The largest surviving marsupial carnivore on mainland Australia: the Tiger or Spotted-tailed Quoll *Dasyurus maculatus*, a nationally threatened, forest-dependent species

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ABSTRACT

Dasyurus maculatus maculatus is a forest-dependent species, the largest surviving marsupial carnivore on mainland Australia and the sole surviving member of its genus in south-east mainland Australia. It is classified as 'Vulnerable' nationally. The species' ecology, and the factors considered responsible for its continuing decline, are reviewed. Loss of forest cover, principally from clearing for agriculture, has resulted in fragmentation and reduction in range of approximately 50%. Clear-fell logging rotation cycles appear to be too short to enable the regrowth forest to develop the habitat characteristics required by tiger quolls. There is reasonably compelling evidence that 1080 poison baiting can cause substantial reductions in tiger quoll populations and poison baiting is likely to be at least partly responsible for the species' decline. There are no data to support competition or predation by introduced predators as a major causal factor in the continuing decline in abundance and range of the tiger quoll. Despite the lack of published studies on the ecology of the *D. m. maculatus,* sufficient is known to allow recommendations to be made for forest management, research and the management of the forest-farm interface.

Key words: Tiger quoll, spotted-tailed quoll, Dasyurus maculatus, logging, 1080

Introduction

The tiger or spotted-tailed quoll *Dasyurus maculatus maculatus* (Kerr 1792) is the largest surviving marsupial carnivore on mainland Australia and the sole surviving member of its genus in south-east mainland Australia. *D. m. maculatus* is a solitary, medium-sized, forest-dependent species and an adept climber (Belcher 1994; 2000*b*; Edgar and Belcher 1995). *D. m. maculatus* was first recorded by Governor Phillip as a spotted marten or marten cat, noting its similarity to the mustelids (Phillip 1789). It is a member of the family Dasyuridae, subfamily Dasyurinae (Iredale and Troughton 1934). There are two subspecies currently recognised, the northern, geographically isolated subspecies *D. m. gracilis* and the southern form, including that found in Tasmania, *D. m. maculatus*. Recent genetic research, however, suggests that the Tasmanian population is phylogenetically different from the mainland population of *D. m. maculatus* and should be considered a separate subspecies (Firestone *et al.* 1999).

Species description

Tiger quolls are sexually dimorphic, with males almost twice as heavy as females. Weight ranges for adult animals are: 1.0–3.0 kg (average 2.0 kg) for females and 1.5–4.5 kg (average 3.0 kg) for males (Green and Scarborough 1990). Maximum weights are 7 kg for males and 4 kg for females (Settle 1978). Length including the tail may be up to one metre.

Distribution

The northern subspecies is found in far north Queensland, from about Townsville to Iron Range (Watt 1993), and is geographically isolated from the southern subspecies. The southern subspecies is distributed on both sides of the Great Dividing Range, from south-eastern Queensland, through eastern New South Wales, eastern and south-western Victoria, to Tasmania. The Tasmanian population is considered to be a distinct subspecies from the mainland population (Firestone *et al.* 1999). *D. m. maculatus* is believed to be extinct in South Australia and now has a disjunct distribution throughout much of its present range (Mansergh 1984; Maxwell *et al.* 1996).

Status

D. m. maculatus is a critical weight range species that is considered to be threatened, has undergone a substantial range reduction and its distribution is now disjunct (Burbidge and McKenzie 1989; Maxwell *et al.* 1996). The northern subspecies *D. m. gracilis* is listed as 'Endangered' nationally while the southern subspecies *D. m. maculatus* is listed as 'Vulnerable' nationally (EPBC Act 1999) and by the Action Plan for Australian Marsupials and Monotremes (Maxwell *et al.* 1996). It is classified as 'Vulnerable' in New South Wales, 'Endangered' in Victoria, 'Rare' in Tasmania, 'extinct' in South Australia and has been recommended for reclassification to 'Endangered' in Queensland. *D. maculatus* is also listed under Schedule 2 of the Victorian *Flora and Fauna Guarantee Act* (1988).

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A female tiger quoll, or spotted-tailed quoll, *Dasyurus maculatus* in Badja State Forest, south-east NSW. Photo: J. Nelson.

Recent systematic surveys in the Otway Ranges (Belcher 1999) and south-west Victoria (Belcher 2000*a*) and reviews of Atlas of Victorian Wildlife records have found that *D. maculatus* has declined significantly in both range and numbers and populations in these areas are believed to be critically endangered. There has been a seven-fold decline in records by decade between 1960 and 1999 in the Otway Ranges and a six-fold decline in records from south-west Victoria between 1970 and 1999 (Belcher 1999; 2000*a*).

Habitat

D. m. maculatus is a forest-dependent species, considered to be dependent on mature or old growth forest (Tyndale-Biscoe and Calaby 1975). It has been recorded from a range of habitat types including rainforest, wet sclerophyll forest, dry sclerophyll forest, woodland and heathy woodland. In Victoria, *D. m. maculatus* is generally restricted to areas with annual rainfall exceeding 600 mm, and to riparian vegetation adjacent to the Murray River (Mansergh 1984; Mansergh and Belcher 1992). It has been recorded from five broad forest alliances in Victoria: closed forest, tall open-forest, open-forest, low open-forest and woodland.

In Tasmania, Jones and Barmuta (2000) found that *D. m. maculatus* utilised structurally complex wet and dry eucalypt forests and rainforest. Jones and Rose (1996) found that the highest densities of *D. m. maculatus* in Tasmania occurred in wet forests (which included rainforest, blackwood swamp forests and tall eucalypt forests), but that it also occurred at lower densities in medium eucalypt forests, farmland adjacent to forest and heathy woodland.

In Queensland, Watt (1993) recorded *D. m. maculatus* in rainforest, riparian forest, wet and dry sclerophyll forest and open pasture, with 62% of sightings being in closed-canopy wet forest. Most records of the northern subspecies, *D. m. gracilis*, are from upland (above 900 m) rainforest in north Queensland, but they are also recorded from lowland (0-300 m) and highland (300-900 m) rainforest (Burnett 1993).

Analysis of habitat use at Suggan Buggan in eastern Victoria found that *D. m. maculatus* used the escarpment and gullies significantly more than proportional availability and avoided mid-slopes (Belcher 2000*b*). Prey numbers appeared to be highest on the escarpment and gullies and quolls were recorded using rock dens on the escarpment and in burrows in gullies (Belcher 2000*b*). At Badja and Tallaganda State Forests in southern NSW, *D. m. maculatus* used riparian flats and gullies significantly more than proportional availability, rocky ridges in proportion to availability and avoided mid-slopes (Belcher 2000*b*). Habitat use was significantly correlated to prey densities at Badja and Tallaganda, which were highest in gullies and riparian flats (Belcher 2000*b*). The other factor that influenced habitat use was availability of rock dens, which mainly occurred on ridges. When complex rocky outcrops were present, quolls appeared to prefer to use them rather than dens in hollow logs (Belcher 2000*b*).

Factors influencing current distribution and status

A number of factors have been advanced as being responsible for the continuing decline in range and status of *D. maculatus* (Mansergh 1984; Green and Scarborough 1990; Mansergh and Belcher1992; Watt 1993; Belcher 1994; Edgar and Belcher 1995; Maxwell *et al.* 1996). They include: habitat loss, modification and fragmentation; poison baiting for wild dogs, foxes and rabbits; competition with, and/or predation by introduced predators (dogs, foxes and cats); disease, such as toxoplasmosis (which is introduced and spread by feral and domestic cats); land management practices that may affect breeding or habitat suitability (for example burning off, which may destroy log dens, reduce prey abundance, and damage or destroy suitable foraging strata); human intolerance, particularly when quolls are killing poultry; and road-kills. Poisoning from ingestion of cane toads has also been implicated in declines of *D. maculatus* and *D. hallucatus* (Watt 1993; Burnett 1997).

There remains a lack of detailed, critical information on the ecology and population dynamics of the species. Additional research as well as publication of earlier research is required to determine what factors or combination of factors are responsible for the continuing decline of *D. m. maculatus*. To date, the only published research has been on the susceptibility of *D. m. maculatus* to 1080-baiting for wild dogs, foxes and rabbits (Belcher 1994; 1998; 2000*b*; Williams and Marshall 2000; Glen 2001; Glen and Dickman 2003; Kortner *et al.* 2003) and selective logging (Belcher 2000*b*), although other studies are underway.

Evaluation of factors believed responsible for the continued decline of *D. m. maculatus*

Habitat Fragmentation and Loss

Between European settlement and 1980, the area covered by forest and dense woodland in Victoria had been reduced from 74% to 33% (Kile *et al.* 1980). Mansergh (1984) found that, due to land clearing, the range of *D. m. maculatus* in Victoria had been reduced by 50% since European settlement and the distribution had become disjunct. Maxwell *et al.* (1996) estimated that the species total range had been reduced by as much as 50%. Lunney and Leary (1988) found that in south-eastern New South Wales *D. m. maculatus* populations plummeted and rarity followed loss of habitat and fragmentation of the region's forests.

Impact of timber harvesting

Loss and fragmentation of habitat through logging has been suggested as a factor responsible for the species' continuing decline in range and abundance (Mansergh and Belcher 1992; Watt 1993; Edgar and Belcher 1995; Maxwell *et al.* 1996; Belcher 1999; 2000*a*). The main silvicultural techniques used in Australia are clear-felling and selective logging. Clear-felling involves the felling of all trees in a compartment, except for seed and habitat trees, where prescriptions require their retention. The logged compartment is then burnt to remove logging debris and create an ash seed-bed to promote regeneration, resulting in an even-age regrowth forest. Selective logging removes selected merchantable trees while retaining other trees. Trees may be removed in groups, creating gaps and clusters, or individually throughout a compartment, resulting in a mixed-aged forest. Regeneration is promoted through mechanical disturbance or burning logging slash. Logging cycles vary from 40-80 years depending on the silvicultural system employed and the market for the timber.

Clear-felling and related land-use practices in forested areas have caused concern for the survival of *D. m. maculatus* (Pattemore 1977; Recher *et al.* 1980; Green and Scarborough 1990; Belcher 1999). *D. m. maculatus* is dependent on elements of old growth forest structure, such as tree hollows, hollow logs, ≥ 50% canopy cover and complex vegetation structure (Belcher 2000*b*). Timber harvesting usually reduces or may eliminate arboreal marsupials through the removal of shelter (tree hollows) and foraging strata (Tyndale-Biscoe and Smith 1969; Recher *et al.* 1980; Ambrose 1982; Lunney 1987; Lindenmayer *et al.* 1993). Howarth (1992) found that greater glider *Petaroides volans* densities decreased with increased logging intensity. Arboreal marsupials are a major dietary component of *D. m. maculatus* (Belcher 1994; 1995; 2000*b*; Jones and Barmuta 1998). The reduction in density or elimination of arboreal marsupials through logging will impact on the suitability of a habitat for *D. m. maculatus*. Prey densities and the availability of suitable den sites have been found to largely determine habitat use by *D. m. maculatus* (Belcher 2000*b*).

D. m. maculatus use of selectively logged forest has been analysed at Badja and Tallaganda State Forests in NSW. *D. m. maculatus* use of logged forest increased with time since logging, except where logging intensity was high resulting in ≤ 40% canopy retention (Belcher 2000*b*). In a mosaic of unlogged and logged forest of different age classes, *D. m. maculatus* was found to use unlogged and 16-20 year-old forest significantly more than their proportional availability, used recently logged forest significantly less than its availability, and 6-10 year forest in proportion to its availability (Belcher 2000*b*). The results allow the conclusion that time since logging and logging intensity influence the time required for selectively logged forest to become suitable habitat. *D. m. maculatus* has disappeared from clear-felled, even-age regrowth forest in Victoria (Loyn *et al.* 1980), suggesting that even-age regrowth forest may not develop into suitable habitat quolls, at least within the logging cycle of 40-80 years.

A systematic survey of the Otway Ranges in Victoria found that *D. m. maculatus* had disappeared from the seven sites where they had been recorded within the previous two years (Belcher 1999). Three of the seven sites had been clear-felled within the previous two years and all sites were within 7 km of 1080 poison baiting for rabbits and other herbivores which damage seedlings and regrowth (Belcher 1999). With both factors operating, it was not possible to determine which factor was predominantly responsible for the species' disappearance.

1080 poison baiting

Information to date provides compelling evidence that *D. m. maculatus* is at risk from 1080 poison baits used for the control of wild dogs *Canis lupus dingo* and *C. lupus familiaris*, foxes *Vulpes vulpes* and rabbits *Oryctolagus cuniculus* (Belcher 1994; 1998; 2000*b*; McIlroy 1999; Williams and Marshall 2000; Glen 2001; Glen and Dickman 2003). Kortner *et al.* (2003), however, considered that in their study sites in north-eastern NSW, fox baiting using "Foxoff" brand 1080 baits was relatively safe for *D. m. maculatus*.

The factors that determine the risk of 1080 poisoning include the species' susceptibility to the poison, which is usually expressed as the $LD_{50,}$ the amount of bait the species can consume and exposure to the bait. McIlroy (1981*b*) found that *D. m. maculatus* was much more sensitive to1080 poison, with an LD_{50} (and 95% confidence levels) of 1.86 (1.28-2.68) mg/kg body weight, than its congeners. By comparison, the northern quoll *D. hallucatus* has an LD_{50} of 5.66 (3.91-8.20) mg/kg and the western quoll *D. geoffroii* 7.5 mg/kg (McIlroy 1981*b*; King *et al.* 1989). Both of these species occur in Western Australia where they have evolved with plant species containing fluroacetate (1080) and have developed higher tolerances to the poison than species in eastern Australia (Twigg and King 1991; King *et al.* 1978; Mead *et al.* 1985). The LD_{50} for eastern quolls *D. viverrinus* has been reported as 3.73 mg/kg (McIlroy 1981*b*) and 1.5 mg/kg (King *et al.* 1989), illustrating the variability in estimations of LD_{50}. Ambient temperature can affect a species' susceptibility to 1080 poison. Oliver and King (1983) found susceptibility to 1080 poison for a range of species increased between 2.5 and 5 times at low (< 13^0 C) and high (>30^0 C) temperatures. Most 1080 baiting for canids occurs in winter when ambient temperatures are low, but the potential for increased susceptibility of target and non-target species has not been taken into account when determining 1080 poison dose rates, nor have the target and non-target species been tested for susceptibility at high and low temperatures.

A sublethal dose to a lactating female may kill her offspring (McIlroy 1981*a*), while a sublethal dose to a male may cause sterility (Sullivan *et al.* 1979) which, while not necessarily permanent, could result in the failure to reproduce. Female *D. m. maculatus* have been recorded eating whole rabbits (Troughton 1954, R. Warneke pers. comm.). Wild caught *D. m. maculatus* has been recorded eating more than 1 kg and regularly more than 500 g of chicken in a meal. Greater gliders are the most common prey of *D. m. maculatus* at Badja and Tallaganda State Forests in southern NSW, and when disturbed with a kill, they have been found to have eaten more than 500 g (Belcher 2000*b*; unpub. data). Similarly, the western quoll has been recorded eating up to 43% of their body weight overnight, with a large proportion eaten in the first hour (Soderquist and Serena 1993). Most meat baits weigh approximately 200-250 g and processed baits, such as Foxoff, weigh approximately 60 g. Most quolls could, therefore, consume more than one bait.

Bait trials and free feed programs have found that *D. m. maculatus* can detect and consume baits on the ground covered with 7 to 10 cm of soil or sand and baits buried below the ground up to a depth of 10 cm (Belcher 1994; 1998; 2000*b*; Williams and Marshall 2000; Glen 2001; Glen and Dickman 2003; State Forests of NSW Southern Region records).

Aerial bait trials using systemic dyes have found that at least 67% of a *D. m. maculatus* population and 86% of breeding female quolls had consumed one or more non-poisoned air-dried fresh meat baits (Belcher 2000*b*). Aerial baiting with non-poisoned 70% dried meat baits found that 33% of a *D. m. maculatus* population had consumed one or more baits (Belcher unpublished data). Monitoring the same population pre- and post 1080 poison aerial baiting found that the population declined by 70%, from 23 to 9 (Belcher 2003). The numbers and densities of *D. m. maculatus* in the unbaited southern section of Badja State Forest was found to be similar to the pre-baiting densities in Tallaganda and has not declined (J. Nelson pers. comm.) indicating that the post-baiting decline was not part of a general population decline.

A fully-grown adult male *D. m. maculatus* (wt 3.4 kg) displaying symptoms of 1080 poisoning (vomiting and convulsions) was trapped several days after aerial baiting along the forest boundary in Tallaganda State Forest in 1998. This quoll was later found dead, collected and autopsied by a veterinary surgeon, who found that the animal was in good condition with good body fat reserves, but he could find no cause of death (Dr George Timmins, pers. comm.). Tissue sample analysis found 1080 poison in the stomach and muscle tissues at a concentration suggesting it had ingested approximately 5.9 mg of 1080 poison (McIlroy 1999).

Monitoring *D. maculatus* populations pre- during and post illegal ground baiting in the northern section of Badja State Forest found that the population declined from 11 quolls to zero, and after two years, the population had not re-established (Belcher 2000*b*; 2003). Populations in the unbaited southern section of Badja have not declined (J. Nelson pers. comm.) indicating that the observed decline was not part of a general population decline.

In a study of the impact of fox baiting on *D. maculatus* populations in north-east New South Wales, Körtner *et al.* (2003) found that dogs, foxes and quolls regularly removed baits, but most baits were not consumed. Track counts of the three species found no significant difference in activity pre- and post-baiting, except for foxes in one of four trials, indicating that 1080 poison baiting in their study area was not effective in reducing canid numbers. Glen (2001) recorded very low bait takes by dogs, foxes and quolls from the same area, despite evidence of moderate levels of activity of all three species and suggested that the previous heavy baiting regimes may have resulted in selection of neophobic or bait shy animals. Körtner *et al.* (2003) concluded that *D. m. maculatus* populations were not at risk from fox baiting using Foxoff baits and that deep burial of baits, free-feed periods and daily monitoring are unnecessary. While this conclusion may be true for their study area, data from elsewhere (Belcher 1994; 1998; 2000*b*; Williams and Marshall 2000; Glen 2001; Glen and Dickman 2003) demonstrates that their conclusions cannot be extrapolated beyond their study sites.

Circumstantial evidence suggests that baiting rabbits with 1080 poison may have a significant impact upon a local population of *D. m. maculatus* (Belcher 1994; 1998). McIlroy and Gifford (1992) analysed rabbit carcasses killed during a 'controlled' 1080 rabbit-baiting program and found 1080-poison residue levels in excess of 7.2 mg per carcass. *D. m. maculatus* is known to consume whole rabbit carcasses and are thus likely to receive a lethal dose of 1080. *D. m. maculatus* has been observed hunting rabbits in their burrows, so 1080-poisoned rabbits, which have died in their burrows, would still be accessible to them.

The conclusion drawn is that aerial, ground and mound baiting can have significant impacts on *D. m. maculatus* populations. The time required for populations to recover after baiting is not known, but the two populations monitored to date had not recovered two years after baiting. Further research is required to develop more target-specific baits and bait presentation methods in order to minimise the impact of 1080 poison baiting on *D. m. maculatus*. Further trials with 70% dried meat baits buried below the surface are warranted as they appear to be substantially less attractive or palatable to *D. m. maculatus* than the fresh meat baits currently used. Monitoring of populations that have declined after aerial and ground baiting should be continued to assess the time required for the populations to recover to their pre-baiting levels.

Competition with and predation by introduced predators

Competition with, and the potential predation by, introduced predators, such as the fox, and feral cat have been proposed as causal factors in the continuing decline of *D. m. maculatus* (Mansergh 1984; Mansergh and Belcher1992; Watt 1993; Belcher 1994; Edgar and Belcher 1995; Catling and Burt 1995; Maxwell *et al.* 1996). There are no published studies to support the hypothesis of competition or predation by introduced predators as a causal factor in the decline of *D. m. maculatus*. The relative abundance of *D. m. maculatus* in Tasmania, where the fox is absent (until recently), has been cited as proof that foxes are a significant factor in the species decline. Feral cats occur throughout the species range, including Tasmania, where both *D. maculatus* and *D. viverrinus* occur in reasonable numbers and are therefore not likely to be a significant factor in the species decline. *D. m. maculatus* occurs at similar densities in areas, such as the Snowy River region, where wild dogs, foxes and feral cats are abundant, to areas where wild dogs and foxes occur at low densities, such as Badja and Tallaganda State Forests (Belcher pers. obs.; P. Catling and R. Burt pers. comm.). Potential dietary overlap between the fox, feral cat and *D. m. maculatus* has been described (Belcher 1994). The fox has a broader diet than *D. m. maculatus*, being able to take larger prey and being able to exist on fruit and invertebrates (Belcher 1994). There is a substantial degree of habitat niche separation, as *D. m. maculatus* is an adept climber, able to exploit arboreal prey, which is largely unavailable to the fox. Dietary overlap occurs between feral cats and juvenile quolls – small mammals, birds, reptiles and invertebrates (Belcher 1994). While it can be expected that some competition between foxes and quolls for prey occurs, particularly where both species are dependent on ground-dwelling rather than arboreal prey, it is unlikely to be a significant factor throughout the quoll's range, given that arboreal prey has been found to be a significant component of the quolls diet in those areas studied to date (Belcher 1994; 1995; 2000*b*; Jones and Barmuta 1998). Therefore, relying on fox control as the major management thrust for quoll conservation is unfounded and likely to fail, while also placing quolls at further risk by exposing them to 1080 poison baits.

Predation by introduced predators is also believed to be a potential factor in the quoll's decline. The age class likely to be most at risk from predation is juvenile quolls (0-1 year) during the period from weaning to post dispersal. Körtner *et al.* (2003) recorded that two female quolls were eaten by foxes, but had no evidence that they had been killed by foxes. They also found a dead male quoll, which they speculated may have been killed by a dog. Despite analysis of thousands of dog and fox scats during fauna surveys, pre-logging surveys, bait trials etc. in Victoria, no canid scats were found to contain *D. maculatus* hair. The possibility does remain, however, that some quolls may be killed by canids, although quolls and dingoes/wild dogs have co-existed for thousands of years prior to European settlement. Therefore, if predation of *D. m. maculatus* does occur, it is unlikely to be a significant factor in the species' continuing decline. Research into competition between foxes and *D. m. maculatus* is warranted, but it is likely to be extremely difficult to undertake, as competition can only be demonstrated when food or space becomes a limiting resource.

Disease

There is a widely held view that an epidemic disease caused a significant decline in all the large dasyurids early last century (e.g. Fleay 1932; Munday 1966; Green 1973; Caughley 1980; Green and Scarborough 1990). Toxoplasmosis, which can be transmitted by cats, has been put forward as a likely cause of the decline in *D. m. maculatus* numbers (Caughley 1980). No evidence of an epidemic disease has been found (Mansergh 1984). Oakwood and Pritchard (1999) surveyed northern quolls for toxoplasmosis but found no evidence of its presence.

Road kills

Being killed on the road is considered to be a major cause of quoll mortality in Tasmania (Green and Scarborough 1990; Jones 2000). During a survey at Dorrigo in northern New South Wales, three of seven *D. m. maculatus* records were from road kills (Belcher unpub. data). All three were dispersing juvenile males. Many of the *D. m. maculatus* museum specimens are from road kills (Mansergh 1984; Australian Museum records). Most were adult males killed during the breeding season, when males are most active.

Human intolerance

D. maculatus is still killed when raiding poultry sheds, for example one radio-collared male was shot during a 1994 study in Victoria (Belcher unpublished data), and a certain high profile radio announcer in Sydney announced on air in the late 1990s that he had solved his poultry problem by getting rid of the quolls. The frequency of human encounters has declined with the decline in the range and abundance of the species.

Inappropriate fire regimes

Fires may destroy den sites, foraging strata and cover and lower prey abundances. The only information available is from latrine monitoring at Suggan Buggan, where a wildfire burnt the understorey. *D. m. maculatus* activity ceased at the site after the fire and did not resume until after the understorey had re-established (Belcher 1994). Results from monitoring quolls in Kosciuszko National Park after the extensive wildfires during summer 2002/03 may provide some worthwhile information. Fuel reduction burns and post-logging slash burns have the potential to render habitat unsuitable. Frequency and area of burning should be considered in order to avoid broadscale alienation of habitat. Intensity of slash burns needs to be considered as hot burns can destroy any logs left on the ground, removing potential den sites.

Conclusions

The loss of 50% or more of the original forest cover since European settlement is likely to be the primary cause of the decline of *D. m. maculatus*. Increased fragmentation of the remaining forest cover has exacerbated the original loss. It is within this context that the management of what remains is so important for the largest forest-dependent marsupial carnivore on mainland Australia. The spatial requirements of *D. m. maculatus* (Belcher and Darrant 2004) preclude relying on reserves for its conservation. Management at the landscape level, across land tenures, is required if the species is to be conserved. Current land management practices, in and out of reserves, are either failing to halt or contributing to the species' continuing decline in range and numbers.

The removal of critical habitat components, such as cover, structural complexity, adequate prey densities and den sites through clearing for agriculture and clear-fell logging are also strongly implicated as causal factors in the tiger quolls decline. Further research is required to determine at what age even-age regrowth forest becomes suitable quoll habitat. The indications from records in Victoria are that the logging cycle of 40-80 years is too short for the quoll habitat requirements to have redeveloped.

Destruction of habitat through clearing for agriculture or clear-fell logging can result in the loss of the species and fragmentation of the species' range. Selective logging where each age class is well represented, including unlogged forest and at an intensity that results in ≥ 50% canopy retention, does not result in the loss of the species. Therefore, within the species range, the silvicultural technique used should be selective rather than clear-fell logging. Harvesting should be planned at the landscape level to ensure that representative age classes are present and form a mosaic. Logging should not occur in clusters, but be spread throughout the forest.

Fuel reduction burns should also be planned at the landscape level and should be small scale unless unsuitable quoll habitat has been identified. Fuel reduction burns should be planned to produce a mosaic of burnt and unburnt habitat, with burnt areas smaller than female quolls home range. Fuel reduction and slash burns should be cool rather than hot to avoid destroying hollow logs. Post-logging slash burns should be avoided if mechanical disturbance has achieved sufficient soil disturbance to promote regeneration.

Most of the available information on 1080 poison baiting for dogs, foxes and rabbits supports the conclusion that it is a causal factor in the continuing decline in range and abundance of *D. m. maculatus*. The introduction and widespread use of 1080 poison throughout the species' range coincides with significant declines in quoll populations (Belcher 1999; 2000*a*: 2000*b*).

The current baits and baiting techniques are not target-species specific and place *D. m. maculatus* at risk throughout its range. Research is required to develop more target-specific baits and baiting techniques for dogs, foxes and rabbits. In the interim, 1080 poison baiting should not be undertaken within *D. m. maculatus* habitat, unless baits are buried below the ground at a depth of 15 cm. Bait stations should be at least 1 km apart, to minimise caching of baits by canids. Research is also required to determine target and non-target species susceptibility at temperatures below 13^0 C and whether 70% dried meat baits are less attractive to quolls when buried. Poison baiting should also be evaluated to determine whether it is an effective method of controlling pest species.

There are no data at present to support the hypothesis that competition with or predation by introduced predators, in particular the fox, is a significant causal factor in the continuing decline in range of *D. m. maculatus*. Research into competition with, or predation by, the introduced dog, fox and cat are warranted, but relying on fox control for quoll conservation is unfounded and has the potential to result in further pressure on the species through the extirpation of local populations, reduction in range and numbers. Other factors, such as inappropriate burning, diseases such as toxoplasmosis and human intolerance may be contributing to the tiger quolls decline, but they are unlikely to be as significant as habitat loss, fragmentation or 1080 poison baiting.

There have been no systematic surveys for *D. m. maculatus* throughout its range, and no information exists on the extent of local populations or on movement between populations. A better knowledge of dispersal patterns and population structure in this species would greatly assist in strategic conservation planning, especially in relation to forest management and utilisation, and in the design of reserves and retained connections or buffer strips.

Finally, further research into the ecology of the species is required, as well as the publication of the research which has been conducted. Some of this research will need to be directed to problems such as 1080 poison, logging and fire, but new approaches need to be encouraged, such as landscape analysis, studies on dispersal, social structure and the arboreal life of quolls. Complementary research is required into the genetics of populations, disease, captive breeding and the pet option investigated (Archer 2002). Unless the factors responsible for the continuing decline of *D. m. maculatus* are identified through further research and addressed by the relevant land managers, the species faces the same fate as the thylacine, the largest marsupial carnivore at the time of European settlement.

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APPENDIX I

A male tiger quoll, or spotted-tailed quoll, *Dasyurus maculatus* visiting a latrine at Suggan Buggan, Victoria.

Photo by C. Belcher.

APPENDIX I

Tiger quoll habitat at Suggan Buggan, Victoria.

Photo: C. Belcher.

Tiger quoll habitat at Tallaganda State Forest, south-east NSW.

Photo: C. Belcher.

Tiger quoll habitat at Badja State Forest, south-east NSW.

Photo: C. Belcher.

A female tiger quoll descending a brown barrel *Eucalyptus fastigata* after killing and consuming a greater glider *Petaroides volans* in Badja State Forest, south-east NSW.

Photo: C. Belcher.

A female tiger quoll leaving a maternal den, Badja State Forest, south-east NSW.

Photo: C. Belcher.

A female tiger quoll visiting a latrine on a rocky outcrop, Tallaganda State Forest, south-east NSW.

Photo: C. Belcher.

APPENDIX I

A complex rocky outcrop containing a tiger quoll den and latrine, Tallaganda State Forest, south-east NSW.

Photo: C. Belcher.

A typical tiger quoll latrine on a rock, Tallaganda State Forest, south-east NSW.

Photo: C. Belcher.

A female tiger quoll in typically structurally complex habitat (rocks, logs and branches), Tallaganda State Forest, south-east NSW.

Photo: C. Belcher.

A radio-collared male tiger quoll in Badja State Forest, south-east NSW.

Photo: C. Belcher.

A tiger quoll in maternal den was located in this rock outcrop, Badja State Forest, south-east NSW.

Photo: C. Belcher.

An adult male tiger quoll being released after capture, Badja State Forest, south-east NSW.

Photo: C. Belcher.

Postscript: *D. m. maculatus* southern mainland population has recently been listed as Endangered under the EPBC Act 1999. The Tasmanian population has also been listed as Vulnerable.