Conservation of the Spotted-tailed Quoll *Dasyurus maculatus*: a conceptual and applied model with particular reference to populations of the endangered *D. m. gracilis*

Scott Burnett[1] and Helene Marsh

School of Tropical Environment Studies and Geography, James Cook University of North Queensland, Townsville 4810.

[1]Present address for corresponding author: Threatened Species and Ecosystems Unit, Queensland Parks and Wildlife Service, PO Box 975, Atherton 4883. email: scott.burnett@epa.qld.gov.au

ABSTRACT

The northern Spotted-tailed Quoll *Dasyurus maculatus gracilis* is Endangered (QNCA 1994; EPBC Act 1999). This study therefore aims to develop a model for the species recovery in north Queensland. Due to the threatened status of *D. m. maculatus* in all mainland states in which it occurs, and the similarity in threatening processes in these states, the model presented below is also broadly applicable throughout the species range. Fieldwork and desktop studies were conducted between 1992 and 1994 inclusive within the Wet Tropics Area of north Queensland. The ecology of *D. m. gracilis* was studied in the field using capture-mark-recapture, radio-telemetry, mapping of latrine sites, scat analysis and quantification of the prey community. The distribution and abundance of the species within north Queensland was documented by accessing sighting records from a range of unpublished and published sources and by field survey. A rank-scoring approach was used to elucidate the potential impacts of eutherian carnivores on *D. m. gracilis*. These data are presented as a conceptual model for the species' conservation, based on the pressure-state-response model developed by the OECD and used in Australian State of the Environment reporting. This model identifies three ecological constraints and eight pressures which act to endanger populations of the Spotted-tailed Quoll in north Queensland. Ten responses required by managers and the community to ameliorate these pressures and return the species to a secure conservation status are also identified. Population Viability Analyses and patterns of historical extinction of marsupial carnivores suggest that even if other pressures are managed, the continued presence of feral populations of eutherian carnivores poses a serious threat to the survival of Australia's marsupial carnivores over evolutionary time.

Key words: conservation model, Spotted-tailed Quoll, *Dasyurus maculatus*.

Introduction

Carnivorous marsupials have been a feature of the Australian fauna for at least the past 25-30 million years. Over that time, two Orders and four Families have contributed at least 38 species to the Australian carnivore guild (Wroe 2003, Long *et al*. 2002). The diversity of marsupial carnivores was halved at around the time of the Glacial Maximum (25 – 35 000 years ago), when both carnivorous Diprotodontian lineages became extinct, leaving only the six contemporary Australian Dasyuromorphian carnivores extant. These six species have not fared well since the advent of Europeans to Australia. The Thylacine *Thylacinus cynocephalus* is now extinct, the Devil *Sarcophilus laniaris* is restricted to the island of Tasmania, and all four quoll species have undergone dramatic collapses of their range. At the same time, the three species of feral eutherian carnivores have expanded their ranges so that they are now the only mammalian carnivores across most of mainland Australia.

Throughout their mainland Australian range, Spotted-tailed Quolls *Dasyurus maculatus* have declined (Maxwell *et al*. 1996) and are regarded as Threatened, Endangered or Extinct. Studies investigating patterns of faunal extinction and decline following European colonisation of Australia have shown that *Dasyurus maculatus* is one of the first species to become locally extinct (or at least very rare) following colonisation by Europeans (e.g. Lunney and Leary 1988; Bennett 1990; Burnett 2001). *D. maculatus* occurs in north Queensland as a disjunct population, separated by at least 1000 km from its nearest southern congeners. Firestone *et al*. (1999) recognised that populations of *D. m. gracilis* represent a distinct management unit of the nominate subspecies *D. m. maculatus.* They also raised doubts about the validity of the sub-specific status of *gracilis*, however there has been no official declassification of the subspecies and the nomenclature is retained throughout this chapter. *D. m. gracilis* is classed as Endangered and is one of the few wet tropical rainforest mammals that disappear from large patches of remnant vine forest following habitat fragmentation (Laurance 1989).

We present a conceptual model for the conservation of *D. m. gracilis*. The model, based on the Pressure-State-Response model developed by the Organisation for Economic Cooperation and Development (OECD) and used in Australian State of the Environment Reporting, explicitly lists the ecological constraints and the pressures resulting in the Endangered conservation status of the subspecies. The model also lists the responses required from managers/society to ameliorate those pressures and

Pp 624 - 638 in the *Conservation of Australia's Forest Fauna* (second edition) 2004, edited by Daniel Lunney. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

return the conservation status of the species to a secure level. While the model presented here is focused on the north Queensland subspecies, the rigidity of the life-history strategy and behaviour of *D. maculatus*, and common land-use issues throughout mesic eastern Australia, render the model applicable throughout the range of *D. maculatus*.

The methods used to gather information for the development of this model are described in Burnett (2001). Briefly, they included field studies of the distribution, population demography, life history strategy, and dietary and ranging behaviour of *D. m. gracilis*. Such field techniques included a capture-mark-recapture study, radio-telemetry, scat and prey community analyses, and field surveys using signs, traps and hair tubes. Information on distribution, and threats were obtained from a review of the published and unpublished literature and of museum specimens. We developed and applied a rank-scoring system to evaluate the potential predatory and competitive impacts of eutherian carnivores. Data for this system were collected during field studies on *D. m. gracilis*, dogs/dingoes *Canis lupus* and cats *Felis catus* in north Queensland, and from literature review. Similarly, Population Viability Analyses (PVA) modelling utilised data collected in the field in north Queensland and from the literature. For details of input variables used in the PVA modelling see Appendix 1.

The model

The model identifies three ecological constraints and eight broad pressures which combine to threaten populations of *D. maculatus*. The model also identifies 10 responses to help ameliorate the identified pressures (Fig. 1).

Ecological constraints

Three general ecological constraints operate on populations of *D. maculatus:*

Short life span and low fecundity. The life history strategy of *D. maculatus,* in particular its short reproductive life-span (3 years in *D. m. gracilis,* Burnett 2001); 5 years in *D. m. maculatus* (Belcher 2003), and rigid breeding system requires low levels of extrinsic mortality and predictably high breeding success each year. Breeding is strictly seasonal, females can raise at most a single litter per year and litter size is constrained by the number of teats, so that life-time fecundity is low. Thus even a relatively small increase in mortality and/or a low level of recruitment can result in extinction of a population over a very short time (Burnett 2001).

Small population size. The life-history strategy (i.e. short life span and low life time fecundity) of *D. maculatus* dictates that the species is restricted to the most equable, predictable and productive environments in eastern mesic Australia, resulting in a limited distribution and concomitantly small population size. In north Queensland this is particularly evident, and *D. m. gracilis* is restricted to three core populations of between 20 and 280 individuals each (Fig. 2). The total adult population of *D. m. gracilis* is estimated at approximately 550 individuals (Burnett 2001). This small population size (which is the reason for the Endangered listing of *D. m. gracilis,* (Burnett 2001), further compounds the problems of elevated extrinsic mortality associated with the species' life history strategy.

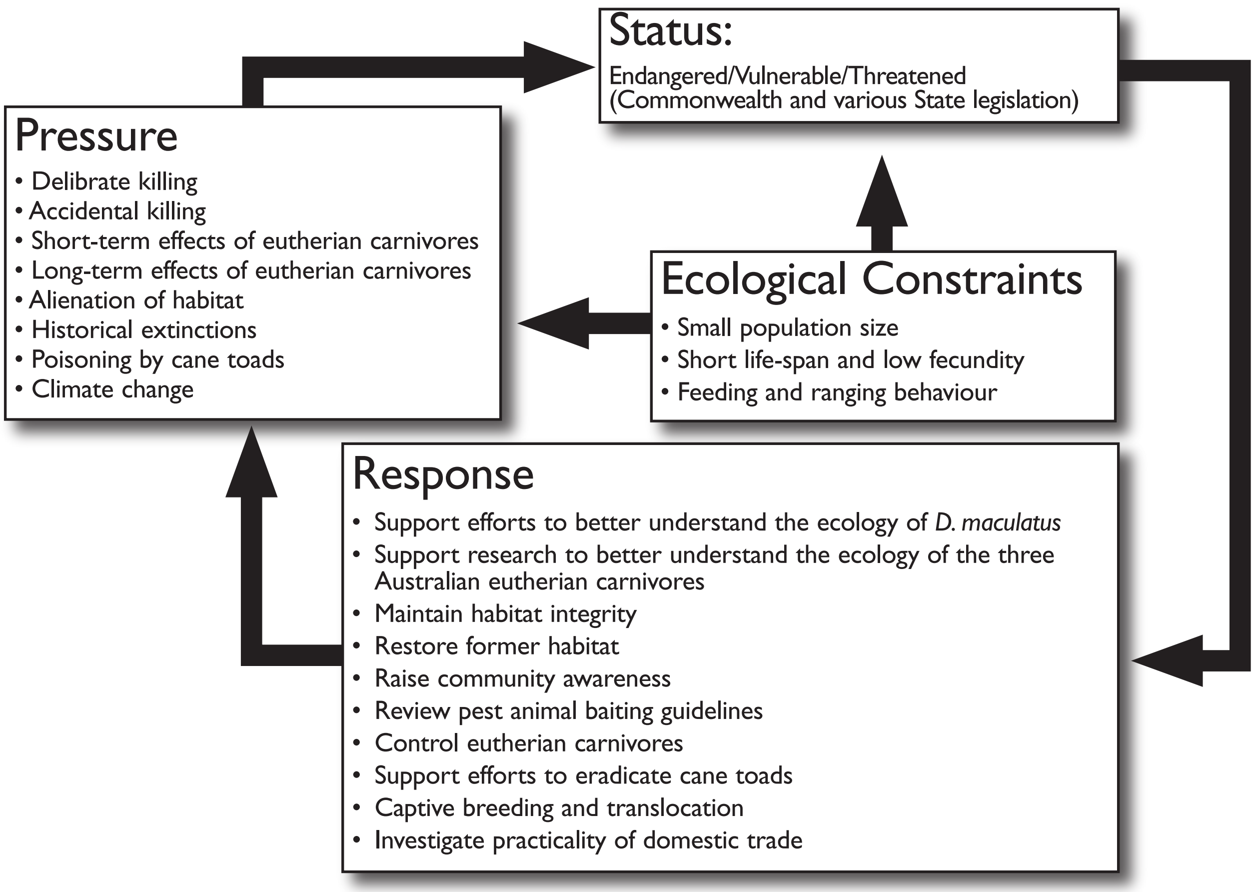

Figure 1. Modified Pressure – State – Response model for the conservation of *D. maculatus.* See the text for descriptions of each of these model components.

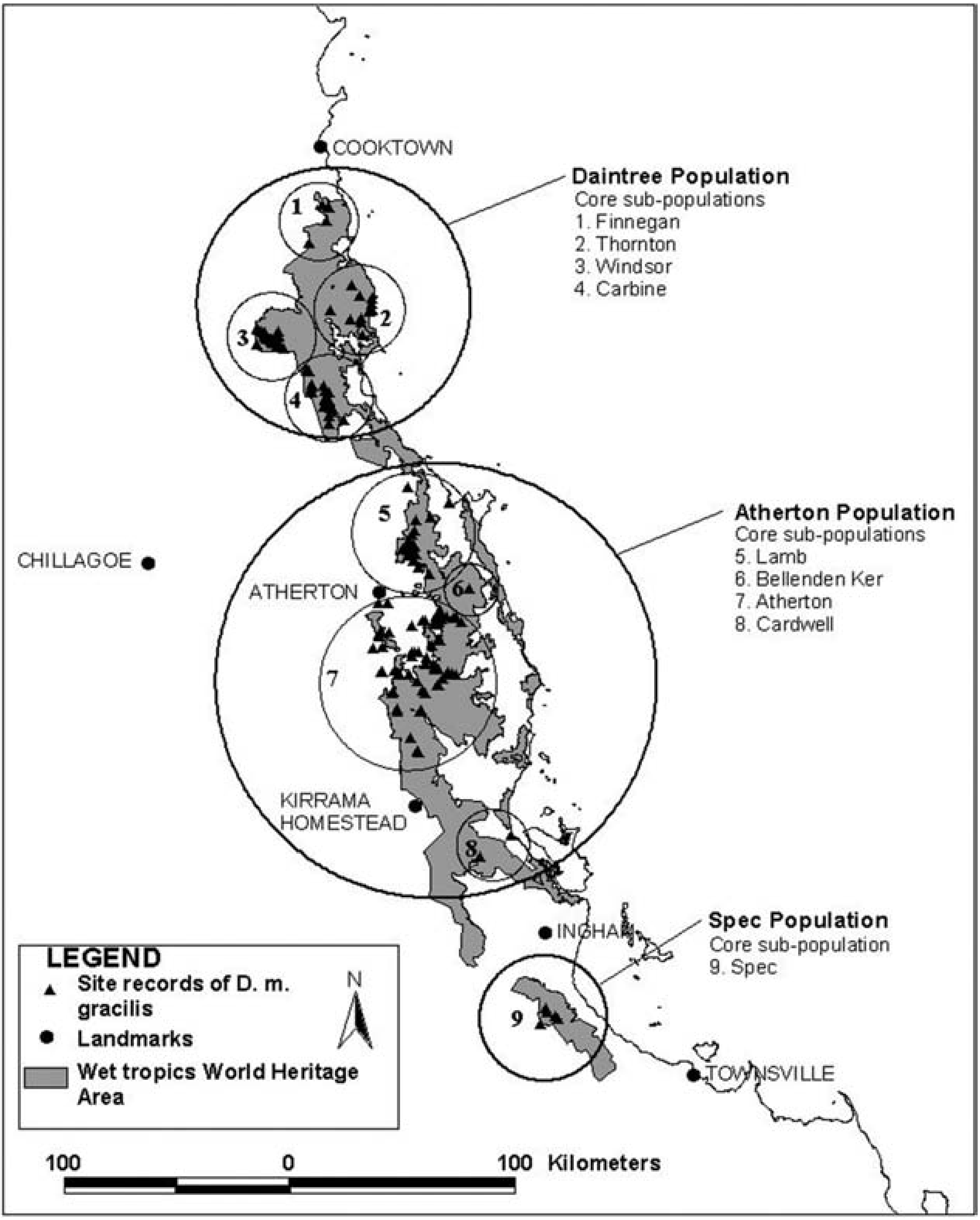

Figure 2. The distribution of the Spotted-tailed Quoll, *D. m. gracilis* in north Queensland based on all records from 1888 to 2000. Numbered core sub-populations named after wet tropics bioregions (after Winter *et al.* 1984). The Wet Tropics World Heritage Area boundary approximates the distribution of closed-forest.

Feeding and Ranging Behaviour. Several aspects of the behaviour of *D. maculatus* render it likely that individuals will come into contact with the human agents of mortality including; (i) humans who deliberately kill quolls when they raid poultry yards and who accidentally kill quolls with poisoned meat baits laid for eutherian carnivores, (ii) deaths from vehicle strike on roads, (iii) and direct or indirect effects from feral animals.

The opportunistic carnivory of quolls, demonstrated by the breadth of dietary items consumed, and a lack of any strong preferences for available prey in the field (Belcher 1995, Burnett 2001), brings quolls into conflict with poultry owners, renders them susceptible to consuming poisoned meat baits, and probably results in poisoning when they attempt to consume cane toads *Bufo marinus* (Burnett 1997).

D. maculatus individuals also range widely. For example, the maximum movements by male and female *D. m. gracilis* between trapping events was 6100 and 2450 m respectively (Burnett 2001). These values suggest that a large proportion of a quoll population is capable of visiting a single point of extrinsic mortality. Using the above maximum values, a poultry yard embedded in a matrix of quoll habitat has the potential to attract male *D. m. gracilis* from a circular area of approximately 117 km^2 and females from an area of 19 km^2. These values are even greater for the larger and more wide-ranging *D. m. maculatus* (e.g. Claridge *et al.,* NSW Department of Environment and Conservation, unpublished). The species' behaviour in north Queensland of using roads to align home ranges, and for placement of latrine sites (Burnett 2001), further increases the chances of a *D. m. gracilis* of encountering many causes of mortality.

Pressures (Threats)

Eight broad pressures affect populations of *D. maculatus.* The importance of these pressures varies between different subspecies and populations of the species. The following examples make particular reference to the north Queensland domain of *D. m. gracilis.*

Deliberate killing

Deliberate killings of Spotted-tailed Quolls occur in retaliation for their depredations upon domestic poultry, and to a lesser extent, when they enter houses, scavenging for food and food scraps. We obtained 152 historical records of *D. m. gracilis*. Ninety-one of these records were of animals that were found at poultry yards or scavenging around houses. The predilection of *D. maculatus* for poultry has been noted in many instances dating back to Gould's observations from the late 1800s (Dixon 1974). In that monograph he described the species as, "a most dreaded enemy to poultry: it is consequently regarded by the settler as one of his greatest pests" (p110). A common theme during the closer settlement of quoll habitat is of immediate quoll depredations upon poultry, retaliation against quolls and their rapid disappearance from those areas (e.g. Wet Tropics area: Short 1988; Frawley 1987; personal communications Tom Conner pers. comm. 24/7/2001; Henry Tranter pers. comm. 3/7/2001. South-eastern Australia: Lunney and Leary 1988; Bennett 1990). A behavioural inclination for *D. maculatus* to return to a food source until it is depleted or the quoll is killed (Burnett 2001) increases the risk that any quoll raiding a human food source will eventually be killed.

Accidental killings

Accidental killings of Spotted-tailed Quolls may take the form of accidental poisoning during dingo/dog *Canis lupus* (hereafter referred to as wild dog or dog) baiting campaigns, secondary poisoning during herbivore baiting campaigns and road kills.

Poison Baiting. Approximately 750 kg of 1080-poisoned fresh meat baits are laid on the Atherton Tablelands each year (Paul Davis, Land Protection Officer, Department of Mines, Energy and Resources, Atherton, pers. comm. 23/9/2000). In line with Queensland guidelines (Queensland Department of Natural Resources 1997), doses of 10 mg of 1080/125g meat bait are used. An individual of the small northern Spotted-tailed Quoll (mean adult weight: female, 1100 g; male, 1600 g), can consume at least a single 250 g bait in a night (Burnett and Van Barnevald unpublished). This equates to a dosage of approximately 18 mg of 1080/kg and 12.5 mg/kg per average sized female and male *D. m. gracilis* respectively. These consumption values translate to doses of approximately 10 and 7 times the LD_{50} dose (1.8mg/kg of animal weight) for 1080 of *D. m. maculatus* calculated by McIlroy (1981).

Captive and field studies provide conflicting evidence on the impact of 1080 baits on *D. maculatus*. Murray *et al.* (2000) and Burnett and Van Barnevald (unpublished data) showed that both *D. m. maculatus* and *D. m. gracilis* readily find and consume non-poisoned meat baits, and circumstantial evidence suggests that accidental poisoning of quolls occurs when they ingest poisoned meat baits laid for wild dog control (Belcher 1998, 2003). However, one field study has demonstrated the opposite; that *D. m. maculatus* does not consume 1080-laden fresh meat baits (Peter Cremasco, Robert Wicks Pest Animal Research Institute, unpublished data). The impacts of 1080-baiting on *D. maculatus* are therefore unresolved.

The impacts of poison baiting potentially also extend to the incidence of secondary poisoning when quolls consume other animals killed or weakened by poisons including herbivores poisoned in and around forestry plantations, and rodents poisoned around buildings. Strychnine, which is less well regulated than 1080, is also of concern and has been known to cause deaths in *D. m. gracilis* in the wild.

Road kills. Green and Scarborough (1990) attribute the majority of human-induced mortality of *D. m. maculatus* in Tasmania today to road kills. Twenty-two (25%) of the 89 *D. m. gracilis* sighting records from the Wet Tropics Area for which we obtained relevant data were road kills. This suggests that road kills are also a significant source of mortality of Spotted-tailed Quolls in some areas of the Wet Tropics Area.

Roads play an important role in scent marking by *D. m. gracilis* (Burnett 2001). Roads also provide a source of carrion, and therefore the incidence of roadkills of *D. maculatus* is potentially much greater than might be expected if quolls encountered roads at random. Roads may also play a more insidious role in depleting quoll populations by acting as routes of invasion into rainforest for eutherian carnivores which may prey upon or compete with quolls (see below), and cane toads (Seabrook and Dettman 1996), which may poison quolls that attempt to eat them.

Short term effects of eutherian carnivores

All known core sub-populations of *D. m. gracilis* occur in at least partial sympatry with at least one eutherian carnivore species (cat or wild dog). Six of these populations occur in at least partial sympatry with two species of eutherian carnivore; the cat and the dog. Despite the fact that there have been no studies examining the impact on *D. maculatus*, such an impact has been suggested previously (e.g. Mansergh 1984; Menkhorst 1995). We therefore explored the potential for predatory and competitive interactions between eutherian carnivores and *D. m. gracilis* in the wet tropics. We inferred a negative impact through predation on the basis of the known incidence of predation on *D. maculatus*, and inferred potential competitive effects by examining the amount of habitat overlap, and dietary overlap. We showed that while the risk of predation in rainforest habitats is low, there is potential for dietary competition especially where more than one eutherian carnivore co-occurs with *D. m. gracilis* (Burnett 2001). However, this is difficult to demonstrate experimentally. The strength of this interaction depends to a great extent on the degree to which the eutherian carnivores penetrate into the rainforest away from roads or other edges. There are no data on this aspect of eutherian carnivore habitat use within the range of *D. m. gracilis* and only limited information for elsewhere in Australia.

In non-rainforest habitats, such as through much of the range of *D. m. maculatus* in southern mainland Australia and where *D. m. gracilis* is historically known from north Queensland, the role of eutherian carnivores as a threatening process is potentially much greater due to their presumed greater dispersion and greater species richness throughout those habitats (e.g. Catling and Burt 1994; Catling and Burt 1997; Kortner *et al.* 2003).

Long-term effects of eutherian carnivores

Historical data, and the results of PVA analyses conducted as part of this study, suggest that there is a greater extinction proneness of quoll populations under regimes of increased mortality and decreased recruitment compared to eutherians (Figs 3 and 4). The PVA analyses presented here suggest that, under certain conditions of zero recruitment, or of elevated adult mortality, eutherian populations may replace quoll populations simply by virtue of differential extinction rates, i.e. quoll populations become extinct while eutherian populations persist. Furthermore, the differential extinction proneness of quolls compared to eutherian carnivores may result in a situation whereby recolonisation by adjacent quoll populations is impeded by the presence of eutherian carnivore populations. This effect has short and long term components. While the extinction of quoll populations can happen rapidly, the effect by which quolls are precluded from re-establishing populations is a longer term and more insidious effect which whittles away at quoll populations over decades to centuries.

Alienation of habitat through land-use practices

Alienation of habitat is the end result of a range of land uses. Such alienation of the habitat of *D. maculatus* potentially occurs as a result of clear-felling and selective timber harvesting, and inappropriate fire regimes. The extent of these land uses varies throughout the range of

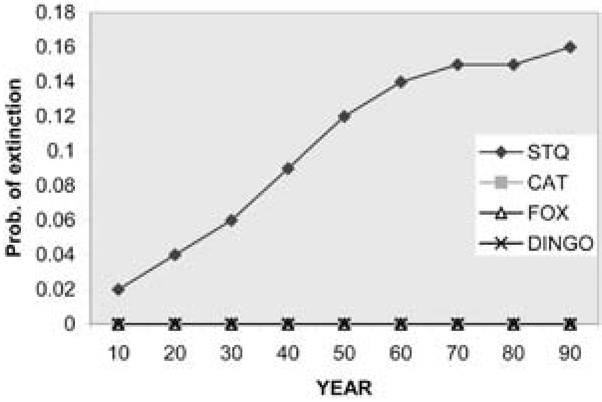

Figure 3. The probability of extinction (modelled by VORTEX) of populations of the northern Spotted-tailed Quoll *D. m. gracilis* and the three eutherian carnivores under conditions of zero recruitment every year in 10. Initial population size 150 individuals.

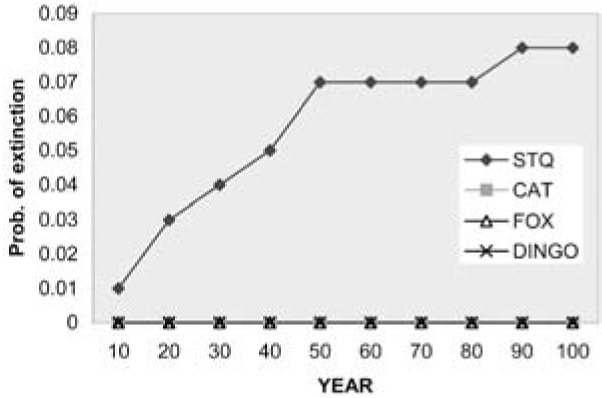

Figure 4. The probability of extinction (modelled by VORTEX) of populations of the northern Spotted-tailed Quoll *D. m. gracilis* and the three eutherian carnivores under conditions of zero recruitment every year in 20. Initial population size 150 individuals.

D. maculatus. Approximately 80,000 hectares of former habitat for *D. m. gracilis* was cleared on the Atherton Tableland between the late 1800s and 1988 (Winter *et al.* 1987; Collins 1994) resulting in a loss of approximately 64% of core habitat for the Atherton population of *D. m. gracilis* (see Fig. 2). Clear-felling no longer occurs in the World Heritage listed range of *D. m. gracilis*, but is still a serious issue throughout the range of *D. m. maculatus* where clearing for timber harvesting, dams and other land development, still occurs. While clear-felling affects quoll populations directly through habitat loss, the secondary effects of clearing may be more insidious, and include fragmentation and the reduction in area of available habitat, and the creation of habitats suited to eutherian carnivores, cane toads and humans. Quolls are highly mobile, so these secondary edge effects can affect quolls for many kilometres into the forest because individuals make routine or occasional forays to forest edges. Similarly, selective timber harvesting occurs at only one or two very localised sites at which *D. m. gracilis* may occur. However, the issue is much more relevant to the conservation of the species in southern mainland Australia and Tasmania. The impacts of selective harvesting are unknown. Fire also has the capacity to impact on quoll populations by removal of cover and food. Fires include deliberate management burns and wildfires. Again, this issue is of very limited importance to the conservation of the primarily rainforest inhabiting *D. m. gracilis*, but is much more relevant to conservation of *D. m. maculatus.*

Historical extinctions of populations of D. maculatus

We have documented the probable historical extinction of *D. m. gracilis* in the Mt Spec Uplands as well as its localised extinction from cleared areas of the Atherton Tablelands (Burnett 2001). It is also possible that populations have become extinct at another three bioregions in north Queensland from which it has not been recorded for over 50 years. The historical extinction of *D. m. maculatus* from South Australia has also been documented (Edgar and Belcher 1995). Historical extinctions result in a decrease in the size of the metapopulations of *D. maculatus*. A decrease in numeric size of the population leads to further pressure on the conservation status of the species due to the suite of effects associated with the small population paradigm (e.g. Caughley and Gunn 1996).

Poisoning by Cane toads

Northern quoll *Dasyurus hallucatus* populations have been shown to crash following cane toad colonisation of their habitat (Burnett 1997; Watson and Woinarski 2003). Western quolls *D. geoffroii* have been shown to be susceptible to toad toxin (Covacevich and Archer 1975) and Spotted-tailed Quolls have been found to eat frogs in Tasmania (Green and Scarborough 1990). It therefore seems likely that Spotted-tailed Quoll mortality rates are increased by colonisation of their habitat by cane toads. Populations of *D. m. gracilis* and of *D. m. maculatus* in south-east Queensland are numerically highest in areas from which toads are absent (Burnett 2001, Watt 1993), although this effect may be confounded by altitudinal and human impacts. The anticipated continued spread of the cane toad down the eastern coast of Australia (Sutherst *et al.* 1995) suggests that naive populations of *D. maculatus* will continue to be exposed to cane toads.

Climate change

Because of their role as top order predators, Spotted-tailed Quolls are expected to be the most vulnerable of mammal species to perturbations of the food web brought about by climate change. In addition, the small population size and relictual mountaintop distribution of *D. m. gracilis* suggest that it will be amongst the most susceptible of the Wet Tropics mammal species to any further restriction of the highland altitudinal zone (Krockenberger *et al.* 2004). Based on current models, the extent of atmospheric warming in Australia is expected to be between approximately 1^0C and 4^0C by the 2050s and between 2 and 5.5^0C by the 2080s (Commonwealth of Australia 2000). A 1^0C increase in temperature in north Queensland is expected to result in a 63% decrease in upland rainforest (core habitat of *D. m. gracilis* and many of its prey species)(Hilbert *et al.* 2001; Williams *et al.* 2003).

Increased atmospheric CO_2 levels are an integral component of the Greenhouse scenario and may also have implications for the food web. For example, Kanowski (2001) contended that increases in atmospheric CO_2 levels within the range predicted in the Greenhouse scenario by the year 2030 will result in a reduction of the nutrient value of leaves. These are important in the diet of ringtail possums, which in turn form an important part of the diet of *D. m. gracilis*.

Concomitant with this decrease in highland habitat is an increase in habitat of species currently restricted to lower altitudes. One such species, the cane toad, is currently absent from much of the high altitude habitat of *D. maculatus*, but temperature gains will probably lift the altitudinal ceiling on the distribution of the former species, resulting in greater encounter rates between quolls and toads.

Responses

A range of responses is required to deal with the pressures that operate on populations of *D. maculatus* (Fig. 5). While most of these responses are relevant throughout the range of the species, the focus here is on specific responses required to conserve populations of *D. m. gracilis*. In some cases, the geographical focus is deliberately ambiguous as a reflection of the applicability of the responses across the species' range. Research and management components are listed beneath each response. The current/past research material is intended to provide a broad indication only, and are not comprehensive listings.

(i) Support efforts to better understand the ecology of D. maculatus. A better understanding of the ecology and habitats of *D. maculatus* is essential for targeted research and management plans that will contribute to the amelioration of all pressures acting on populations of the species throughout its Australian range.

Current/Past Research on D. m. gracilis. Field research on the ecology of *D. m. gracilis* including: (i) dietary ecology, (ii) population ecology, (iii) ranging behaviour, and (iv) broad distribution and habitat associations has been conducted by Burnett (2001). A broad overview of these data are presented in this manuscript. Current research by Burnett is investigating the distribution of *D. m. gracilis* across ecological gradients in north Queensland.

Future Research requirements. To effectively manage quoll populations, future research is required to; (i) elucidate quoll/human interactions in the agricultural mosaic, (ii) examine fine scale habitat associations of *D. maculatus,* in particular, home range attributes that lead to successful breeding, (iii) clarify home range sizes and movement behaviour of each sex, (iv) refine population estimates, (v) verify the existence of *D. maculatus* in historical sites and in sites not yet surveyed.

(ii) Support research to better understand the ecology of the three Australian eutherian carnivores. Research on the ecology of eutherian carnivores is required to better understand the impacts of these species on *D. maculatus* and to direct management of these species, and quoll habitat, appropriately.

Current/Past research. Burnett (2001) conducted a desktop investigation of the potential competitive and predatory interactions between cats, foxes and dingo/dogs, and *D. m. gracilis*. The Queensland Parks and Wildlife Service is currently undertaking a community survey of fox distribution on Atherton Tablelands. Al Glen (University of Sydney) is currently investigating the interactions of foxes and wild dogs with *D. maculatus* in northern New South Wales.

Future Research requirements. Future research is required to better elucidate the impacts of eutherian carnivores on *D. maculatus,* including; (i) examination of habitat utilisation including the dispersion of eutherian carnivores throughout quoll habitat, (ii) collection of ecological information on eutherian carnivores in sympatry with *D. maculatus,* throughout the range of *D. maculatus*, in order to refine knowledge of their impacts on the species and, (iii) collection of habitat-specific schedules of birth and death for dogs, cats and foxes in order to more confidently model their responses to specific environmental conditions and to efforts to control them.

(iii) Maintain habitat integrity. Maintenance of habitat integrity (i.e. vegetation structure and floristics) potentially buffers the effects on populations of *D. maculatus* from a range of pressures including the effects of eutherian carnivores, cane toads and climate change. Although

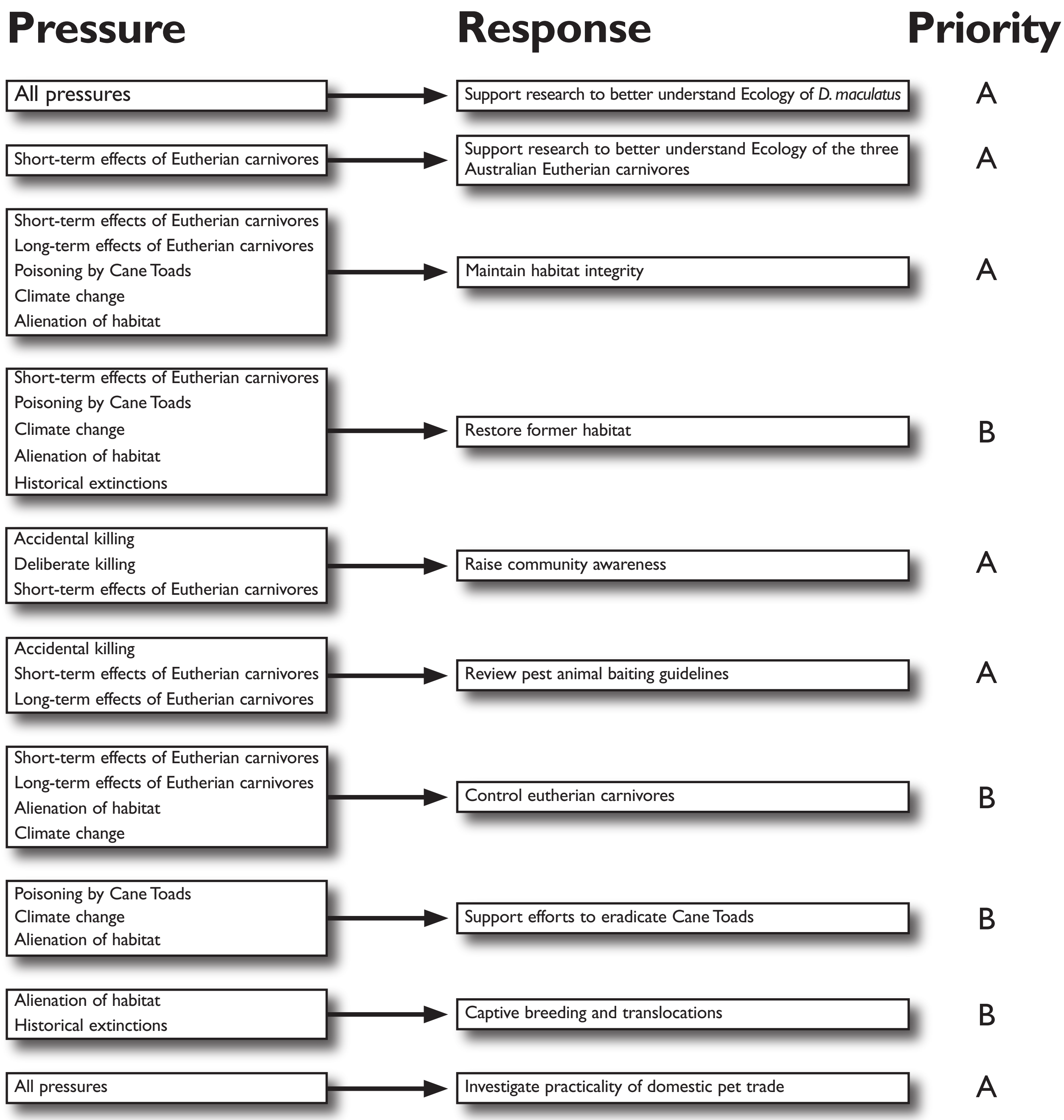

Figure 5. The relationships between the pressures and responses listed in Fig 1. See text for full descriptions of each pressure and of each response. See text for details of each pressure and response.

there are no firm data, it appears that within forest systems, eutherian carnivores and cane toads reach their highest abundances in disturbed areas and along roads (Seabrook and Dettman 1996; Burnett 2001). Maintenance of habitat integrity should alleviate some of the impacts of climate change by providing areas for quolls to occupy in the event of wide-spread environmental change.

Current/Past research. None.

Future Research requirements. Future research requirements include the development of a refined model of Spotted-tailed Quoll habitat, in particular the identification of habitat thresholds which determine habitat suitability for *D. maculatus*. A model of the anticipated impacts of global warming is required to identify which areas of habitat are most at risk from global warming, and which are likely to be important corridors and reservoirs.

Management requirements. Maintenance of existing habitat requires that road construction, upgrading of disused roads, dam building, powerline construction and other infrastructure developments are excluded from areas known to support populations of *D. maculatus*. With particular reference to populations of *D. m. gracilis*, road or other infrastructure development on the Mt Windsor Tableland, the Mt Carbine Tableland (Mt Lewis and Mt Spurgeon Roads), and the Lamb Range (Mt Haig and Mt Edith Roads) needs to be limited. Similar conditions apply to areas identified as important refuges and movement corridors under conditions of the enhanced greenhouse effect. Maintenance of existing quoll habitat may also require the control of eutherian carnivores and cane toads although that will depend upon the results of research on habitat use by these species.

(iv) Restore former habitat. Restoration of former habitats includes replanting of cleared habitats, especially where replanting acts to reconnect areas of known or potential quoll habitat. Revegetation needs to proceed hand in hand with other responses, including the control of eutherian carnivores and cane toads and reducing the deliberate and accidental killing by humans. Restoration of former habitats might also include control of the above pressures in relatively intact habitats from which *D. maculatus* has disappeared (e.g. Mt Spec Uplands) prior to relocation there. Restoration of former habitats potentially increases the amount of suitable habitat and potentially buffers the effects on populations of *D. maculatus* from a range of threats including the effects of: (1) eutherian carnivores, (2) cane toads, (3) historical extinctions, (4) alienation of habitat and (5) climate change.

Current/Past Research on D. m. gracilis. Research by Burnett (2001) used collated sightings records of *D. m. gracilis* to model the potential distribution of the species in north Queensland. This identified high altitude closed forests as the key habitat of the sub-species and highlighted areas of potential habitat from which *D. m. gracilis* has never been recorded. This research also identified those populations and sub-populations which have not yielded any records for more than 50 years and which may therefore be extinct.

Future research requirements. These include the rigorous investigation of the habitat requirements of *D. maculatus* to ensure that restoration results in quoll-suitable habitats, and monitoring of quoll populations in areas adjacent to and within alienated habitats to determine the uptake of these restored habitats by *D. maculatus*.

Management Requirements. Restoration of former habitats of *D. maculatus* that have been alienated requires tree planting and protection of remnant vegetation. Within the range of *D. m. gracilis,* cleared areas adjacent to the forests of the eastern and southern margins of the Atherton Tablelands, and adjacent to extant populations of *D. m. gracilis,* are the priority areas for restoration of quoll habitat. The tenuous forest connection that links the main body of rainforest on the southern edge of the Tablelands with the isolated forests of the Herberton Range is also a high priority area for revegetation.

(v) Raise community awareness. Raised community awareness of the conservation value of *D. maculatus*, and of the value of private land for conservation of the species, is critical in the long-term as human land-use pressure increases adjacent to the core habitats of *D. maculatus*. Raising community awareness is a key response to most pressures operating on populations of *D. maculatus:* (1) accidental killing, (2) deliberate killing, (3) short-term effects of eutherian carnivores.

Current/Past Research. Burnett (2001) documented the incidence of negative interactions between humans and *D. m. gracilis* based on historical anecdotes, Queensland Museum records and community surveys in north Queensland. These data revealed high levels of human induced mortality of *D. m. gracilis* in the human landscape, and much lower levels of mortality in more remote regions. Major causes of mortality included roadkills and killings at poultry yards.

Future Research Requirements. Future research requirements include an investigation into the contemporary nature and frequency of Spotted-tailed Quoll/human interactions, (ii) monitoring of quoll-related community enquiries to management agencies/community groups, and (iii) the response of the community to public talks and displays.

Management Requirements. Raising awareness among the community must be conducted in a consistent manner and requires that community requests for information or other assistance are dealt with promptly. The establishment of a single contact point for community queries is essential in order to meet these aims. A project aimed at raising community awareness about *D. m. gracilis* has been in operation on the Atherton Tablelands since 2000. It is run by a local community group (Tree Kangaroo and Mammal Group) with Threatened Species Network funding. The project aims are, "to reduce the incidence of accidental and deliberate killings of Spotted-tailed Quolls on the Atherton tablelands by raising public awareness about quolls and their endangered status, and the importance of private land for conservation of this species". Activities include: (i) the establishment of a quoll web site; (ii) establishment of a community contact point for dissemination of quoll related information based in the Atherton Office of the Queensland Parks and Wildlife Service; (iii) development of displays for community markets; (iv) a series of talks to schools and community groups on the Atherton Tablelands; (v) delivering radio interviews, (vi) a brochure which highlights the main threats to Spotted-tailed Quolls on the Atherton Tablelands from human activities, (vii) a pamphlet which describes ways of reducing predation from quolls on poultry, and, (viii) provision of bird wire to quoll-proof poultry yards.

(vi) Review of poison baiting guidelines. Direct and secondary poisoning is possibly one of the most serious yet manageable threats to populations of *D. maculatus*. Revision of guidelines used for poisoning wild dogs and foxes, for poisoning herbivorous mammals and commensal rodents, and experimentation with alternative techniques will reduce the risks of accidentally killing quolls when they take poison baits laid for eutherian carnivores or consume poisoned animals.

Current/Past Research. Past research in north Queensland has been limited to studies of non-poisoned bait uptake rates, feeding rates, and the effects of bait burial on uptake by *D. maculatus* (Burnett and Van Barnevald unpublished). These studies suggest that wild *D. m. gracilis* readily consume fresh meat baits and that they are capable of consuming lethal doses of 1080 during a single sitting. However, burying baits not less than 10 cm below ground level is an effective method for restricting access by *D. m. gracilis*. Research by Belcher (1998, 2003) and Cremasco (unpublished data) provide conflicting evidence of the impact of 1080 baiting on *D. maculatus*.

Future Research Requirements. Future research requirements include a continuation and expansion of investigations, throughout the species range, into the ability of *D. maculatus* to detect and avoid meat baits laced with 1080 (as intimated by the unpublished study of Cremasco). Dependent on the results of such an investigation, other research requirements include; (i) an evaluation of the LD_{50} dose for *D. m. gracilis*, (ii) identification of alternative models for wildlife-friendly carnivore baiting. Further research is also required to (iii) investigate the incidence and impacts of secondary poisoning of quolls during baiting campaigns against herbivorous mammals in agricultural/silvicultural systems, and, (vi) the incidence and impacts of secondary poisoning resulting from pest rodent baiting in and around human dwellings.

Management Requirements. Until research into the ability of quolls to detect 1080 baits is conducted, and the incidence and impact of secondary poisoning on quolls is known, quoll-friendly baiting guidelines must be implemented on all properties that lie adjacent to known or potential habitat of *D. maculatus*. In the range of *D. m. gracilis*, such properties lie on the eastern and southern Atherton Tablelands within the Atherton, Eacham and Herberton Shires.

(vii) Control eutherian carnivores. Population level impacts by eutherian carnivores on *D. maculatus* are largely hypothetical. Until negative impacts by these species on *D. maculatus* are demonstrated, and because of the possible negative consequences of 1080-baiting on quoll populations, the control of eutherian carnivores by baiting should be considered a low priority for quoll conservation.

Current/Past research. Burnett (2001) provided a preliminary risk assessment of the impacts of eutherian carnivores on *D. m. gracilis*, showing that direct predation and dietary overlap occurred. This suggests the mechanisms by which eutherian carnivores may affect *D. maculatus*, but such an effect remains unproven. Current research by Al Glen (University of Sydney) is investigating the interactions between foxes, wild dogs and *D. maculatus*.

Future Research requirements. Future research requirements include, (i) an investigation into the potential impacts of eutherian carnivores in order to evaluate the need for their control and, dependent upon that, (ii) an examination the extent and nature of incursions by free-ranging domestic eutherian carnivores into quoll habitat. Future research requirements listed under "*(ii) Support research to better understand the ecology of the three Australian eutherian carnivores*" also apply.

Management Requirements. Dependent on research that shows that eutherian carnivores have a negative impact on *D. maculatus,* a sustained, quoll-friendly control program for eutherian carnivores throughout the range of *D. maculatus* may be required. In such a case, the control of all eutherian carnivores in an area should be conducted simultaneously to avoid increases in some species through competitive or predator release. For example, evidence suggests that fox numbers increase when dog numbers are reduced (Jarman 1986), and that cat numbers similarly increase when fox and dog populations are reduced (Christensen and Burrows 1994). Areas of known sympatry between *D. m. gracilis* and cats are priority areas for cat control and include; (i) the summit area of Mt Bartle Frere, (ii) the summit area of Mt Bellenden Ker, (iii) the western Mt Windsor Tableland, (iv) the road network of the South Johnstone River catchment, (v) the Mt Lewis Rd and, (vi) the cleared areas of the Atherton Tablelands. Areas of narrow allopatry and probable sympatry between *D. m. gracilis* and the fox are priority areas for fox control. In north Queensland these areas include; (i) the cleared areas of the Atherton Tablelands, especially in the southern and eastern portions, and, (ii) the Kuranda/Speewah area. Areas of sympatry between *D. m. gracilis* and dogs are priority areas for dog control and in north Queensland, and they include all areas from which core sub-populations of *D. m. gracilis* are known (see Fig. 2).

This issue of eutherian carnivore control raises another issue, that being the role of the dingo in Australian ecosystems. Burnett (2001) has argued that, from an evolutionary point of view, any of the eutherian carnivores, including the dingo, represent a threat to the continued survival and future radiation of marsupial carnivores. On the other hand, the presence of dingoes seems to suppress the density of cats and foxes, so in the short term they may play a positive role in the conservation of *D. maculatus,* especially in forested environments where they are an insignificant predator on quolls (Burnett 2001).

(viii) Support efforts to control Cane Toads. The impacts of cane toads on *D. maculatus* are speculative although the likely whole-of-ecosystem benefits of cane toad removal justify their control irrespective of their impacts on quolls. Control of cane toads will ameliorate their potential effects on *D. maculatus*, and in turn will ameliorate this one aspect of the effects of historical habitat clearing and climate change.

Past/current research. Past research has investigated anecdotal impacts of cane toads on the Northern quoll and examined the potential impacts of cane toads on *D. m. maculatus* and *D. m. gracilis*, using a rank scoring approach (Burnett 1997). This research indicated that there is a threat posed to quoll populations from cane toads.

Future Research Requirements. Future research requirements include; (i) research into the impact of cane toads on populations of *D. maculatus*. Dependent upon the results of such study, research then needs to, (ii) evaluate current and potential distribution and abundance of cane toads throughout quoll habitat, and, (iii) investigate the efficacy of hand removal of cane toads from upland roads in the Wet Tropics Area.

Management requirements. Dependent upon research results that indicate that cane toads do pose a risk to populations of *D. maculatus*, six road systems, which pass through core habitat of *D. m. gracilis,* need to form the basis of a cane toad control program in north Queensland. These roads include; (i) the Mt. Windsor Tableland Road (15 km), (ii) the Mt. Spurgeon Rd (10 km), (iii) the Mt. Lewis (42 km) Road, (iv) the Mt. Edith (15 km) and Mt. Haig (15 km) Roads on the Lamb Range, (v) the South Johnstone Forestry area road network (c. 100 km) and, (vi) the Tully Falls/Koombooloomba Rd in the Tully Falls area.

(ix) Captive Breeding and Translocation. Captive breeding and translocation is possibly one of the most important tools for the conservation of *D. maculatus*, although more information is required on genetics and distribution of the species before translocation can be undertaken. Captive breeding and subsequent translocations will ameliorate the effects of historical and future extinctions of *D. maculatus*.

Current/past research. Karen Firestone (Taronga Zoo, Sydney, NSW) is investigating the population genetics of *D. maculatus* in north Queensland and Australia-wide. Captive husbandry techniques have been developed over several generations of captive quolls by Featherdale Wildlife Park (NSW), and Healesville Sanctuary (Victoria) (e.g. Jackson 2003).

Future Research requirements. Future research needs to examine whether there is a genetic basis for survival in areas of sympatry with cane toads and with humans, and to develop habitat models for *D. maculatus*, so that release sites can be chosen.

Management requirements. Captive bred quolls must be sourced from local wild stocks as no northern Spotted-tailed Quolls are held in captivity. Local provenance is also required to ensure that no new pathogens are introduced into the north Queensland population isolate. Quolls for the initial captive breeding stock should be sourced from populations that are experienced with cane toads and closer settlement with humans. If there is any genetic basis for survival in sympatry with these agents of mortality, this will ensure a greater chance of survival of translocated animals. Captive-bred quolls will be translocated to areas of their former range from which the species is now extinct, (e.g. Mt Spec within the former range of *D. m. gracilis*), and other areas from which they have disappeared, dependent upon further studies.

The removal of animals from the wild for establishment of a captive stock must not adversely affect wild populations. This may be achieved by taking sub-adults during their early dispersal phase (November-January), when natural attrition is high. A stud book of all captive bred quolls needs to be developed to ensure that the genetic diversity of wild populations is maintained within the captive population, and so that translocations of captive-born young into the wild contribute to genetic diversity of the wild population.

(x) Investigate practicality of domestic animal trade. This may be the only option for the medium-term survival of *D. maculat*us and is a potentially important way of subsidising captive breeding for translocation and an important tool for raising public awareness.

The development of a well-managed domestic animal trade in Spotted-tailed Quolls will not ameliorate any of the pressures listed above, but it will circumvent them by ensuring a robust and genetically diverse captive stock of quolls in captivity. These stocks will provide a bank of animals that can be used for translocations into the wild, and will ensure that the species survives, should large-scale and uncontrollable forces send wild populations extinct (e.g. climate change, introduced animals or pathogens). We also argue that exposure of the public to native animals through a native animal pet industry will contribute to raising community awareness about the aesthetic and conservation values of native animals and the need to conserve their habitats (see Archer 2002 for a discussion of these and other issues). Because there is only a very poorly developed native animal pet industry in Australia, any such moves in that direction for *D. maculatus* would require the development of a base-line model for the development and maintenance of such an industry, as well as a model specific to the needs of *D. maculatus*. A preliminary model for such an industry has been developed by Hopwood (2002).

Current/Past Research. Oakwood and Hopwood (1999) have published their study into the practicalities of keeping quoll species as pets, including temperament, costs, and special requirements. Their study revealed a rift among biologists who displayed divergent views on the suitability of quolls as house pets ranging from an assessment of high to low suitability.

Future Research requirements. Future research requirements include the development of a model for a sustainable native animal pet industry. Such a model needs to be economically and environmentally sustainable and needs to be developed within the following constraints: (i) self-funding so as not to draw funding away from other conservation works, (ii) well policed to ensure that quolls are housed comfortably and are not taken from the wild and, (iii) that no pressure is placed on populations of native fauna as a consequence of high abundance of free-ranging quolls.

Future research requirements also include the development of a model for the captive breeding and distribution among the public of quolls, and the accountability of State agencies and private individuals in dealing with quolls.

Management requirements. A stud book of all captive bred quolls needs to be maintained to ensure that the genetic diversity of wild populations is maintained within the captive population, and so that translocations of captive born young into the wild contribute to genetic diversity of the wild population.

Conclusions

In north Queensland, and across its Australian range, the future of *D. maculatus* is uncertain. In the short-term, both sub-species are threatened by land-use practices including habitat degradation and loss, wild dog baiting, and killings at poultry yards. These threats can be effectively neutralised by simple changes in human behaviour and as such these management actions should be a priority. However, these actions themselves are not enough to ensure the survival of the species in north Queensland or throughout its Australian range. The risks posed by small population size and fragmentation of populations through historical habitat loss is, theoretically, able to be rectified through targeted habitat restoration, in combination with awareness-raising activities.

The survival of *D. maculatus* into the longer term is more difficult to ensure in the face of global climate change and evolutionary scale processes of replacement by eutherian carnivore faunas. Apart from the unlikely event of ridding Australia of feral eutherian carnivore species, the scale of climate change, and the lag effects between changes in public policy and climate effects, leaves no alternative we believe, but to establish a robust captive breeding program, representing all management units of *D. maculatus* as defined by Firestone *et al.* (1999). Such a captive breeding program also provides insurance against local, rapid population extinction to which *D. maculatus* is predisposed. Such a program is a large undertaking, requiring a large allocation of resources. Perhaps the weight of such a program can be shared broadly across the community by the development of a native animal pet industry based on *D. maculatus*. This is not a suggestion that we make lightly, and we are aware of many issues that need to be addressed before the idea gains widespread support from the community and from policy makers. However, if at the end of the day, we are faced with the choice of quolls in captivity or no quolls, then we believe that the correct choice is clearly the development of such a native animal pet industry. Such an industry should never be viewed as the only solution to the extinction problem, but one of several potential solutions in the conservation biologists' toolkit.

Acknowledgments

This study was supported by the Wet Tropics Management Authority, James Cook University of North Queensland, the Australian Research Council and the Australian Post-Graduate Research Award scheme. Technical staff in the School of Tropical Environment Studies and Geography, James Cook University, Townsville provided critical logistic report during all stages of this study. The authors would like to thank Queensland Parks and Wildlife Service and DPI Forestry for permission to undertake field work on *D. m. gracilis*. The comments of Chris Dickman, Al Glen, Dan Lunney and two anonymous referees considerably improved this manuscript.

References

Archer, M. 2002. Confronting crises in conservation: a talk on the wild side. Pp. 12-52 in *A Zoological revolution. Using native fauna to assist in its own survival*, edited by D. Lunney and C. Dickman. Royal Zoological Society of New South Wales, Mosman, and the Australian Museum, Sydney.

Belcher, C.A. 1995. Diet of the Tiger quoll (*Dasyurus maculatus*) in East Gippsland, Victoria. *Wildlife Research*. **22**: 341-57.

Belcher, C. 1998. Susceptibility of the Tiger Quoll, *D. maculatus*, and the Eastern Quoll, *D. viverrinus*, to 1080-poisoned baits in control programs for vertebrate pests in eastern Australia. *Australian Wildlife Research.* **25**: 33-40.

Belcher, C. 2003. Demographics of tiger quoll (*Dasyurus maculatus maculatus*) populations in south-eastern Australia. *Australian Journal of Zoology*. **51**: 611- 626.

Bennett, A. F. 1990. Land use, forest fragmentation and the mammalian fauna at Naringal, south-western Victoria. *Australian Wildlife Research*. **17**: 325-47.

Burnett, S. 1997. Colonising Cane Toads cause population declines in native predators: reliable anecdotal information and management implications. *Pacific Conservation Biology* **3**: 65-72.

Burnett, S. E. 2001. *Ecology and conservation status of the Spotted-tailed quoll Dasyurus maculatus with reference to the future of Australia's carnivorous mammals*. PhD Thesis, James Cook University of North Queensland, Townsville.

Catling, P.C., and Burt, R.J. 1994. Studies of ground-dwelling mammals of Eucalypt forests in south-eastern New South Wales: the species, their abundance and distribution. *Wildlife Research.* **21**: 219-39.

Catling, P. C. and Burt, R. J. 1997. Studies of ground-dwelling mammals of Eucalypt forests in north-eastern New South Wales: the species, their abundance and distribution. *Wildlife Research.* **24**: 1-19.

Caughley, G. and Gunn, A. 1996. *Conservation biology in theory and practice*. Blackwell Scientific; Cambridge.

Christensen, P. and Burrows, 1994. Project desert dreaming: experimental reintroduction of mammals to the Gibson Desert, W. A. Pp. 199-207 in *Reintroduction biology of Australian and new Zealand fauna* . Edited by M. Serena. Surrey Beatty and Sons, Chipping Norton, NSW.

Collins, M. 1994. Patterns and rates of rainforest conversion on the Atherton and Evelyn Tablelands, northeastern Queensland, 1978-1988. *Proceedings of the Royal Society of Queensland.* **104**: 1-10.

Commonwealth of Australia 2000. *The Heat is on: Australia's greenhouse future*. Report to the Senate Environment, Communication, Information Technology and the arts references committee, November 2000 (Submission # 220; Dr Barry Pittock)..

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**: 305-10.

Dixon, J. (ed.) 1974. *Gould's Australian marsupials and monotremes, Fascimile edition*. Macmillan Press, Melbourne.

Edgar, R. and Belcher, C. 1995. Spotted-tailed quoll *Dasyurus maculatus.* Pp. 67-68 in *The Mammals of Australia*, edited by R. Strahan. Australian Museum and Reed Books: Sydney.

Environment Protection and Biodiversity Conservation Act 1999. Commonwealth of Australia.

Firestone, K., Elphinstone, M. S., Sherwin, W. B., and Houlden, B. A. 1999. Phylogeographical population structure of tiger quolls *Dasyurus maculatus* (Dasyuridae: Marsupialia), an endangered carnivorous marsupial. *Molecular Ecology*. **8**: 1613-1625.

Frawley, K. J. 1987. *The Maalan group settlement north Queensland 1954*. Monograph Series 2. University of New South Wales. Australian Defence Force Academy.

Green, R. and Scarborough, T. 1990. The Spotted-tailed quoll *Dasyurus maculatus* in Tasmania. *The Tasmanian Naturalist*. **100**: 1-15.

Hilbert, D. W., Ostendorf, B., and Hopkins, M. 2001. Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. *Austral Ecology* **26**:590-603.

Hopwood, P. 2002. Native Australian mammals as pets: an overview. Pp. 77-83 in *A Zoological revolution. Using native fauna to assist in its own survival,* edited by D. Lunney and C. Dickman. Royal Zoological Society of New South Wales, Mosman, and the Australian Museum, Sydney.**Jackson, S. 2003.** *Australian mammals. Biology and captive management*. CSIRO Publishing, Collingwood, Victoria.

Jarman, P. 1986. The Red fox- an exotic large predator. Pp. 44-61 *The ecology of exotic animals and plants* edited by R. L Kitching. John Wiley and Sons, Brisbane.

Kanowski, J. 2001. Effects of elevated CO_2 on the foliar chemistry of seedlings of two rainforest trees from north-east Australia. *Austral Ecology* **26**: 165-172.

Kortner, G. Gresser, S. and Harden, B. 2003. Does Fox baiting threaten the spotted-tailed quoll, *Dasyurus maculatus? Wildlife Research* **30**: 111-118.

Krockenberger, A. K, Kitching, R.L. and Turton, S. M. 2004. *Environmental crisis: climate change and biodiversity in Queensland*. Cooperative Research Centre for Tropical Rainforest Ecology and management. Rainforest CRC, Cairns.**Laurance, W. F. 1989**. *Ecological impacts of tropical forest fragmentation on nonflying mammals and their habitats*. Unpublished PhD Thesis, University of California, Berkeley, USA.

Long, J., Archer, M., Flannery, T., and hand, S. 2002. *Prehistoric mammals of Australia and New Guinea*. University of New South Wales Press Ltd, Sydney.

Lunney, D., and Leary, T. 1988. The impact on native mammals of land-use changes and exotic species in the Bega district, New South Wales, since settlement. *Australian Journal of Ecology* **13**: 67-92.

Maxwell, S., Burbidge, A. and Morris, K. (eds). 1996. *The 1996 Action Plan for Australian Marsupials and Monotremes*. Endangered Species Program Project Number 500. Wildlife Australia: Canberra.

Mansergh, I. 1984. The status, distribution and abundance of *Dasyurus maculatus* (Tiger quoll) in Australia, with particular reference to Victoria. *Australian Zoologist* **21**(2): 109-122.

McIlroy, J.C. 1981. The sensitivity of Australian animals to 1080 poison. II. Marsupial and eutherian carnivores. *Australian Wildlife Research.* **8**: 385-99.

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

Murray, A. 1998. Tigers and 1080 *The threat posed by buried poison baits to Spotted-tailed Quolls in the Australian Alps National Parks*. Report to the Natural Heritage Working Group of the Australian Alps Liaison Committee. Project No. 3.6, 1995-1996 works program.

Murray, A. J., Belcher, C., Poole, R.N., and Darrant, J. 2000. *The effect of aerial baiting on a population of Spotted-tailed Quolls.* Unpublished Report to Alps Liaison Committee and New South Wales National Parks and Wildlife Service.

Nix, H. and Switzer, M. 1991. *Rainforest animals. Atlas of vertebrates endemic to Australia's Wet Tropics. Kowari 1*. Australian National Parks and Wildlife Service, Canberra.

Oakwood, M. and Hopwood, P. 1999. A survey of the attributes and requirements of quolls that may affect their suitability as household pets. *Australian Zoologist*. 31(2): 365- 375.

Queensland Nature Conservation (Wildlife) Regulation. 1994. Reprint 2G. Queensland Government.

Queensland Department of Natural Resources 1997. *Vertebrate Pesticide Manual. A guide to the use of Vertebrate Pesticides in Queensland*. Department of Natural Resources, Land Protection Branch. Brisbane.

Seabrook, W.A. and Dettman, E. B. 1996. Roads as activity corridors for Cane Toads in Australia. *Journal of Wildlife Management*. **60**: 363-368.

Short, E. 1988. *The nation builders*. Edgar Short, Yungaburra.

Sutherst, R.W., Floyd, R. B., and Maywald, G. F. 1995. The potential geographical distribution of the Cane Toad, *Bufo marinus* L., in Australia. *Conservation Biology* **9(6)**: 294-299.

Watson, M., and Woinarski, J. 2003. *Vertebrate monitoring and resampling in Kakadu National Park, 2002*. Report to Parks Australia North. (Parks and Wildlife Commission of the Northern Territory: Darwin.)

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

Williams, S.E., Bolitho, E.E., and Fox, S. 2003. Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society, London. Series B.* In press.

Winter, J. W., Bell, F. C., Pahl, L., and Atherton, R. 1984. *The specific habitats of selected northeastern Australian rainforest mammals*. Report to World Wide Fund For Nature.

Winter, J. W., Bell, F. C., Pahl, L., and Atherton, R. 1987. Rainforest clearfelling in northeastern Australia. *Proceedings of the Royal Society of Queensland*. **98**: 41-57.

Wroe, S. 2003. Chapter 7. Australian marsupial carnivores: recent advances in palaeontology. Pp. 102-123 in *Predators with pouches The biology of carnivorous marsupials,* edited by M, Jones, C. Dickman, and M. Archer. CSIRO Publishing, Collingwood.

APPENDIX I

Appendix I

Appendix A. Population attributes[1] and sources used for VORTEX modelling the persistence of closed populations of cats, dingoes, foxes and quolls *D. m. gracilis* under a 10 and 20 year cycle of zero recruitment but without a change to adult survival.

Attribute	Spot-tailed Quoll[2]	Dingo[3]	Fox[4]	Cat[5]
Simulation repeated	100	100	100	100
Simulation run	100 years	100 years	100 years	100 years
Migration?	0	0	0	0
Incorporate inbreeding depression?	N	N	N	N
EV (rep'n) correlated with EV(survival)?	N	N	N	N
How many catastrophes?	1	1	1	1
Monogamous or polygynous breeding?	P	P	P	P
At what age females begin breeding?	1 year	1 year	1 year	1 year
At what age males begin breeding?	1 year	1 year	1 year	1 year
What is the maximum age beyond which all animals die?	3 years	12 years	12 years	10 years
Sex ratio at birth?	1:1	1:1	1:1	1:1
Maximum number of young per year per female	6	9	10	14
Is reproduction density dependent?	N	N	N	N
Are good years for reproduction good years for survival?	N	N	N	N
% females breeding?	88	93	85.5	90
Exponential steepness, B?	2 (default)	2 (default)	2 (default)	2 (default)
Allee parameter, A?	1 (default)	1 (default)	1 (default)	1 (default)
Of females which breed, what % produce,				
litter size				
1?	0	0.01	2	0.13
2?	4	0.07	5	0.47
3?	0	0.62	15.5	0.9
4?	20	12	19	1
5?	24	33.81	29.5	6
6?	59	33.81	6.5	6
7?	N/A	12	4	11
8?	N/A	0.6	2	23
9?	N/A	0.08	0	26
10?	N/A	N/A	2	11.5
11?	N/A	N/A	N/A	8.5
12?	N/A	N/A	N/A	4
13?	N/A	N/A	N/A	0.8
14?	N/A	N/A	N/A	0.7
What is SD in % producing litters?	13.4	12.25*	12.25*	12.25*
Mortality of females;				
age 0 to 1	60%	21.5%	70%	60%
SD in above	default	default	default	default
annual adult mortality	34%	5%	34%	34%
SD in above	default	default	default	default
Mortality of males				
age 0 to 1	60%	21.5%	60%	60%
SD in above	default	default	default	default
annual adult mortality	59%	5%	59%	59%

APPENDIX 1

Attribute	Spot-tailed Quoll[2]	Dingo[3]	Fox[4]	Cat[5]
SD in above	default	default	default	default
Probability (as a %) of catastrophe	5%	5%	5%	5%
Severity of catastrophe as a multiplicative factor				
Reproduction	0.0	0.0	0.0	0.0
Adult survival	1	1	1	1
All adult males in breeding pool?	Y	Y	Y	Y
Start at stable age distribution?	Y	Y	Y	Y
Carrying capacity?	as per population size	as per population size	as per population size	as per population size
Trend in k predicted?	N	N	N	N
Harvest?	N	N	N	N
Supplement?	N	N	N	N

Note. 1. No published information on mortality schedules or numerical distribution of litters of different sizes is available for the eutherian carnivores. Numerical values for Quoll populations have been used for the eutherians in PVA modelling.

Sources: 2, (*D. m. gracilis*) Burnett 2001; 3, (dingo) Jones and Stevens 1988, Corbett 1995; 4, (fox) Sheldon 1992, Lloyd 1980; 5, (cat) Jones and Coman 1982.

APPENDIX 2

Roads such as this are a threat to *D. maculatus.* In dense rainforest environments, roads may provide foraging and ranging habitat to a range of feral species including wild dogs, cats and cane toads. The carrion that periodically accumulates along such roads can also attract quolls, making them prone to car strikes. *D. m. gracilis* use roads such as this one as latrine sites, further increasing the risk of their being struck by motor vehicles. Photo. Scott Burnett

Upland rainforest provides core habitat to the endangered northern Spotted-tailed quoll, *D. m. gracilis.* Although situated at tropical latitudes, this forest experiences a sub-tropical or temperate climate. It is characterised by high mammalian species richness and abundance, and high moisture availability. Photo. Alastair Freeman

APPENDIX 2

A road-killed *D. m. maculatus* in northern New South Wales. Photo. Scott Burnett

One of the critical habitat features for populations of *D. maculatus* may be the presence of specific maternity den sites. Three females radio-tracked to their maternity dens were all utilising sites with long and narrow access, such as this hollow buttress root which provides egress into the hollow trunk of this living rainforest tree. The entrance to the hollow can be seen in the far right of this image. Photo. Scott Burnett

Much of the life-history information used in the development of the model presented in this study, was gathered via a live-trapping study of *D. m. gracilis* on the Mt Windsor Tableland. Here, a newly trapped quoll adopts a classic defensive pose at my approach. Photo. Scott Burnett