committed to acting in accordance with the plan and to implementing the plan as it applies to Commonwealth areas.

The plan has been developed with the involvement and cooperation of a broad range of stakeholders, but individual stakeholders have not necessarily committed to undertaking specific actions. The attainment of objectives and the provision of funds may be subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge.

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The Australian Government, in partnership with the Queensland Department of Environment and Resource Management, facilitates the publication of recovery plans to detail the actions needed for the conservation of threatened native wildlife.

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SUMMARY

At the time of European settlement, the northern quoll *Dasyurus hallucatus* was distributed widely across northern Australia (Parker 1973; Oakwood 2008a). It is now confined to a set of disjunct populations across the north of Australia. Quolls are carnivorous marsupials and are susceptible to cane toad toxins, fire and introduced predators; foxes and cats. Local populations of northern quolls typically collapse soon after an area is colonised by cane toads. Cane toads now occupy about 60% of the prior range of northern quolls, and are likely to occur across most of the rest of that range in the next 10-20 years. The spread of cane toads poses the greatest current threat to northern quoll populations on a national scale, but declines have also occurred in the absence of cane toads. The causes of declines in these areas are not clear but may be related to inappropriate fire regimes, clearing, habitat degradation through over-grazing, predation by feral and domestic animals and destruction by humans.

The northern quoll occurs in Queensland, the Northern Territory and Western Australia. This species is classified as Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, is listed as Critically Endangered under the Northern Territory's *Territory Parks and Wildlife Conservation Act 2000*, is on Schedule 1 – 'Fauna that is rare or is likely to become extinct' of Western Australia's *Wildlife Conservation Act*, and 'Least Concern' under Queensland's *Nature Conservation Act 1992*. It is also listed as Endangered on the 2009 IUCN Red List.

This recovery plan aims to minimise the rate of decline of the northern quoll in Australia, and ensure that viable populations remain in each of the major regions of distribution into the future. The recovery actions proposed here emphasise protecting key populations from colonization by cane toads and cats (especially through quarantine of offshore islands); fostering recovery of populations that have collapsed following cane toad arrival; managing secure populations (including captive and translocated); identifying and managing the threats to the northern quoll in the absence of cane toads; raising public awareness and native support of northern quoll in the absence of cane toads; raising public awareness and active support of northern quolls; and enhancement of cane toad management, including quarantine.

SPECIES INFORMATION

Taxonomy

The northern quoll *Dasyurus hallucatus* is a marsupial and a member of the Dasyuridae family. There are six species in the genus *Dasyurus*. Unfortunately the distribution and/or abundance of all four Australian species has declined since European settlement, with three of the four quoll species now listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The northern quoll occurs in the northern regions of Australia (more detailed information on its distribution below). The chuditch or western quoll *D. geoffroii* had the largest distribution of all quoll species with its range previously extending throughout central Australia to the Western Australian coast. It is now restricted to south-western Western Australia (Serena and Soderquist 1995). The western quoll is classified as 'Endangered' under the EPBC Act. The spot-tailed or tiger quoll *D. maculatus* has two recognised subspecies: *D. m. gracilis* occurs in northern Queensland and is listed as 'Endangered' under the EPBC Act; *D. m. maculatus* has a mainland population which occurs in southeastern Queensland, eastern New South Wales and Victoria, and a Tasmanian population. The spot-tailed quoll's distribution in Victoria has declined with only a few remnant populations remaining (Edgar and Belcher 1995) and the mainland population of the species is listed as 'Endangered' under the EPBC Act. The Tasmanian population of the spot-tailed quoll is classified as 'Vulnerable'. The eastern quoll *D. viverrinus* previously ranged over most of south-eastern Australia. It is now most likely extinct in the wild on the mainland, but is relatively common in Tasmania (Godsell 1995) and thus is not a species of conservation concern nationally. However, it is listed as 'Extinct' in Victoria and 'Endangered' in New South Wales.

The Zoological Catalogue of Australia (1988) lists three subspecies of northern quolls, *D. h. exilis* from the north-east Kimberley described by Thomas in 1909, *D. h. predator* from Cape York Peninsula in Queensland described by Thomas in 1926, and *D. h. nesaeus* from Groote Eylandt in the Northern Territory (Bannister et al. 1988). However, these subspecies are not commonly referred to in the literature, probably because they were based on geographic and morphological data (Firestone *pers. comm.* 2008), and an incomplete consideration of variation across the range of the species. Recent analyses show a marked genetic disjunction between the Queensland populations and those of the Northern Territory plus Western Australia. This disjunction is at near specific level (Firestone *pers. comm.* 2008). Similarly, How *et al* (2009) found the Western Australian populations differed to those from east Queensland and the Northern Territory and differentiation occurred even between the Western Australian populations in the Pilbara and Kimberley. Work on the genetic diversity of a translocated island population found some divergence from founder populations within three years (Cardoso et al. in press). In light of these results it is likely that recently isolated populations in the Northern Territory (due to cane toads) may also become more genetically distinct from each other. Considerable reduction in diversity in endemic island populations that are isolated from the mainland has also been recorded (e.g. Marchinbar Island and islands off the Kimberley coast: How et al. 2009).

The presence of potential subspecies or Evolutionarily Significant Units has important implications for the conservation management and recovery management for northern quolls. For instance, distinct population segments within the species that are genetically differentiated from each other (and thus have begun the process of diverging along different evolutionary lineages) ideally should be managed separately and should not be interbred. However,

managers have to be pragmatic and determine if it is important to have northern quolls functioning in the environment even if there is interbreeding among different units.

Distribution

The northern quoll previously occurred across most of the northern third of Australia, but its range has significantly declined over the past century (Braithwaite and Griffiths 1994), with declines particularly in lowland areas and/or the semi-arid inland fringes of its range (e.g. the south-west Kimberley (McKenzie 1981); Purnululu National Park in south-east Kimberley (Woinarski 1992)). The species previously extended into the northern parts of the Great Sandy Desert in Western Australia, but has not been seen in that area since 1931 (Burbidge and McKenzie 1983).

The current distribution is discontinuous across northern Australia, with core populations in rocky and/or high rainfall areas (Figure 1; see also DEWHA in prep.). In Queensland, some populations of northern quolls have persisted following colonisation by cane toads. These areas include, but are not restricted to, upland rocky areas (Cape Cleveland/Mt Elliott, Mareeba, Crediton, Eungella, Clarke Range) and several coastal sites (Cleveland, Cape Upstart, Cape Gloucester, Condor Range) in north and central Queensland (Threatened Species Scientific Committee 2005, Ball *pers. comm.* 2008). Northern quolls occur across the Top End of the Northern Territory, but populations are currently declining as cane toads spread. In Western Australia the northern quoll has been recorded from many areas in the Kimberley (Start et al. 2007), and several areas in the Pilbara, including the lower reaches of the Fortescue River (King 1989); Wittenoom Gorge (in the early 1990s); and banded ironstone ranges north-east of Marble Bar (WA Department of Environment and Conservation *unpublished data*). There are two records from the Little Sandy Desert; one old record and a more recent one (collected in the 1990s) that yielded a tissue sample used in genetic analysis by How et al. (2009).

Northern quolls also occur on a number of offshore islands in the Northern Territory (Vanderlin, Channel, Marchinbar, Inglis, Groote and North-east) and Western Australia (Adolphus, Augustus, Bigge, Boongaree, Capstan, Dolphin, Hidden, Koolan, Purrungku, Uwins and Wollaston: Burbidge and McKenzie 1978; Palmer (*pers. comm.* 2008). In 2003, northern quolls were translocated to Astell and Pobassoo Islands, part of the English Company archipelago in the Northern Territory.

The land tenure of these areas is diverse and includes National Parks, Indigenous Protected Areas, pastoral land, Aboriginal lands, private conservation reserves (e.g. the Australian Wildlife Conservancy properties of Mornington and Brooklyn), semi-urban fringes and Commonwealth areas including Kakadu National Park and military areas (Yampi Sound Military Reserve, Bradshaw Defence Area and Mount Bundy Military Training Area), unallocated Crown land and in C class reserves (recreation reserves) in Western Australia.

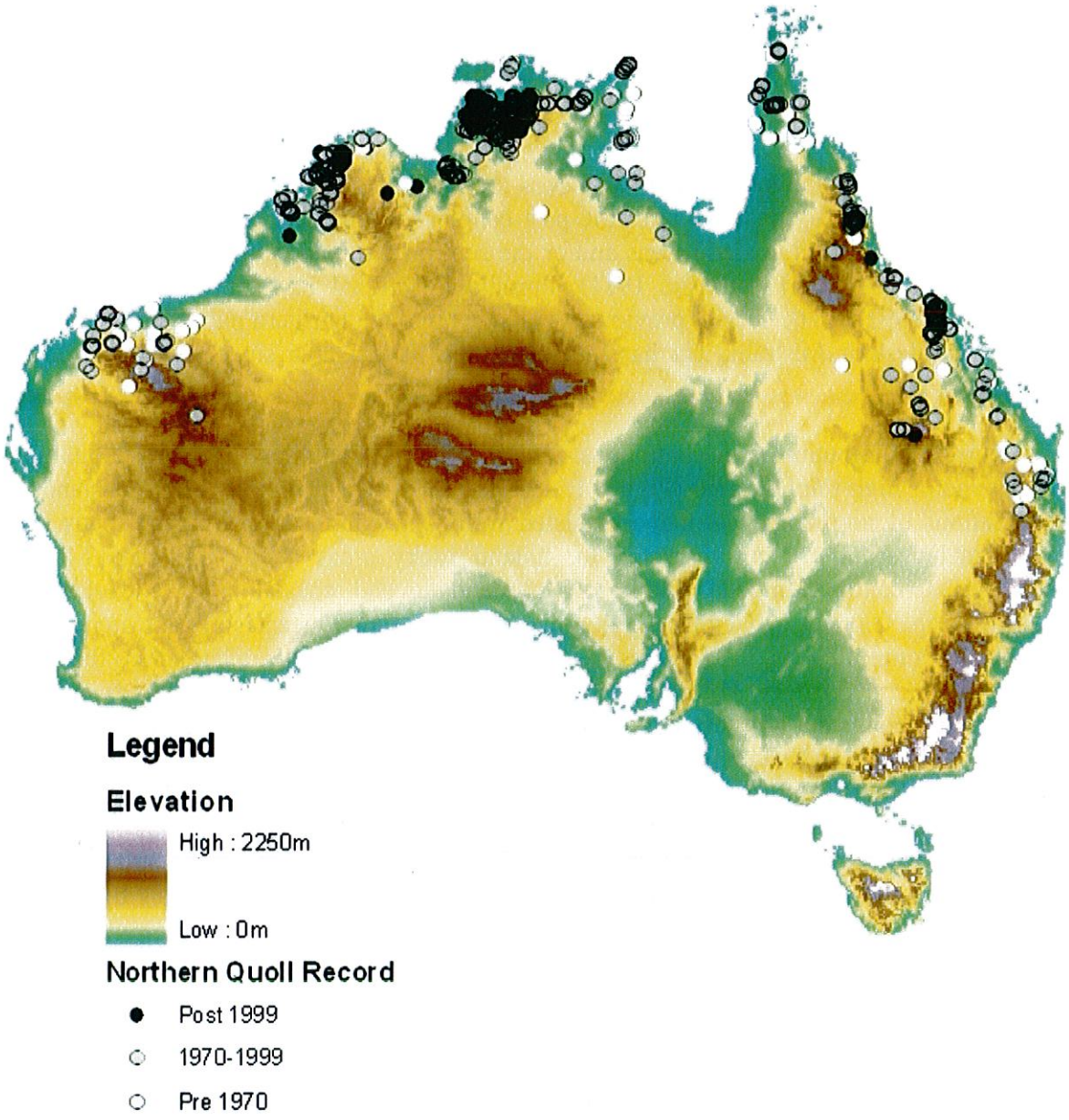

Figure 1: Capture records of northern quolls in Australia, before 1970, between 1970 and 1999 and after 1999. The records are plotted on a digital elevation model showing elevation above sea level

Habitat critical to survival

Northern quolls do not have highly specific habitat requirements. They occur in a variety of habitats across their range. They are opportunistic foragers that feed on a broad range of items switching dietary resources according to season and availability (Pollock 1999, Oakwood 2000, 2008a). Daytime den sites provide important shelter and protection for northern quolls from predators and weather. However, shelter sites are also non-specific; rocky outcrops, tree hollows, hollow logs, termite mounds, goanna burrows and human dwellings have all been recorded (Dixon and Huxley 1985, Braithwaite 1990, Oakwood 2002). Therefore habitat critical to survival is that where northern quolls are least exposed to threats or least likely to be

in the future. Given the threats outlined below, two particular broad habitat types fall into this category: rocky areas and offshore islands.

Rocky areas provide prime habitat for northern quolls (Begg 1981, Braithwaite and Griffiths 1994, DEWHA in prep.) and many other declining animal species (Freeland et al. 1988, Burbidge and McKenzie 1989). Recent modeling of island populations in the Northern Territory established that occurrence of northern quolls was related to ruggedness or topographic complexity (Woinarski et al. 2007). Analyses by Woinarski et al. (2008) show that northern quoll declines in Queensland have mainly been in lowland and flatter (less rugged) areas and a recent survey found the most abundant remnant populations on the Queensland coast were at sites with large boulders (Foster and Oakwood *pers. comm.* 2008). Rocky areas retain water and have a diversity of microhabitats, so support higher floristic diversity and productivity and thus greater prey density and/or diversity compared to non-rocky adjacent country (Burnett 1997). In addition, cats forage less effectively in rocky areas. Their topographic complexity may also serve to ameliorate fire impacts, and they are typically not used for livestock production. Whilst rocky habitats support denser populations of quolls, the diverse and dispersed nature of rocky areas makes them very difficult to define or map on a national scale.

Offshore islands provide habitat where many threats to northern quolls are absent, restricted or moderated. Most northern offshore islands have been exposed to relatively little development and livestock are restricted to only a very few islands. Cane toads and feral cats are known to be present on only a small proportion of islands and for the more isolated islands with little human traffic, are unlikely to arrive there unaided (Woinarski et al. 2007). The most obvious of these are offshore islands of the Northern Territory and Western Australia. Any islands with quoll populations are critical and some without quolls may provide suitable habitat free of cane toads and other threats for future translocation. These offshore islands include the English Company Islands, Groote Eylandt and associated archipelago, and the Wessel Islands in the Northern Territory, and Adolphus, Augustus, Bigge, Boongaree, Dolphin, Hidden, Koolan and Wollaston islands in Western Australia. Vanderlin Island, in the Sir Edward Pellew island group of the Northern Territory, has a much reduced remnant quoll population (most recent sighting by traditional owners in 2008; Ziembicki *pers. comm.* 2008) despite the fact that it, and other major islands in the group, was colonised by cane toads when the McArthur River flooded in 2001/02.

Population

The northern quoll distribution has contracted to a small number of geographic regions across northern Australia (see above), but not to the point of having only a few isolated populations that can be easily defined, although Braithwaite and Griffiths (1994) suggested that the species was now restricted to six isolated regions. There is no overall assessment of northern quoll population size available. Important populations referred to in this recovery plan are:

i) remnant populations of northern quolls that persist alongside threats. These include populations in Queensland that have persisted long after cane toad invasion.

ii) populations that may be exposed to threats in the future but have the potential to persist (based on habitat, etc.). These populations should be defined as part of the recovery process and need to be monitored and protected.

iii) populations on offshore islands in the Northern Territory and Western Australia that are unlikely to be naturally colonised by cane toads or cats.

iv) Populations in the Pilbara region of Western Australia, as these are outside the predicted range of cane toads.

THREATS

Cane toads are currently considered the main threat to northern quoll populations in parts of their range within Australia. However, northern quolls have also declined or disappeared from large areas in Western Australia where cane toads have not yet reached, and declined in less mesic parts of their Northern Territory range before the invasion of toads. In Queensland, some quoll populations have persisted following the invasion of cane toads. Cane toads do not appear to represent a major threat to these populations and individuals appear to either avoid eating can toads or have adapted mechanisms to cope with the toxin. There is some evidence that decline is associated with habitat degradation, although the mechanisms are not well defined. Inappropriate fire regimes are an issue for many threatened and declining animal species in northern Australia (Franklin 1999, Woinarski 1990, Oakwood 1997, 2000, Woinarski et al. 2004, 2005). The issues associated with this are complex and not well known at this stage. Habitat degradation caused by inappropriate grazing regimes is another potential cause of declines, but again, is not well understood (McKenzie et al. 2007). In the western, coastal and parts of eastern Pilbara the distribution of the northern quoll now overlaps with the introduced European red fox *Vulpes vulpes* (King and Smith 1985), and competition and direct predation may also be contributing to the decline of the northern quoll in this part of its range.

Cane Toads

The Draft Threat abatement plan for cane toads (DEWHA 2010) identifies a high negative population level threat to northern quolls from the cane toad and identifies responses to the threat focusing on northern quolls. The material in this recovery plan is consistent with the recommendations of the threat abatement plan for cane toads. Death by ingestion of cane toad toxin is considered the most immediate threat to northern quolls in the Northern Territory and Western Australia. The paratoid glands of cane toads produce toxins that are lethal to quolls and many other predators (Covacevich and Archer 1975, Burnett 1997, Catling et al. 1999, Phillips et al. 2003), and cane toads are poisonous at all stages of their life cycle. Quolls may be killed when ingesting toxin while attempting to eat toads, even when toads are only mouthed and not consumed (Oakwood 2004). Recent studies investigated whether 'conditioned taste aversion' could be used to modify quoll predatory behaviour and mitigate toad impacts (O'Donnell et al. 2010). This study compared the survival after reintroduction of two cohorts of northern quolls; one cohort treated with toad meat containing a nausea-inducing chemical and a control cohort fed uncontaminated toad meat. Treated quolls had higher apparent survival rates than untreated ones. The authors of that study conclude that broad-scale application of taste aversion baits ahead of the toad invasion front may mitigate the impacts of toads in that area. This avenue of enquiry may warrant further study, but no action has been included in the current recovery plan because the likelihood of such a treatment having an effect past the initial generation of quolls is small.

Cane toads were introduced into Queensland in 1935 and have been expanding in range ever since (Covacevich and Archer 1975, Sutherst et al. 1995). Declines and local extinctions of northern quoll populations co-incident with cane toad colonisation have been documented in Cape York Peninsula (Burnett 1997) and Kakadu National Park (Watson and Woinarski 2003a, 2003b, Oakwood 2004, 2008b).

Cane toads now occur throughout all of the quoll's distribution in Queensland and are spreading westwards across the north of the Northern Territory (Sutherst et al. 1995). Recent records show the colonisation front is now west of the Victoria River and has extended north to Darwin and Cobourg Peninsula. All of Arnhem Land is now colonised. There are programs

currently in place to reduce movement into Western Australia, but they are having no measurable impact on the westward movement of cane toads (Peacock 2007).

Northern quoll populations have survived in some areas alongside toads in northern and central Queensland (Braithwaite and Griffiths 1994, Burnett 1997, Woinarski et al. 2008; Figure 1). These populations typically occur in small, high altitude areas associated with rocky habitats and in some coastal areas of central to northern Queensland. Recent analyses indicate that northern quoll declines in Queensland have mainly been in lowland and flatter (less rugged) areas (Woinarski et al. 2008). The extent and density of the remaining populations are not well known, but some of these quoll populations are at a high density (Foster and Oakwood *pers comm.* 2008). Although northern quolls have survived in these localised areas they do not appear to be recolonising areas of their former distribution (Burnett 1997). However, there is some evidence that sightings west of Proserpine have increased in the past few years (Foster and Oakwood *pers. comm.* 2008).

Cane toads remain a threat to most northern quoll populations within the Northern Territory. Based on their current rate of spread, cane toads are predicted to reach all remaining areas of the range of the northern quoll on the Australian mainland within the next 10-20 years (Sutherst et al. 1995), perhaps with the exception of the Pilbara and western parts of the Kimberley Region. Cane toads can tolerate high levels of salinity and may colonise some islands that currently support northern quolls, particularly those that are closest to shore, and those in the course of floodwaters from river mouths or with favourable tides. However, the biggest threat to island populations of northern quolls is likely to be cane toads carried on freight. Intense interest in establishing petroleum and gas processing facilities on offshore islands in the Pilbara and Kimberley may further increase the risk of cane toads invading islands that would otherwise be considered safe from natural colonisation by toads.

Feral Predators

Feral predators may have impacts on quoll populations through competition for food or direct predation, and these impacts may be exacerbated after fire (Oakwood 2004). The National Recovery Plan for the western quoll lists both predation and competition from feral cats and foxes as threats contributing to the decline of that species (Orell and Morris 1994) and the National Threat Abatement Plan for Cats lists competition as a factor impacting on spot-tailed quoll populations (Biodiversity Group Environment Australia 1999). Being the smallest quoll species in Australia, northern quolls are probably most vulnerable to direct predation by these feral predators, but competition for prey may also be an important factor. Over much of Australia, rabbits form a large proportion of the diets of these feral predators and rabbit populations sustain higher population densities of feral predators (Williams et al. 1995; Newsome et al. 1996). However, rabbits are absent from much of the north of Australia (Williams et al. 1995). In the north, fox populations are generally absent and cat population densities may be lower, but reliant on native animals as prey. The range of foxes only overlaps that of northern quolls probably in the Pilbara and in central and south-eastern Queensland. The impact of these feral predators on northern quoll populations has not been assessed, but attempts should be made to protect quolls from these species. Current techniques for controlling feral cats and foxes have proven to be ineffective in eradicating these predators over most of their range, but local control is possible. Eradication of feral cats has been achieved on a number of islands in Australia (Copley 1991; Burbidge 1989), New Zealand (Veitch 1985, 2001, Burbidge 1989) and elsewhere (e.g. Rodríguez et al. 2006). Eradication from islands is expensive, so prevention of colonisation is the preferable alternative.

Inappropriate fire regimes

Inappropriate fire regimes have been implicated in the declines of many animal species in northern Australia (Woinarski 1990, Franklin 1999, Woinarski et al. 2001, 2004, McKenzie et al. 2007). The exact mechanisms for these declines are not fully understood. The detrimental impact of fire on quolls is likely to be through consequential changes in habitat structure and floristics (McKenzie et al. 2007). Too-frequent burning may reduce the abundance of food if there is insufficient time to allow prey species, predominantly invertebrates, to complete their life cycles. However, a radio-tracking study at Kapalga found no decline in body weight or condition after fire. The opportunistic nature of the northern quoll diet makes them less vulnerable to starvation, and their vertebrate prey are probably more exposed and easier to catch after fire (Oakwood 2000).

One study in a rocky area at Kakadu found that fire affected reproductive characteristics of quolls rather than causing direct mortality. Breeding was delayed by one month, and the mean number of young leaving the pouch per female was lower after fire (Begg 1981). This study was carried out for 13 months post-fire and population size was maintained at pre-fire levels. A longer study (3 years) at Kapalga in Kakadu found no evidence that the timing of breeding or the number of young leaving the pouch was affected by fire (Oakwood 2000). However, during this study a number of adult females died post-fire, resulting in the subsequent mortality of their dependent young in-the-den. Floristic and structural changes to habitat would occur over a longer time scale and therefore the long term effect of fire on quolls would not be detected by these studies. Woinarski et al. (2004) found that northern quolls were more abundant in sites burnt annually, compared with sites that had not been burnt for 23 years, on a property in outer Darwin. The season, frequency, extent and severity of fires are all likely to be key factors influencing quoll populations. Woinarski et al. (2004) also noted that the sites burnt annually were in unusually good condition compared with similar open forest elsewhere in this region and may represent an ideal early dry season burning regime.

The greatest threat posed by fire may be increased predation of quolls after removal of cover. When fire has removed the ground cover, quolls are more vulnerable to predators such as dingos, cats and raptors (Oakwood 2004). This may particularly be the case in habitats without rocky outcrops where quolls rely on tree hollows or hollow logs for daytime shelter, as frequent fires are likely to reduce the availability of hollow logs.

Habitat degradation

Woodland and forest habitats are susceptible to degradation by trampling and grazing by large herbivores, including feral pest species and cattle. Grazing may alter habitat by reducing ground layer cover and in some cases increasing shrub cover by promoting vegetation thickening and weed invasion. Loss of cover may increase the vulnerability of quolls to predation but also increases exposure of vertebrate prey for quolls. Burnett (1997) considered that remnant northern quoll populations in Queensland were in areas where cattle stocking rates were lower than average. However, recent work has found northern quolls at two sites under heavy grazing (Foster and Oakwood *pers. comm.* 2008). Management of fire in grazed areas will differ from that under other land uses. Loss of ground cover by grazing reduces fuel loads for burning and fire reduction may improve the persistence of refuge sites such as hollow logs, reducing the quoll's vulnerability to predation.

Northern quoll populations declined in the Northern Territory prior to arrival of cane toads (Oakwood 1997, Woinarski et al. 2001) and in Western Australia the population in the Pilbara region and populations in southern areas of the Kimberley region have declined in numbers and distribution in the absence of cane toads. In the Pilbara, the distribution of quolls is

fragmented and the species is mostly confined to ironstone formations and some river systems and the Burrup Peninsula and adjacent offshore islands. Northern quoll populations in these areas have been declining at least since the 1980s, during a time when altered fire regimes plus habitat degradation through over-grazing have occurred, although a causal link has not been established (McKenzie et al. 2007). Modeling habitat preferences of northern quolls in a region on the outskirts of Darwin exposed to various degrees of fragmentation and habitat loss, showed a strong negative response to fragmentation. No quolls were recorded from fragments with less than 65% woodland within a 4 km radius of the trapping site. Further modeling predicted that northern quolls would disappear from landscapes with less than approx 70% woodland within a 4 km radius (Rankmore and Price 2004).

Habitat Destruction

Development for mining, housing, agriculture, etc., in areas of native vegetation within the distribution of the northern quoll is likely to result in clearing and loss of quoll habitat, particularly in rocky areas. This will be at a smaller scale than the habitat degradation described above, but may still have a significant impact on critical habitat for the species. In recognition of this, the Australian Government drafted a set of policy guidelines for the assessment and mitigation of impacts of development on the northern quoll (DEWHA in prep.). That document provides advice, survey guidelines and mitigation measures for proponents of projects that will potentially have a significant impact on the northern quoll.

Weeds

Exotic pasture grasses, notably such as gamba grass *Andropogon gayanus* and mission grasses *Pennisetum* spp., may disadvantage quolls because (1) their unusually high density, biomass and rigidity may inhibit ground movements and hunting by quolls, and (2) they may foster fire regimes that are more intense which are more likely to cause direct mortality, reduce availability of shelter and reduce habitat heterogeneity.

Disease

The increased degree of isolation of northern quoll populations increases the potential for disease to have a locally detrimental effect. Elsewhere in Australia, there is widespread, but largely anecdotal evidence of episodes of sudden population crashes of quolls (and other larger dasyurids), most probably being caused by disease. There is no direct evidence of such disease affecting northern quolls, but Finlayson (1934) noted population crashes of dasyurid species in central Queensland that may have been attributable to disease. A similar drastic population crash was reported for eastern quolls in Victoria during the early 1900s, and has been attributed to an unknown epidemic that swept through populations of several marsupial species at the time (Jones 1923, Le Souef 1923, Fleay 1932).

In a more recent and systematic review, Abbott (2006) compiled historic records of observations of diseased native mammals and proposed that an exotic epizootic disease triggered faunal collapse sequentially across Western Australia, particularly from the 1880s to 1920s. He considered quolls showed only weak partial immunity to this disease, and suggested that the disease spread to the Kimberley region in about 1910. It is plausible that subsequent episodes of this or other diseases may have continued to diminish populations of quolls and other native mammals across northern Australia.

Note that a recent study involving histological examination from 28 northern quolls around Kakadu (Oakwood and Pritchard 1999) found no evidence of toxoplasmosis, a disease associated with exotic parasites (for which cats are the primary hosts) and known to cause mortality in infected marsupials elsewhere. Similarly, Oakwood and Spratt (2000) investigated parasite loads and concluded it was unlikely that parasitism is a major factor in the decline of northern quolls in Kakadu. There have been no other substantial studies that have considered disease status in northern quolls.

Hunting

All quoll species have suffered some destruction from humans, although this is probably now far less than previously. Like other medium-sized mammals, northern quolls were previously hunted for food by Aboriginal people (Dixon and Huxley 1985, Bradley et al. 2006). While such hunting pressure may have been pervasive across the quoll's range, it was probably sustainable for all open quoll populations. However, it is possible that hunting may have compromised some closed quoll populations, such as on smaller islands. For Australian islands, especially those in northern Australia, Abbott (1980) demonstrated that Aboriginal occupation was the most plausible explanatory factor for macropod extinctions or reduced diversity. However, it is far less likely to have driven local extinctions of quolls, given that these were probably a less favoured food source, were more likely to evade capture, and they probably had higher population densities and carrying capacities than macropods.

European settlers killed quolls. In some regions of Australia, a bounty was paid for their scalps (e.g. Victoria; Menkhorst 1995). Low level targeted destruction probably continued until recent decades across much of the northern quoll's range where this overlapped with human habitation.

Perhaps more pervasively, northern quolls probably suffered some population reductions due to broad-scale poisoning targeting dingoes on pastoral and other agricultural lands. As an example of the extent of these poisoning programs, Kerr (1967) reported that in one year alone (1964), 1 300 000 baits, typically strychnine-laced, were dropped from light aircraft over a route of 15 000 miles in the north of Western Australia. Such broad-spectrum poisons were widely available and used (often with little or no regulation) across much of the pastoral lands and over many decades. These may have caused at least some fatalities for northern quolls, and may have contributed to the decline and local extinction, especially in the pastoral portions of its range. More recently, baiting programs have become more regulated and paid more attention to the consequences for non-targeted wildlife. The poison 1080 is still widely used: while some field studies have reported that 1080 baiting causes some fatalities in other quoll species, and laboratory studies suggest that northern quolls may be susceptible (Calver et al. 1989), the only field study assessing its impact on northern quolls found no direct mortality (King 1989).

Population Isolation

The semelparous (reproducing only once in a lifetime) nature of the life history of some northern quoll populations may render them particularly susceptible to local extinction when those populations become isolated. Northern quolls breed only once per year (Oakwood 2000). In populations in Kakadu National Park studied by Oakwood, males died after the mating season, reducing the populations to adult females and young (Oakwood 2000). Therefore the availability of males for the following breeding season relies on the survival of those offspring. Mortality of females post-breeding is also high, often with less than 30% surviving to

reproduce in their second year (Dickman and Braithwaite 1992, Oakwood 2000). Only in exceptional circumstances, such as in the boom phase of introduced populations on Astell and Pobassoo Islands in the Northern Territory (Rankmore et al. 2008), has a third breeding season been recorded in a quoll population. On these islands some males survive well into their second year (Rankmore et al. 2008). Local extinctions of quoll populations may occur in a given year if disturbance causes complete juvenile mortality. Dispersal from adjacent populations may re-establish that population, although this is unlikely where populations are highly isolated (Braithwaite and Griffiths 1994, Males and Hirst 2000, Oakwood 2000).

RECOVERY INFORMATION

This plan addresses the recovery actions for the northern quoll on a national scale. As cane toads have been identified as a major threat to northern quoll populations throughout much of their range, recovery actions in this plan focus on mitigating this threat. Recovery actions listed below address regions where cane toads are currently invading (western Northern Territory and eastern Kimberley), where cane toads have not yet invaded (predominantly Western Australia) and where northern quolls have been sympatric with cane toads for some time (Queensland). Priorities for quoll recovery will differ between states and regions and actions are not presented here in order of priority. However, each action has been allocated as a high, medium or low priority for the national recovery of the northern quoll. A summary of the relationship between objectives, performance criteria and actions is presented in Table 1.

Actions described here may be best read in conjunction with, and be complementary to, current threat abatement actions. These actions assume that there is little likelihood of toad elimination occurring over the course of this plan, so this plan describes actions that may minimise their impacts rather than eliminating the source of the problem.

Overall Objective

This recovery plan aims to minimise the rate of decline of the northern quoll in Australia, and ensure that viable populations remain in each of the major regions of distribution into the future.

Specific objective 1: Protect northern quoll populations on offshore islands from invasion and establishment of cane toads, cats and other potential invasive species

Action 1.1 Maintain biosecurity of important offshore islands through quarantine measures on the mainland and those islands

Performance criterion: All islands with northern quolls that are free of cane toads or other invasive species remain that way

Justification: Islands are and will remain important refuges for quolls from cane toads and other invasive species. Whilst cane toads have reached some islands 'naturally' by riding floodwaters from tropical rivers, such as the Sir Edward Pellew Islands off the mouth of the McArthur River (Taylor and Edwards 2004), the most likely way that cane toads might arrive on other islands is by inadvertent transport by humans. This may be on goods and equipment (especially construction or road-building plant) barged out to islands, or in camping, fishing or personal gear carried by small boats launched from boat ramps or beaches. The likelihood of larger vertebrates, such as cats, getting to these islands by accident is lower than for cane toads but vigilance for these species should also be conducted.

Methods: Support and bolster quarantine initiatives already in place and initiate where they currently do not exist.
These include:

i) provision of wash-down and inspection facilities at mainland centres of coastal shipping companies;
ii) construction of toad-proof storage at barge loading facilities;
iii) education and awareness for shipping company staff;
iv) development and implementation of a communication strategy for shipping companies to inform clients;
v) signage at boat ramps alerting users to the possibility they might be transporting cane toads and urging them to "check their load" (nb. further public education initiatives are covered in Objective 6);
vi) establishment and operation of toad traps or attracting devices within facilities operated by coastal shipping, mining, construction and petroleum and gas exploration companies that ship to offshore islands;
vii) development and implementation of a biosecurity program targeted to charter boat and recreational yachting and boating interests and others that may not operate from major ports;
viii) development and implementation of a biosecurity program targeted to island based industries and ventures.

Potential contributors: NT NRETAS, WA DEC, DoIR, ALC, NLC, KLC, YMBBMAC, coastal shipping companies, coastal charter boat operations, mining, exploration and construction ventures, commercial pearl farm ventures, recreational boating and yachting groups

Priority: High

Action 1.2 Monitor offshore islands supporting quoll populations to detect the presence of cane toads, cats and any other potential invasive predator

Performance criterion: All islands with northern quolls that are free of cane toads or other invasive species remain that way

Justification: No control efforts to prevent spread of invasive species from the mainland (or other islands) are likely to be 100% efficient. However, invasive species may be eradicated from islands if detected early enough.

Methods: Provide Indigenous rangers and other groups with the knowledge, skills, equipment and financial resources to monitor the presence of cane toads and other invasive species on their islands. This will include the implementation and maintenance of trapping regimes, and regular night-time patrols of likely entry points (ports, boat ramps, shipping offices, etc). Surveillance will be most effective if those undertaking the monitoring are trained at appropriate identification of toad calls and can reliably identify toads from native frogs. There must be a program of visits to important but less-visited islands early in the wet season, to listen for cane toads at night, and early in the dry season, to search and trap for cane toads that may have arrived on floodwaters. Some of these actions are currently in place and should be continued.

Potential contributors: NT NRETAS, WA DEC, DoIR, ALC, NLC, KLC, YMBBMAC, coastal shipping companies, mining, exploration and construction ventures, commercial pearl farm ventures

Priority: Medium

Action 1.3 Develop and, where required, implement a strategy for rapid-response control of cane toad or cat outbreaks on offshore islands occupied by northern quolls

Performance criteria: Strategy is developed and funding resources available. All islands with northern quolls that are free of cane toads or other invasive species remain that way

Justification: A rapid-response strategy for control of cane toads needs to be developed which can be implemented in the event of cane toads reaching an offshore island inhabited by quolls. Since the location of an outbreak of cane toads or cats is difficult to predict, providing training and equipment to all potential islands is probably not feasible. A stockpile of equipment and trained personnel in Darwin and Broome or Kununurra is likely to be a better alternative.

The current threat abatement plan for predation by feral cats (DEWHA 2008) highlights the development and implementation of a contingency plan containing and exterminating cat incursions onto offshore islands (Action 1.3). Although northern quolls are not highlighted under the draft plan as a species that may be adversely affected by cats, evidence from Oakwood (2004) shows that cats do prey on quolls and this may be especially important when land management practices are affecting their habitat (i.e. inappropriate fire regimes; see section on threats above).

Methods: Assess options for controlling cane toads under the different possible scenarios of island types and cane toad numbers present. Draft procedures for control of cane toads under the different scenarios. Estimate costs associated with purchase and storage of appropriate equipment and materials and training of staff in their use. Ensure that control procedures target the toad at each stage of its life cycle, not just the adult stage. For cats, follow the draft threat abatement plan for predation by feral cats. Identify sources of funding that can be accessed at short-notice for control of invasive species on islands.

Potential contributors: DSEWPC, NT NRETAS, WA DEC, DoIR, ALC, NLC, KLC, YMBBMAC, coastal shipping companies, mining, exploration and construction ventures, commercial pearl farm ventures

Priority: High

Specific objective 2: Foster the recovery of northern quoll sub-populations in areas where the species has survived alongside cane toads

Action 2.1 Determine which factors affect survival and recovery of northern quolls in areas with cane toads

Performance criterion: Increased understanding of the ecology of populations of northern quolls in Queensland and the Northern Territory that co-occur with cane toads

Justification: Small pockets of northern quolls have survived in Queensland for many generations in sympatry with cane toads, and quolls have persisted (to date for a shorter time-period), albeit in reduced numbers, in some areas of the Northern Territory that have been colonised by cane toads (e.g. Vanderlin Island in the Sir Edward Pellew Group of islands). Identification of the factors that have allowed these populations to persist will help to manage these populations (Action 2.2) and populations in areas yet to be colonised by cane toads (Action 2.3). A recent study by Woinarski et al. (2008) reports that northern quoll declines in Queensland have mainly been in lowland and flatter (less rugged) areas, but our knowledge of the health of the remaining populations is limited.

Methods: Instigate or continue ecological studies and monitoring of northern quoll populations living alongside cane toads. These studies should consider quoll and toad densities in these areas, microhabitat-use and preferences of both species, and barriers to quoll reproduction and colonisation of adjacent areas, including consideration of fire history and land use.

Potential contributors: DSEWPC, PA, Qld DERM, NT DNRETAS, NLC, ALC, AWC, QLD land councils (where relevant), universities

Priority: High

Action 2.2 Use information from Action 2.1 to assist surviving populations to recover in sympatry with cane toads

Performance criterion: Increases in quoll density and distribution in areas already occupied by cane toads

Justification: Localised pockets of northern quolls have persisted alongside cane toads in Queensland for many generations, and a similar pattern probably now exists on mainland Northern Territory. However, such small populations are more prone to chance events and localised extinction. Expansion of the size and number of extant populations will reduce the probability of regional extinction. Prevention of fragmentation and further genetic isolation of these populations is essential.

Methods: Dependent on the findings of Action 2.1, but may include localised cane toad control, dual predator control and/or habitat manipulation and removal of other threatening processes such as heavy grazing or inappropriate fire regimes.

Potential contributors: DSEWPC, PA, NT DNRETAS, Qld DERM, NLC, Qld NRM bodies & Qld land councils (where relevant)

Priority: Medium

Action 2.3 Identify potential refuge habitats in Western Australia and the Northern Territory where quolls might be most likely to persist in the long-term alongside cane toads

Performance criterion: Characterisation of habitat types with the potential to act as refuges for quolls in Western Australia and the Northern Territory once cane toads have colonised

Justification: Northern quoll populations are likely to continue to decline as toads colonise new areas. Experience from Queensland, and now some areas of the Northern Territory, shows that local quoll populations may become locally extinct in some areas, but in other areas quolls can persist in lower numbers. In those areas yet to be colonised by cane toads, conservation efforts are best concentrated in these potential refuge habitats (Action 3.3), in the expectation that these will provide natural source populations for future expansion of quoll populations (natural or management-assisted). Prevention of fragmentation and further genetic isolation of these populations is essential.

Methods: Using the findings of Action 2.1, collaborate across the three jurisdictions and use habitat suitability criteria to identify likely refuges in areas recently or not yet colonised by cane toads in WA and NT.

Potential contributors: NT DNRETAS, WA DEC, NLC, ALC, KLC, YMBBMAC, AWC

Priority: High

Specific objective 3: Halt northern quoll declines in areas not yet colonised by cane toads

Action 3.1 Collect baseline data on population densities and monitor trends of quolls at a series of key sites not currently occupied by cane toads

Performance criterion: Estimates of current population sizes and trends from 5 key sites in Western Australia

Justification: Quoll populations have declined in parts of Western Australia, especially in the Pilbara region, and were declining in parts of the Northern Territory (as were those of many other small mammals) prior to the arrival of cane toads. However, there are insufficient data on the scale of the declines or their causes. High-rainfall coastal sites in the northern Kimberley region of Western Australia have northern quoll populations in which declines have not been apparent (Start et al. 2007).

Methods: Use repeatable survey methods, such as trapping, hair-tubing, etc., to collect data to estimate population densities of quolls (or sufficient to detect population trends in the future) at 5 sites in Western Australia (Pilbara, coastal Kimberley, inland Kimberley). Tissue samples should be collected from any quolls captured for use in studies of the genetic factors influencing susceptibility to cane toad toxins (Action 2.4) and exposure to disease. Some of this work is being undertaken in the central Kimberley bioregions. However, there is a need to secure long term funding and technical advice on data collection and analysis.

Potential contributors: WA DEC, Rangelands NRM, KLC, YMBBMAC, AWC

Priority: High

Action 3.2 Investigate factors causing declines in northern quoll populations not yet affected by cane toads

Performance criterion: Development of evidence-based models for declines in northern quoll populations not yet affected by cane toads

Justification: The reasons for these declines are not currently well known, but inappropriate fire regimes, weed invasion and other forms of habitat degradation have been implicated. Oakwood (1997) investigated some of these factors in Kakadu NP. Continuing this work at a statistically rigorous number of sites is required.

Methods: At the sites set up in Action 3.1, collect information on habitat structure and complexity, floral diversity, fire frequency and severity, habitat degradation, etc. Use this information to assess which factors are likely to be contributing to quoll declines. Where possible, test management strategies (fire regimes, weed control, feral animal control) that may mitigate those factors. This work should be integrated across jurisdictions.

Potential contributors: WA DEC, Rangelands NRM, KLC, YMBBMAC, AWC

Priority: High

Action 3.3 Manage key quoll populations in areas not currently affected by cane toads to halt population declines

Performance criterion: Declines halted at a number of key sites in Western Australia and the Northern Territory, defined by action 3.2

Justification: Actions 3.1 and 3.2 will provide data on the scale of declines and factors causing them. Action 2.3 will also indicate areas of potential refuge habitat types where quoll populations may persist after colonisation by cane toads. Combining this information will indicate key quoll populations that can be managed with an expectation that they will persist, albeit in reduced numbers, if or when cane toads colonise those areas. These populations may also provide natural source populations for future expansion of quoll populations (natural or management-assisted). Prevention of fragmentation and further genetic isolation of these populations is essential.

Methods: Dependent on the findings of Actions 3.1 and 3.2 and the areas identified in Action 2.3, but may include altering fire regimes, grazing regimes, feral predator control, etc. Once cane toads colonise areas, localised control of their numbers may also be required.

Potential contributors: NT DNRETAS, WA DEC, NLC, ALC, KLC, YMBBMAC, AWC

Priority: Medium

Action 3.4 Identify the effect of pastoral land management practices on northern quoll persistence

Performance criterion: Recommendations to reduce the impact of pastoral land management practices on northern quoll populations produced

Justification: Pastoral management practices considerably alter habitat for northern quolls and other species through grazing, cropping, land clearance, weed control and changes in fire

regime. Other management practices such as poisoning of pest species with 1080 may also have a negative impact on northern quolls if they eat bait and are susceptible to the poison.

Methods: Identify land management practices on properties where northern quolls do and do not occur. Model quoll occurrence and land management practices and look for relationships with management practices that may require further testing or controlled experimentation. If feasible, conduct controlled experimentation *in situ* testing the effect of management practices on quolls and use the outcome to make recommendations to managers. This action is linked to Actions 2.1, 2.2, 2.3, 3.1, 3.2 and 3.3 where quoll populations associated with these actions occur on pastoral lands. Some more specific and direct management actions such as 1080 poisoning may require more detailed observations such as testing bait-uptake by northern quolls and/or direct monitoring of quoll populations (or individuals) before and after baiting (including post-mortem to determine cause of death).

Potential Contributors: DSEWPC, Qld DERM, NPWS, NT NRETAS, WA DEC, land managers

Priority: High

Action 3.5 Interim fire management at potential key quoll populations

Performance criteria: Managed burning regimes with less extensive fires and longer intervals between fires at sites with high population densities of quolls

Justification: It will take 2-3 years to get statistically rigorous results from Actions 3.1 and 3.2 and act on them in Action 3.3. However, late dry season fires have already been identified as a threat to northern quoll populations and as an interim measure fire management should be instigated at a number of sites that currently carry high densities of quolls (and may be expected to be identified as key sites in Action 3.1. There are good precedents set (in central Arnhem Land) for Indigenous fire management and many Traditional Owners have the willingness and skills to manage fire on their lands. Such measures also build the capacity and raise the awareness of threats to quolls in anticipation of the delivery of Action 3.3.

Methods: There is now good evidence of an inverse relationship between extent of early dry season fire and extent of late dry season fire, indicating that fuel reduction and buffer burning fire management practices early in the dry season should be beneficial. This could be delivered in a fee-for-environmental services framework. Satellite imagery of fire scars should be used to monitor effectiveness and area covered. This action should be run until Action 3.3 starts.

Potential contributors: Qld DERM, NT DNRETAS, WA DEC, PA, NLC, ALC, KLC, YMBBMAC, AWC.

Priority: Medium

Action 3.6 Refine models of the current and expected distribution of cane toads and northern quolls, incorporating predictions of climate change

Performance criterion: Annually updated maps of the current and predicted distribution of northern quolls and cane toads

Justification: Our knowledge of both the biology of cane toads and of possible changes in climate is currently changing rapidly, yet both these factors have a major impact on our predictions of the distribution of cane toads and therefore their expected impact on northern quolls.

Methods: Use the latest information available on predicted climates across northern Australia, cane toad biology and rates of spread in models to produce maps of the current distribution of toads, their likely spread over 12 and 24 months, and the total possible distribution, overlaid on the current distribution of northern quolls.

Potential contributors: DSEWPC, NT DNRETAS, WA DEC, research institutions, CSIRO, Qld DERM

Priority: Low

Specific objective 4: Halt declines in areas recently colonised by cane toads

Action 4.1 Continue research into the susceptibility of quolls to cane toad poisoning

Performance criterion: Increase understanding of the susceptibility of quolls to cane toad poisoning

Justification: Cane toad toxins are lethal to quolls if sufficient toxin is ingested, however some northern quolls have survived in the presence of cane toads in Queensland for many years. It is not known whether northern quolls have undergone drastic selection or developed resistance to cane toad toxin (action 2.3) or aversion behaviours which may render them less susceptible to poisoning.

Methods: Controlled experiments observing survival of northern quolls in sympatry with cane toads.

Potential contributors: NT DNRETAS, WA DEC, CSIRO, TWP, research institutions.

Priority: Low

Action 4.2 Test the efficacy of control measures for cane toads and whether they allow local persistence of quoll populations

Performance criterion: Increased understanding of the efficacy of cane toad control and its impact on local quoll populations

Justification: Controlling the westward spread of cane toads is likely to be difficult, but it may be possible to slow down the spread of cane toads and reduce cane toad populations in a localised area using trapping, or other techniques. If these localised areas are large enough, cane toad control may be a useful management option for important or key quoll populations (see Actions 2.2, 3.3).

Methods: Controlled experiments monitoring the persistence of quoll populations in areas with cane toad control and similar areas without cane toad control. Cane toad control may be through trapping, exclosure fencing, hand collection, etc.

Potential contributors: NT DNRETAS, WA DEC, Frogwatch and similar community organisations, research institutions.

Priority: Low

Specific objective 5: Maintain secure populations and source animals for future reintroductions/introductions, if they become appropriate

Action 5.1 Manage translocated populations of northern quolls on Astell and Pobassoo Islands

Performance criterion: Maintenance of viable habitat and breeding populations of quolls on these islands

Justification: Northern quolls were translocated to these islands in 2003 and have established large breeding populations. These islands are Aboriginal Land and the Gumurr Marthakal Rangers and traditional owners have played a key role in translocating and monitoring the populations. It is possible that these have now reached or over-shot the carrying capacities of the islands, and the populations need to be monitored and managed to ensure long-term survival of the species and island ecosystems (Rankmore et al. 2008).

Methods: Annual trapping trips to determine population size, health, survivorship and reproductive rates of the northern quoll. Monitoring of the islands' native species to determine the impact the northern quoll is having on the health of the ecosystem. Ongoing work needs to be carried out with the support of traditional owners and the engagement of the ranger group. This requires adequate resourcing of the ranger group.

Potential contributors: DSEWPC, NT DNRETAS, NLC

Priority: Medium

Action 5.2 NT and WA to maintain captive breeding population(s) of northern quolls

Performance criterion: Maintenance of one or two captive populations of northern quolls with >50 individuals and appropriate genetic diversity

Justification: Captive populations provide sources of recruits bred in a secure environment for future translocations, should they become necessary (see Action 5.4). They also provide the opportunity to breed animals sourced from populations sympatric with toads that may supply founders for re-introduction or translocation which can survive in the presence of cane toads.

Captive colonies must be of sufficient size and be managed appropriately to ensure they contain sufficient genetic diversity to remain viable in the long-term. Only one such captive population exists, at the Territory Wildlife Park near Darwin. Note that the maintenance of this colony involves some complex logistical issues arising from the semelparous nature of the life history: individual males don't live more than one year and female fertility drops after one

year, so breeding stock must be replaced each year, and a surplus of young is likely to be produced every year.

Methods: Appropriate captive management of quolls, including careful management of genetic diversity, at an ARAZPA-accredited institution. Investigate options for sourcing animals sympatric with cane toads for incorporation into the existing colony. A second option may be to maintain viable "natural" populations within toad-proof exclosures or areas intensively managed for toads. A management plan must be produced to guide the number of animals required and what is to happen to excess animals for any future colonies, such as the in-house management plan for the existing colony at the Territory Wildlife Park.

Note that any proposal to remove quolls from the wild, for breeding programs, translocation, etc., must include prior and appropriate consultation with Traditional Owners.

Potential contributors: NT DNRETAS, WA DEC, TWP

Priority:	Managing existing colony	High
	Establishment of new colony/ies	Low

Action 5.3 Protection of key secure populations through protection of habitat in National Parks and Conservation Agreements

Performance criterion: Maintenance of key quoll populations on appropriately managed and legally secured land

Justification: Some remnant northern quoll populations occur on land where they continue to be exposed to land management threats. Populations in Queensland and the Northern Territory that have survived invasion by cane toads and those in Western Australia that are in potential refuge sites (identified by Action 2.1 and 2.3) need to be protected from threats. Formal agreements for the protection and appropriate management of northern quoll habitat should protect these important populations.

Methods: Assess the degree of representation of quoll habitat within legislatively protected areas and increase where required. Assess the management practices of protected land where key quoll populations occur and implement appropriate management techniques for the conservation of northern quolls. Ensure long-term security of management regimes through conservation agreements and property management plans where possible. This action is linked to objectives 2 and 3 for the identification of key populations and appropriate land management for the maintenance of northern quoll populations. Where appropriate management is required to maintain northern quoll habitat, stewardship service arrangements may be an effective method of maintaining quoll populations.

Potential Contributors: DSEWPC, NT DNRETAS, Qld DERM, WA DEC, PA

Priority: Medium

Action 5.4 NT and WA to determine the status of northern quolls on islands with suitable habitat and assess the potential for future translocations to these islands

Performance criterion: Completed surveys for northern quolls on islands where northern quoll presence is expected based on habitat modeling and evaluation of the necessity to establish new populations on suitable islands

Justification: Offshore island quoll populations provide an important insurance policy against future catastrophes as they provide sources of recruits for future translocations, should they become necessary. There are a number of islands that may support quolls but it is not known at present whether quolls occur there. Knowledge of the presence and abundance of quolls on islands is important information to determine the security of the species and to determine whether future translocations to islands are necessary.

Methods: Model suitability of unsurveyed islands. Conduct surveys for northern quolls and potential prey on islands determined suitable habitat. Review survey results and evaluate the need for further translocations of northern quolls to islands based on evidence of mainland trends and cost-effectiveness relative to other actions.

Potential Contributors: DSEWPC, NT NRETAS, WA DEC, relevant Land Councils

Priority: Medium

Specific objective 6: Reduce the risk of northern quoll populations being impacted by disease

Action 6.1 Increase knowledge and monitoring for disease in northern quoll populations

Performance criterion: Broad scale surveillance program established and initial sampling completed

Justification: There is widespread but largely anecdotal evidence of episodes of sudden population crashes of quolls (and other larger dasyurids), most probably being caused by disease. Although there is no direct evidence of such disease affecting northern quolls, only one study (Oakwood and Pritchard 1999) has directly tested for disease in northern quolls, and only toxoplasmosis was considered in this case. Given the capacity for disease to further isolate, fragment and reduce northern quoll populations already under pressure from other threats, monitoring the disease status of northern quolls will allow early detection, which has the potential to reduce spread.

Methods: Establish and maintain a broad-scale surveillance program that aims to monitor the disease status of northern quolls (and selected other mammal species) across their range.

Potential Contributors: Qld DERM, NPWS, NT NRETAS, WA DEC, research institutions

Priority: Medium

Specific objective 7: Reduce the impact of feral predators on northern quolls

Action 7.1 Assess the impacts of feral predators on populations of northern quolls

Performance criterion: Increased understanding of the interactions between feral predators and northern quolls

Justification: Feral cats and dogs are present across much of the range of northern quolls, and foxes overlap the range in central and southern Queensland and in the Pilbara region of Western Australia. It is likely that northern quolls suffer both direct predation from these feral species and competition for prey and safe resting sites. Some scientists believe that the presence of a healthy dingo population in an area has positive impacts on the local native mammal populations through suppression of feral predator numbers.

Methods: Experimental manipulation of feral predator populations and dingo populations in areas of known quoll populations will help to explain the interactions between the species. In some cases this can be done through baiting programs for dogs or foxes (but note Action 3.4), but may require predator exclosures to manipulate cat populations.

Potential Contributors: DSEWPC, PA, Qld DERM, NPWS, NT NRETAS, WA DEC, research institutions, AWC

Priority: High

Action 7.2 Implement efforts to protect key northern quoll populations from the impacts of feral predators

Performance criterion: Reduced feral predator numbers at key populations of northern quolls

Justification: If Action 7.1 shows a significant detrimental relationship between feral predator numbers and northern quoll numbers, protection of quolls from these predators is required. Given that broad-scale control of feral predators is unlikely to be possible in the foreseeable future, this action will best be achieved through localised control in the areas of extant populations in Queensland and the Northern Territory and in potential refuge habitats in Western Australia identified in Action 2.3.

Methods: Implement the best-practice techniques for feral predator control at sites with remnant populations and potential refuge habitats. AWC is currently trialing the use of cat-finding dogs to detect cats and enhance cat-control in the Kimberley region of Western Australia.

Potential Contributors: DSEWPC, PA, Qld DERM, NPWS, NT NRETAS, WA DEC, research institutions, AWC

Priority: Medium

Specific objective 8: Raise public awareness of the plight of northern quolls and the need for biosecurity of islands and WA.

Action 8.1 Develop new and promote existing materials for educating the public on the need for quarantine measures at important island habitat for quolls and along major routes westward into Western Australia

Performance criteria: Increased public adherence to quarantine measures to protect quolls from invasive species

Justification: The inadvertent transport of cane toads by people and or their goods and equipment is the most likely way that cane toads will reach islands considered habitat critical to the survival of the northern quoll. Some material is already available and in place explaining the need for quarantine measures and for people to check their gear (including boats and cars/trailers/caravans) before it is transported to islands or driven westward through the current cane toad colonisation front. More material is needed and some needs to be tailored to apply to specific locations or groups of people and should be developed in consultation with Indigenous ranger groups (see Action 8.2).

Methods: Potential materials for public education include signs at beaches likely to be visited, signs along roads leading westward, websites, powerpoint presentations or DVDs that can be shown at local meetings or in schools.

Potential contributors: NT DNRETAS, WA DEC, NLC, ALC, KLC, TSN, Frogwatch, TWP, commercial and recreational fishing groups, charter boat and large private vessel owners

Priority: Medium

Action 8.2 Provide materials and support to Indigenous rangers and other groups responsible for habitat critical to the survival of northern quolls to educate their communities on the importance of cane toad and cat control and quarantine measures

Performance criterion: An increase in public awareness in communities, and their visitors, on islands and areas of the mainland containing habitat critical to survival for northern quolls

Justification: In order for quarantine initiatives to be effective, people must be aware of the problem, its importance and their potential role in preventing it. The important islands are typically on Indigenous lands and Indigenous ranger groups are important points of contact, have the respect of their communities and can spread information if given the appropriate materials and support. Extend to other important habitat identified in Action 2.3 and 3.1. Over the period 2004-06 the Island Ark program initiated much of this work in the Northern Territory. This work should be expanded to other groups outside of the Northern Territory.

Methods: Funding programs and supply of materials developed in Action 8.1.

Potential contributors: NT DNRETAS, WA DEC, NLC, ALC, KLC, YMBBMAC

Priority: Medium

Action 8.3 Implement a broader public education and awareness campaign on quolls and feral species (particularly cane toads and cats)

Performance criterion: An increase in public awareness on threats feral species pose to the northern quoll

Justification: The materials developed in Action 8.1 need to be used to educate other communities in northern Australia on invasive species (particularly cane toads and cats) and quarantine. Targets for education include tourists, local communities, shipping companies, mining and road construction companies, and any other groups regularly moving vehicles or equipment westwards in northern Australia. The capacity of island residents to recognise cane toads needs to be increased and avenues for reporting need to be established (see public education action 8.2). Public awareness within the NT has been raised by a large media campaign as part of existing programs. The high profile of the issues should be maintained and expanded into other areas.

Methods: Dependent on the materials produced in Action 8.1, but might include signage, brochures, web-based delivery, ranger talks in National Parks, local radio, etc.

Potential contributors: NT DNRETAS, WA DEC, NLC, ALC (+ WA equiv), TSN, TWP, Australian Marine Safety Authority (AMSA) Dept of Defence, Customs, Qld DERM

Priority: Medium

Action 8.4 Develop and implement public education and awareness campaign on land management threats to quolls

Performance criterion: An increase in public awareness on the land management threats (including clearance, grazing and inappropriate fire regimes) to the northern quoll

Justification: Although the land management threats are not yet well known or defined, education of land owners and managers on how their management may affect northern quoll populations is required. Raising awareness of the importance of remnant quoll populations in areas that are grazed or burnt and production of guidelines on how to reduce these threats is required. The prevention of persecution of northern quolls may also be required in some instances.

Methods: Objectives 2, 3 and 7 aim to define the land management threats to northern quolls. This information should be used to produce land management guidelines for the protection of northern quolls. Grazing, fire and control of exotic plant species may be treated separately or together and a range of materials may be used for delivery depending on the target land management group.

Potential contributors: Qld DERM, NT DNRETAS, WA DEC, NLC, ALC, KLC, TSN

Priority: Medium

Costs

The total cost of the recovery program is $2.875 million over five years. Given the large geographic area over which these actions are to take place and the unknown outcomes of many of the actions that influence subsequent actions, the costs given here are to be used as a rough guide only.

Action	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
1.1	40 000	10 000	10 000	10 000	10 000	80 000
1.2	40 000	30 000	30 000	30 000	30 000	160 000
1.3		10 000				10 000
2.1	60 000	60 000	60 000			180 000
2.2			60 000	60 000	60 000	180 000
2.3			40 000			40 000
3.1	60 000	60 000	40 000	40 000	40 000	240 000
3.2	50 000	50 000	50 000			150 000
3.3			50 000	20 000	20 000	90 000
3.4	60 000	40 000	40 000			140 000
3.5	40 000	40 000				80 000
3.6	10 000	10 000	10 000	10 000	10 000	50 000
4.1	10 000	10 000	10 000			30 000
4.2	25 000	25 000				50 000
5.1	30 000	30 000	30 000	30 000	30 000	150 000
5.2	65 000	65 000	65 000	65 000	65 000	325 000
5.3	10 000	10 000	10 000			30 000
5.4	20 000	10 000				30 000
6.1	40 000	40 000	30 000	30 000	30 000	170 000
7.1	100 000	100 000	40 000	40 000	40 000	320 000
7.2	50 000	45 000	40 000	35 000	30 000	200 000
8.1	25 000		10 000		10 000	45 000
8.2		25 000	10 000	10 000	5 000	50 000
8.3		20 000	5 000	5 000	5 000	35 000
8.4			20 000	10 000	10 000	40 000
Total required	$735 000	$695 000	$650 000	$380 000	$415 000	**$2 875 000**

Relationship between recovery objectives, performance criteria and actions

Objective	Performance Criteria	Action
Protect northern quoll populations on offshore islands from invasion and establishment of cane toads, cats and other potential invasive species	All islands with northern quolls that are free of cane toads or other invasive species remain that way	1.1 Maintain biosecurity of important offshore islands through quarantine measures on the mainland 1.2 Monitor offshore islands supporting quoll populations to detect the presence of cane toads, cats and any other potential invasive predator
	Strategy is developed and funding resources available	1.3 Develop and where required implement a strategy for rapid-response control of cane toad or cat outbreaks on offshore islands occupied by northern quolls
Foster the recovery of northern quoll sub-populations in areas where the species has survived alongside cane toads	Increased understanding of the ecology of populations of northern quolls in Queensland and the Northern Territory that co-occur with cane toads	2.1 Determine which factors affect survival and recovery of northern quolls in areas with cane toad
	Increases in quoll density and distribution in areas already occupied by cane toads	2.2 Use information from Action 2.1 to assist surviving populations to recover in sympatry with cane toads
	Characterisation of habitat types with the potential to act as refuges for quolls in WA and the NT once cane toads have colonised	2.3 Identify potential refuge habitats in WA and NT where quolls might be most likely to persist in the long-term alongside cane toads
Halt northern quoll declines in areas not yet colonised by cane toads	Estimates of current population sizes and trends from 5 key sites in Western Australia	3.1 Collect baseline data on population densities and monitor trends of quolls at a series of key sites not currently occupied by cane toads
	Development of evidence-based theories for declines in northern quoll populations not yet affected by cane toads	3.2 Investigate factors causing declines in northern quoll populations not yet affected by cane toads

Objective	Performance Criteria	Action
	Declines halted at a number of key sites in Western Australia and the Northern Territory	3.3 Manage key quoll populations in areas not currently affected by cane toads to halt population declines
	Recommendations to reduce the impact of pastoral land management practices on northern quoll populations produced	3.4 Identify the effect of pastoral land management practices on northern quoll persistence
	Reduced fire scale and increased fire return times at sites with high population densities of quolls	3.5 Interim fire management at potential key quoll populations in areas not currently affected by cane toads
	Annually updated maps of the current and predicted distribution of northern quolls and cane toads	3.6 Refine models of the current and expected distribution of cane toads and northern quolls, incorporating predictions of climate change
Halt northern quoll declines in areas recently colonised by cane toads	Increased understanding of the susceptibility of quolls to cane toad poisoning	4.1 Continue research into the susceptibility of quolls to cane toad poisoning
	Increase understanding of the efficacy of cane toad control and its impact on local quoll populations	4.2 Test the efficacy of control measures for cane toads and whether they allow local persistence of quoll populations
Maintain secure populations and source animals for future reintroductions/ introductions, if they become appropriate	Maintenance of viable habitat and breeding populations of quolls on these islands	5.1 Manage translocated populations of northern quolls on Astell and Pobassoo Islands
	Maintenance of one or two captive populations of northern quolls with >50 individuals and appropriate genetic diversity	5.2 NT and WA to maintain captive breeding populations of northern quolls
	Maintenance of key quoll populations on appropriately managed and legally secured land	5.3 Protection of key secure populations through protection of habitat in National Parks and Conservation Agreements
	Completed surveys for northern quolls on islands where northern quoll presence is expected based on habitat modeling and evaluation of the necessity to establish new populations on suitable islands	5.4 NT and WA to determine the status of northern quolls on islands with suitable habitat and assess the potential for future translocations to these islands

Objective	Performance Criteria	Action
Reduce the risk of northern quoll populations being decimated by disease	Broad scale surveillance program established and initial sampling completed	6.1 Increase knowledge and vigilance of disease in northern quoll populations
Reduce the impact of feral predators on northern quolls	Increased understanding of the interactions between feral predators and northern quolls	7.1 Assess the impacts of feral predators on populations of northern quolls
	Reduced feral predator numbers at key populations of northern quolls	7.2 Implement efforts to protect key northern quoll populations from the impacts of feral predators
Raise public awareness of the plight of northern quolls and the need for biosecurity of islands and WA.	Increased public adherence to quarantine measures to protect quolls from invasive species	8.1 Develop new and promote existing materials for educating the public on the need for quarantine measures at important island habitat for quolls and along major routes westward into Western Australia
	An increase in public awareness in communities, and their visitors, on islands and areas of the mainland containing habitat critical to survival for northern quolls	8.2 Provide materials and support to Indigenous rangers and other groups responsible for habitat critical to survival for northern quolls to educate their communities on the importance of cane toad and cat control and quarantine measures
	An increase in public awareness on threats cane toads pose to the northern quoll	8.3 Implement a broader public education and awareness campaign on quolls and feral species (particularly cane toads and cats)
	An increase in public awareness on the land management threats (including clearance, grazing and inappropriate fire regimes) to the northern quoll	8.4 Develop and implement public education and awareness campaign on land management threats to quolls

Management Practices

The biological effects, including lethal toxic ingestion, caused by cane toads are listed as a key threatening process for biodiversity in Australia. There is a considerable amount of work already being carried out on cane toad control within Australia. The National Cane Toad Taskforce has representatives from all states and territories and the Australian Government working to make recommendations for a national strategy for cane toad control in Australia. This does not directly address issues related to northern quolls, but initiatives should be of benefit to them. Some of the initiatives in the Northern Territory included the one-off funding for the NHT Strategic Reserve Program, which built on earlier work of the Island Ark project run by the NT Department of Natural Resources, Environment The Arts and Sport (then Department of Infrastructure, Planning and Environment). The two main parts of Island Ark were the translocation of northern quolls to Astell and Pobasso Islands and strengthening island biosecurity, which included a large educational and community awareness component. The Strategic Reserve Project followed up these actions through monitoring of translocated quoll populations, assessment and maintenance of status of wild populations on islands, determination and status of co-existing populations of quolls and toads and the establishment and maintenance of a captive breeding colony of northern quolls. Island biosecurity actions included working with barge operators, and community awareness and management of cane toads in the Victoria River District. The other significant contributor to cane toad control activity in the Northern Territory is Frogwatch who facilitate and coordinate community based cane toad management activities.

In Western Australia, significant cane toad management activities are being carried out by Kimberley Toad Busters, Stop the Toad Foundation and WA Department of Environment and Conservation Kununurra Cane Toad Team. In addition, AQIS reduces risk of toad spread by using sniffer dogs and border checkpoints inspecting vehicles and consignments of plants being brought into the state.

Fire management on private land and in conservation protected areas (including National Parks, State Forests, Indigenous Protected Areas and privately managed conservation reserves) will affect northern quolls. Appropriate burning regimes for the conservation of the northern quoll generally include ensuring that fires are not too intense, extensive or frequent; such fire regimes should be prescribed through management plans for national parks and property management plans for individual properties. Organisations such as Bushfires NT assist land managers with appropriate fire management and planning.

The national *Threat abatement plan for predation by feral cats*, addresses management practices to reduce the threats to biodiversity of feral cats (Department of the Environment, Water, Heritage and the Arts 2008).

Biodiversity Benefits

Throughout northern Australia populations of a number of mammal species are declining (Woinarski et al. 2001, McKenzie et al. 2007), but the precise reasons for these declines are unknown. Potential causes are inappropriate fire regimes, predation by feral cats, and habitat degradation through weeds and over-grazing. Any further quantification of how these affect different species will contribute significantly to understanding the mechanisms producing these declines and assist in managing a range of northern Australian habitats.

Cane toads have been found to have a negative effect on a range of snake species, monitors and other lizards, frogs and fish (Covacevich and Archer 1975, Burnett 1997, Catling et al. 1999 van Dam et al. 2002, Watson and Woinarski 2003a and Phillips et al. 2003). Actions to reduce the spread or impact of cane toads will benefit a broad suite of species that are susceptible to cane toad poisoning and/or compete with cane toads for resources.

Strengthening biosecurity on offshore islands will raise community awareness of other pests, such as tramp ants and weeds and will help prevent their spread.

Social and economic impacts

Relative to most Australian mammals, quolls are a conspicuous part of our native fauna, such that they have cultural importance to many Indigenous groups and have recently developed a higher profile in the wider Australian community. In the Northern Territory, the effects of cane toads on quolls have been, and will continue to be, the vanguard of community education programs on the potentially devastating impacts of the spread of cane toads. Consequently, implementation of the recovery plan is expected to receive broad community support.

Biosecurity measures may provide a small amount of employment in remote indigenous communities. One negative economic impact will be the extra burden (both in time and costs) of biosecurity measures on people or companies shipping goods and equipment in coastal areas of northern Australia. A further impact may be restrictions on movements between sensitive areas to reduce the potential for spread of threats.

Interests that will be affected by the Recovery Plan's implementation

Because the northern quoll occurs across two states and one territory on land with highly varied tenancy there are a number of interests that will be affected by the implementation of the Recovery Plan. Whilst all effort has been made to consult as widely as possible during the development of this plan, further intensive consultation will be required as part of the implementation of the plan, particularly with land owners/managers (including indigenous groups).

Stakeholders affected by the implementation of the Recovery Plan are listed below:
(abbreviations used for these organisations in this plan are provided in brackets)

Government Agencies

Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) - formerly the Department of the Environment, Water Heritage and the Arts (DEWHA)
Queensland Department of Environment and Resource Management (Qld DERM)
Northern Territory Department of Natural Resources Environment The Arts and Sport (NT DNRETAS) – includes the Territory Wildlife Park (TWP)
Western Australian Department of Environment and Conservation (WA DEC)
Western Australian Department of Industry and Resources (WA DoIR)
Parks Australia (PA)
Commonwealth Department of Defence
Australian Marine Safety Authority
Customs
Australian Quarantine and Inspection Service (AQIS)

Indigenous Agencies
Northern Land Council (NLC)
Anindilyakwa Land Council (ALC)
Cape York Land Council
Carpentaria Land Council Aboriginal Corporation
Central Queensland Land Council
North Queensland Land Council
Gurang Land Council Aboriginal Corporation
Kimberley Land Council (KLC)
Yamatji Marlpa Barna Baba Maaja Aboriginal Corporation (YMBBMAC)

Regional Agencies
Rangelands NRM Coordinating Group
Natural Resource Management Board (NT) Inc.
Cape York Peninsula Development Association
Terrain Natural Resource Management
Northern Gulf Natural Resource Management Group
Southern Gulf Catchments Ltd.
Burdekin Dry Tropics Board
Mackay Whitsunday Regional NRM Group
Fitzroy Basin Association
Burnett Mary Regional Group for NRM Inc.

Other groups
Kimberley Marine Tourism Association
Australian Wildlife Conservancy (AWC)
Frogwatch
pastoralists
other landholders
Scientists conducting research on quolls within University and the private sector

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References

Abbott I. (1980). Aboriginal man as an exterminator of wallaby and kangaroo populations on islands around Australia. *Oecologia* **44**, 347-354.

Abbott I. (2006). Mammalian faunal collapse in Western Australia, 1875 – 1925: the hypothesised role of epizootic disease and a conceptual model of its origin, introduction, transmission and spread. *Australian Journal of Zoology* **33**: 530-61.

Ball, D. 2008. Personal communication by email, December 2008, Reef Catchments Mackay Whitsunday, Queensland.

Bannister J.L., Calaby J.H., Dawson L.J., Ling J.K., Mahoney J.A., McKay G.M., Richardson B.J., Ride W.D.L. and Walton D.W. (1988). *Zoological catalogue of Australia Volume 5 Mammalia.* Commonwealth of Australia, Brown Prior Anderson, Burwood.

Begg R.J. (1981). The small mammals of Little Nourlangie Rock, N.T. III. Ecology of *Dasyurus hallucatus* the Northern Quoll (Marsupialia: Dasyuridae). *Australian Wildlife Research* **8**: 73-85.

Biodiversity Group Environment Australia (1999). *Threat Abatement Plan for Predation by Feral Cats.* Environment Australia / Natural Heritage Trust, Canberra.

Bradley J. Holmes M., Marrngawi D., Karrakayn A., Wuwarlu J. & Ninganga 1. 2006, *Yumbulyumbulmantha ki-Awarawu: all kinds of things from country: Yanyuwa ethnobiological classification.* Aboriginal and Torres Strait Islander Studies Unit, University of Queensland, Brisbane, viii+174pp

Braithwaite R.W. (1990). Australia's unique biota: implications for ecological processes. *Journal of Biogeography* **17**: 347-354.

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

Burbidge A. (ed.) (1989). Australian and New Zealand islands: nature conservation values and management. *Occasional Paper 2/89,* Department of Conservation and Land Management, Perth.

Burbidge A.A. and McKenzie N.L. (1978). *The islands of the North-west Kimberley, Western Australia.* Wildlife Research Bulletin No. 7 Department of Fisheries and Wildlife, Perth, Western Australia.

Burbidge A.A. and McKenzie N.L. (1983). *Wildlife of the Great Sandy Desert.* Wildlife Research Bulletin Western Australia No 12. Department of Fisheries and Wildlife, Perth, Western Australia.

Burbidge A.A. and McKenzie N.L. (1989). Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation* **50**: 143-198.

Burnett S. (1997). Colonising cane toads cause population declines in native predators: reliable anecdotal information and management implications. *Pacific Conservation Biology* **3**:65-72.

Calver M.C., McIlory J.C., King D.R., Bradley J.S. and Gardener J.C. (1989). Assessment of an approximate lethal does technique for determining the relative susceptibility of non-target species to 1080 toxin. *Australian Wildlife Research* **16**: 33-40.

Cardoso M.J., Eldridge M.D., Oakwood M., Rankmore B.R., and Sherwin W.B. *(in prep)*. Effects of founder events on the genetic variation of translocated northern quoll (*Dasyurus hallucatus*) island populations – Implications for conservation management.

Catling P.C., Hertog A., Burt R.J., Womby J.C. and Forrester R.I. (1999). The short-term effect of Cane Toads *Bufo marinus* on native fauna in the gulf country of the Northern Territory. *Wildlife Research* **26**: 161 – 185.

Copley P. (1991). Feral and domestic cats in South Australia. In: C. Potter (ed), *The impact of cats on native wildlife.* Australian National Parks and Wildlife Service, Canberra.

Covacevich J. and 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.

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

Department of the Environment, Water, Heritage and the Arts (DEWHA) (in prep.). *Significant impact guidelines for the endangered northern quoll* Dasyurus hallucatus. Nationally threatened species and ecological communities guidelines, DEWHA, Canberra, ACT.

Department of the Environment, Water, Heritage and the Arts (DEWHA) (2010). *Threat abatement plan for the biological effects, including lethal toxic ingestion, caused by cane toads (Draft).* DEWHA, Canberra, ACT.

Dickman C.R.and Braithwaite R.W. (1992). Post-mating mortality in the Dasyurid marsupials, *Dasyurus* and *Parantechinus*. *Journal of Mammalology* **73:** 143-147

Dixon J.M. and Huxley L. (1985). *Donald Thompson's Mammals and Fishes of Northern Australia.* Thomas Nelson: Melbourne.

Edgar R. and Belcher C. (1995). Spotted-tailed Quoll *Dasyurus maculatus* (Kerr, 1792). In *The Mammals of Australia*. Ed R Strahan, Reed Books, Chatswood, NSW.

Finlayson H.H. (1934). On mammals from the Dawson and Fitzroy valleys; central coastal Queensland – Part II. *Transactions of the Royal Society of South Australia* **58**, 218-231.

Firestone, K. 2008. Personal communication by email, November 2008, Australasian Conservation Genetics Centre, Zoological Parks Board of NSW.

Fleay D. (1932). The rare dasyures (native cats). *Victorian Naturalist* **49**, 63-68.

Foster, P. and Oakwood, M. 2008. Personal communication by email, July 2008, Envirotek, Coffs Harbour, NSW.

Franklin D.C. (1999). Evidence of disarray amongst granivorous bird assemblages in the savannas of northern Australia, a region of sparse settlement. *Biological Conservation* **90**: 53-68.

Freeland W.J., Winter J.W. and Raskin S. (1988). Australian rock-mammals: A phenomenon of the seasonally dry tropics. *Biotropica* **20**: 70-79.

Godsell J. (1995) Eastern Quoll *Dasyurus viverrinus* (Shaw, 1800). In *The Mammals of Australia*. Ed R Strahan, Reed Books, Chatswood, NSW.

How R.A. Spencer P.B.S. and Schmitt L.H. (2009). Island populations have high conservation value for northern Australia's top marsupial predator ahead of a threatening process. *Journal of Zoology* 1-12.

Jones F. Wood (1923). *The mammals of South Australia. Part 1. The Monotremes and the Carnivorous Marsupials.* (South Australian Government Printer, Adelaide.)

Kerr A. (1967). *Australia's North-west.* (University of Western Australia Press, Perth.)

King D.R. (1989). An assessment of the hazard posed to Northern Quolls (*Dasyurus hallucatus*) by aerial baiting with 1080 to control dingoes. *Australian Wildlife Research* **16**: 569-574.

King D.R. and Smith L.A. (1985). The distribution of the European red fox (*Vulpes vulpes*) in Western Australia. *Records of the Western Australian Museum* **12**: 197-205.

Le Souef A.S. (1923). The Australian native animals: how they stand today and the cause of the scarcity of certain species. In *Save Australia: a plea for the right use of our flora and fauna* (ed. Sir James Barrett.) pp. 175-184. (MacMillan, Melbourne.)

Males G. and Hirst S. (2000). Northern quolls: a challenge to halt the decline. *Thylacinus* **24**: 12-15.

McKenzie N.L. (1981). Mammals of the Phanerozoic South-West Kimberley, Western Australia: biogeography and recent changes. *Journal of Biogeography* **8**: 263 – 280.

McKenzie N.L., Burbidge A.A., Baynes A., Brereton R.N., Dickman C.R., Gordon G., Gibson, L.A., Menkhorst P.W., Robinson A.C., Williams, M.R. and Woinarski J.C.Z. (2007). Analysis of factors implicated in the recent decline of Australia's mammal fauna. *Journal of Biogeography* **34**: 597-611.

Menkhorst P.W. (ed.) (1995). *Mammals of Victoria: distribution, ecology and conservation.* (Oxford University Press, Melbourne.)

Newsome A., Pech R., Smyth R., Banks P., and Dickman, C. (1996). *Potential impacts on Australian native fauna of rabbit calicivirus disease.* Report to the Australian Nature Conservation Agency, Canberra.

Oakwood M. (1997). *The ecology of the northern quoll,* Dasyurus hallucatus. PhD Thesis, Australian National University.

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

Oakwood, M. (2002). Spatial and social organization of a carnivorous marsupial, *Dasyurus hallucatus*. *Journal of Zoology, London* **257**: 237-248.

Oakwood M. (2004). *The effect of cane toads on a marsupial carnivore, the northern quoll,* Dasyurus hallucatus. Report to Parks Australia.

Oakwood, M. (2008a). Northern Quoll *Dasyurus hallucatus* Gould, 1842. In *The Mammals of Australia 3rd Edition* (ed. S. Van Dyck and R. Strahan.) pp. 57-59. (Reed New Holland, Sydney.)

Oakwood, M. (2008b) *Monitoring extinction of the northern quoll.* Report to the Australian Academy of Science, Canberra, Australia.

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

Oakwood, M. and Spratt, D.M. (2000). Parasites of the northern quoll, *Dasyurus hallucatus* (Marsupialia: Dasyuridae) in tropical savanna, Northern Territory. *Australian Journal of Zoology* **48:** 79-80.

O'Donnell, S., Webb, J.K. and Shine, R. (2010) Conditioned taste aversion enhances the survival of an endangered predator imperiled by a toxic invader. *Journal of Applied Ecology* **47:** 558-565.

Orell P. and Morris K. (1994) *Chuditch Recovery Plan 1992-2001.* Western Australian Wildlife Management Program No. 13. Western Australian Department of Conservation and Land Management

Palmer, R. 2008. Personal communication by email, March 2008, Department of Environment and Conservation, WA.

Parker, S.A. (1973). An annotated checklist of the native land mammals of the Northern Territory. *Records of the South Australian Museum* **16:** 1-57

Peacock T. (2007). *Community on-ground cane toad control in the Kimberley.* Invasive Animals Cooperative Research Centre, University of Canberra, Canberra.

Pollock A.B. (1999). Notes on status, distribution and diet of the northern quoll *Dasyurus hallucatus* in the MacKay-Bowen area, mid-eastern Queensland. *Australian Zoologist* **31**:388-395

Phillips B.L., Brown G.P. and Shine R. (2003). Assessing the Potential Impact of Cane Toads on Australian Snakes. *Conservation Biology* **17**: 1738 – 1747.

Rankmore B.R. and Price O.F. (2004). Effects of habitat fragmentation on the vertebrate fauna of tropical woodlands, Northern Territory. Pp 425 – 473 In *Australian Forest Ecology.* Ed D. Lunney, Royal Zoological Society of New South Wales, Sydney.

Rankmore B.R., Griffiths A.D., Woinarski J.C.Z., Lirrwa Ganambarr B., Taylor R., Brennan K., Firestone K.and Cardoso M. (2008). *Island translocation of the northern quoll* Dasyurus hallucatus *as a conservation response to the spread of the cane toad* Chaunus [Bufo] marinus *in the Northern Territory, Australia.* Report to the Natural Heritage Trust.

Rodríguez C., Torres R. and Drummond H. (2006) Eradicating introduced mammals from a forested tropical island. *Biological Conservation* **130,** 98-105.

Serena M. and Soderquist T. (1995) Western Quoll *Dasyurus geoffroii* Gould, 1841. . In *The Mammals of Australia.* Ed R Strahan, Reed Books, Chatswood, NSW.

Start A.N., Burbidge A.A., MacKenzie N. and Palmer C. (2007). The status of mammals in the North Kimberley, Western Australia. *Australian Mammalology* **29**: 1-16.

Sutherst R.W., Floyd R.B. and Maywald G.F. (1995). The potential distribution of the cane toad, *Bufo marinus* L. in Australia. *Conservation Biology* **10**: 294-299.

Taylor R.and Edwards G. (2004). *A review of the impact and control of cane toads in Australia with recommendations for the future.* A report to the Vertebrate Pests Committee.

Threatened Species Scientific Committee (TSSC) (2005). Northern Quoll (*Dasyurus hallucatus*). Advice to the Minister for the Environment and Heritage from the Threatened Species Scientific

Committee (TSSC) on Amendments to the list of Threatened Species under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) 12 April 2005

van Dam R.A., Walden D.J., and Begg G.W. (2002). *A preliminary risk assessment of cane toads in Kakadu National Park.* Scientist Report 164, Supervising Scientist, Darwin NT.

Veitch C. R. (1985). Methods of eradicating feral cats from offshore islands in New Zealand. *ICBP Technical Publication 3:*125-141.

Veitch C. R. (2001). The eradication of feral cats (*Felis catus*) from Little Barrier Island, New Zealand. *New Zealand Journal of Zoology* **28,** 1-12.

Watson M. and Woinarski J. (2003a). *A preliminary assessment of impacts of cane toads on terrestrial vertebrate fauna in Kakadu National Park.* Report to Parks Australia, Tropical Savannas Cooperative Research Centre, Darwin

Watson M. and Woinarski J. (2003b). *Vertebrate monitoring and re-sampling in Kakadu National Park, 2002.* Report to Parks Australia, Tropical Savannas Cooperative Research Centre, Darwin.

Watson M. and Woinarski J. (2004). *Vertebrate monitoring and re-sampling in Kakadu National Park, Year 3, 2003-04.* Report to Parks Australia, Tropical Savannas Cooperative Research Centre, Darwin.

Williams K., Parer I., Coman B., Burley J. and Braysher M. (1995). *Managing vertebrate pests: rabbits.* Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Woinarski J.C.Z. (1990). Effects of fire on the bird communities of tropical woodlands and open forests in northern Australia. *Australian Journal of Ecology* **15**: 1-22.

Woinarski J.C.Z. (ed) (1992). *The Widllife and Vegetation of Purnululu (Bungle Bungle) National Park and Adjacent Area.* Wildlife Research Bulletin no. 6 Department of Conservation and Land Management, Perth.

Woinarski J.C.Z., Milne D.J. and Wanganeen, G. (2001). Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. *Austral Ecology* **26**:360-370.

Woinarski J.C.Z., Risler J., and Kean L. (2004). The response of vegetation and vertebrate fauna to 23 years of fire exclusion in a tropical Eucalyptus open forest, Northern Territory, Australia. *Austral Ecology* **29**: 156-176.

Woinarski J.C.Z, Williams R.J., Price O. and Rankmore B. (2005). Landscapes without boundaries: willdlife and their environments in northern Australia. *Wildlife Research* **32**, 377-388.

Woinarski J.C.Z., Rankmore B.R., Fisher A. and Milne D. (2007). *The natural occurrence of northern quolls* Dasyurus hallucatus *on islands of the Northern Territory: assessment of refuges from the threat posed by cane toads* Bufo marinus. Report to the Natural Heritage Trust.

Woinarski1 J.C.Z., Oakwood M., Winter J., Burnett S., Milne D., Foster P., Myles H. and Holmes B. (2008) *Surviving the toads: patterns of persistence of the northern quoll* Dasyurus hallucatus *in Queensland.* Report submitted to the Natural Heritage Trust Strategic Reserve Program.

Ziembicki, M. 2008. Verbal personal communication, December 2008, Department of Natural Resources, Environment, the Arts and Sport, NT.