Spatial and temporal variation in declining eastern quoll (*Dasyurus viverrinus*) populations in Tasmania

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THE NATIVE CAT

By May Kendall
(1907)

'Twas a native cat, and a hungry one,
Who came late one night to the house of Dunn;
And he wore his best furry-spotted coat
Buttoned tightly up round his slender throat.

'Twas a frightened hen, and she had twelve chicks
When the morning came there were only six,
And the wrath was great of good Farmer Dunn:
"'Twas a cat," quote he, "and a native one."

'Twas a wooden trap, and it had a lid
Down a narrow groove, which completely slid;
When it shut its mouth with an angry snap,
'Twas a gruesome thing to be in that trap.

'Twas a moonlight night when the cat returned
That the chicks had gone he with sorrow learned;
At the trap he sniffed, and it smelt first-rate,
So he slipped inside to investigate.

'Twas a tiny hole, but he scratched and tore,
For the time endowed with the strength of four,
Then he squeezed and squashed and ignored the pain,
Till at last crish, crash! he was free again.

'Twas a hollow log, and he called it "home,"
And his kits rejoiced when they saw him come:
"Dearest dad," they cried, 'we're so glad you're free."
For though but a cat, he was loved, you see.

Declaration

This thesis contains no material previously accepted for the award of any other degree in any tertiary institution. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is given in the text.

Bronwyn Fancourt   8th November, 2010

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Acknowledgements

Jaffa and **Jack**, whilst you couldn't be here in Tassie, you were always here with me.

And to the **eastern quolls**, who never failed to remind me why I left the world of accounting and high finance to work in the "real world".

Abstract

The Australian fauna has endured numerous extinctions and declines in recent history. In particular, Australian mammals have experienced disproportionately more extinctions than their overseas counterparts, with many other species now only persisting on offshore islands after disappearing from their former mainland habitats.

Once widespread throughout south-eastern Australia, the eastern quoll (*Dasyurus viverrinus*) is now considered extinct on the mainland, with the last confirmed sighting in Sydney in 1963. By contrast, eastern quoll populations in Tasmania were, until recently, presumed to be relatively stable and secure. However, spotlighting survey results suggest that the species may now be undergoing rapid and continuing decline.

The aim of the current study was to further investigate this suspected decline, by measuring long-term changes in eastern quoll populations at a number of sites across Tasmania, and identifying factors that could have contributed to any observed population changes.

Eastern quoll populations were surveyed using live capture and release at three study sites, with three replicate surveys performed at two-monthly intervals at each site. Results from the present study were compared with historical data from previous studies at these sites to gauge the extent of any local population changes. Significant reductions of >60% were observed in the number of quolls trapped at both Cradoc and Cradle Mountain, with no eastern quolls observed during any surveys at the Buckland study site. These declines appear to meet the criteria for listing the species as endangered under the Tasmanian *Threatened Species Protection Act 1995* and the IUCN Red List of Threatened Species.

A range of morphometric data and biological samples was collected from captured eastern quolls to assist in identifying potential causes of decline. Population structure, body condition, reproductive output and the health and disease status of captured quolls were compared across sites and between years. Several significant trends were observed in areas such as the development and timing of key reproductive stages, changes in population demographics and shifts in coat-colour ratios.

From the findings of this study, critical information gaps were identified and several hypotheses were formulated to guide the management of key threats, halt further reductions, and ideally reverse the recent declines in eastern quolls.

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List of Abbreviations

ANOVA	Analysis of variance
asl	above sea level
BCI	Body condition index
BH	"Bait and hook" or "bait and string" trigger mechanism
BI	Bruny Island
CM	Cradle Mountain
CMR	Capture mark recapture
CR	Cradoc
CRL	Crown rump length
CRT	Capillary refill time
CWR	Critical weight range
Diff WBC	Differential leukocyte count, differential white blood cell count
DFTD	Devil Facial Tumour Disease
DPIPWE	Department of Primary Industries, Parks, Water and Environment
DQ	Diff Quik / Rapid Diff
EDTA	Ethylenediamine tetra-acetic acid
FEB	Fox Eradication Branch, DPIPWE
IgG	Immunoglobulin G
IUCN	International Union for the Conservation of Nature
MNKA	Mean number of individuals known to be alive
MAT	Modified agglutination test
NVA	Natural Values Atlas
PCV	Packed cell volume
PIT	Passive integrated transponder
RFA	Regional Forest Agreement
RFID	Radio-frequency identification
s.d.	standard deviation
SEM	Standard error of the mean
STTDP	Save The Tasmanian Devil Program
TL	Testicle length
TP	Total plasma protein
TT	Treadle type trigger mechanism
TV	Testicular volume
TW	Testicle width
TWCC	Total leukocyte count, total white cell count
UTAS	University of Tasmania
WBC	White blood cell

Chapter 1: General Introduction

1.1 AUSTRALIAN MAMMAL DECLINES

The Australian fauna has suffered numerous extinctions and declines throughout history. Whilst the fossil record indicates the extinction of species has occurred throughout geological time without any human intervention (Caughley 1994), Australian ecosystems have endured especially profound changes to the natural environment since European settlement around 200 years ago, leading to further changes in the richness and composition of Australian mammalian fauna (Bennett 1990). Terrestrial mammals have been particularly susceptible to extinctions and declines in both abundance and range (Burbidge and McKenzie 1989; Maxwell *et al.* 1996; Burbidge and Manly 2002), with Australian mammal extinctions in recent history unparalleled on any other continent (Short and Smith 1994; Baillie *et al.* 2004; Johnson 2006). Declines have not occurred evenly throughout the Australian mammalian fauna, however, with native medium-sized ground-dwelling mammals suffering at a disproportionately higher rate (Burbidge and McKenzie 1989; Short and Smith 1994; Maxwell *et al.* 1996; Johnson and Isaac 2009).

Many factors are associated with Australian faunal declines and extinctions, yet identifying the patterns of decline and the many processes that contribute to those declines is one of the most challenging aspects of wildlife ecology. In reviewing recent mammal declines in Australia, Burbidge *et al.* (2008) and McKenzie *et al.* (2007) found a strong, geographically based pattern of attrition, with losses being greatest in arid regions and least in areas of high rainfall. Dickman *et al.* (2001) highlighted a marked disparity in the correlates of decline among different taxonomic groups of mammals, showing that while body weight and ground-dwelling habits may be good correlates of risk for macropodids (e.g. Johnson *et al.* 1989), they are not associated strongly with the high "extinction-proneness" of many native rodents (e.g. Dickman *et al.* 2000). Clearly there is no single factor responsible for all species declines, but rather a plethora of stressors and agents of decline, often

working in combination to bring about the demise of a species (Caughley and Gunn 1996; Hone *et al.* 2005).

With the notable exception of the thylacine (*Thylacinus cynocephalus*), Tasmania has remained unaffected by local mammal extinctions in recent history (Short and Smith 1994). However, many species have suffered significant declines in range and abundance, with 12 Tasmanian mammal species currently on State and Federal threatened species listings (DPIPWE 2010). Whilst the patterns of decline and extinction of marsupial carnivores accord with the general patterns for Australian mammals (Short and Smith 1994), the large carnivorous marsupials (such as quolls, devils and the thylacine) appear to have suffered more than other mammals in both Tasmania and continental Australia.

1.2 THE EASTERN QUOLL IN DECLINE?

Once widespread throughout Australia (Figure 1.1), the eastern quoll (*Dasyurus viverrinus*) is now unofficially considered extinct on the mainland, with the last recorded sighting occurring in NSW in the 1960s in the Sydney suburb of Vaucluse (Dickman *et al.* 2001). Whilst the species is still considered widespread and locally common in Tasmania (McKnight 2008), annual statewide spotlighting surveys performed by the Department of Primary Industries, Parks, Water and Environment's Wildlife Management Branch (DPIPWE) have indicated a significant reduction in eastern quoll sightings in recent years (G. Hocking, DPIPWE, unpublished raw data). To explore the possible implications of this finding, details of the spotlighting method, the ecology of the eastern quoll and some potential agents of decline are outlined below.
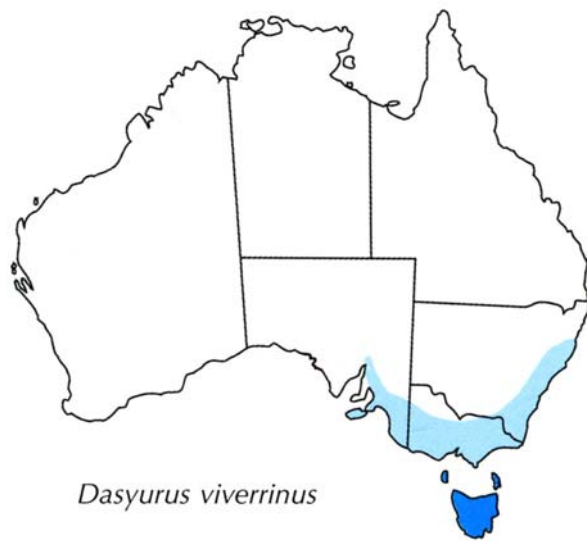
Figure 1.1. Distribution of the eastern quoll (*Dasyurus viverrinus*). Light grey shading indicates former known distribution through south-eastern Australia, dark grey shading indicates the species' current distribution (*Source: Van Dyck and Strahan (2008)).*

1.2.1 Spotlighting surveys

The DPIPWE spotlighting surveys commenced in 1975 to monitor species subject to culling such as brushtail possums (*Trichosurus vulpecula*) and Bennett's wallabies (*Macropus rufogriseus*). All non-domestic species observed were recorded, however, including eastern quolls (Hocking and Driessen 1992). Both the methods and survey routes adopted have changed over the years, with a three-fold increase in the number of survey routes and a more stringent, standardised set of protocols implemented from 1985 following an independent review by Southwell and Fletcher (1985). Additional routes were progressively added in subsequent years, with 189 transects surveyed across the state in 2009 (see Appendix 1 for map of transect locations). Variables such as observer height from ground, type of spotlight, vehicle survey speed, weather and moon phase, time of year and time of night are all now standardised where possible to help preserve consistency of data, ensure repeatability, reduce observer bias and increase precision and validity of observations (Hocking and Driessen 1992).

Over the past ten years, spotlighting surveys have found annual mean eastern quoll sightings per 10 km transect have steadily decreased across Tasmania (Figure 1.2), with the decline commencing around 1999-2000. The data show a significant overall mean reduction of 52% statewide (one-tailed paired *t* test (1997-1999) > (2007-2009): *t* = 3.165, d.f. = 174, *p* = 0.001) with some areas showing more marked declines than others. If the decline in sightings corresponds to a real decline in eastern quoll numbers, then such a reduction appears to meet the criteria for listing the species as endangered under the Tasmanian *Threatened Species Protection Act 1995* (DPIPWE 2008) and the IUCN Red List of Threatened Species (IUCN 2001).

1.2.2 Species description

1.2.2.1 Physical appearance

The eastern quoll is a medium-sized sexually dimorphic marsupial, with mean body mass of 1250 g (range: 900–2000 g) for males and 850 g (700–1100 g) for females (Godsell 1983; Jones and Rose 2001). It is also dimorphic with respect to coat colour, having either black- or tan-coloured pelage (Figure 1.3), with both colours commonly occurring within the one litter (Figure 1.4) (Godsell 1983; pers. obs.).

1.2.2.2 Reproduction

Males are only sexually active during late-autumn and early-winter (Godsell 1983; Fletcher 1985), while females are seasonally polyoestrous (Godsell 1983; Fletcher 1985). Individuals are sexually mature in their first year (Bryant 1988a), with reproductive effort concentrated in their first two breeding years (Godsell 1983; Bryant 1988a). The high synchrony of births in June-July suggests that most females conceive on their first oestrus from late May to early June (Godsell 1983; Fletcher 1985), although in rare cases where females do not initially conceive or subsequently lose their young, they may come into a second oestrus around 31-35 days later (Green 1967; Fletcher 1985). Only one litter is supported each year (Godsell 1983; Bryant 1988b). Mean gestation is around 20 days (Fletcher 1985) at which time up to 36 young are born, but only the first 6 young to reach the pouch and attach to one
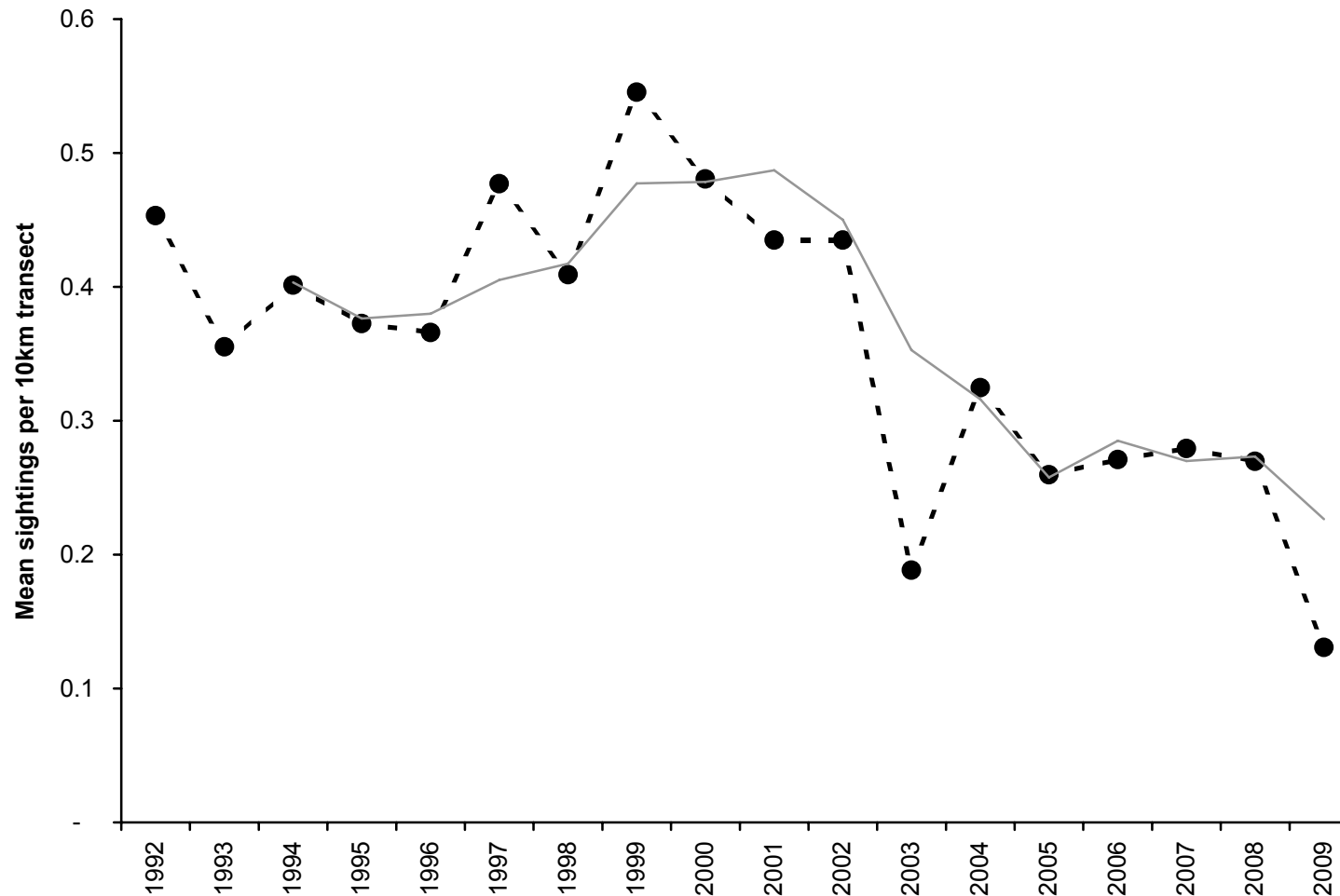
Figure 1.2. Statewide eastern quoll sightings from annual spotlighting surveys across Tasmania. Mean annual (black circles, dotted line) and three-year rolling mean (solid line) sightings per 10 km transect (*n* = 175 transects) shown from 1992 to 2009. Data shown exclude transects that were not surveyed every year and those with no recorded sightings in all years (*Source*: *G. Hocking, DPIPWE, unpublished raw data***).**

(a)

(b)

Figure 1.3. The two colour morphs of the eastern quoll, being (a) tan (sometimes referred to "grey", "fawn" or "light brown") and (b) black (*Photos: B. Fancourt*).

Figure 1.4. Eastern quoll pouch young, estimated 60 days old. Different coat colours are evident at this age, with both black (top and left quolls) and tan (right) coats observed in the one litter (*Photo: B. Fancourt*).

of the 6 teats survive, with most mothers carrying 5-6 young (Godsell 1983). The mother carries the young in the pouch for around 8-9 weeks (Godsell 1983) at which time she deposits them in a den until fully weaned at around 20-30 weeks of age, depending on litter size (Merchant *et al.* 1984).

1.2.2.3 Population structure

Godsell (1983) found only half the number of young observed in winter were subsequently trapped in spring. This suggests high juvenile mortality, although emigration may also be a factor. Numbers trapped fluctuate over an annual cycle, with peaks in summer as juveniles become independent and troughs in winter and early spring (Godsell 1982). Mean sex ratios bias males (1.25:1), but ratios fluctuate between seasons and years (Godsell 1982). The number of males visiting any one area increases over the May-June breeding season each year (Godsell 1982; Bryant 1986), with the more mobile males covering a mean home range of around 44 ha compared to females with 35 ha (Godsell 1983). Annual adult mortality appears high, increasing from between 17-50% mortality by their second mating season in May to between 67-91% by the following February, giving most individuals a life expectancy of around 3-4 years in the wild (Godsell 1983).

1.2.2.4 Diet

Eastern quolls are both active predators and scavengers (Blackhall 1980; pers. obs.).
They are predominantly insectivorous, with pasture grubs such as corbies (*Oncopera intricata*) and southern army worms (*Persectania ewingii*) being the predominant invertebrate prey (Blackhall 1980; Godsell 1983). Small mammals, birds, blackberries and other plant matter are also eaten, although diet depends on location and seasonal fluctuations in prey availability (Blackhall 1980; Godsell 1983; Jones and Barmuta 1998).

1.2.2.5 Habitat

Eastern quolls are commonly associated with bush-pasture interfaces that provide open pastures for foraging at night, with nearby areas of natural bushland providing ideal habitat for den sites (Godsell 1983). They are also found in sub-alpine buttongrass (*Gymnoschoerus sphaerocephalus*) moorlands (Jones and Barmuta 2000), sedgelands (Taylor and Comfort 1993) and a mix of wet and dry schlerophyll forest (Hocking and Guiler 1983; Driessen *et al.* 1991), but are notably absent in large tracts of rainforest (Rounsevell *et al.* 1991).

1.2.2.6 Ecological interactions

Known predators include feral cats (Rolls 1969) and owls (Wakefield 1964; Mooney 1993), with foxes presenting a more recent predation risk in Tasmania (Mooney *et al.* 2005). Whilst Tasmanian devils are known to scavenge dead quolls (Jones 2000) and display competitive aggression towards them when feeding around carcasses (Jones 1998b), it is unclear whether devils prey on live eastern quolls. Differences in diet and habitat preferences between eastern quolls and devils suggests that competition between the two is unlikely to be substantial (Taylor 1986; Jones and Barmuta 1998). Jones and Barmuta (1998) found that dietary overlap occurred between female and young spotted-tailed quolls and adult male eastern quolls at Cradle Mountain and suggested that these species may compete for resources at certain times of year. Whether spotted-tailed quolls prey on live eastern quolls is currently unknown.

1.2.3 Potential agents of decline

A plethora of factors have been identified as potentially contributing to declines in the large marsupial carnivores. The processes affecting the status of the Dasyuroidea have been implied in many studies, however the magnitude and relative importance of most threats remains largely speculative (Dickman *et al.* 2001). Jones *et al.* (2003) listed some of the causes and correlates of decline considered most relevant to Australia's large marsupial carnivores as including: loss, degradation and fragmentation of habitat (Orell and Morris 1994; Oakwood 2000; Burnett and Dickman 2008; Morris *et al.* 2008); introduced species (Orell and Morris 1994; Dickman 1996; Burnett 1997); and direct human-induced mortality (Green 1967; Jones 2000). Table 1.1 lists the large Australian marsupial carnivores, together with the causal factors implicated in their respective declines.

Whilst the factors contributing to the apparent recent decline in eastern quoll numbers are currently unknown, a range of possible agents have been linked to historic fluctuations in the species. These include: predation by introduced European red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*) (Wood Jones 1923; Jones *et al.* 2004; Saunders *et al.* 2006); habitat modification through changes in land-use (Jones and Rose 1996); road mortality (Jones 2000); direct killing by humans (Backhouse 1843; Wood Jones 1923; Green 1967; Bennett 1990); non-target poisoning (McIlroy 1981; King *et al.* 1989); disease (Wood Jones 1923; Guiler 1961; Green 1967; Obendorf and Munday 1983); or even climatic factors such as drought (Abbott 2006; Levinsky *et al.* 2007). Given that agents of decline tend to interact to bring about population declines (Hone *et al.* 2005), a combination of these factors may be responsible.

1.2.3.1 Foxes

Foxes have caused devastation to both wildlife and agriculture on the Australian mainland (Saunders *et al.* 1995), costing over $200 million annually in biodiversity and economic losses (McLeod 2004). Whilst foxes are considered a major contributor to the demise of numerous mainland species (Kinnear *et al.* 1998; Burbidge and Manly 2002; Johnson 2006), Tasmania has escaped such devastation

Table 1.1. Summary of the six large Australian carnivorous marsupials, their IUCN conservation status and the potential causal factors that have been implicated in their decline. Analysis commences around 4000 years ago with the introduction of the dingo to the Australian mainland, through to modern agents of decline that still operate across both the mainland and Tasmania.

		Species	Thylacine	Tasmanian devil	Spotted-tailed quoll	Eastern quoll	Western quoll	Northern quoll
		IUCN Classification	Extinct	Endangered	Vulnerable	Near Threatened	Near Threatened	Endangered
Agent of decline	Introduced species	Foxes			● 12	● 6,22,23,24	● 29,30,31	
		Feral cats			● 13,14	● 6,14,24	● 29,30,31	● 34
		Cane toads			● 15			● 35,38
		Dogs / dingoes	● 1,2,3	● 5,7	● 16	● 5	● 30,31	● 34
		Habitat modification	● 37	● 5	● 17,18,19	● 19	● 31	● 34
	Direct human-induced mortality	Road mortality		● 8	● 20	● 8	● 30	● 36
		Poisoning (direct / indirect)		● 9	● 16,21	● 5,9,25,26	● 32	
		Persecution	● 1,4,5,39	● 4,5	● 15	● 5,6,27,28	● 31	
		Disease	● 1,6,40	● 6,10,11	● 6,11	● 5,6,11	● 33	

References:

1 Guiler (1985)
2 Corbett (1995)
3 Jones *et al.* (2003)
4 Johnson and Wroe (2003)
5 Green (1967)
6 Wood Jones (1923)
7 Guiler (1982)
8 Jones (2000)
9 Statham (2005)
10 Hawkins *et al.* (2006)

11 Guiler (1961)
12 Glen and Dickman (2005)
13 Taylor (1986)
14 Rolls (1969)
15 Maxwell *et al.* (1996)
16 Körtner (2007)
17 Belcher (2008)
18 Belcher and Darrant (2006)
19 Jones and Rose (1996)
20 Burnett and Dickman (2008)

21 Belcher (1998)
22 Saunders *et al.* (2006)
23 Burbidge and McKenzie (1989)
24 Jones *et al.* (2004)
25 King *et al.* (1989)
26 McIlroy (1981)
27 Bennett (1990)
28 Backhouse (1843)
29 Morris *et al.* (2003)
30 Orell and Morris (1994)

31 Glen *et al.* (2009)
32 Soderquist and Serena (1993)
33 Abbott (2006)
34 Oakwood (2000)
35 Burnett (1997)
36 Oakwood and Pritchard (1999)
37 Mooney and Rounsevell (2008)
38 Woinarski (2010)
39 Johnson (2006)
40 Paddle (2000)

by remaining relatively fox-free until the late 1990's (Taylor 1986; Short and Smith 1994; Saunders *et al.* 2006). It has been claimed that foxes have had a disproportionately negative effect on mammals within a critical weight range (CWR) i.e. those species with a body mass between 35–5500 g (Burbidge *et al.* 1988; Burbidge and McKenzie 1989; Johnson *et al.* 1989; Johnson and Isaac 2009). Whilst some authors have challenged this supposition (e.g. Cardillo and Bromham 2001; Fisher *et al.* 2003; Abbott 2006), several CWR threatened species have shown marked recovery following targeted fox-control programs (Friend 1990; Bailey 1996; Burbidge *et al.* 1997; de Tores *et al.* 1998; Kinnear *et al.* 1998; Morris *et al.* 1998) or following their reintroduction into areas without foxes (Short *et al.* 1992).

The establishment of foxes in Tasmania presents a very real and imminent threat to the eastern quoll, and one that may already be a contributing agent to their recent decline. At present, foxes remain rare and elusive throughout Tasmania (Saunders *et al.* 2006; Berry *et al.* 2007), although their cryptic nature may contribute to their apparent low densities (Saunders *et al.* 1995). If foxes become established in Tasmania, numerous species that have persisted in the relative safety of Tasmania may suffer the same fate as many of their mainland counterparts (Burbidge and Manly 2002). The eastern quoll is one such CWR species under threat (Mooney *et al.* 2005), with their decline in southern Australia coinciding with the arrival of foxes (Wood Jones 1923). Eastern quolls in Tasmania demonstrate a lack of appropriate anti-predator response to acoustic cues of foxes (Jones *et al.* 2004), further suggesting their vulnerability to the establishment of foxes in Tasmania. Compounding the threat of predation is the inference that competition for dens may be a limiting factor for the eastern quoll (Godsell 1982). This may be further exacerbated with the establishment of foxes, as previously illustrated by the arctic fox (*Alopex lagopus*) following invasion of its range by red foxes (Hersteinsson *et al.* 1989).

1.2.3.2 Feral cats

Whilst cats and quolls have co-existed in Tasmania for many years, some variables could tip the historic balance between these species in favour of cats. Feral cats have been a widespread part of the Tasmanian landscape since European settlement (Hocking and Guiler 1983), even being deliberately released by farmers in an attempt to control rabbit numbers (Bennett 1990). Whilst they are implicated in the decline of numerous species (e.g. Short and Smith 1994; Oakwood 2000) and are known to depredate eastern quolls (mainly juveniles) (Wood Jones 1923; Rolls 1969), cats and quolls have not only co-existed but thrived together for hundreds of years without significant negative effects on either species. Similar co-existence relationships have persisted between mainland native species and feral cats (e.g. Johnson *et al.* 1989; de Tores *et al.* 1998; Abbott 2006), with many of these native species often only declining after foxes became established. However, historical records suggest that feral cats have sometimes acted in conjunction with a range of other variables such as alteration of habitat, drought and disease to contribute to the decline of native taxa (Oakwood 2000; Burbidge and Manly 2002; Abbott 2006). This suggests that variables such as the prolonged drought affecting Tasmania for the past 10 years (Tasmanian Planning Commission 2009) in combination with ongoing habitat changes may have been enough to unsettle the historic balance between these species in favour of cats, possibly contributing to the recent decline in eastern quolls.

1.2.3.3 Habitat loss and changes in land-use

Conversion of land into monocultures such as plantations remove either foraging or denning habitat for eastern quolls and may present a threat for the species. Whilst up to 95% of Australia's woodland and shrubland habitats have been cleared since European settlement, no extinctions have been attributed solely to clearing, although the resultant fragmentation of habitat may have increased the risk of extinction from other causes (Short and Smith 1994). Tasmania has undergone considerable changes to its natural environment during this time (Tasmanian Planning Commission 2009) particularly in areas used for agriculture, with continuous areas of natural vegetation being fragmented into remnant copses interspersed amongst crops and pastures dominated by exotic grasses (Bennett 1990). Despite the effects such drastic

landscape modification may have on many species, the eastern quoll appears to have benefited from much of this change in land-use (Green 1967). The establishment of pastures are typically accompanied by increases in pasture grubs and pests that form a substantial portion of the eastern quoll's diet (Blackhall 1980; Godsell 1983). Whilst these pastures may provide substantial feeding grounds for quolls to hunt by night, during the day they rest in underground dens or hollow logs located just inside the forest margin in adjacent areas of natural bush (Green 1967; Godsell 1983), or in open grasslands if bush habitat is absent (Jones and Rose 1996). Hence, whilst the modification of land for agricultural purposes does not appear to present a high risk to the eastern quoll, conversion of agricultural land or natural bush into plantations removes either foraging or denning habitat for the species, and this may present the main habitat threat for eastern quolls.

1.2.3.4 Road mortality

As roads have been a part of the Tasmanian landscape for many decades, road mortality is unlikely to be a significant contributor to recent statewide declines in eastern quolls. Road mortality has been demonstrated to affect populations locally, with a road-upgrade in 1991 accounting for the temporary extinction of the entire resident population of 19 eastern quolls (and half the resident 39 devils) along the northern entrance into the Cradle Mountain-Lake St. Clair National Park (Jones 1998a; 2000). Traffic slow points and signage were later installed, with the local population re-establishing to 50% of its former level within two years (Jones 2000). Whilst the decline was only temporary, it highlights the susceptibility of the species to road mortality, as quolls are often attracted to the road surface by the congregating insects during summer and the opportunity to scavenge roadkills throughout the year (Jones 2000). Compounding this risk is the eastern quoll's preference for open habitats (Jones and Barmuta 2000) and their use of roads and tracks for travelling long distances (Jones 2000). Whilst road mortality can have a dramatic impact on quoll populations in a relatively short period, it appears that the effects at Cradle Mountain were only felt locally and recovery was reasonably rapid due to the persistence of nearby source populations to replenish roadside sink populations.

1.2.3.5 Poisoning

The non-target effects of 1080 fox baiting on eastern quolls in the landscape is poorly understood. The former practice of controlling rabbits with strychnine in the late 1940s may have resulted in secondary poisoning as eastern quolls scavenged on rabbit carcasses (Statham 2005), however there are no records of eastern quoll numbers from that period. Strychnine has since been replaced with compound 1080 (sodium fluoroacetate) which now presents a novel risk to the eastern quoll through possible non-target poisoning (McIlroy 1981; 1986; King *et al.* 1989). A major reason for the success of 1080 fox-baiting on the mainland is the high tolerance that many native non-target species have to this compound, evolving through their long-term exposure to fluoroacetate bearing plants of the genera *Gastrolobium* and *Oxylobium* which are widespread throughout south-western Australia (King *et al.* 1989). However this native exposure does not extend to Tasmania (King *et al.* 1989), with the eastern quoll being one of several non-target species having a considerably lower tolerance to 1080 and as such, being at much higher risk of poisoning than their mainland counterparts. Operational 1080 fox baiting commenced in Tasmania in September 2002 (Saunders *et al.* 2006), around the same time as eastern quoll numbers appear to have declined. Whilst limited research into the effects on non-target species was carried out in parallel with initial operational baiting programs in Tasmania, most field trials focussed on the risk to spotted-tailed quolls and Tasmanian devils (Fox Eradication Branch 2010a), with no trials performed in areas of medium or high eastern quoll densities (Mooney *et al.* 2005). Accordingly, the likely contribution of 1080 poisoning to the recent decline in eastern quolls is currently unknown.

1.2.3.6 Persecution

Whilst persecution of eastern quolls was common throughout recent history, it seems unlikely that this historic agent of decline would contribute significantly to a modern population-level decline in this species. Historically, the eastern quoll was persecuted as an agricultural pest, both on the mainland (Wood Jones 1923; Lindsay 1962; Bennett 1990) and in Tasmania (Backhouse 1843; Green 1967). Backhouse (1843) reported that in the days of early Tasmanian settlement, eastern quolls were

thought to be so numerous that at one time 600 skins were brought in from hunting on one property in the southern midlands. Green (1967) argued that when predation on domestic poultry and stock became excessive, population control became a necessary part of "good pasture and stock management". The subsequent shrinkage in their range was later attributed to a combination of persecution and destruction of forest habitat associated with spreading settlement (Green 1967). Whilst the species is now legally protected, there may still be cases of eastern quolls being killed, however it seems unlikely that ongoing persecution would be sufficient to have driven eastern quolls to their recent decline.

1.2.3.7 Disease

Pathogens and parasites can be major drivers of population decline in some species. Disease is often considered a normal stabilising occurrence in animal populations (Abbott 2006; Hawkins *et al.* 2006) and has been described by Colebatch (1929) as "one of those inexplicable calamities that now and again decimate wild animal communities." In certain circumstances, however, disease can bring about the rapid decline of a species, as recently evidenced by DFTD in Tasmanian devils (Hawkins *et al.* 2006; McCallum *et al.* 2009) and the Ebola virus in western gorillas (Leroy *et al.* 2004).

Dasyurids host a diverse fauna of helminth, arthropod and protozoan parasites, and whilst many cause observable lesions, the full effects of parasitism often go beyond the visible effects, where they may have adverse effects on the metabolic processes and reproductive success of their hosts (Beveridge and Spratt 2003). Freeland (1993) argued that the majority of Australian mammal extinctions since European settlement reflect the instability of ecosystems that lacked co-evolved host-parasite relationships with introduced species and their naïve hosts. Whilst both introduced and endemic parasites may have deleterious effects on their hosts, no experimental studies have comprehensively investigated their full potential effects in dasyurids (Beveridge and Spratt 2003). Even though parasites and pathogens do not always result in the host's death, the presence of other threats such as nutritional stress or adverse environmental conditions may amplify the effects, leading to population declines.

Toxoplasmosis, caused by the protozoan *Toxoplasma gondii*, is common in marsupials as both a subclinical infection and an overt disease (Munday 1978). *T. gondii* is a common intestinal parasite of cats, with intermediate stages occurring in the tissues of many birds and mammals (Frenkel 1970; Beveridge and Spratt 2003; Holz 2008). Animals contract the disease through exposure to cat faeces, food or water that has been contaminated by cat faeces, or through eating the flesh of animals that contain the encysted parasite in its muscles (Frenkel 1970; Holz 2008). Whilst deaths from toxoplasmosis may constitute a major form of mortality for some native mammals (Obendorf and Munday 1983), affected individuals often die suddenly without clinical signs of illness (Canfield *et al.* 1990a; Oakwood and Pritchard 1999), so the prevalence of afflicted animals may not be evident in the landscape. Furthermore, individuals suffering neurological effects such as paresis may become more susceptible to predation and motor vehicles (Oakwood and Pritchard 1999), effectively reducing the apparent prevalence in wild populations. Whilst the significance of toxoplasmosis in wild dasyurids has not been investigated (Beveridge and Spratt 2003), it was not considered a contributing factor to mortality in northern quolls in the Kakadu region of the Northern Territory (Oakwood and Pritchard 1999). However, the significance of toxoplasmosis in other dasyurids such as the eastern quoll and its contribution to their recent decline has not yet been investigated.

A number of neoplastic conditions have been described in marsupials, with dasyurids appearing to suffer more frequently than other groups (Munday 1978; Twin and Pearse 1986; Canfield *et al.* 1990b). For example, the Devil Facial Tumour Disease (DFTD) currently devastating the Tasmanian devil population (Hawkins *et al.* 2006) is a very rare form of infectious cancer, however the cell line responsible is very unlikely to grow in other species (McCallum and Jones 2006). Whilst most neoplastic conditions historically reported in eastern quolls have been in captive animals from zoological parks (Canfield *et al.* 1990b), a small number of cases have been found in wild quolls (e.g. Twin and Pearse 1986). The potential contribution of neoplastic conditions to the recent declines in eastern quolls is currently unknown.

1.2.3.8 Mesopredator release

The loss of devils due to DFTD has led to suggestions that declining devil numbers may enable feral cats, spotted-tailed quolls and foxes numbers to increase, and subsequently exert increased predatory or competitive pressures on medium-sized prey species (Jones *et al.* 2007) as they have already done on mainland Australia (Burbidge and McKenzie 1989). Spotlight surveys suggest an increase in feral cats has already occurred, although reported increases in spotted-tailed quoll numbers are less convincing (G.Hocking, DPIPWE, unpublished data). An increase in these mesopredators could pose additional threats to the eastern quoll through competition for den sites and increased exposure to novel diseases and pathogens such as toxoplasmosis. The likelihood and extent of these complex interactions are unclear, with research currently underway into the broader ecological impacts of DFTD on Tasmanian ecosystems and marsupial carnivores such as the eastern quoll (T. Hollings, pers. comm.).

1.3 THESIS AIMS

Prior to the present study, no investigation had attempted to evaluate the validity of the decline indicated by the spotlighting data, or to identify likely major drivers of the decline. This information is crucial for the preparation of an effective recovery plan for the species, not only to limit further declines, but also to promote recovery of affected eastern quoll populations in their last remaining stronghold.

Therefore, the aims of this study were two-fold:

1) To measure long-term changes in the size of eastern quoll populations at a number of sites across Tasmania by:
    *   deriving current population abundance estimates at three study sites, and
    *   comparing current results to historical studies to quantify any long-term changes in populations at these sites.

2) Assess eastern quolls for potential factors contributing to population declines by:
    *   examining captured individuals and collecting a range of samples and measurements to help assess body condition, health, reproductive success and population structure
    *   comparing results between periods and sites to identify any spatial or short-term temporal variation in these factors, and
    *   comparing results to historical studies to assess any long-term changes in any of these variables that may correlate with observed changes in local population abundance.

1.4 THESIS OUTLINE

This thesis is presented as five separate chapters.

Chapter 2: General Methods

In this chapter, I describe the study sites, the site selection process, and the fieldwork methodology adopted. I also outline the timing of the replicate surveys performed at each site.

Chapter 3: Measuring long-term declines in eastern quoll populations

In Chapter 3, I investigate the current eastern quoll population status at three study sites, and compare this to historical studies for each site to establish any long-term population changes at each study site. I compare my findings to observed trends in spotlighting surveys and consider the implications of the observed changes for the future viability of the species.

Chapter 4: Factors potentially causing eastern quoll declines

This chapter describes the collection and analysis of a range of morphometric data and biological samples in order to identify factors most likely to have contributed to declines. I compare findings between periods, sites and years to identify significant changes and trends that may suggest potential agents of decline.

Chapter 5: General Discussion

In the final chapter, I draw on the conclusions from chapters 3 and 4 in prioritising the future directions necessary for the management of the species. Current knowledge gaps are discussed, together with recommendations as to where future research should be directed to gain a better understanding of the factors driving population abundance in the eastern quoll.

Chapter 2: General Methods

2.1 STUDY SITES

I performed fieldwork at four study sites across Tasmania (Figure 2.1). The first three sites ("declining sites") were used primarily to collect capture-mark-recapture (CMR) data to assist in confirming any long-term changes in eastern quoll populations at each site. I also collected information on population structure and demographics for each site, and a range of morphometric data and various biological samples were collected to assist in identifying possible causative factors that may be contributing to any population declines at each site. A fourth site was included in the study to provide a spatial comparison for causative factors being analysed at each of the three main study sites.
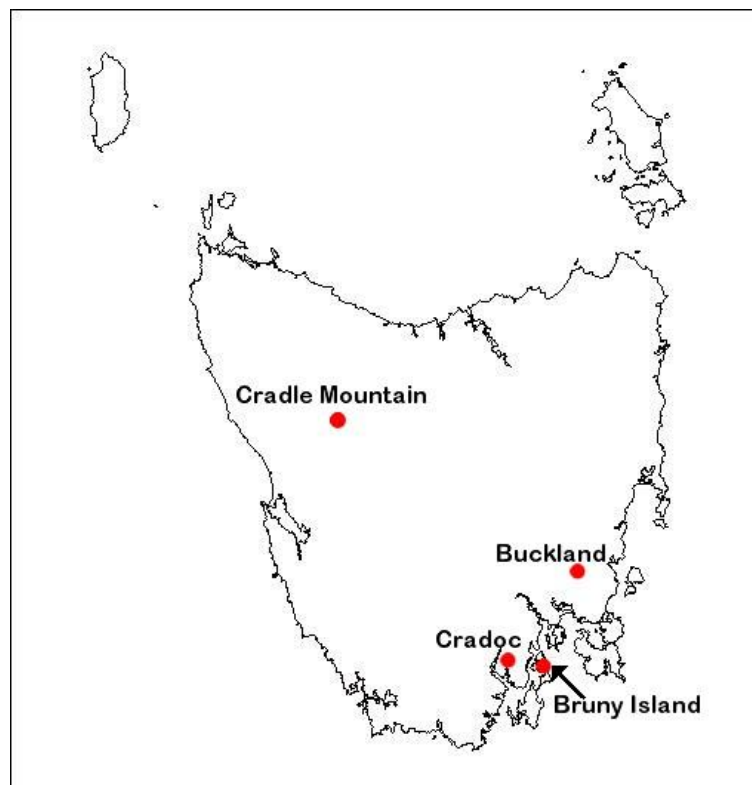
Figure 2.1. Map of Tasmania illustrating location of study sites

2.1.1 Site selection – declining sites

I selected study sites on the basis of three key criteria:

1) availability of historic studies incorporating CMR data, to facilitate long-term
    comparison of eastern quoll populations on or near the site;

2) those prior studies having been undertaken at a time prior to the recent decline as
    suggested by statewide spotlighting trends (i.e. pre-2000), to enable current
    population status to be compared to a pre-decline state; and

3) availability of local annual spotlighting data indicative of long-term declines in
    eastern quoll sightings for comparison to CMR data, to help establish the
    appropriateness of spotlighting as a method for monitoring long-term trends in
    the relative abundance of eastern quolls.

No published study sites met all three criteria. However, a small number of sites met
some criteria to varying degrees, as outlined below.

2.1.1.1 Prior studies

The most comprehensive study on the ecology of the eastern quoll was performed at
Cradoc in south-eastern Tasmania between 1978 and 1980 (Godsell 1982; 1983).
Additional studies were performed on the diet (Blackhall 1980) and seasonal
breeding (Bryant 1986; 1988b; 1992) of the species in 1977 and from 1983 to 1985
respectively. All three studies were performed on adjacent properties located within
a 1.5 km^2 area. Each study collected different types of data for use in CMR analysis,
and given their close proximity and significant temporal spread over a nine-year
period, multiple historic comparisons could be made for the one site.

The Cradle Mountain-Lake St. Clair National Park in the central highlands of
Tasmania was the focus of an extensive study on the guild structure of the large
Tasmanian marsupial carnivores from 1990 to 1992 (Jones 1995; Jones and Barmuta
1998). Eastern quoll abundance was incorporated in this study, and hence raw CMR
data was also available for this site.

All historic studies for Cradoc and Cradle Mountain were performed prior to the
recent decline in eastern quolls. Accordingly, they provide data on the status of their

respective eastern quoll populations prior to the decline, enabling comparisons to be made to a pre-decline state at both sites.

No further published studies could be found that provided the required level of CMR data for long-term comparison. However, the Buckland region was cited in past studies as being an historic eastern quoll "hotspot" (e.g. Godsell 1983; Jones and Rose 1996) with the area used to capture eastern quolls on an ad-hoc basis for use in other studies (e.g. Fletcher 1977; Pearse 1981).

A review of available unpublished studies failed to yield any further comparative data. Whilst the Save The Tasmanian Devil Program (STTDP) retained some data on eastern quolls captured as by-catch in their devil monitoring programs, individuals were not marked in a reliable manner sufficient for CMR analyses (C. Hawkins, DPIPWE, pers. comm.). Furthermore, as the data collected related to the post-decline period for eastern quolls, it could not be used to provide a pre-decline comparison.

2.1.1.2 Spotlighting data

I reviewed long-term DPIPWE spotlighting data for 189 transects statewide (see map in Appendix 1) to identify regions that illustrated a high historic frequency of eastern quoll sightings between 1985 and 2000. Buckland and Cradle Mountain regions, representing only 6% of all regions statewide, yielded over 22% of statewide eastern quoll sightings for this period, indicating a disproportionately high rate of sightings when compared across regions. Further analysis revealed that Buckland and Cradle Mountain regions also contained the two individual transects with the highest number of eastern quoll sightings statewide, accounting for 14% of statewide sightings for the period whilst representing only 1% of transects.

Cradoc, Buckland and Cradle Mountain were selected as the three declining study sites, based on a combination of high frequency of eastern quoll sightings and availability of comparative data for these sites.

2.1.2 Site selection - other sites

In addition to the three main declining study sites, I included a fourth site (Bruny Island) in the study to provide a spatial comparison for potential causative factors being analysed at each of the three main study sites. Bruny Island was selected primarily on the basis of anecdotal evidence from landholders that suggested eastern quolls were still in high numbers locally relative to the other three sites.

2.1.3 Study site descriptions

2.1.3.1 Cradoc

Cradoc is a small rural town located in the Huon Valley, approximately 35 km south-west of Hobart, Tasmania. The study site ($43^{o}06$'13" S, $147^{o}02$'40" E) was situated on a 32 ha private grazing property to the north-east of the town (Figure 2.2). The property had been predominantly used for cattle grazing since the late 1800's. Two lower paddocks were formerly cultivated as apple orchards between 1961 and 1998 but were subsequently removed and returned to pasture. The remainder of the property had remained unchanged since the late 1960's, comprising open cleared areas for grazing surrounded by contiguous areas of remnant eucalypt forest to the northern, eastern and southern peripheries of the property (Figures 2.3 and 2.4).

The remnant dry sclerophyll forest on the study site was dominated by stringybark (*Eucalyptus obliqua*) interspersed with Tasmanian blue gum (*E. globulus*) and white gum (*E. viminalis*). The understorey comprised common native-cherry (*Exocarpos cupressiformis*), silver wattle (*Acacia dealbata*) and silver banksia (*Banksia marginata*), whilst the forest floor was dominated by bracken fern (*Pteridium esculentum*), blackberry (*Rubus fruticosus* subsp. *aggregate*), cutting grass (*Gahnia grandis*) and various rushes (*Lomandra longifolia, Juncus* spp.). Adjacent paddocks were mainly unimproved pasture with large patches of bracken fern and *Juncus* spp..

Figure 2.2. Aerial image of Cradoc area, with study site identified by red outline *(Base image from Google Earth)*.

Figure 2.3. View of Cradoc study site facing north towards bush-pasture interface *(Photo: B. Fancourt)*

Figure 2.4. View of Cradoc study site facing west along northern bush-pasture interface *(Photo: B. Fancourt).*

The property is undulating, with elevation increasing from 60 m asl in the north-west to around 150 m asl in the south-eastern corner of the property. Records for nearby Huonville (9 km north) and Geeveston (11 km south-west) indicated an average of 740 mm annual rainfall, with mean daily minimum and maximum temperatures ranging from 2 and 12°C respectively during winter, up to 10 and 22°C in summer (Australian Bureau of Meteorology 2010 data).

2.1.3.2 Buckland

The small rural village of Buckland is located in the southern midlands, approximately 45 km north-east of Hobart. The study site (hereinafter referred to as "Buckland") was situated along the southern boundary of the Swanport State Forest (42°31'32" S, 147°39'3" E), approximately 11 km to the north-west of the village (Figure 2.5). The state forest was actively harvested to the north of the study site during the study, however, there was no active harvesting in the immediate area of the study site. Along the southern periphery, forest to the east of Buckland Road was protected as an informal reserve. Coupes to the west were classified as future production forest and were last harvested by clearfelling around 1974 (V. Thompson, Forestry Tasmania, pers. comm.). The southern margin of the state forest adjoined expansive agricultural pastures grazed by sheep and hence created a definitive bush-pasture interface that formed the basis of the study area (Figures 2.6 and 2.7).

The state forest was a mix of dry sclerophyll forest and regenerating woodland, dominated by black peppermint (*Eucalyptus amygdalina*) and stringybark (*E. obliqua*) interspersed with cabbage gum (*E. pauciflora*), white gum (*E. viminalis*) and black wattle (*Acacia dealbata*). The understorey comprised prickly box (*Bursaria spinosa*), silver banksia (*Banksia marginata*), common native-cherry (*Exocarpos cupressiformis*), teatrees (*Leptospermum spp.*) and yellow dogwood (*Pomaderris elliptica*), whilst the forest floor was dominated by bracken fern (*Pteridium esculentum*), common heath (*Epacris impressa*) and various rushes (*Lomandra longifolia, Juncus* spp.). Adjacent paddocks were primarily grazing pasture with small patches of bracken fern, *Juncus* spp. and fireweed groundsel (*Senecio linearifolius*).
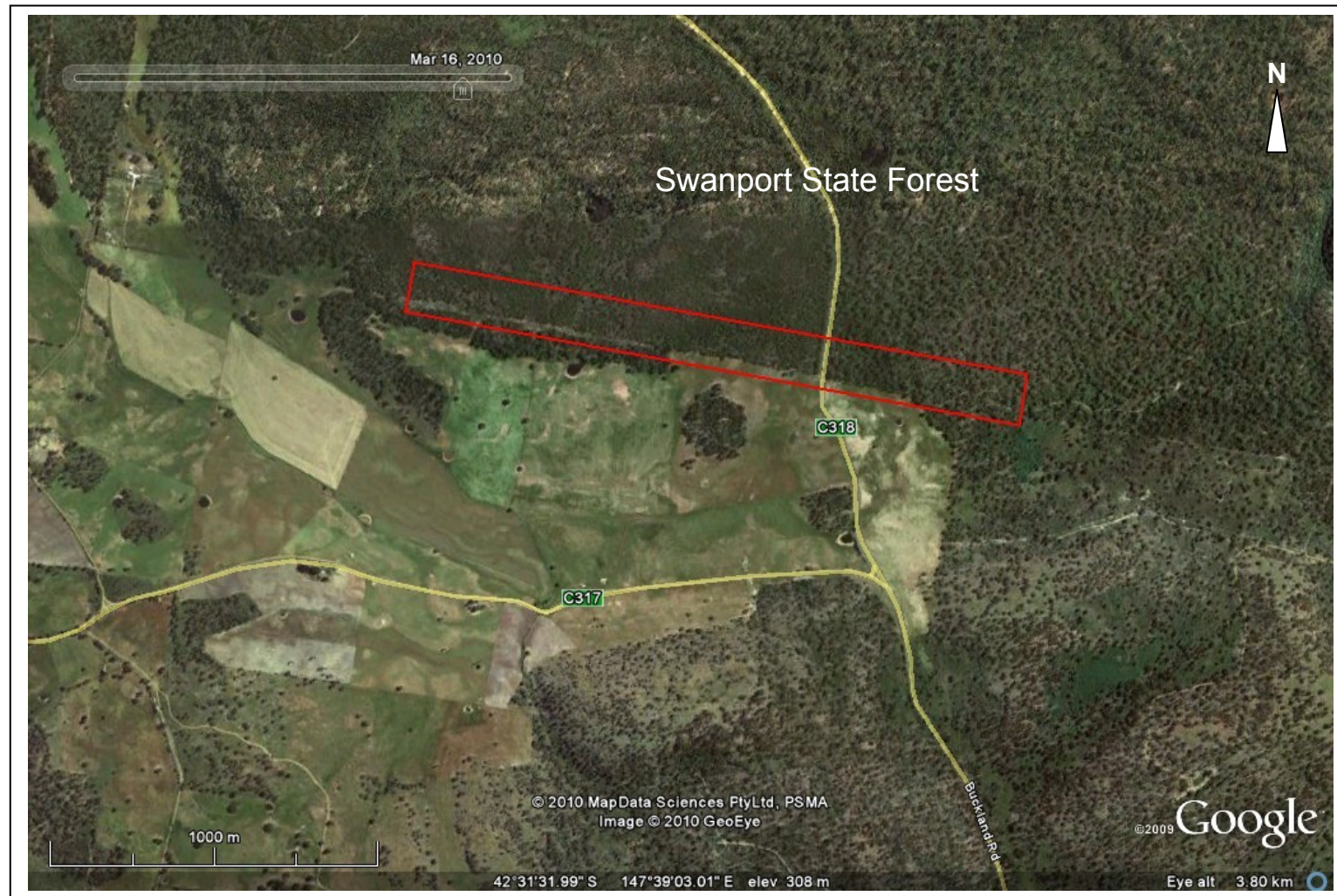
Figure 2.5. Aerial image of Buckland study site along the southern boundary of the Swanport State Forest, with study area outlined in red *(Base image from Google Earth).*

Figure 2.6. Buckland study site, facing west along Cutting Grass Road towards interface between grazing paddocks and Swanport State Forest *(Photo: B. Fancourt).*

Figure 2.7. View of Buckland study site facing east from Buckland Road along the bush-pasture interface *(Photo: B. Fancourt).*

The elevation of the study site is variable, ranging from 300 m asl at Buckland Road up to 320 m asl in the east and 360 m asl in the west. Records for nearby Levendale (5 km west) and Tunnack (16 km north-west) indicate the area receives around 750 mm rainfall annually, with mean daily minimum and maximum and temperatures ranging from 1 and 11°C respectively during winter, up to 9 and 22°C in summer (Australian Bureau of Meteorology 2010 data).

Spotlighting surveys were performed along six separate 10 km transects in the Buckland area each year. Transect routes 2 and 3 intersected adjacent to the study site (see Figure 2.9), rendering these transects the most relevant for comparative analysis in the current study. The numbers of eastern quoll sightings along these transects from 1985-2009 are plotted in Figure 2.8. The graph illustrates two distinct periods – one of historically high eastern quoll sightings (1985-1997) and a more recent period of low sightings (1998-2009), with 1998 marking the point of decline on both transects.
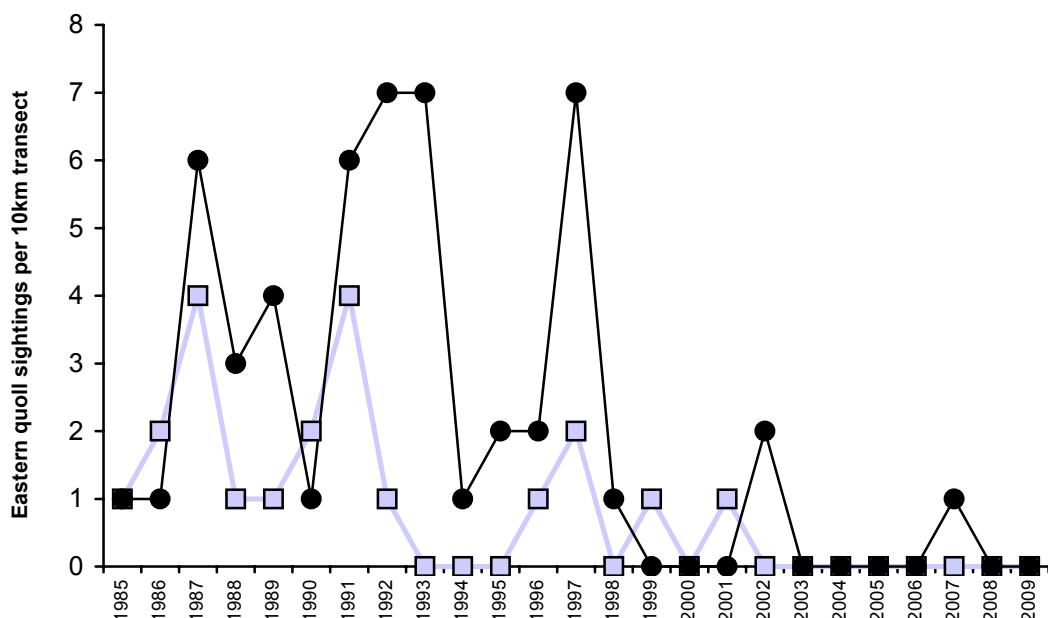
Figure 2.8. Eastern quoll sightings near the Buckland study site (1985-2009). Sightings reflect observations made as part of the DPIPWE annual spotlighting surveys along transect route 2 (grey squares) and route 3 (black circles). Data from earlier years not included here due to differing transect routes prior to 1985. *(Source: G. Hocking, DPIPWE, unpublished raw data).*
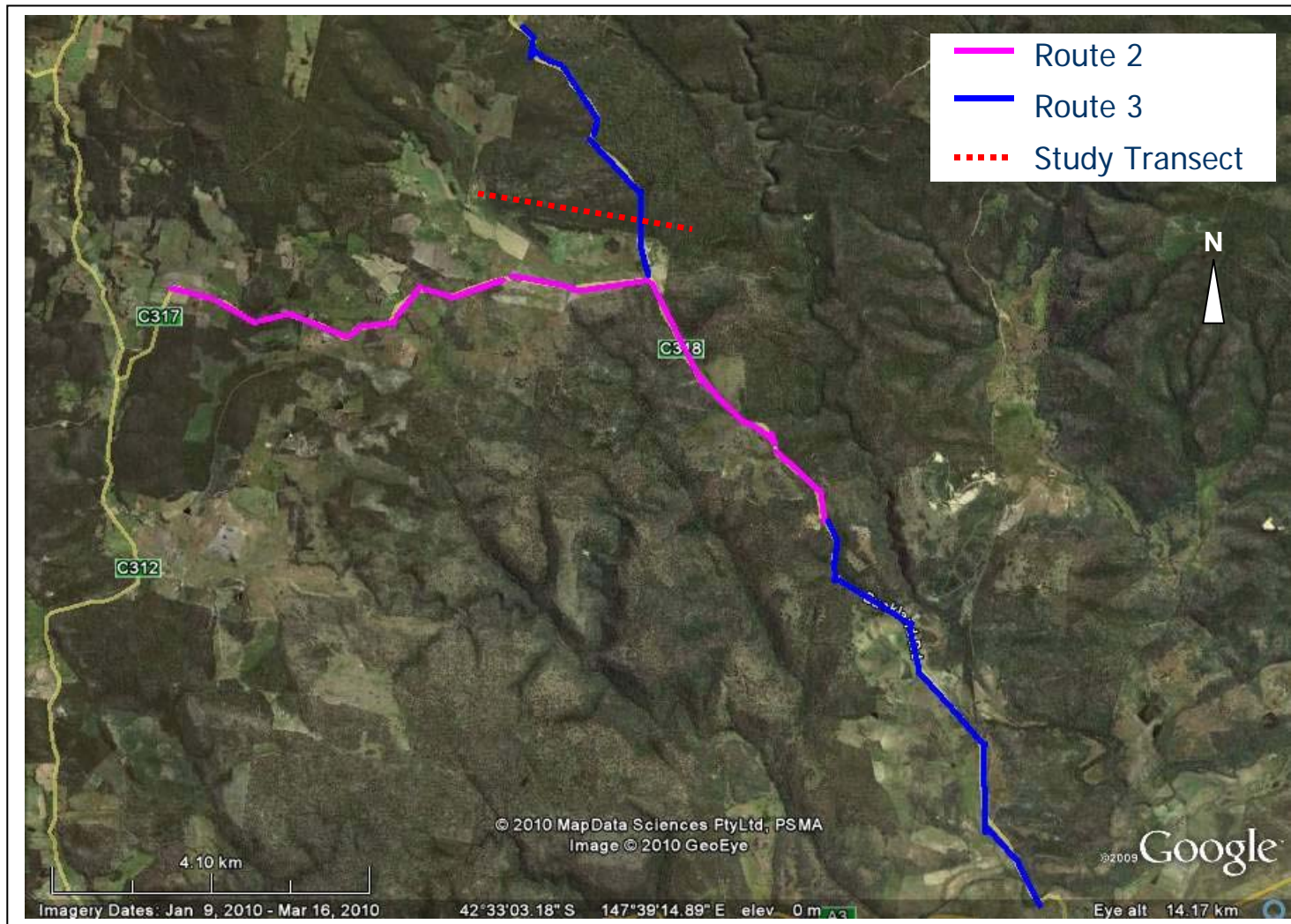
Figure 2.9. Aerial image of area surrounding Buckland study site, illustrating path of spotlighting survey transects in relation to study site location *(Base image from Google Earth).*

2.1.3.3 Cradle Mountain

The Cradle Mountain area refers to the northern part of the Cradle Mountain-Lake St. Clair National Park in the central highlands, forming part of the Tasmanian Wilderness World Heritage Area. The study site (41°35'47" S, 145°55'46" E) was situated at the northern end of the park, covering 4 km immediately outside the northern park boundary and a further 8 km section inside the park, stretching from the park entrance southward to the Dove Lake carpark (Figure 2.10). The section outside the park is increasingly subject to significant human impacts, with remnant natural vegetation interspersed with several properties supporting extensive tourist accommodation, restaurant and café facilities as well as a wildlife park and workshop compounds. Most visitors parked their cars in a large purpose-built carpark at the visitors information centre and tourist transit area located outside the park, designed to encourage tourists to utilise the shuttle buses in order to minimise traffic inside the park. The area around Leary's Corner to the north of the study area had been subject to annual burning, cattle grazing and logging for at least 50 years (P. Hawthorne, DPIPWE, pers. comm.), with only sparse forest and open grasslands remaining. The 8 km stretch of road to Dove Lake inside the park entrance was sealed in 2003 and carried a variable traffic load fluctuating seasonally, with volume peaking over the summer months. The area is dominated topographically by Cradle Mountain (elevation 1545 m asl) to the south of the study site, the steep Dove River Canyon to the east and the vast open buttongrass (*Gymnoschoenus sphaerocephalus*) moorlands of the Vale of Belvoir to the west (Figures 2.11 and 2.12).

Vegetation throughout the study area was a mixture of cool temperate rainforest, wet eucalypt forest, mixed forest, buttongrass moorlands and grasslands. Rainforest communities were variably dominated by myrtle beech (*Nothofagus cunninghamii*), sassafras (*Atherosperma moschatum*), king billy pine (*Athrotaxis selaginoides*) and pencil pine (*Athrotaxis cupressoides*) with a notable absence of understorey layers and a ground covering of various mosses and lichens. Wet eucalypt and mixed forests were generally dominated by alpine yellow gum (*Eucalyptus subcrenulata*), cider gum (*E. gunnii*) or snow peppermint (*E. coccifera*) with understorey, shrub layers and edges dominated by celery-top pine (*Phyllocladus aspleniifolius*),

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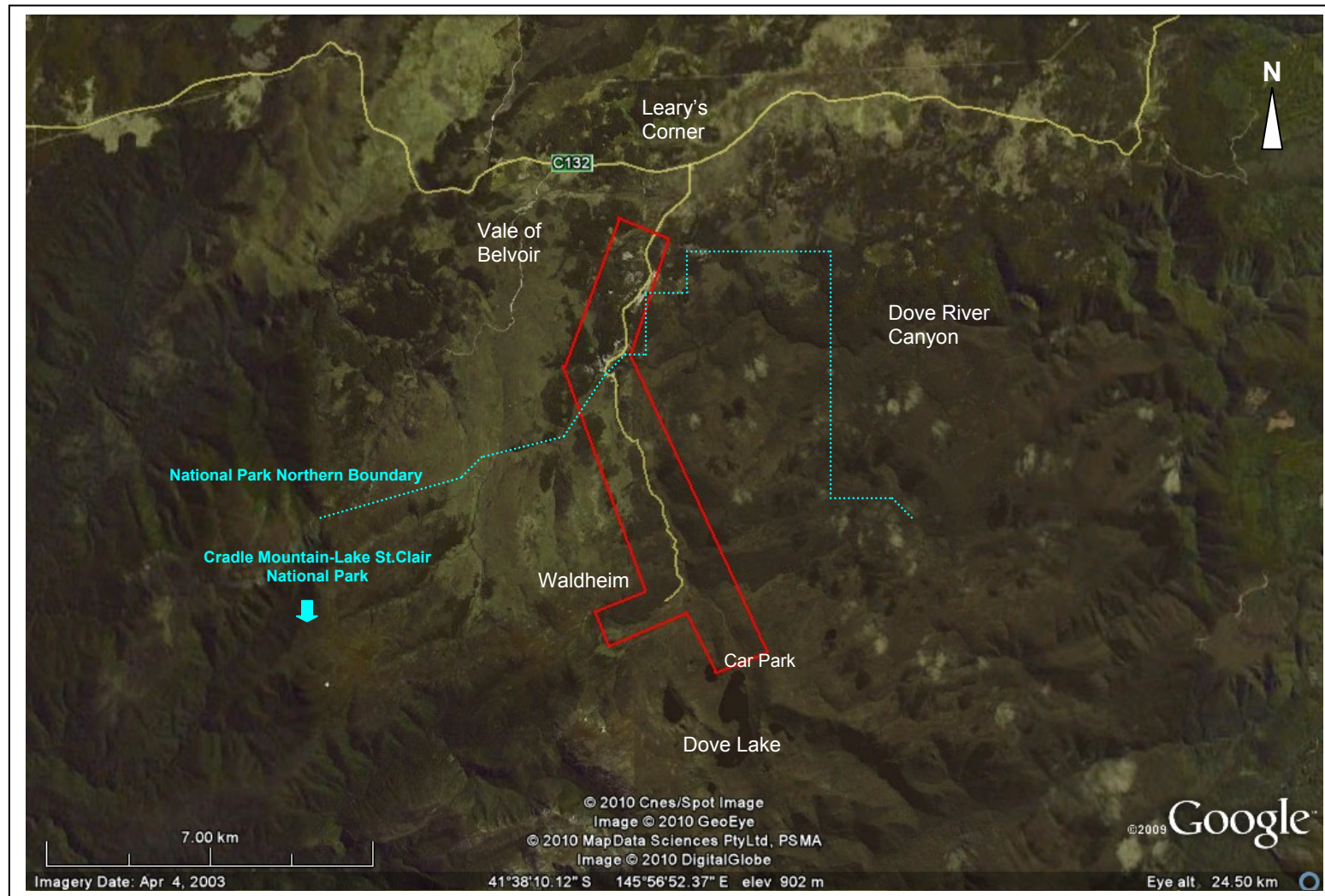
Figure 2.10. Aerial image of Cradle Mountain study site and key landmarks. Study area is outlined in red *(Base image from Google Earth).*

common dogwood (*Pomaderris apetala*), pandani (*Richea pandanifolia*), teatree (*Leptospermum glaucescens*), mountain pepper bush (*Tasmannia lanceolata*), grass trigger plant (*Stylidium graminifolium*), cutting grass (*Gahnia grandis*) and dog rose (*Bauera rubioides*). Open moorlands and grassland areas comprised a mix of large tussock grasses and herbs dominated by buttongrass and Tasmanian snow grass (*Poa gunnii*).

The Cradle Mountain Road runs along the entire length of the study site following a winding, undulating path with elevation ranging from 800 m asl at Leary's Corner in the north to a maximum of 950 m asl at the Waldheim cabins to the west and Dove Lake to the south, although topography varied considerably along either side of the road. The area is considered a wet, sub-alpine region, with records for Cradle Valley (Waldheim) in the centre of the study site indicating a mean annual rainfall of 2830 mm falling over an average 155 days each year. Mean daily minimum and maximum temperatures ranged from -1 and 5°C respectively during winter, up to 4 and 17°C in summer (Australian Bureau of Meteorology 2010 data).

Spotlighting surveys have used a range of eight different transect routes in the Cradle Mountain region over the years, with seven of these used consistently since 1991. The two transect routes closest to the current study site were transect route 1 that ran from Leary's Corner on the Cradle Mountain Link Road south through the northern section of the National Park, and transect route 8 than ran east along the Cradle Mountain Tourist Road from Leary's Corner to the north of the park. Figure 2.14 illustrates the path of these 10 km transects in relation to the study site. The numbers of eastern quoll sightings along these transects from 1985-2009 are plotted in Figure 2.13. The graph illustrates a marked decline in observations, with almost no sightings occurring from 1991 to 2009. Transect route 8 only commenced in 1991, hence no data was available for this transect prior to this date.

Figure 2.11. Setting traps west of Waldheim cabins along interface between wet forest and open grasslands (Fig 2.12 below). Vegetation was dominated by pencil pines (*Athrotaxis cupressoides*) and pandani (*Richea pandanifolia*) *(Photo: A. Fancourt).*

Figure 2.12. Facing south from Waldheim cabins across open grasslands and buttongrass (*Gymnoschoenus sphaerocephalus*) plains towards Dove Lake (not visible in photo) *(Photo: B. Fancourt).*
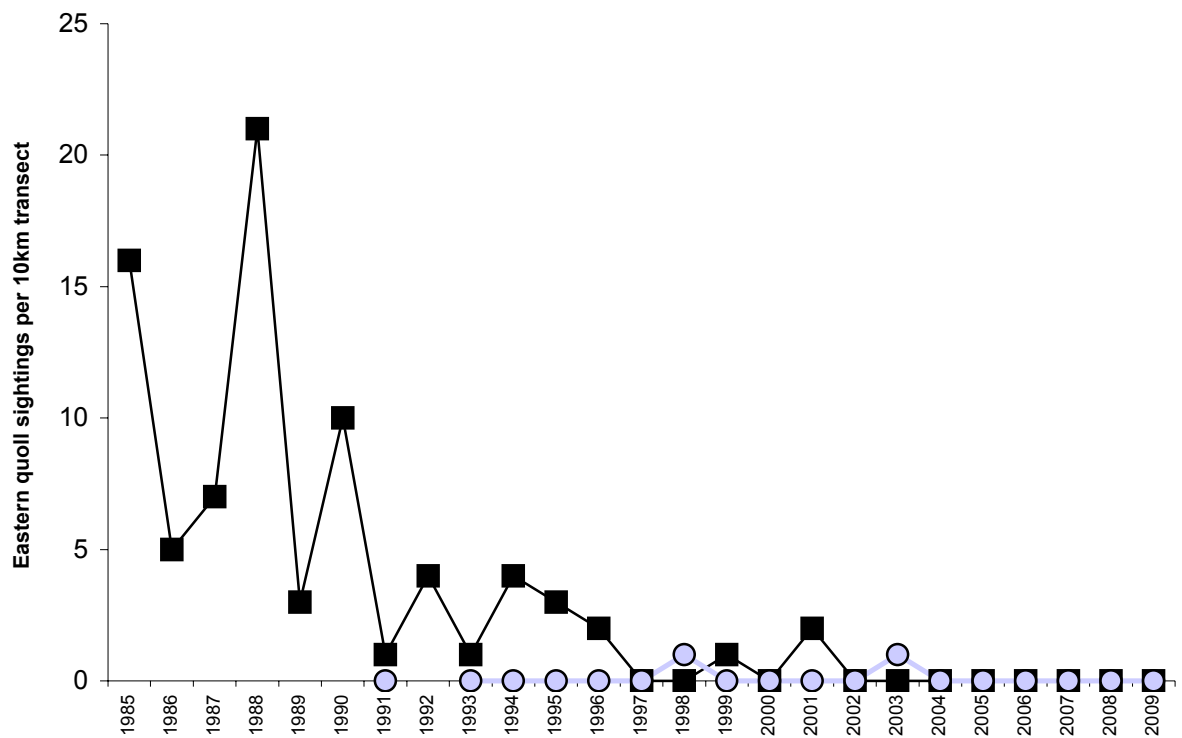
Figure 2.13. Eastern quoll sightings near the Cradle Mountain study site. Sightings reflect observations made as part of the DPIPWE annual spotlighting surveys along transect route 1 (black squares) from 1985 to 2009 inclusive, and transect route 8 (grey circles) from 1991 to 2009 *(Source: G. Hocking, DPIPWE, unpublished raw data).*
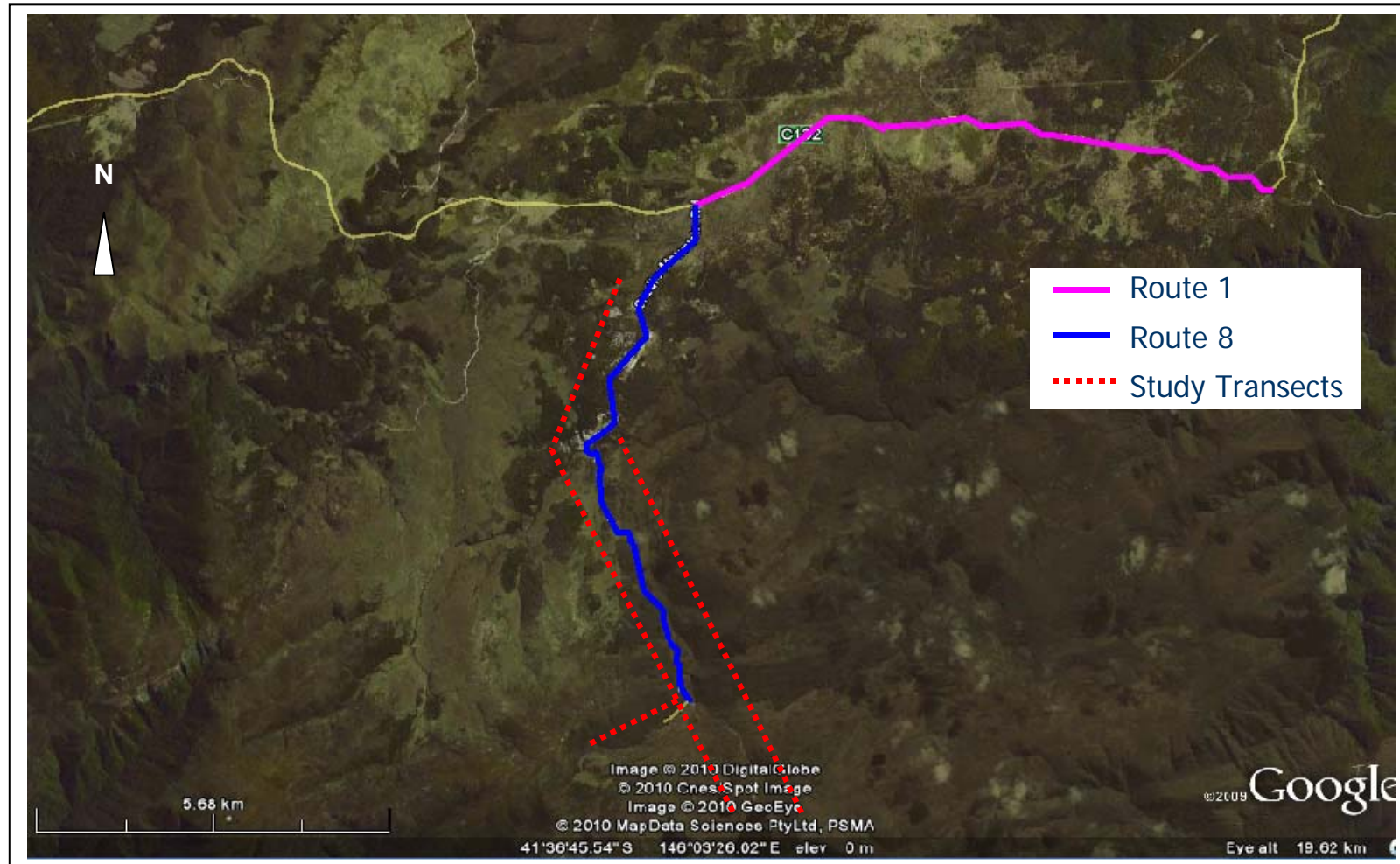
Figure 2.14. Aerial image of area surrounding Cradle Mountain study site, illustrating path of spotlighting survey transects in relation to study site location *(Base image from Google Earth).*

2.1.3.4 Bruny Island

Bruny Island is located off the coast of Kettering, approximately 25 km south of Hobart. The island is split into north and south sections by a 4 km sandy isthmus, with each section experiencing considerably different climates and supporting significantly different vegetation and land-use. The study site (43°09'56" S, 147°21'20" E) was located on the north section of the island, within the Murrayfield sheep-grazing property that occupies 4097 ha of North Bruny (Figure 2.15). The property has been predominantly used for sheep grazing for most of the last century, although a change in ownership and management occurred in 2001, with stocking levels reduced to a more sustainable level soon after (B. Nichols, Murrayfield, pers. comm. 2010). The property comprised large areas of cleared paddocks for grazing, although almost half the property retained copses of remnant woodland and dry sclerophyll forest. Some bush habitat had been fenced to exclude sheep access, however most areas were accessible by stock grazing in adjacent paddocks (Figures 2.16 to 2.19).

The remnant forest was dominated by stringybark (*Eucalyptus obliqua*), white gum (*E. viminalis*) and peppermint gums (*E. amygdalina, E. pulchella*). The understorey comprised silver banksia (*Banksia marginata*), drooping sheoak (*Allocasuarina verticillata*) with patches of southern grass trees (*Xanthorrhoea australis*) whilst the forest floor was dominated by bracken fern (*Pteridium esculentum*), cocksfoot (*Dactylis glomeratus*) and various rushes (*Lomandra longifolia, Juncus* spp.). Adjacent paddocks were primarily improved grazing pasture with patches of *Juncus* spp..

The study site was located on a gently sloping section of the property, surrounded by relatively flat paddocks. Elevation ranged from 30 m asl in the north-western corner of the site up to 80 m asl along the eastern side. Records for nearby Great Bay (5 km south-east) and Bull Bay (8 km north-east) indicated an average of 650 mm annual rainfall, with mean daily minimum and maximum temperatures ranging from 6 and 13°C respectively during winter, up to 13 and 21°C in summer (Australian Bureau of Meteorology 2010 data).

Figure 2.15. Aerial image of Bruny Island study area, with study site outlined in red *(Base image from Google Earth).*

Figure 2.16. Bruny Island study site, looking east towards bush-pasture interface used for eastern trap-line *(Photo: B. Fancourt).*

Figure 2.17. Southern end of eastern trap-line (Bruny Island study site), showing dominant eucalypts and *Juncus* spp. undergrowth. Remnants of a sheep carcass scavenged by eastern quolls and wedge-tailed eagles are evident in the foreground *(Photo: B. Fancourt).*

Figure 2.18. Bruny Island study site, looking west towards bush-pasture interface used for western trap-line *(Photo: B. Fancourt).*

Figure 2.19. Forest vegetation along western bush-pasture interface trap-line (Bruny Island study site), showing prominence of southern grass trees (*Xanthorrhoea australis*) *(Photo: B. Fancourt).*

2.2 FIELD METHODOLOGY

2.2.1 Trapping

Current study methodology

Eastern quolls were surveyed using live capture and release. Standard PVC pipe devil traps (315 mm diameter x 875 mm length) (N. Mooney and D. Ralph, unpublished) were used in preference to wire mesh cage traps to reduce the risk of injury to the animal (such as canine breakage) and to provide increased insulation and protection from adverse weather conditions and predators. The PVC pipes also enabled ease of cleaning to reduce the risk of disease transmission which was considered a high risk during this study, especially given that the Devil Facial Tumour Disease (DFTD) was known to be prevalent at three of the four study sites.

Traps were baited with strips of lamb heart tied securely to one end of a piece of biodegradable sisal inserted through the top of one end of the trap, with the string running along the outer top surface of the trap and tied to a trigger pin inserted through the trap door at the other end of the trap (Figures 2.20 to 2.22). The trigger pin was lubricated with petroleum jelly to increase the sensitivity of the trigger point and reduce the likelihood of an animal taking a bait without triggering the trap door closure. During July, traps were lined with straw (Cradoc and Buckland) or cotton waste/nesting material (Cradle Mountain) to provide additional insulation and bedding material, predominantly for nursing mothers.

Traps were placed just inside the bush perimeter along a bush-pasture interface where possible, positioned with the rear of the trap pushed into dense vegetation, against tree stumps or under fallen logs, and secured in place by placing several rocks along each side and to the rear of the trap (Figure 2.23).

Figure 2.20. Set devil trap, illustrating bait and string trigger mechanism. Bait is tied to end of string through hole in top rear of trap (right of picture). String is then tied to trigger pin inserted through hole in trap door (left of picture) *(Photo: B. Fancourt).*

Figure 2.21. Close-up of trigger mechanism on devil trap. Animal taking bait from inside the trap pulls on string, pulling trigger pin (A) out of door, allowing trap door to close *(Photo: B. Fancourt).*
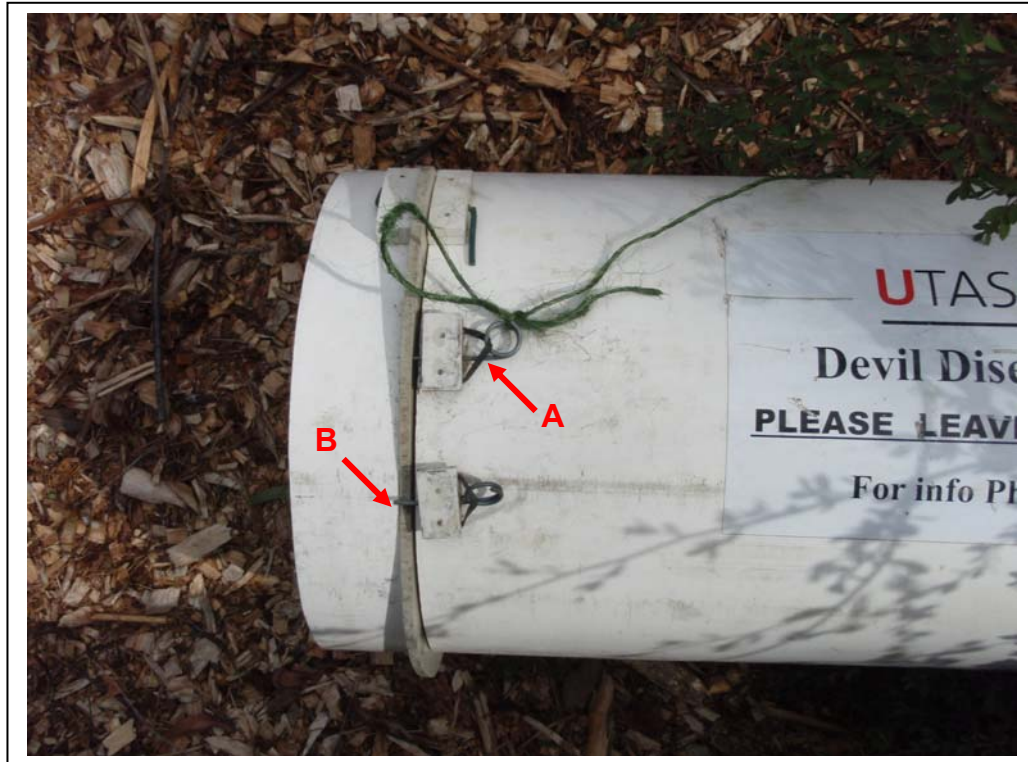
Figure 2.22. Close-up of sprung trap. Note trigger pin (A) has been pulled out of cage door and locking pin (B) has locked trap door closed, preventing animal from escaping *(Photo: B. Fancourt).*

Figure 2.23. Traps were placed with the rear of the trap in thick vegetation for protection and positioned close to tracks used as animal thoroughfares wherever possible *(Photo: B. Fancourt).*

Traps were cleared in the early morning each day. Captured individuals were processed as outlined in 3.2.1 and 4.2.1, then released immediately at the point of capture. Mothers with pouch young were taken up to 10 m further into the bush for release, to provide the animal with more dense vegetation cover to minimise the need to run for cover and consequently reduce the risk of pouch young detaching.

Successful traps were washed with water and a hand-held scrubbing brush to remove any gross biological contamination (faecal matter, urine, blood, etc.), rinsed then disinfected with F10 (Health and Hygiene Pty Ltd, Sunninghill, South Africa). Traps were re-baited with fresh bait and string and filled with clean straw or bedding material, then reset.

Historic studies methodology

There were several differences in trapping methodologies between the current study and historical studies, including differences in trap design and construction, trap trigger mechanisms and type of bait used. These variables may have contributed to a difference in quoll trappability and hence any observed reduction in trap success may have been a function of reduced trappability, fewer quolls, or a combination of both.

Whilst the traps used in the current study were constructed of PVC pipe, all historic studies used cage traps constructed of wire mesh. The different trap design may have reduced capture probability, essentially exaggerating any real decline. Cage traps used in previous studies were generally covered with plastic, hessian sacks or vegetation to mask the appearance of the cage and to provide added protection to the trapped animal. Traps in the current study were hidden in vegetation wherever possible, similarly masking the external appearance of the trap. Given the species prominence around human infrastructure such as huts, houses and wood sheds (Wood Jones 1923; Green 1967; Jones and Rose 1996) and their boldness around humans (Jones and Rose 1996; pers. obs.), it is unlikely that treading on a foreign substrate such as PVC would reduce their capture probability any more than treading on a wire mesh cage floor. In fact, the PVC traps may have resulted in increased trappability by providing increased protection from predators through reduced

visibility. For example, devils which could see through the wire cage walls were known to dig around cage traps in attempt to get to the trapped eastern quoll inside, (M. Jones, pers. comm.) causing undue stress to the trapped quoll and almost certainly reducing the future trappability of that quoll.

There is as yet no indication that the differences between trapping methods for the past and current studies would have a significant effect on trap success. Lachish (pers. comm.) used Program MARK to assess whether capture probabilities differed between years where cage traps were used and those where PVC traps were used. No significant differences in capture probabilities were found for devils. Whilst similar testing has not been performed for eastern quolls, there was no expectation that capture probabilities would differ significantly between trap types (M Jones, pers. comm.).

Notwithstanding differences in trap construction, the PVC traps used a "bait and hook" or "bait and string" type trigger mechanism (BH), whereas the cage traps used either a bait and hook arrangement or a treadle type trigger mechanism (TT). Bryant (1988b) used a mix of both trap types, although the exact proportions of each trap were not recorded (S. Bryant, pers. comm.). The different trigger mechanisms could result in different trap success, with behavioural responses of eastern quolls resulting in different capture probability between trap types. For example, if a quoll enters a BH type trap to investigate the bait but decides not to take it, it may exit the trap without triggering the trap and would not be captured. However, in a TT trap, once the quoll steps on the treadle, the trap is triggered and the animal is captured regardless of whether it takes the bait. This could result in a higher probability of capture in a TT trap compared to a BH trap. However, recent mammal surveys performed on Bruny Island returned similar trap success using TT traps (32.4%) (DPIPWE unpublished data) and PVC devil traps (34%) (current study). Both trap types were located in close proximity over the same nights, suggesting that different trap types do not significantly affect capture probabilities for eastern quolls.

The type of bait used in the traps also differed between studies. A variety of different baits has been used in historic studies, ranging from beef/sheep liver (Godsell 1983; Jones 1995; 2000), lamb scraps (Blackhall 1980), beef/lamb hearts (Jones 2000; this study), cockerel chickens (Bryant 1988b) and unspecified raw meat (Pearse 1981). Whilst trapping eastern quolls on omnivore baits such as peanut butter/oats/vanilla essence (Flynn *et al.* in press) indicates their willingness to investigate and take a range of bait types, studies targeting eastern quolls have predominantly used meat baits. As scavengers, eastern quolls appear to be attracted to any sort of meat, and hence differences between types of meat bait is unlikely to have had any significant negative impact on capture probabilities.

2.2.2 Spatial replication

To ensure comparability of data, nightly trap effort and intensity for each site was based on that used in prior studies for each site. Spatial replicates were performed at the four sites as outlined below.

2.2.2.1 Cradoc

I set twenty traps per night for five consecutive nights per session, giving a trap effort of 100 trap nights per session. Traps were placed just inside the forest edge along the bush-pasture interface to the north and south of the property. The trap line covered a linear distance of around 2 km and encompassed a 15 ha area of the property. Trap spacing was strategic with traps being placed near cleared tracks used as animal thoroughfares, near logs and stumps suitable for den sites, and in thick clumps of vegetation. Accordingly, trap spacing varied from 20 m between traps up to 130 m between traps in some places. The nightly trap effort, linear distance and strategic trap placement closely followed that adopted by Bryant (1988b).

2.2.2.2 Buckland

In the absence of any comparative studies for this site, I replicated the trap effort used at Cradoc for the Buckland study site. Given the similar climate, land-use and vegetation at these two sites, replicating the Cradoc trap effort provided an opportunity to perform spatial comparisons between the two sites. I set twenty traps per night for five consecutive nights per session, giving a trap effort of 100 trap nights per session (two traps were stolen on the fifth night of the March trapping session, reducing the trap effort for this session to 98 trap nights). Traps were placed up to 50 m inside the forest edge along the bush-pasture interface running east-west along the southern boundary of the state forest. The trap line covered a linear distance of around 2 km and encompassed an area of 15 ha. Trap spacing followed the strategic approach used at Cradoc, with trap spacing varying from 50 m between traps up to 140 m between traps in some places.

2.2.2.3 Cradle Mountain

I set thirty traps per night for five consecutive nights per session, giving a trap effort of 150 trap nights per session. Traps were placed just inside the forest edge along interfaces between buttongrass moorlands or open grasslands and adjacent forest. The trap line covered a linear distance of around 12 km commencing at the Cradle Mountain Chateau to the north and stretching to Dove Lake in the south and the Waldheim cabins to the west (see Figure 2.10). The trap line followed Cradle Mountain Road, Connells Avenue and Lake Dove Road, with traps being well hidden in vegetation up to 50 m off the road along both sides of the road, encompassing a total study area around 20 km^2. As for all sites, trap spacing was strategic rather than evenly spread, with traps being placed near cleared tracks used as animal thoroughfares, near logs and stumps suitable for den sites, and in thick clumps of vegetation. Trap spacing varied from 20 m between traps to a maximum of around 2500 m between traps (the latter spacing only occurring in one location due to an extensive stretch of steep inaccessible rainforest not used as part of the 1991 study). The nightly trap effort, linear distance and strategic trap locations closely followed those adopted by Jones (1995).

2.2.2.4 Bruny Island

As this site was only used as a spatial comparison, trapping effort replicated that used at Cradoc and Buckland due to the similar climate, vegetation and land-use across these three sites. Twenty traps were set per night for five consecutive nights, giving a trap effort of 100 trap nights. Traps were placed up to 50 m inside the forest edge along the bush-pasture interface to the east and west of the study area. The trap line covered a linear distance of around 2 km and encompassed an area of around 15 ha. Strategic trap spacing followed that used at Cradoc, with trap spacing varying from 70 m up to a maximum of 150 m between traps.

2.2.3 Temporal replication

Trapping was performed for 5 consecutive nights at each site, with replicate trappings sessions performed throughout 2010 as outlined in Table 2.1.

Table 2.1. Schedule of 2010 trapping sessions and trap dates for each study site.

Study Site	March	May	July	August
Cradoc	15th March to 20th March	16th May to 21st May	13th July to 18th July	
Cradle Mountain	21st March to 26th March	22nd May to 27th May	19th July to 25th July *	
Buckland	27th March to 1st April	28th May to 2nd June	26th July to 31st July	
Bruny Island				22nd August to 27th August

* Heavy frost overnight on 20th July resulted in 11 traps being frozen open and baits taken without animal capture. Accordingly, data for this day only was excluded and an additional night added to the end of the session to give 5 complete data nights.

Chapter 3: Measuring long-term declines in eastern quoll populations

3.1 INTRODUCTION

3.1.1 *Measuring population declines*

Population declines can be classified into two main categories: 1) a temporary fluctuation in numbers from which the species would be reasonably expected to recover in time without intervention; and 2) a sustained decline from which the species is unlikely to recover without timely intervention. The latter is of more concern for the ongoing viability of a species and requires an understanding of the magnitude of decline, the identification of any agent(s) of decline, and the appropriate management of those agents and the species in order for it to recover.

Population estimates and monitoring of population trends are required to identify whether a declining species is under threat (Clarke *et al.* 2003). Such estimates underpin many of the International Union for the Conservation of Nature (IUCN) criteria for listing a species as threatened, which stipulate that a declining population reduce by more than 20% (vulnerable), 50% (endangered) or 80% (critically endangered) over 10 years or three generations, whichever is the longer (IUCN 2001). This information then forms the basis of recovery action planning and the development of formal recovery plans for the species (Foin *et al.* 1998).

To measure a population decline, the current population abundance must first be established, and then compared to the population's historical abundance. Caughley (1977) outlined three ways of measuring population abundance: the number of individuals in a population, the number of individuals per unit area (absolute density), or an index of population abundance at a point in time relative to that at some other time (relative abundance). For many species, an accurate estimate of population size or absolute density is difficult to obtain due to the considerable

investment of time and resources (Witmer 2005) and the inability to meet assumptions necessary to estimate population size (Caughley 1977). To assess whether a species is in decline, an index of relative abundance will often suffice to measure trends over time.

Witmer (2005) argued that while indices are generally easier to obtain than other abundance measures, they are also influenced by many unknowns. For example, a key assumption underlying the use of an abundance index is that the index is proportional to the abundance, and that the relationship is constant (Caughley 1977), yet often this relationship or how the relationship may change over space and time is unknown.

So given a range of necessary assumptions and the plethora of indices adopted in wildlife surveys, which index do we use? Engeman (2005) lists the desirable qualities for an index as being: practical to apply, sensitive to differences in population size, precise (including an inherent estimate of variance) and robustness (burdened with as few assumptions as possible about the data structure and the distribution of the observations). Further complicating the decision is the reality that cost effectiveness must often be weighed against qualities such as precision (e.g. Gese 2001) whilst different methods may prove better or worse under different conditions, at different locations and at different times (Southwell and Fletcher 1993; Edwards *et al.* 2000).

Selection of a method should also be influenced by a range of variables pertaining to the species or taxa of interest, including: dietary and habitat preferences, home range size, distribution, behavioural attributes and body size (Clarke *et al.* 2003; Garden *et al.* 2007). For example, top predators are often cryptic, nocturnal species that generally occur at low densities over large home ranges, making them inherently difficult to monitor with intensive methods such as trapping (Green and Young 1993; Wilson and Delahay 2001). Edwards *et al.* (2000) compared two methods of estimating the relative abundance of two low density carnivore species (dingoes (*Canis lupus*) and feral cats (*Felis catus*)) and found passive-track surveys were more

time-efficient and offered higher precision than spotlighting surveys. However, under suitable conditions with experienced personnel, spotlighting has been found to be an effective method for deriving estimates of relative abundance for nocturnally active carnivores such as red foxes (*Vulpes vulpes*) (Weber *et al.* 1991), striped skunks (*Mephitis mephitis*) (Schowalter and Gunson 1982) and black-footed ferrets (*Mustela nigripes*) (Campbell *et al.* 1985) as well as certain higher density nocturnal mammals such as rabbits (*Oryctolagus cuniculus*) (Poole *et al.* 2003), squirrel gliders (*Petaurus norfolcensis*) (Goldingay and Sharpe 2004) and greater gliders (*Petauroides volans*) (Lindenmayer *et al.* 2001).

Depending on the ecological objective and the species of interest, a combination of methods may be necessary to measure a decline. For example, to assess the impact of the Devil Facial Tumour Disease (DFTD) on the Tasmanian devil (*Sarcophilus harrisii*) population, Hawkins *et al.* (2006) incorporated a combination of spotlighting survey data, live trapping data, roadkill post-mortem data and anecdotal evidence, with the trapping and spotlighting data being used to assess the impact of the disease on devil populations. The relationship between devil spotlighting sightings and devil density has not been quantified, but trends identified in spotlighting data appeared consistent with findings from other methods such as live trapping, suggesting that spotlighting surveys may be an appropriate method for detecting trends in this species. Whilst the statewide spotlighting data indicated overall and regional population declines, trapping data provided more detailed information on prevalence and dynamics at the local level, with both techniques pointing to dramatic declines in areas where the disease was first observed (Hawkins *et al.* 2006). In terms of assessing the extent of the decline, the spotlighting data provided an important long-term picture over a broad geographic area, enabling detection of regional variation in abundance that could be correlated to variation in DFTD levels.

Detection success and precision for a particular taxon may vary considerably between survey methods (Witmer 2005; Garden *et al.* 2007). To establish the most appropriate method to measure population abundance and any associated declines,

consideration needs to be given both to the ecology of the species, and to testing and comparing different methods to assess which is more appropriate for the target species.

3.1.2 *Measuring long-term declines in eastern quoll populations*

As the eastern quoll has historically been considered widespread and common throughout Tasmania, there has been limited long-term monitoring of eastern quoll populations over past decades. Whilst live-trapping has been used in a limited number of ecological studies to monitor eastern quoll abundance, monitoring was generally restricted to a maximum 2.5 year period. Furthermore, studies were limited spatially to very localised populations, with most studies performed in the Cradoc region of south-eastern Tasmania (e.g. Blackhall 1980; Godsell 1982; Bryant 1988b) and one additional study performed at Cradle Mountain in the central tablelands of Tasmania (Jones and Barmuta 1998). With the last detailed study performed almost 20 years ago, there have been no recent studies for monitoring abundance of eastern quolls at either a local or widespread spatial scale.

A small number of eastern quoll records have been collected by a few individuals and agencies over recent years, however much of it is of limited use to monitoring long-term trends in eastern quoll populations. Since its formation in 2004, the Save the Tasmanian Devil Program (STTDP) has collected data on eastern quolls trapped as by-catch at a number of sites as part of their ongoing devil monitoring program. However, as outlined in section 2.1.1.1, the method used to mark quolls was not reliable enough for CMR analysis, nor does it provide a baseline status prior to the apparent decline indicated by the spotlighting data. Similarly, eastern quoll observations recorded in the Tasmanian Natural Values Atlas database (www.naturalvaluesatlas.tas.gov.au © State of Tasmania) incorporate one-off sightings by researchers and members of the public. However, often these people have no reliable method to enable them to distinguish between individuals and hence there is no control over possible repeat sightings of the same individuals by different observers. This limits the application of such observations to measures such as

presence/absence, range and distribution, with little value to abundance or density estimates necessary to assess long-term population changes. They may, however, provide useful anecdotal evidence to supplement quantitative data at some locations.

The only long-term monitoring of eastern quoll populations in Tasmania has been through the annual DPIPWE statewide spotlighting surveys. In evaluating whether these surveys are an appropriate method for monitoring long-term trends in eastern quoll populations, three key considerations must be explored. Firstly, a thorough understanding of the species to determine whether there are any aspects of its ecology that may affect detection probability and possibly render it unreliable for monitoring by means of vehicle-based road spotlighting transects. Secondly, whether any factors would result in variable reliability of observations between years and hence raise doubt as to the validity of any long-term trends identified by the surveys. Finally, whether the use of alternative survey methods to establish long-term changes in eastern quoll populations identifies comparable long-term trends to those identified by the spotlighting surveys. If different methods yield similar results, this would *prima facie* suggest that spotlighting surveys appear to be a reasonable method for monitoring the species such that long-term trends may be identified from appropriate analysis of the observation data so obtained.

Eastern quolls are nocturnal predators that traverse the landscape using roads and tracks (Jones 2000; pers. obs.), lending themselves to detection using road-based spotlighting surveys. They are regularly observed emerging from around dusk through until around midnight to forage and hunt (Blackhall 1980; Jones *et al.* 1997; pers. obs.) suggesting they would be readily observed during surveys performed at these times, such as those performed by DPIPWE. However, eastern quolls are commonly associated with bush-pasture interface habitat (Godsell 1983) that does not always coincide with roads and tracks along which surveys are performed. Whilst use of road-based transects may not be ideal for estimating population abundance, the use of the same permanent transects between years ensures any road-bias remains constant between years, and hence the transect position is unlikely to affect any long-term trends in relative abundance detected in the data.

The timing of juvenile dispersal should also be considered in comparing spotlighting data between years. The annual dispersal of juveniles during summer results in a marked increase in populations from early November through to around February (Godsell 1983; Bryant 1988b), creating a seasonal spike in numbers. As DPIPWE spotlighting protocols stipulate that surveys be carried out between the third week of November and the end of December each year (where possible), this ensures that surveys will always be performed during the juvenile dispersal period when population numbers are at their highest. Whilst very few years had surveys performed outside of this period, caution must be taken in comparing data from such years to ensure fluctuations are not merely a function of the survey falling before, during or after the period of dispersal.

As with any long-term survey method, various factors may result in significant interannual variation in reliability of observations. Whilst the DPIPWE surveys follow a rigid set standardised procedures (as outlined in section 1.2.1), unforeseen logistical problems will inevitably lead to occasional deviations from protocols. Different observers will vary in their experience, resulting in an element of observer bias between transects and between years. Climatic factors such as high rainfall in some years may be followed by an increase in vegetation height and density, reducing the ability of the observer to detect species away from the immediate roadside. Conversely, drought years may lead to herbivores concentrating along road-edges where food resources are often more plentiful due to water run-off from the road (Forman and Alexander 1998; Klöcker *et al.* 2006). Increases in roadkilled herbivores may follow, leading to greater eastern quoll activity along roadsides where they are attracted to verges to scavenge on roadkills (Jones 2000). Sightings in such years may be inflated due to the change in spatial distribution of quolls away from usual feeding areas to road edges where they are more visible to the observer. Furthermore, changes in local council protocols regarding the removal of roadkills over the years may also contribute to fluctuations in sightings of scavengers such as quolls along road transects.

Whilst standardising survey methodology will considerably reduce bias and variability of observations between transects and years, the extent to which all of these factors may be controlled is questionable, raising concern as to how much reliance may be placed on any resulting trends highlighted by such a monitoring approach. Given the recent decline in eastern quoll observations suggested by the long-term spotlighting data (Figure 1.2), could this be confidently interpreted as a true decline, and not merely a function of inconsistencies between years?

To increase confidence in the ability for spotlighting to accurately reflect changes in eastern quoll populations, trends should ideally be compared to those detected using alternative approaches such as live-trapping to see if both methods yield similar trends. Unfortunately, most studies involving the live-trapping of eastern quolls were performed prior to the 1985 standardisation of spotlighting protocols, preventing any comparison of trapping results to spotlighting data. However, the quantitative data collected through these studies does provide the opportunity to replicate these studies at those sites, and to compare trapping results between studies to identify any long-term population changes. This will enable comparison of long-term trends obtained through both trapping and spotlighting data to establish if the two methods yield consistent results, thus providing increased confidence that spotlighting surveys will detect such trends in this species.

Accordingly, the aims of this part of the study were to:
- replicate prior trapping studies at a number of sites
- compare trapping results from the current study to historic studies in order to establish any long-term changes in eastern quoll populations at those sites, and
- compare trends identified through trapping to those evident in the DPIPWE spotlighting data to establish if both methods yield similar trends.

3.2 METHODS

3.2.1 Microchipping

Individual eastern quolls were trapped at each study site using live capture and release as described in section 2.2.1.

Each trapped individual was transferred to a polyester-fleece handling bag and scanned with an RS200 hand-held ISO compatible RFID compact reader (Allflex Australia, Capalaba, Queensland) to check for the presence of any existing microchip. If the animal had not been previously microchipped, an Allflex ISO compliant FDX-B transponder (passive integrated transponder (PIT) tag, or "microchip") was inserted subcutaneously between the shoulder blades at the back of the neck along the dorsal midline, and the unique 15-digit microchip number was recorded. Once processed (as outlined in section 4.2.1), the animal was released at the point of capture.

I repeated this process each morning for each trapping session, resulting in a capture-recapture history for each individual quoll at each site for each trapping session.

3.2.2 Data analysis

For each of the three declining sites, I established long-term changes in numbers of eastern quolls trapped by comparing results obtained in the current study to those obtained during prior studies (where available). In the absence of comparative historic studies at Buckland, results from the current study were considered in light of available anecdotal evidence for the area. All statistical analyses in this chapter were performed using statistiXL version1.8 (http://www.statistixl.com) with minimum significant p-values at $\alpha \leq 0.05$.

3.2.2.1 Capture-mark-recapture (CMR)

The current study design was formulated to enable CMR data to be analysed using the various models within Program MARK (White and Burnham 1999) in order to

derive absolute population abundance estimates at each site for both the current and previous studies, and to quantify any significant long-term changes between the two studies. The three primary trapping sessions, each containing five secondary sampling periods, were designed to meet the minimum requirements of analysis under both the closed population models (Otis *et al.* 1978) and the robust open population model (Pollock 1982). However, given the downward trend evident in the spotlighting data, I expected that only low numbers of individuals may be captured at each site, resulting in low sample sizes that may not facilitate analysis under any of these models.

Whilst the problem of low sample sizes can sometimes be overcome through an increased sampling effort (Krebs 1999) (e.g. increased number of traps, trap nights or trapping sessions), I was unable to do this in the current study due to the need to replicate the trap effort used in previous studies, in order to render the data comparable to those studies. Pooling capture details for both sexes would increase the number of data points and potentially facilitate such analysis, however I did not consider this appropriate given the ecology of the species and the known seasonal fluctuations in numbers of each sex at different times of the year (Godsell 1982; Bryant 1988b).

Whilst application of a closed population model for each individual trapping session was not possible due to the low numbers of individuals captured, I also considered an analysis across all three trapping sessions using either an open population model such as the Cormack-Jolly-Seber model (Lebreton *et al.* 1992; Pledger *et al.* 2003) or the robust model that incorporates methodology from both closed and open models (Pollock 1982) in MARK. However, the low number of captures resulted in the number of parameters exceeding the number of data points for the study, again precluding any estimation of population abundance for the current study. Confounding this further was the seasonal spike in numbers over the breeding season in May/June each year (Godsell 1982), complicating such analysis using an open population model.

Given the expectation of low sample sizes, I adopted a range of alternative analyses to complement CMR analyses. Alternative analyses included comparing and contrasting the number of unique individuals trapped and trap success to historic studies to establish any corresponding long-term changes in eastern quoll populations at each of the study sites.

3.2.2.2 Number of unique individuals trapped

The mean number of individuals known to be alive (MNKA) has often been used as a measure of relative population abundance in similar studies (e.g. Godsell 1982; Jones 1995; Shevill and Johnson 2008). In establishing abundance at any point in time, this method takes into account not only those individuals captured during the current session but also those that were not trapped in the current session but were trapped at some time both before and after the current session (i.e those individuals that were obviously alive during the current session, just not trapped). However, as the current study only incorporated 3 trapping sessions, this measure could only be established for May (using capture data from March and July) and in the event that individuals were found to be highly re-trappable, it is unlikely that MNKA would differ significantly from the number of unique individuals captured. Calculations could not be made for March or July due to the absence of prior or subsequent trapping data respectively, with the MNKA effectively equal to the number of individuals trapped in each of these periods. Given the low number of trapping sessions in the current study, MNKA was not considered an appropriate measure, with the number of unique individuals trapped used as a more meaningful measure of relative population abundance.

Given the variation in number of trap nights used in the different historic studies, I plotted the cumulative number of unique individuals trapped during the current study against progressive trap nights, creating a "discovery curve" or "accumulation curve" for each trapping session for each site. Discovery curves have been used in relatively small, localised populations of readily identifiable individuals to assess whether total enumeration has been achieved (i.e. when the curve asymptotes) and to establish whether a population is open or closed (e.g. Karczmarski *et al.* 1999; Baker *et al.*

2006), demonstrating similar efficiency to more complex statistical models with sufficient levels of precision (Wanger *et al.* 2009). Whilst this has clear application for curves that demonstrate total enumeration, extrapolation of incomplete discovery curves (i.e. those for which total enumeration has not been achieved with a given sampling effort) has been found to be inadequate for generating unbiased abundance estimates (Baker *et al.* 2006), with low sampling effort yielding an unacceptably high coefficient of variation (Krebs 1999), and an acceptable level of precision only being attained with increasing number of sampling sessions (Wanger *et al.* 2009). Furthermore, the necessary assumption of no individual recapture heterogeneity (i.e. that animals don't vary in capture probabilities according to age, sex, social status and many other factors (Pollock 1982)) is unlikely to be met in many natural populations (Krebs 1999).

Given the relatively low sampling effort adopted in both the current and previous studies and the predicted individual capture heterogeneity, the extrapolation of incomplete discovery curves was not considered an appropriate method for estimating abundance of eastern quolls. However, they did provide an opportunity to compare cumulative number of unique individuals trapped between years. Accordingly, any available data from historic studies was plotted on a graph for each trapping session, and a visual comparison made to establish any apparent changes between years. A one-tailed paired *t* test was used to establish if there was a significant long-term reduction in the mean number of unique individuals captured over the study period.

(i) Cradoc

At Cradoc, the 1984 monthly trapping sessions generally fell during the first calendar week of each month whilst the current study sessions were performed during the third week of each month, creating a 2 week divergence in timing either side of the current study timing. Given the relatively short synchronised 3 week mating season for this species and the corresponding rapid changes in population levels with the influx of transient males during the May/June breeding season (Godsell 1982), data from two 1984 trapping trips were included for comparison on the graph for each of

May and July trappings sessions i.e. data from early May and early June 1984 were included as a comparison for late May 2010, whilst data from early July and early August 1984 were included as a comparison for late July 2010.

As trapping in 1984 was only performed over 4 nights (i.e. 80 trap nights per session) and to ensure comparisons used equivalent trap effort, the *t* test for this site only included individuals trapped during the first 4 nights for each trapping session from the current study.

(ii) Cradle Mountain

At Cradle Mountain, the local eastern quoll population was detrimentally impacted by a major road upgrade of the Cradle Mountain tourist road in 1991, with a corresponding increase in local road mortality at this site (Jones 2000). A 7 km stretch of the main tourist road into the northern end of the National Park was upgraded in May-June 1991 (Jones 2000). The road was widened and sealed to facilitate better access to the park by tourist buses, but also resulted in an increased traffic volume as well as both modal and maximum traffic speed. All 19 known eastern quolls disappeared within 17 months, with a corresponding increase in roadkill over the same period (Jones 2000). This impact is clearly evident in the spotlighting data for this site (see Figure 2.13), with a marked reduction from 1991 onwards. Whilst initial eastern quoll losses were dramatic, implementation of mitigation measures such as traffic slow points and signage, wildlife reflectors and escape ramps during 1996 resulted in a gradual recovery of eastern quolls, with re-establishment evident within 6 months, and populations up to 50% of their former levels by 1998 (Jones 1998a; 2000). Given the apparent recovery of the local population, the road upgrade did not appear to have created a permanent population "sink" for eastern quolls in the area, with a reasonable expectation that local populations would recover to pre-upgrade levels. Accordingly, comparative data for March and May 1991 was used in the current study to compare long-term temporal trends in the number of individuals trapped, effectively providing a comparison to a pre-upgrade state. However, given the increased road mortality associated with the upgrade, July 1991 data could not reasonably be used in any statistical analysis of

long-term temporal comparisons. I still collected trapping data for July 2010 to assess seasonal and spatial fluctuations in abundance, as well as establishing the reproductive status of females and collection of blood and other samples as described in section 4.2.1.

I adopted a trap effort of 30 traps per night in the current study based on that used in 1991 by Jones (1995). However, 1991 trapping effort varied for the periods used in the current study (i.e. March, May and July 1991), with trap effort ranging from 19 to 31 traps per night over these months. To ensure long-term temporal analyses were based on a comparable trap effort, I standardised data for both the current study and the 1991 study on a pro-rata basis back to an equivalent of 20 traps per night. This also enabled spatial comparisons to all other sites where a consistent trap effort of 20 traps per night was adopted throughout.

As trapping in 1991 was only performed over 3 nights per session, only individuals trapped during the first 3 nights for each trapping session from the current study were included in the paired *t* test, effectively comparing individuals captured over 60 trap nights per session.

3.2.2.3 Trap success

Trap success for each trapping session was calculated as the total number of eastern quoll captures in each trapping session divided by the total number of traps set for that session. Results for each trapping session in the current study were then compared to trap success recorded in historic studies, and a one-tailed Fisher exact test used to establish if there was a significant long-term reduction in trap success.

(i) Cradoc

As Bryant (1988b) only recorded unique individuals captured each session, recapture data within each trapping session was not available for the 1984 study, so 1977 data collected by Blackhall (1980) was used to compare long-term temporal changes in trap success . Comparative data from this study was not available for the May trapping session, however, March and July 1977 results were available.

(ii) Cradle Mountain

Historic raw trapping data for 1991 at Cradle Mountain revealed a large number of traps where baits were taken from the trap, but no animal was captured. Whilst it is not unreasonable to have the occasional bait taken, bait loss in 1991 was substantial, ranging from 9% to 30% of baits lost each night. This effectively reduced the number of traps available to eastern quolls, and as such, trap success was calculated using the number of eastern quolls captured as a percentage of the number of traps available to animals (number of traps available = number of traps set - number of traps with bait taken but no animal captured).

For 2010, a heavy frost on the night of 20th July resulted in 9 traps (30% of traps set) where baits were taken by animals, but the animal was not captured due to a heavy layer of ice preventing the trap door from closing. The CMR data from this day was excluded from all analyses of numbers of quolls trapped and trap success (although biological samples collected from quolls on this day were included in analyses in chapter 4), and an additional day was added to the end of the trapping session to ensure five complete days of CMR data were collected for the July trapping session.

Long-term temporal comparisons for July were excluded from the statistical analysis for this site, as explained in section 3.2.2.2.

3.2.2.4 Review of other evidence

In the absence of any historical quantitative data for the Buckland study site, I reviewed results from the current study qualitatively in light of other evidence available for the region.

Raw spotlighting data for the area was assessed for consistency and experience of observers to ensure observations recorded over the past 25 years appeared reliable. Timing of surveys was reviewed to ensure spotlighting was consistently performed around the same time of year, minimising the impact of juvenile dispersal inflating numbers in some years but not others. Additionally, historic literature was reviewed

to identify how current results compared to historical accounts of eastern quoll numbers in the area over time.

Additional spotlighting was performed along the current year trap-line for two nights at the conclusion of both the March and May trapping sessions (to avoid affecting trapping results) to further investigate whether the downward trends implicated by the spotlighting data appear correct.

Images collected on camera traps set by the STTDP on the nearby Buckland Military range between 27th April and 13th May 2010 were also reviewed to provide an alternative monitoring approach for comparison with current study findings.

3.3 RESULTS

3.3.1 Cradoc

3.3.1.1 Capture-mark-recapture

As predicted, low numbers of individuals (especially females) were captured during the current study (refer Table 3.1), resulting in low sample sizes that prohibited CMR analysis to estimate current population abundance in program MARK for this site. The absence of key historical recapture data for this site also prevented population estimates being established for previous studies, effectively precluding any long-term comparison of population estimates to quantify any resultant declines in eastern quolls at this site. Accordingly, reliance was placed on the alternative measures assessed at this site.

3.3.1.2 Number of unique individuals trapped

A total of 11 individual eastern quolls ($3\female$, $8\male$) were captured over the study period as outlined in Table 3.1. Total captures each month peaked in May during breeding season, with March yielding the lowest number of quolls trapped for both sexes.

Table 3.1. Total number of unique individual eastern quolls captured at Cradoc over the duration of the 2010 study period.

Trapping session	Females	Males	Total
March	1	4	5
May	3	7	10
July	3	4	7
All sessions	3	8	11

The cumulative number of unique individuals trapped throughout the study showed a marked reduction from all prior studies in all trapping sessions, with >50% reduction observed across all periods (Figure 3.1).
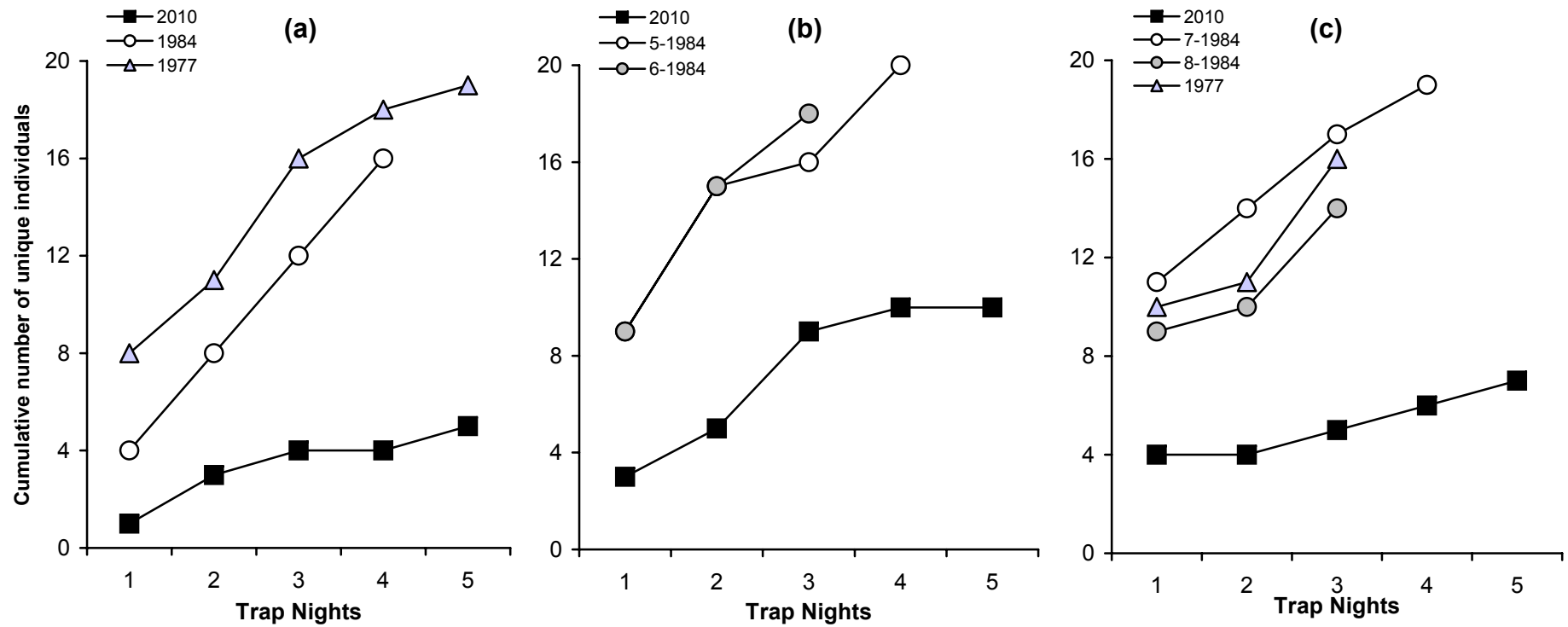
Figure 3.1. **Cumulative number of unique individual eastern quolls captured at Cradoc over successive trap nights for (a) March; (b) May; and (c) July trapping sessions compared to 1984 and 1977. Trap effort in all studies was 20 traps per night.**

As predicted, the low sampling effort and individual recapture heterogeneity illustrated by the individuals trapped in the current study (individuals were captured anywhere from 1-5 nights out of a possible 5 nights per trapping session) precluded the use of a discovery curve model to estimate population abundance. However, I was still able to compare results to historical studies, enabling assessment of any long-term changes in eastern quolls trapped at this site.

A significant reduction in the total number of individual quolls trapped during the first 80 trap nights (4 nights, 20 traps per night) of each trapping session was observed in the current study compared to equivalent periods in 1984 (Figure 3.2). A mean ($\pm$ s.d.) of 6.67 ± 3.06 individuals captured per 80 trap nights per session in the current study represented a significant reduction from the mean of 18.33 ± 2.08 quolls captured on the same study site in 1984 ($t = 13.229$, d.f. $= 2$, $p = 0.003$).
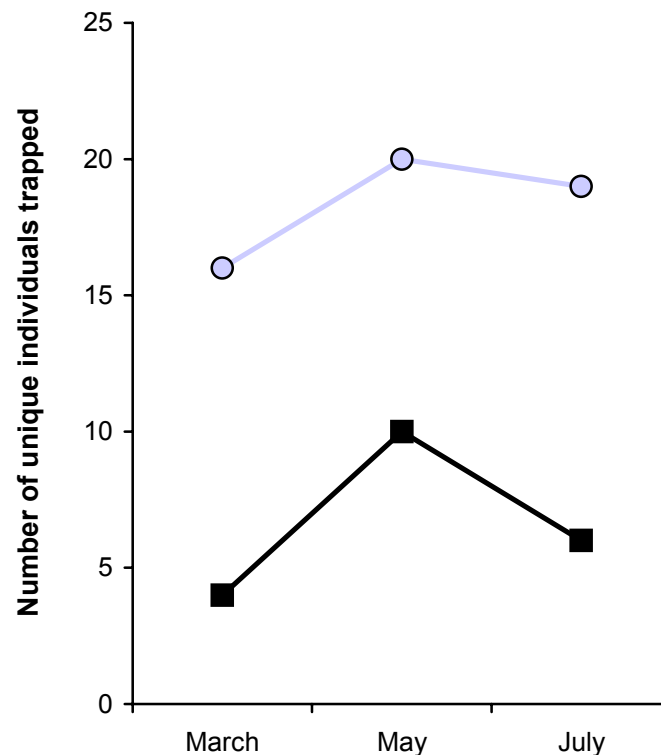
Figure 3.2. Total number of unique individuals trapped at Cradoc during the current study (black squares) compared to 1984 (grey circles). Results show animals captured during the first 4 nights of each trapping session for both studies, illustrating the total number of individuals captured over the first 80 trap nights (as described in section 3.2.2.2).

3.3.1.3 Trap success

Trap success varied between sessions, with considerably lower trap rates recorded in March (10%) than both May (21%) and July (24%). Trapping for the current study yielded significantly lower trap success than 1977 for both March ($p < 0.001$) and July ($p < 0.001$), with no comparative data available for May 1977 (Figure 3.3). Whilst comparative data from Godsell (1982) was not available for individual months, the trap success for the 2.5 year study of 63% was markedly higher than trapping results achieved in the current study.
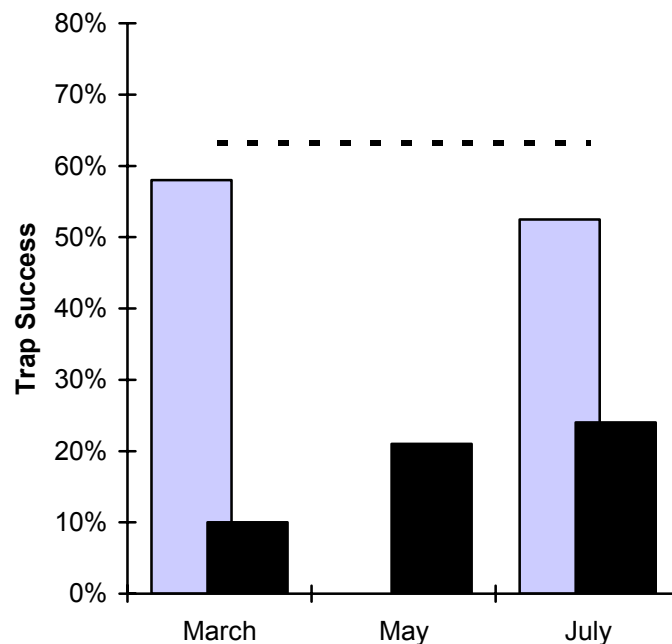
Figure 3.3. Trap success at Cradoc for 2010 (black bars), showing reductions from 1977 (grey bars) (Blackhall 1980) and 1978-80 (dotted line) (Godsell 1982). Trap effort for 2010 and 1977 based on 20 traps per night for 5 nights, except July 1977 (4 nights). 1978-80 based on 25 traps per night across the 2.5 year study.

By-catch was minimal at this site, with a one-year old female devil captured in March, and another one-year old female captured in May (see Appendix 2). No other species were trapped.

3.3.2 Buckland

3.3.2.1 Trapping results

No eastern quolls were captured during the current study, precluding estimation of population abundance. Accordingly, no analysis of the number of quolls captured or trap success could be performed.

Low levels of by-catch were recorded throughout the study, including two feral cats, a spotted-tailed quoll (*Dasyurus maculatus*) and six Tasmanian devils as outlined in Appendix 2.

3.3.2.2 Spotlighting data - observers

The individual observers responsible for performing spotlighting surveys in the Buckland region over the past 25 years were found to recur for most of this period, with the same observer performing the surveys from 1985-2002 inclusive. This observer was highly experienced, with over 20 years spotlighting experience in Tasmania at the time the surveys were performed. Whilst there was a change in observer from 2003, the apparent decline commencing around 1998 (refer Figure 2.9) did not coincide with this change, with the original observer continuing for a further 5 years from the start of the decline (i.e. 1998-2002). Three different observers performed the surveys over the period 2003-2009, however all were highly experienced, with some having performed spotlighting surveys across Tasmania for over 25 years.

3.3.2.2 Spotlighting data - timing

The timing of the Buckland annual surveys between 1985 and 2009 was reasonably consistent, with 76% of the surveys occurring in either November or December each year during the peak time of juvenile dispersal. However, there was no major difference in the timing of surveys over the years, with 69% of surveys performed during the period of high eastern quoll observations (1985-1997) falling during the peak dispersal period, compared with 83% of surveys performed during the recent period of low eastern quoll sightings (1998-2009) falling during the same peak period of dispersal.

3.3.2.3 Historic accounts

A review of the literature revealed several studies where eastern quolls were recorded or captured in the Buckland area. As part of his study on eastern quoll reproduction, Fletcher (1977) trapped 29 eastern quolls during 1977 at several sites in the Buckland area including Tiger Hill, Levendale, Buckland and the Buckland Military Range. Whilst additional animals were captured from other sites such as Cradoc, Plenty and Lake Leake, the four Buckland sites were the main source of quolls, indicating a reliable population in the area at that time.

Pearse (1981) trapped eastern quolls at both Buckland (Tiger Hill) and Glen Huon, with the objective of collecting fleas for her study on the biology of *Uropsylla tasmanica*. Pearse (1981) indicated that of the two sites used, eastern quolls were more plentiful at the Buckland site. Twelve traps were set each night, with 12 or more quolls caught each night (A. Pearse, pers. comm.).

As part of a pilot study in 1978, Godsell (1983) trapped at 18 different sites across Tasmania to identify those sites with the highest trap success. Whilst Cradoc returned the highest trap success, Buckland yielded the fourth highest trap success of the 18 sites sampled, suggesting that the area was once one of the highest density locations for eastern quolls in Tasmania.

In 1996 as part of a comprehensive regional assessment of eastern quoll distribution for the Tasmanian Regional Forest Agreement (RFA), Jones and Rose (1996) collected anecdotal evidence of eastern quoll distribution and abundance in the form of public surveys. Responses indicated that the Buckland region was considered an eastern quoll "hotspot", corroborating earlier studies to suggest that the area supported a reasonably high density of eastern quolls.

A review of the NVA revealed only two additional eastern quoll records since 1990 within a 5 km radius from the study site. Both records related to animals captured in November 2008 as part of a brushtail possum study approximately 2.5 km to the north of the study site, further into the Swanport State Forest (Flynn *et al.* in press).

3.3.2.4 Additional spotlighting

No eastern quolls were sighted from spotlight surveys conducted along the trap lines in either March or May. One black eastern quoll was observed in March on a road verge scavenging on a roadkilled possum approximately 1 km north of the Buckland general store, however this was approximately 11 km south of the study site.

3.3.2.5 Camera traps

Over 2200 camera trap images were reviewed from the STTDP camera traps set on the Buckland Military range to the north-east of the study site, with no eastern quolls observed in any images. Other species captured in the images included: spotted-tailed quolls, Tasmanian devils, common brushtail possums (*Trichosurus vulpecula*), Bennett's wallabies (*Macropus rufogriseus*), Tasmanian pademelons (*Thylogale billardierii*), long-nosed potoroos (*Potorous tridactylus*), short-beaked echidnas (*Tachyglossus aculeatus*) and common wombats (*Vombatus ursinus*).

3.3.3 Cradle Mountain

3.3.3.1 Capture-mark-recapture

As for Cradoc, given the low number of females captured in the current study (refer Table 3.2), population estimates and comparisons could not be made using either open or closed models in Program MARK for this site. Instead, I relied on alternative analyses such as number of unique individuals trapped and trap success.

3.3.3.2 Number of unique individuals trapped

A total of 14 individual eastern quolls (2♀, 12♂) were captured over the study period as set out in Table 3.2. Whilst only one female was captured during each session, total captures and number of males increased with successive trapping sessions, with March yielding the lowest and July yielding the highest number of male quolls trapped.

Table 3.2. Number of unique individual eastern quolls captured at Cradle Mountain throughout the 2010 study period.

Trapping session	Females	Males	Total
March	1	3	4
May	1	5	6
July	1	8	9
All sessions	2	12	14

The cumulative number of unique individuals trapped throughout March and May showed a marked reduction from 1991, with reductions of around 50% observed in both months. As expected, no corresponding reduction was evident in July, with similar numbers of individuals trapped in both 1991 and 2010 (Figure 3.4).
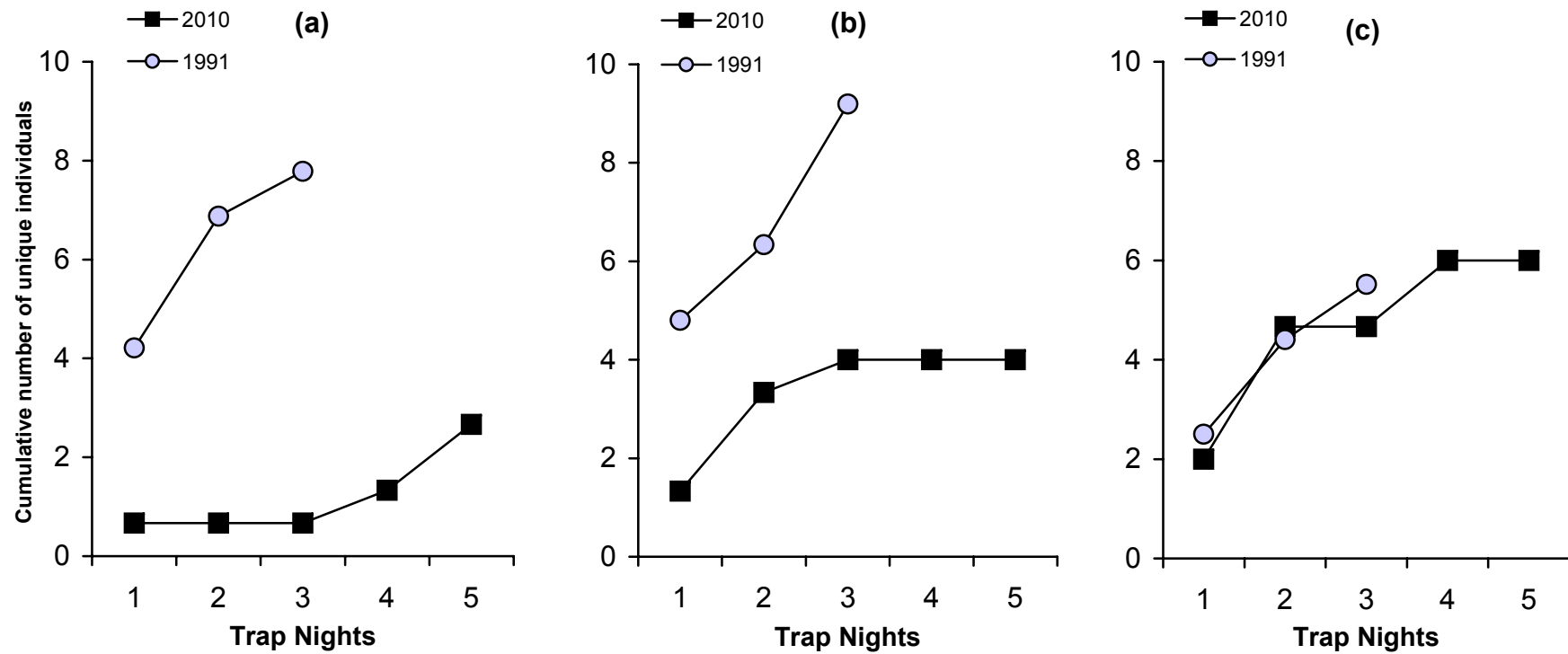
Figure 3.4. Cumulative number of unique individual eastern quolls captured at Cradle Mountain over successive trap nights for (a) March; (b) May; and (c) July trapping sessions compared to 1991. Note: results are standardised to an equivalent 20 traps per night for both years to facilitate comparison.

The mean (± s.d.) of 2.33 ± 2.36 individuals captured per 60 trap nights per session in the current study (March and May) was significantly lower than the 1991 mean of 8.49 ± 1.00 ($t = 6.401$, d.f. = 1, $p = 0.049$) (Figure 3.5). July was not included in this statistical comparison for the reasons outlined in section 3.2.2.2
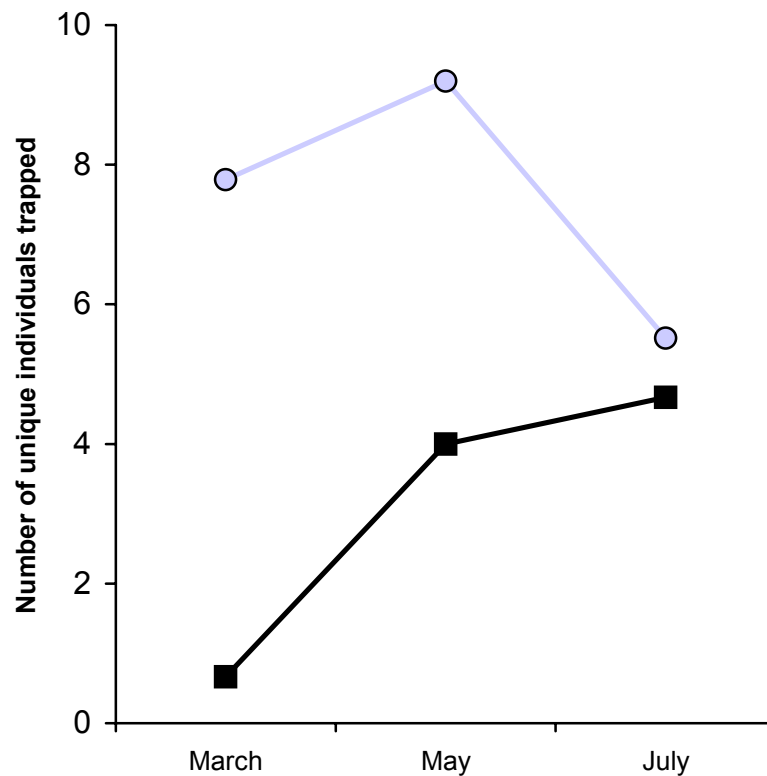
Figure 3.5. Total number of unique individuals trapped at Cradle Mountain during the current study (black squares) compared to 1991 (grey circles). Results reflect animals captured during the first 3 nights of each trapping session, standardised to an equivalent 20 traps per night for both studies (as described in section 3.2.2.2).

3.3.3.3 Trap success

Trap success increased throughout the year, from 4% in March up to 12% and 15% in May and July respectively. Trapping for the current study yielded significantly lower trap success than 1991 for both March ($p = 0.001$) and May ($p = 0.040$) (Figure 3.6). Long-term statistical comparisons for July were not performed, as discussed in section 3.2.2.2.
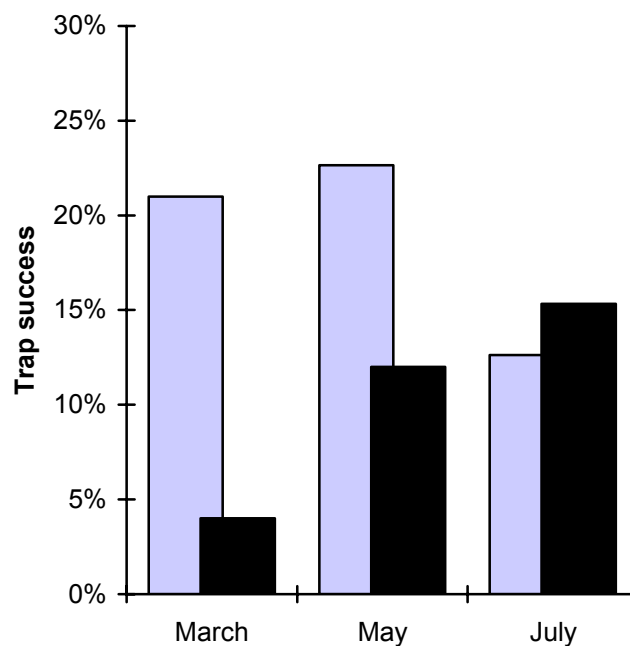
Figure 3.6. Trap success at Cradle Mountain for 2010 (black bars), showing reductions from March and May 1991 (grey bars), with similar results in July. The 2010 results were based on 30 trap nights per night for 5 nights each trapping session, whereas 1991 results were based on a variable trap effort (adjusted for significant bait loss as described in section 3.2.2.3), with available trap effort ranging from 14-26 traps per night for 3 nights each trapping session.

By-catch at Cradle Mountain included 12 Tasmanian devils, 3 spotted-tailed quolls and 7 common brushtail possums, accounting for a total of 34 captures (Appendix 2).

3.4 DISCUSSION

Despite facing several challenges in obtaining sufficiently robust data in both the current and historic studies, results from all study sites suggest a concerning decline in eastern quoll populations. Reductions identified at each of the sites reflect those highlighted by the spotlighting data, raising questions about the species' ability to recover and prosper into the future.

3.4.1 Cradoc

Trapping results at this site demonstrate a significant reduction in eastern quolls from all previous studies. Marked reductions were observed in both the number of unique individuals trapped and the overall trap success, with reductions evident across all trapping sessions. Whilst spotlighting surveys are not performed locally for this site, the magnitude of the observed reduction correlates with the overall trends identified in the statewide spotlighting data (section 1.2.1).

Whilst the number of eastern quolls trapped during the current study was significantly less than in historic studies, the validity of the decline must be assessed by considering the variables that differed (but were not controlled) between those historic studies and the current study. Such variables include trap design and construction, trap trigger mechanisms and bait type. As discussed in section 2.2.1, these variables were considered unlikely to have resulted in significant differences in capture probabilities between studies.

Recapture rates at Cradoc provide additional evidence to support this assumption. I considered eastern quolls captured in the current study to be "trap happy" individuals, with many quolls being re-trapped on successive nights and in subsequent months. Individual eastern quolls trapped in March were captured on average 2.0 nights per 5 trap nights, compared to 2.3 nights per 5 trap nights in March 1977 (S. Blackhall, unpublished raw data). Similarly in July, recapture rates were 2.6 nights per 3 trap nights, compared to 2.2 nights per 3 trap nights in July

1977 (only 3 nights trapped in July 1977). Hence, whilst numbers are too small for statistical evaluation, recapture rates using PVC traps do not appear markedly different to those recorded in 1977 using wire mesh treadle type traps.

Accordingly, the high recapture rates attained at Cradoc in the current study suggest that differences in trap design did not have a negative influence on eastern quoll trappability and hence is unlikely to have been a significant factor in the lower trap success recorded in the current study. In the absence of any other variables that may have led to a reduction in trappability, it appears that significantly fewer eastern quolls were trapped in the current study compared to historic studies, with declines similar to those indicated in the statewide spotlighting data.

3.4.2 *Buckland*

Despite adopting a multifaceted approach, the failure to detect any eastern quolls at Buckland during the current study clearly suggests a reduction in numbers at this site. But to establish whether this lack of quolls constitutes a difference from the species' historic status at the study site requires consideration of all available anecdotal evidence.

Based on a review of spotlight survey observers experience and competence, there is nothing to suggest that the historic spotlighting sightings illustrated in Figure 2.8 were not valid, with references to the local quoll populations in historic studies well supporting the area's former status as an eastern quoll "hotspot". Furthermore, given there was no significant difference in the timing of spotlighting surveys between years, it does not appear that dispersal of juvenile quolls over summer would have made any significant contribution to long-term declines in eastern quoll sightings.

Most of the historic spotlighting observations occurred in close proximity to the study site, suggesting that the study site was well positioned in what was formerly an eastern quoll "hotspot". Whilst spotlighting surveys do not record the exact location along a transect where each animal is observed, observations are split between the first half and the second half of each 10 km transect, giving a maximum 5 km range

for each observation. A review of the raw spotlighting data sheets indicates that the majority of observations recorded for transect 2 occurred along the second half of the transect, closest to the study site. Observations for transect 3 occurred more evenly, with around half the observations occurring in each half of the transect. This is further supported by references in historic studies, with both Fletcher (1977) and Pearse (1981) collecting many of their quolls from Tiger Hill and the Buckland Military range, which are both located adjacent to the eastern end of the trap line.

There are various additional lines of evidence that the failure to capture eastern quolls at this site was not a function of inadequate methodology. The methodology adopted at this site mirrored that used at Cradoc, where eastern quolls were repeatedly trapped on each of the 15 trap nights throughout the study period. The experience of spotlight observers in recent years appears excellent, further validating the lack of eastern quoll observations in recent years. This was further supported by the additional spotlighting I performed along the trap-line in both March and May 2010 that yielded no eastern quoll sightings, and the absence of any eastern quolls recorded on the STTDP camera trap images from the nearby Buckland military range in May 2010. Discussions with the landowner adjacent to the study site confirmed that eastern quolls have not been observed in the area for many years (B. McConnon, pers. comm.).

In conclusion, the study found convincing evidence that eastern quolls have declined at this site, supporting the findings of the spotlighting data from the area. While the absence of historical trapping data precludes quantification of any such decline, the failure to capture or observe any eastern quolls at this site, despite substantial effort, indicates a marked decline from what was once known as an eastern quoll "hotspot".

3.4.3 Cradle Mountain

Trapping results demonstrate a significant reduction in the number of quolls trapped at Cradle Mountain in both March and May. As with Cradoc, the validity of the decline should be assessed by considering variables such as trap design, trigger

mechanism and bait type to determine whether reductions are a function of reduced capture probabilities or representative of a true decline in eastern quoll numbers.

The potential impacts of differences in trap design have been discussed in section 2.2.1. Recapture rates at Cradle Mountain using PVC traps were 2.0 captures and 1.8 captures per individual per 3 trap nights in March and May respectively, compared to 1.4 and 1.5 for the corresponding periods in 1991. As recapture rates for both trapping sessions were higher in the current study, differences in trap design did not appear to reduce trappability at this site.

The trigger mechanism used in the cage traps in 1991 were all bait and hook type triggers (Jones 1995). Likewise, the type of bait used by Jones (1995) was similar to that used in the current study. Given the similarity in both trap trigger mechanism and type of bait used between studies, no significant difference in trappability would be expected as a result of these variables.

Whilst the declines observed in March and May appear valid, the similarity between years observed in July warrants further exploration. The July results appear to be a function of two factors – an unusually low number of quolls trapped in July 1991, and an unusually high number of quolls trapped in July 2010.

The reduction in quolls trapped from May to July 1991 (see Figure 3.5) far exceeds the typical decline seen in the post-breeding season (as illustrated for Cradoc in Figure 3.2). This reduction coincided with the road upgrade and associated increase in road mortality as explained in section 3.2.2.2.

The unusually high number of eastern quolls trapped in July 2010 (compared to May 2010) does not appear to conform to the typical seasonal fluctuation seen in this species at other locations. Typically quoll numbers increase due to the mobility of males throughout the short 3-week breeding season in May and June. By July, numbers have usually fallen to almost pre-breeding season levels (see Figure 3.2), with minimal numbers generally returned by August (Godsell 1983; Bryant 1988b).

This "typical" cycle is based on studies performed around the Cradoc area and may not necessarily correlate with seasonal cycles followed in colder climates such as Cradle Mountain. However, with the impact of the road mortality in July 1991 and no seasonal data for Cradle Mountain prior to this date, the species' typical seasonal cycle for this site cannot be assessed.

Whilst the low number of captures in the current study preclude any conclusive analysis of a possible delay in breeding season in the current year, several findings provide evidence in support of this hypothesis. The high proportion of males captured in July (8 of 9 individuals) suggests that the breeding season was still active during July, contradicting the post-breeding drop in male numbers typically seen in July-August. Furthermore, the one female captured in July did not have any pouch young at the time of capture (20th July 2010), although the appearance of both the pouch and the cloaca indicated that she was due to give birth any day (some three weeks later than the breeding season depicted at other sites), further supporting the possibility of a delayed breeding season. Whilst it is possible that this female may have already given birth and lost her young early in lactation, there was no evidence from the pouch appearance to support this. Jones (1995) found the two females captured in mid-July 1991 already had pouch young, suggesting that the mating period at this site in 1991 conformed to that described for Cradoc. Whether such a delay in the current year is a function of a late winter or some other factor is unknown, and not able to be teased out from the data obtained in the current study. However, a delayed start to the breeding season due to climatic factors is not uncommon in natural populations, with breeding in bandicoot species found to be affected by the rate of change in minimum temperature (Barnes and Gemmell 1984). Similarly, Tasmanian echidnas in the southern midlands were observed to start their 2010 breeding season some three weeks later than normal (G. Morrow, pers. comm.) with the warmer start to winter thought to have contributed to the delay.

In conclusion, given the factors affecting the results in July and the observed significant reductions in both March and May, trapping data from the current study appear to support the downward trend evident in the spotlighting data.

3.4.4 General discussion

The reductions observed at all three study sites strongly suggest that the recent reduction in eastern quoll numbers is in the nature of a real, sustained decline. The apparent reduction of more than 50% over the past 10 years appears to meet the IUCN criteria for listing the species as endangered (IUCN 2001), highlighting the need for the eastern quoll to be nominated for listing as a threatened species.

Whilst the reasons for this decline are not currently understood, the precautionary principle states that a lack of full scientific certainty should not be used as a reason for postponing measures to protect the species and prevent further declines (Lindenmayer and Burgman 2005). On this basis, it would be prudent to nominate the eastern quoll for listing as a threatened species as a matter of urgency, whilst concurrently focussing research efforts on identifying the causative factors, stressors and associated agents of decline.

Chapter 4 starts this process of identifying potential causative factors implicated in the eastern quoll's recent decline. Chapter 5 emphasises the need to nominate the eastern quoll for threatened species listing immediately, and draws on results identified in chapters 3 and 4 to prioritise the direction of future research for the species.

Chapter 4: Factors potentially causing eastern quoll declines

4.1 INTRODUCTION

If a species is declining, how then do we approach the questions: why is this species declining, and what might be done about it? For some species, the evidence implicating an agent of decline may be compelling, such as the loss of Tasmanian devils to DFTD (Hawkins *et al.* 2006) or the decline of woodland birds due to extensive loss of habitat (Ford *et al.* 2001). However, many agents of decline are less obvious, often interacting to complicate the identification of possible contributors (Caughley and Gunn 1996; Hone *et al.* 2005). In these cases, identifying potential causes of decline requires a more considered approach.

A range of approaches has been used to identify responsible agents of decline. Such approaches include: investigating the natural history of the species and experimentally manipulating possible limiting factors (Caughley 1994; Cooper and Walters 2002); comparing modelled population responses to potential causal factors with actual population data (Pascual and Adkison 1994); comparing rates of decline among populations experiencing different environmental conditions (Green 1995); comparing rates of decline amongst species with similar life-histories (Davies *et al.* 2000); relating the timing of a population decline to changes in candidate limiting factors (Stallard 2001; Wyatt *et al.* 2008); and testing multiple competing hypotheses of candidate causes (Peery *et al.* 2004; Wolf and Mangel 2008).

Whilst each approach differs with respect to its relative benefits and shortcomings, several approaches may not be applicable to some species (Peery *et al.* 2004). For example, many threatened species may not be in sufficiently high numbers to enable experimental manipulation. Likewise, accurate population data for periods prior to a decline may not be available, preventing application of the timing of decline approach. The most appropriate approach will ultimately depend on the abundance, distribution and other ecological factors of the species in question, with some species possibly requiring a combination of approaches.

The potential agents of decline for eastern quolls were outlined in Chapter 1 and include: climatic factors such as rainfall and drought and the corresponding effects on food availability; persecution; road mortality; poisoning; disease; loss or modification of critical habitat; and changes in key ecological interactions such as predation and competition. It is prudent to dedicate limited resources to measuring and testing those agents that are most likely to present a significant threat. In this chapter, I address this intermediate step by collecting information to assist in prioritising potential contributing agents of decline.

Specifically, the aims of this part of the study were to:

- collect a range of morphometric data and biological samples (such as blood and ectoparasite samples) from captured eastern quolls

- measure population structure, body condition, health and reproductive output

- compare results between sites and trapping sessions to identify any spatial or short-term temporal variation

- compare results to historical studies (where available) and to established reference intervals (for haematological measures) to identify any long-term temporal variation in these variables

- analyse above data for correlations between variables and relative population abundance.

The aim of these analyses was to help identify trends or areas suggestive of potential causal factors and help eliminate others. Combined with the background data evaluated in Chapter 1, these analyses will help prioritise the direction of future research necessary to identifying key threats and potential contributing agents of decline in the eastern quoll.

4.2 METHODS

4.2.1 Sample collection from captured individuals

I trapped eastern quolls at each study site using live capture and release as described in section 2.2.1. Individual quolls were transferred to a polyester-fleece handling bag, and microchipped for identification as described in section 3.2.1. The first time each quoll was trapped, I collected a range of samples and measurements as outlined below. Samples and measurements were not repeated on subsequent mornings within each trapping session, however the process was repeated the first time each individual was recaptured in subsequent trapping sessions.

4.2.1.1 Morphometric data

Eastern quolls were weighed to the nearest 10 g using a Salter 2 kg tubular spring balance. Quolls were sexed, coat colour recorded, then pes length and head width measured with digital vernier calipers accurate to 0.01 mm. The pes was measured using the right hind foot as per Jones (1995) as the skeletal distance from the back of the heel to the end of the metatarsals excluding the phalanges, as illustrated in Figure 4.1. The zygomatic arch width (Figure 4.2) was used for maximum head width.

To reduce measurement error, I recorded two replicate measurements for each character on each quoll as recommended by Blackwell *et al.* (2006) . To reduce any bias in the second replicate, the calipers were reset between replicate measurements and the second replicate was not read until calipers had been removed from the animal.

4.2.1.2 Ageing individuals

Eastern quolls have a brief, synchronised 3-week breeding season in May-June each year resulting in the vast majority of quolls being born each July (Godsell 1982; Bryant 1986). Male eastern quolls typically reach adult mass and sexual maturity by their first breeding season in the following May-June, and whilst females are also sexually mature by this stage, they generally don't attain adult body mass until

Figure 4.1. Measurement of pes (right hind foot). The toes are folded forward and excluded from the measurement, which is taken from the back of the heel to the distal end of the metatarsals *(Photo: B. Fancourt).*
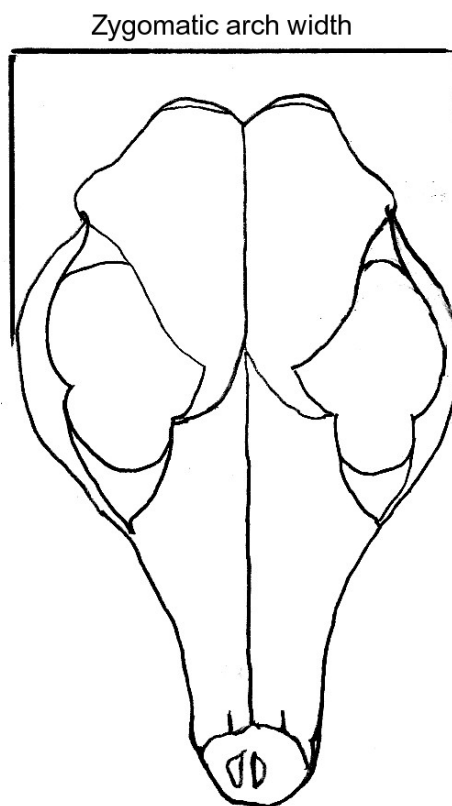
Figure 4.2. Sketch of eastern quoll skull, showing measurement of maximum head width across the zygomatic arch.

July (Godsell 1983; Bryant 1986). At Cradle Mountain, both sexes appear to take two years to attain adult body mass (Jones 1995; personal observation).

In the current study, I aged individuals as either juvenile (estimated to be born in 2009) or adult (estimated to be born in 2008 or earlier). Whilst juveniles in March and May were technically adults in July, for the purpose of this study they remained classified as juveniles for all four trapping sessions. Further ageing of adults into 2, 3 or 4 year olds was not possible with any degree of certainty. Ageing was based on a combination of factors including body mass, head width, pes length, molar eruption, molar tooth wear, progression of dentine-enamel junction on upper canine, and pouch condition (in females).

The dental formula for the eastern quoll is: $I\frac{4}{3}$; $C\frac{1}{1}$; $P\frac{2}{2}$; $M\frac{4}{4}$ (Green 1967). Tooth eruption for the two lower posterior molars was classified as: 0 - below surface; 1 - one cusp; 2 - two cusps; 3 - fully erupted. Teeth are generally fully erupted before reaching maturity.

Whilst severe tooth wear is not often seen in eastern quolls, some molar wear is noticeable (Green 1967; Jones 1995). Tooth wear for the three lower posterior molars was classified according to the following scale (as used by the STTDP for assessing tooth wear in devils): 0 - no wear; 1 - tip missing; 2 - dentine visible; 3 - cusps identical; 4 - stump, less than half tooth present; 5 - worn flat to gum. Juveniles generally had almost pristine teeth and minimal wear, with increased wear typically occurring with increased age. Tooth wear was not used to definitively age quolls, but more as a general indicator of age in conjunction with other characters.

Unlike eutherian carnivores, the teeth of the large marsupial carnivores grow continually throughout their lives so that tooth wear is partially compensated by growth (Jones 1995). New growth evident at the base of the tooth lacks the enamel coating present on the lower part of the tooth, and hence the progression of the dentine-enamel junction on the upper canine as the tooth grows and the gums recede can be used to help estimate the animal's age (Figure 4.3). To establish the
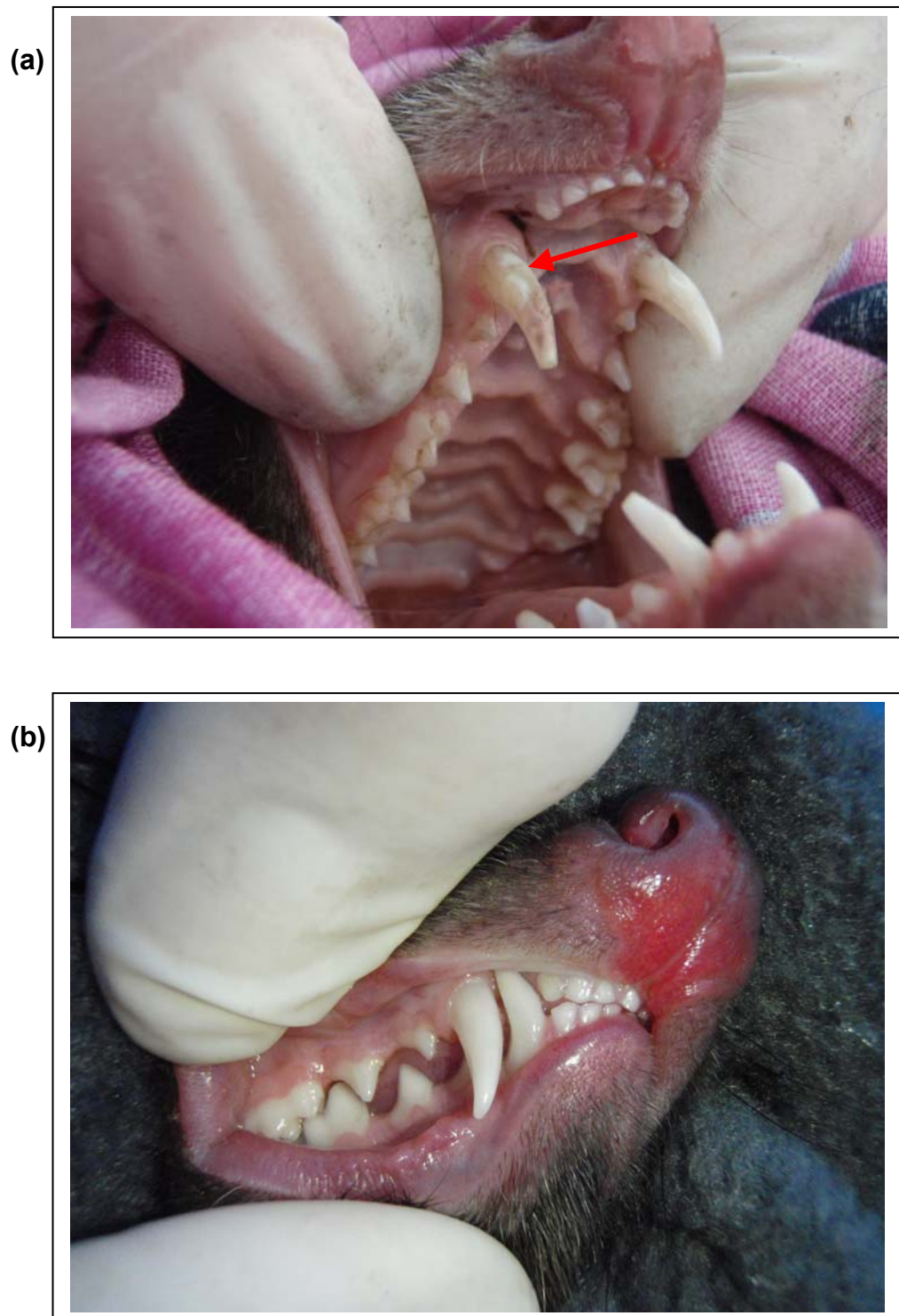
Figure 4.3. Images of eastern quoll upper canine, showing differences between (a) an estimated three year old; and (b) an estimated one year old (juvenile). The progression of the dentine enamel junction (arrow) and tooth discolouration is evident in the older quoll but is notably absent in the juvenile, the latter having almost pristine teeth (*Photos: R. Harris and B. Fancourt*).

progression of this junction, I took two measurements on the upper right canine using digital vernier calipers accurate to 0.01 mm: (1) the tip to gum length; and (2) the tip to dentine-enamel junction length. The difference between these two measurements represented the progression of the upper canine and hence the increasing age of the animal (with increasing length). However, the dentine-enamel junction was not always obvious, so this measurement was used in conjunction with other factors to help establish age.

Signs of reproductive maturity such as pouch status were also used to help establish age in females. Godsell (1983) found that the majority of females bred in their first year. Fur discolouration and residual wax at the base of the hairs surrounding the teats generally signified that the female had bred in the previous year(s). Evidence of this prior to the May-June breeding season indicated that the female was already an adult. Whilst the absence of wax and fur discolouration did not automatically mean the quoll was a juvenile, I took its presence to help confirm classification as an adult. Descriptions of pouch development are outlined in Appendix 3.

Whilst scrotal size has also been used to determine age in males (Godsell 1983; Bryant 1986), there is usually no significant difference in scrotum measurements between juveniles and adults by February (Godsell 1983). As animals in the current study were only examined commencing in March, I could not use scrotal measurements to help determine age.

4.2.1.3 General condition

I assessed general body condition by examining a range of factors including muscle tone (back of neck, back/top of skull, along spine) and prominence of ribs, pelvis and peri-pubic bone. Scoring was performed on an arbitrary scale ranging from 1 (very poor) to 5 (excellent). A quoll scoring 1 exhibited negligible fat and muscle tone, ribs easily visible, with scapular and peri-pubic bone prominent. A score of 3 indicated good muscle coverage around neck, hindlegs and along spine, with some tissue covering evident over ribs and peri-pubic bone. A score of 5 indicated

difficulty in palpating ribs, scapular and cervical vertebrate, with a roll of flesh evident between the base of the neck and shoulders.

Wounds were assessed using the classification adopted by the STTDP for devils. Wounds were categorised as a puncture (spherical penetrating wound), laceration (linear tearing of skin) or avulsion (piece of skin missing) and recorded according to the position on the body (head/neck, body, tail, limbs).

Gait was assessed as the animal's ease of movement as it was released, and was measured on an arbitrary scale ranging from 1 (paresis) to 5 (excellent). A quoll showing slight stiffness or restricted range of movement was scored as 3.

Gum colour was observed and recorded as an indicator of a potential range of health conditions including anaemia, cyanosis, and several blood disorders. Gum colour was classified as white, pale pink, pink, dark pink, blue or grey.

CRT is an indicator of peripheral blood circulation and was measured by momentarily applying fingertip pressure to the quoll's gum, and recording the time in seconds until gum colour returned to the depressed area.

Both eyes were examined for any abnormalities such as corneal oedema (cloudiness), cataracts, wounds or scarring.

4.2.1.4 Blood samples

Blood tests such as packed cell volume (PCV), total plasma protein (TP) and differential leukocyte (white blood cell) counts can serve as indicators of a wide range of conditions including anaemia, dehydration, clotting disorders, haemoparasites, inflammation, infection and viral disease. To help assess the overall health of each animal, I collected blood samples from each quoll and performed a range of blood analyses as outlined below.

Blood collection

I collected blood samples from a peripheral ear vein whilst the animal was restrained in a dark coloured polyester-fleece handling bag with just the ear exposed. Quolls generally sat calmly for this procedure and needed minimal physical restraint. The perimeter of the ear was sterilised with an alcohol swab and allowed to air-dry. The marginal ear vein was held up using gentle compression between thumb and forefinger, then the vein was punctured using a sterile 26G needle. Blood samples were collected as follows:

i) 2 x 75 μL heparinised microhaematocrit capillary tubes (Na-hep) filled to around 50-60 μL.

ii) 1 x 75 μL plain microhaematocrit capillary tube filled to around 20 μL.

iii) Approximately 100-120 μL collected in an eppendorf tube.

Bleeding was stopped by covering the puncture site with a gauze swab and gently applying pressure to the site until a clot formed. Once bleeding ceased, the animal was kept in the bag for observation for an additional 2-5 minutes prior to release to ensure bleeding did not recommence. Blood was collected from all captured individuals except current year pouch young.

Packed cell volume (PCV) and total plasma protein (TP)

The two heparinised capillary tubes were immediately plugged at one end with putty, and stored in a cooler bag with ice until processed in the laboratory later the same day, usually with 5-6 hours.

In the laboratory, capillary tubes were plugged with critocaps over the putty to prevent sample leakage, and centrifuged in a microhaematocrit centrifuge (Hawksley Gelman Instruments, Lancing, Sussex, U.K.) for 5 minutes (no difference in compaction observed between 5, 6 and 7 minutes). The PCV ($L.L^{-1}$) was read using an MSE microhaematocrit reader, and the process repeated for the second sample.

A drop of plasma from the centrifuged capillary tube was placed on a refractometer (Bellingham and Stanley, Tunbridge Wells, UK), and the TP ($g.L^{-1}$) recorded for each of the two samples.

Peripheral blood films

I prepared blood films in the field using the wedge approach as per Canfield (1998) using whole blood from the plain capillary tube immediately after collection. The blood film was air dried, labelled, then returned to the laboratory later that day for staining. Two blood films were prepared for each individual.

In the laboratory, I stained dried blood films with a Leishman's-Wright's stain mix (1:1) as described in Appendix 4 and allowed to air dry. During the study period, unidentified artefacts (black dots) were discovered in the stain and on the stained films, so new batches of stain were prepared and filtered through a fine gauge filter paper to remove any precipitate or undissolved contaminants that may be in the stain. This did not completely rectify the problem so for subsequent blood films, one slide was stained with the filtered Leishman's-Wright stain and the second slide for each animal was stained with Rapid Diff (Australian Biostain Pty Ltd, Traralgan, Victoria), a Romanowsk stain variant ("DQ") as described in Appendix 4. The DQ stained slide provided an alternative for performing leukocyte counts should the issues with stain contamination continue.

Total leukocyte counts (TWCC)

I examined stained blood films using a compound microscope on high-dry (x 400) magnification. Specific attention was paid to the leading edge of the film where a monolayer of cells could be clearly examined. Total leukocytes were counted from 10 adjacent fields of view. Total leukocyte concentration, or total white cell count (TWCC) was then calculated according to the following formula (Rodak *et al.* 2007):

TWCC = mean number of leukocytes per field x 2 = number of WBC x 10^9 L^{-1}

Differential leukocyte counts (Diff WBC)

Stained blood smears were examined under high-dry magnification (x 400) on a compound microscope, paying particular attention to the edge of the monolayer where leukocytes typically are found. Each leukocyte was identified by type (neutrophil, lymphocyte, monocyte, eosinophil, basophil and annual (ring form)

leukocyte). I performed counts using a palisading or battlement technique (Sirios 1995) to move systematically along the edge of the monolayer, and counting continued until a total of 100 leukocytes was reached. Differential percentages of each cell type were calculated and converted to absolute values using the following formula (Canfield 1998):

$$\frac{\% \text{ of each WBC type } \times \text{ TWCC}}{100} = \text{ number of WBC type } \times 10^9 \, L^{-1} \text{ blood}$$

Leukocyte and erythrocyte morphology

The size and appearance of both erythrocytes (red blood cells) and leukocytes were examined under high magnification (x 1000 oil immersion) for any morphological characteristics and abnormalities. Cell measurements were made using a Nikon DS-Fi1 high definition camera head (Nikon Corporation, Tokyo, Japan) attached to a Zeiss Axiolab compound microscope (Carl Zeiss Light Microscopy, Göttingen, Germany). Images were viewed using a Nikon DS-L2 image control unit and recorded as digital still images. A micrometer scale bar was calibrated to the number of pixels per micrometer using ImageJ (National Institutes of Health, USA http://rsb.info.nih.gov/ij) and added to each image to enable measurement of the cells. The presence of any abnormal cells was also noted and reviewed in light of haematological profiles previously established for the species.

Haemoparasites

Blood films were examined using a compound microscope at high-dry magnification (x 800) to search for the presence of haemoparasites such as kinetoplastid flagellates (e.g. *Trypanosoma* spp.) and haemogregarine apicomplexans (e.g. *Hepatozoon* spp.). If I observed a single hameoparasite, I classed the host quoll positive for haemoparasites. Parasite prevalence was not assessed.

Toxoplasmosis

The eppendorf tube containing the whole blood sample was kept in a cooler bag with ice until processed in the laboratory later that day, usually within 5-6 hours. Once the blood had clotted and the clot retracted, the blood was centrifuged in an

eppendorf centrifuge (HST Technology Pty Ltd, Hobart) for 5-8 minutes until the serum had separated from the clot. Serum was pipetted off the top of the sample and 50 μL transferred to a clean eppendorf tube labelled with the quoll's sample number. The serum was then frozen at -20° C until processed. Serum was defrosted 1-24 weeks later and tested for *Toxoplasma*-specific IgG antibodies (latent infection) by T. Hollings (UTAS) using a modified agglutination test (MAT).

4.2.1.5 Ectoparasites

I examined quolls for ectoparasites, with total parasite loads graded as for *Uropsylla tasmanica* larvae burdens per Pearse (1981). Infestations were graded into one of the following four categories:

- none – no evidence of ectoparasites;
- light – lightly scattered over tip and base of tail, rump, cloaca, scrotum, feet and ears (density in affected area ~4 per cm^2);
- medium – as for "light" but also including area between cloaca and scrotum, middle of tail and area surrounding mouth (density in affected area ~12 per cm^2);
- heavy – as for "medium" but with increased numbers in addition to flanks and shoulders, forelimbs, hindlimbs and back. For *Uropsylla* larvae, commonly several larvae per lesion, and larvae in open sores with extensive areas of inflammation (density in affected area ~40 per cm^2).

Parasite counts on parts of the body such as ears have been found to be representative of the overall burden with some parasites (e.g. Matthee *et al.* 1997). Accordingly, I also recorded the number of fleas, mites, ticks and *Uropsylla* larvae found on the right ear as an index of overall ectoparasite burden.

4.2.1.6 Reproductive status

Males

Males' testicular dimensions (width (TW) and length (TL)) were measured using vernier digital calipers accurate to 0.01 mm. I then estimated testicular volume (TV) using the formula for a prolate spheroid (Bailey *et al.* 1998; Power *et al.* 2009):

$$TV\ (cm^3)\ =\ 0.5236\ x\ TL\ x\ TW^2$$

Females

The pouch of each captured female eastern quoll was examined during each trapping session and a reproductive status assigned based on the criteria outlined in Appendix 3. The number of pouch young was recorded (where present) and the crown-rump length (CRL) of one pouch young was recorded to help estimate the age of pouch young as outlined in section 4.2.3.4. During May, females were also examined for evidence of recent mating (e.g. bite, scratch or puncture wounds to the back of the neck).

4.2.2 Other sample and data collection

Post mortem examination

Road-killed quolls were opportunistically collected throughout the study period and dissected to identify any obvious conditions that may suggest potential factors contributing to the apparent recent decline in eastern quolls (e.g. tumours, heavy endoparasite burdens, etc).

4.2.3 Data analysis

All statistical analyses in this chapter were performed using statistiXL version1.8 (http://www.statistixl.com). Minimum significant *p*-values were $\alpha \leq 0.05$.

4.2.3.1 Population structure

Sex ratios

Sex ratios were calculated for each trapping period for each site, and a χ^2 goodness of fit test performed to establish if any sex ratios differed significantly from parity and/or historic sex ratios (where raw comparative data available). For all comparisons, adjustment was made for only 1 degree of freedom by applying Yates correction for continuity. Sex ratios for July were also compared to those observed on Bruny Island in August to identify any significant differences between declining sites and Bruny Island where eastern quolls are believed to still be in high numbers.

Population demographics

The number of individual eastern quolls in each of the four demographic classes (adult males, juvenile males, adult females and juvenile females) was compared across trapping sessions and to historic raw data (where available) to identify any population classes that may have demonstrated inconsistent fluctuations in numbers. Statistical comparison could not be performed at this level due to the small number of individuals in each class in the current study. Analyses of demographic classes were instead illustrated graphically and a visual assessment made to detect whether any demographic class demonstrated more marked reductions than others. Spatial comparisons were also made between Cradoc, Cradle Mountain and Bruny Island populations to identify any disparity in population demographics across sites.

Colour ratios

Eastern quoll coat colour ratios were derived for each site to compare the relative prevalence of each of the two coat colours (black or tan). Ratios were also derived for comparative periods in historic studies for Cradoc (only site where comparative raw data available), and long-term temporal comparisons made using a χ^2 goodness of fit test (adjusted for Yates correction for continuity) to identify if colour ratios in the current study differed significantly from those observed historically. Colour ratios were further dissected by analysing colours within each sex to identify if long-term changes in colour ratios were more marked in either sex. Colour ratios for July were also compared to those observed on Bruny Island in August to identify any significant differences between declining sites and a population where eastern quolls appear to still be in high numbers.

4.2.3.2 Body condition

Body condition of captured individuals was compared between years using a body condition index (BCI) that compares body mass with a linear body measurement that does not change with fluctuations in nutritional status. This BCI was used by Jones (1995) to assess seasonal changes in body condition of devils and quolls at Cradle Mountain and was formulated based on the methodologies adopted by

Le Cren (1951) and later Kruuk *et al.* (1987). The index adopted by Jones (1995) used the following formula:

$$\text{BCI} = \frac{W}{a.L^n}$$

where *W* is the quoll's mean body mass (in kg), *L* is a linear body measurement (in cm), and *a* and *n* are both constants specific to each species (and to each sex within each species). Jones (1995) found that head width was a better predictor of body size for eastern quolls than pes, and subsequently calculated the constants *a* and *n* for male and female eastern quolls as per Le Cren (1951) using head width as the linear measurement (*L*) as follows:

Constant	Male	Female
a	0.01	0.006
n	3.034	3.391

Body condition was only assessed for adult quolls due to juveniles preferentially diverting extra energy into growth instead of body fat (Jones 1995).

For Cradle Mountain, mean BCI for each sex was compared across trapping sessions and between years using a two-way analysis of variance (ANOVA), with Tukey *post hoc* multiple comparison tests used to identify where significant differences occurred.

At Cradoc, mean BCI for each trapping session during the current study was compared across trapping sessions using a one-way ANOVA to identify any significant seasonal fluctuations in body condition for each sex. Head width was not recorded in historic studies at Cradoc, so I assessed long-term changes in body condition at this site by comparing mean body mass across trapping sessions and between years for each sex using a two-way ANOVA. Due to the difference in monthly timing of studies in 1984 (early May, early June) compared to the current study (late May) and the rapid change in body condition typically seen over this period (Bryant 1986), I included weights recorded from both May and June in the 1984 comparatives, and the mean across the two months taken as the May

comparative to give a mean body mass comparable to those recorded in the current study. Similarly, the July 1984 comparative averaged both July and August 1984 weights to given an equivalent body mass for late July.

Spatial comparisons in BCI were also made between Cradoc, Cradle Mountain and Bruny Island populations for July/August using a one-way ANOVA to identify any significant differences in body condition across sites.

4.2.3.3 Health

Haematology

(i) Packed cell volume (PCV)

Mean PCV was established for each sex and compared between sexes and to reference intervals derived by Melrose *et al.* (1987). Where two PCVs were recorded for an individual on any day, the mean of the two PCVs for that individual was used in the overall analysis.

The mean PCV for each sex was compared between sites and between trapping sessions using one-way ANOVAs to identify any significant site or seasonal effects, with Tukey *post hoc* multiple comparison tests used to identify which sites or trapping sessions contributed to those differences. One-way ANOVAs were used for this analysis as not all sites were sampled during all trapping sessions, precluding the use of a two-way ANOVA.

PCV data have not been previously recorded for any study site, however reference intervals were derived using eastern quolls captured predominantly from the Cradoc area in the mid 1980's (Melrose *et al.* 1987) and hence serve as a long-term temporal comparative for most haematological parameters. Accordingly, I plotted the PCVs derived for each quoll against reference intervals established for each sex to assess whether quolls sampled in the current study fell within the defined reference intervals for the species.

(ii) Total Plasma Protein (TP)

The mean TP for each sex was compared between sites and between trapping sessions using one-way ANOVAs to identify any significant site or seasonal effects, with Tukey *post hoc* multiple comparison tests used to identify which sites or trapping sessions contributed to those differences. As for PCV, where two samples were collected for an individual on any day, the two TPs for that individual were averaged and the mean included in the overall analysis.

TP data were not recorded in any historical studies. Similarly, reference intervals have not been established for TP in this species. To assess whether observations from the current study warrant further investigation, samples were plotted against TP reference intervals for the congener western quoll (*Dasyurus geoffroii*), a related species that has similar haematological profiles to the eastern quoll (Svensson *et al.* 1998).

(iii) Total leukocyte count (TWCC)

Mean TWCC was calculated for each sex as described in section 4.2.1.4 and compared between sexes and to reference intervals derived by Melrose *et al.* (1987). The mean TWCC for each sex was then compared between sites and between trapping sessions using one-way ANOVAs to identify any significant site or seasonal effects.

Long-term temporal comparisons were made using reference intervals established by Melrose *et al.* (1987) to visually assess if the TWCC of quolls sampled in the current study fell within the defined reference intervals for the species.

(iv) Differential leukocyte counts (Diff WBC)

Mean differential leukocyte counts for each sex were compared between sites and between trapping sessions using one-way ANOVAs to identify any significant site or seasonal effects, with Tukey *post hoc* multiple comparison tests used to identify which sites or trapping sessions contributed to the differences.

Reference intervals derived by Melrose *et al.* (1987) for each sex were used as a long-term temporal comparative to visually assess if the leukocyte differentials of quolls sampled in the current study deviated from the defined reference intervals for the species.

Toxoplasmosis

Prevalence of *Toxoplasma gondii* antibodies in eastern quolls was reviewed to identify if prevalence differed by sex, site and age of quoll. Differences between sexes were tested using Fisher's exact test. Comparisons between sites and age categories were made using two-way contingency tables, with the χ^2 test statistic adjusted for only 1 degree of freedom by applying Yates correction for continuity (age comparison only).

Ectoparasites

Due to the low numbers of ectoparasites observed and collected during the current study, individual quolls classified as medium or high ectoparasite loads were considered in light of any other factors such as age or general condition of the quoll that may account for increased parasite burdens.

4.2.3.4 Reproduction

Males

Mean testicular volume was compared across trapping sessions at Cradoc and Cradle Mountain using a two-way ANOVA to identify any significant seasonal differences between sites. July means for Cradoc and Cradle Mountain were also compared to August means for Bruny Island using a one-way ANOVA to assess any significant spatial variation in testicular volume.

As Bryant (1988b) also recorded testicular dimensions at Cradoc, I converted the historic dimensions to testicular volume (using the formula in section 4.2.1.6) and compared means between trapping sessions and between years using a two-way ANOVA to assess any long-term changes in testicular volume. As was the case for

body mass (see section 4.2.3.2), 1984 comparatives for May included both May and June 1984 data, and July included both July and August 1984 data.

In all cases where ANOVAs revealed significant differences, Tukey *post hoc* multiple comparison tests were performed to identify where significant differences occurred.

Females

The number of females with and without pouch young was compared across sites for July/August to identify any spatial variation in reproductive success. For females with litters, the mean number of pouch young per litter was calculated and reproductive output compared across sites. Due to the low number of females captured in the current study, no statistical analysis of female reproductive output was possible.

The CRL of pouch young was used to estimate their age using a growth chart established by Bryant (1988b) as illustrated in Appendix 5. Using the estimated age and an average gestation period of 20 days for this species (Fletcher 1985; Bryant 1986), an estimated mating date was established to determine if breeding fell within the typical 3-week breeding season (late May/early June) or if breeding deviated from the described timing.

4.3 RESULTS

4.3.1 Population structure

Sex ratios

Sex ratios fluctuated across the trapping sessions for both Cradoc and Cradle Mountain. Cradoc ratios ranged from a male bias in March ($4\male$:$1\female$) to almost parity in July ($1.33\male$:$1\female$) whereas Cradle Mountain showed the reverse trend, increasing from a moderate male bias in March ($3\male$:$1\female$) up to a strong male bias in July ($8\male$:$1\female$).

The overall sex ratio at Cradoc ($2.67\male$:$1\female$) was not significantly different from parity ($\chi^2 = 1.455$, d.f. = 1, $p = 0.228$) as illustrated in Table 4.1. This is consistent with historic ratios for the site, with 1984 sex ratios ($2.38\male$:$1\female$) yielding no significant difference from parity ($\chi^2 = 3.704$, d.f. = 1, $p = 0.054$). Sex ratios for this site did not differ significantly from historic studies ($\chi^2 = 0.025$, d.f. = 1, $p = 0.874$) (Table 4.2).

Table 4.1. Comparison of eastern quoll sex ratios to parity for the current study.

Site	Period	Sex ratio ($\male$:$\female$)	n	χ^2	Significant difference? (α = 0.05, d.f. = 1)
Cradoc	March	4.00:1	5	0.800	ns
	May	2.33:1	10	0.900	ns
	July	1.33:1	7	0.000	ns
	Overall	2.67:1	11	1.455	ns
Cradle Mountain	March	3.00:1	4	0.250	ns
	May	5.00:1	6	1.500	ns
	July	8.00:1	9	4.000	*p* = 0.046
	Overall	6.00:1	14	5.786	*p* = 0.016
Bruny Island	August	1.83:1	17	0.941	ns

ns = not significant

Table 4.2. Comparison of 2010 eastern quoll sex ratios at Cradoc to 1984 ratios.

Period	2010 Sex ratio (♂:♀)	n	1984 Sex ratio (♂:♀)	n	χ^2	Significant difference? (α = 0.05, d.f. = 1)
March	4.00:1	5	1.00:1	16	0.800	ns
May	2.33:1	10	1.50:1	20	0.104	ns
July	1.33:1	7	1.71:1	19	0.004	ns
Overall	2.67:1	11	2.36:1	27	0.025	ns

ns = not significant

At Cradle Mountain, the overall ratio (6♂:1♀) was significantly different from parity ($\chi^2 = 5.786$, d.f. = 1, $p = 0.016$) (Table 4.1). A similar disparity was historically evident at Cradle Mountain, with the 1991 sex ratio (7.5♂:1♀) differing significantly from parity ($\chi^2 = 8.471$, d.f. = 1, $p = 0.004$). Despite this, overall sex ratios in the current study did not differ significantly from those found in 1991 ($\chi^2 = 0.015$, d.f. = 1, $p = 0.903$) (Table 4.3).

Table 4.3. Comparison of 2010 eastern quoll sex ratios at Cradle Mountain to 1991 ratios.

Period	2010 Sex ratio (♂:♀)	n	1991 Sex ratio (♂:♀)	n	χ^2	Significant difference? (α = 0.05, d.f. = 1)
March	3.00:1	4	6.00:1	7	0.010	ns
May	5.00:1	6	4.50:1	11	0.188	ns
July	8.00:1	9	4.00:1	5	0.063	ns
Overall	6.00:1	14	7.50:1	17	0.015	ns

ns = not significant

Neither Cradoc ($\chi^2 = 0.001$, d.f. = 1, $p = 0.981$) nor Cradle Mountain ($\chi^2 = 1.367$, d.f. = 1, $p = 0.242$) yielded any significant difference to the sex ratio observed on Bruny Island (1.83♂:1♀).

Population demographics

At Cradoc, adult males increased in numbers from March to May, but returned to March levels by July. Numbers of adult females and juveniles of both sexes remained fairly consistent across all trapping periods, although juvenile females were notably absent during March. Reductions were evident in all classes when compared to 1984 demographics, with adult females and juveniles of both sexes showing the most marked reductions (Figure 4.4).

At Cradle Mountain, numbers of adult males remained consistent through March and May, but increased markedly in July. Juvenile males followed a similar trend, although they increased slightly earlier than the adults. Adult females remained fairly constant, although they were absent in March. Juvenile females followed the reverse trend to adults, being present in March but absent in both May and July.

When compared to 1991, adult males appeared less prevalent in March and May, but more prevalent in July. Juvenile males showed no obvious differences between years. The number of females remained fairly consistent between years, although the composition between adults and juveniles switched from a juvenile bias in 1991 to an adult bias in 2010. The changes in demographics between years is illustrated in Figure 4.5.

The spatial comparison between Cradoc, Cradle Mountain and Bruny Island revealed similarities between Cradoc and Bruny Island, with Cradle Mountain illustrating a markedly different population structure to the other two sites. The most obvious difference was the overwhelming dominance of both adult and juvenile males at Cradle Mountain, confounded by the absence of any juvenile females. Spatial comparison of population demographics across sites are shown in Figure 4.6.
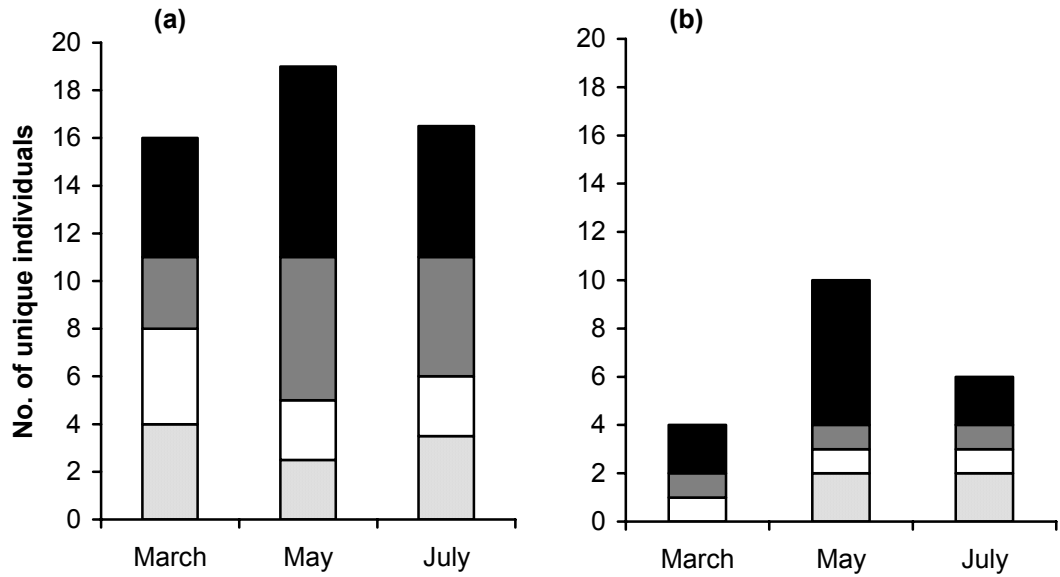
Figure 4.4. Comparison of eastern quoll population demographics at Cradoc between (a) 1984 and (b) 2010. Graphs show quolls captured during first 80 trap nights each trapping session. Demographics classified as adult males (black shading), juvenile males (dark grey shading), adult females (white shading) and juvenile females (light grey shading).
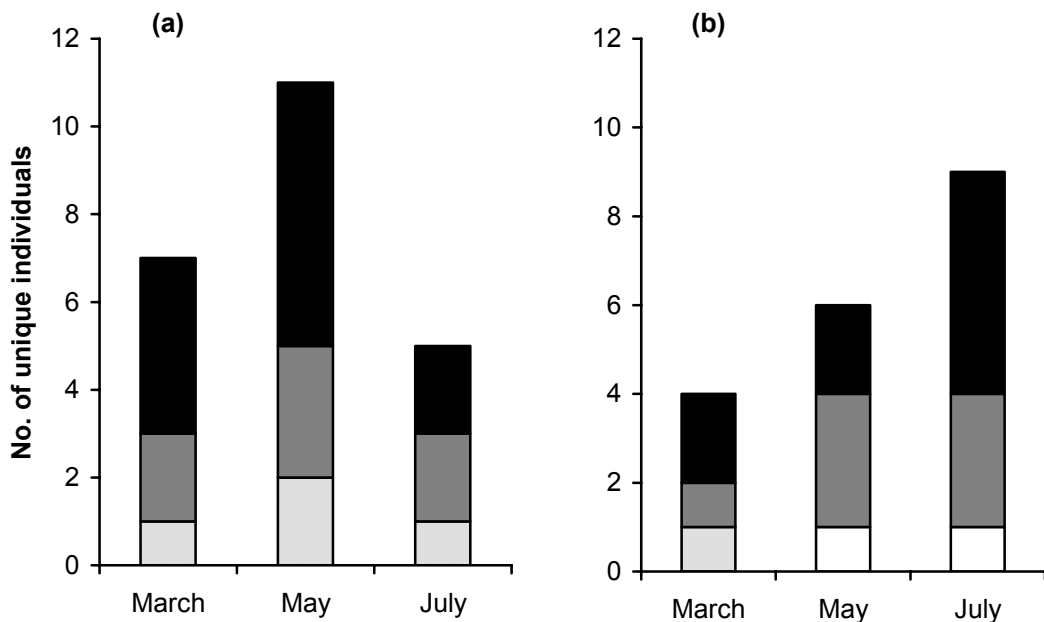
Figure 4.5. Comparison of eastern quoll population demographics at Cradle Mountain between (a) 1991 and (b) 2010. Graphs show quolls captured during first 3 trap nights each trapping session, with variable nightly trap effort in 1991 ($n = 17$-31 traps night^{-1}) and constant trap effort in 2010 ($n = 30$ traps night^{-1}). Demographic classes identified as for Figure 4.4.
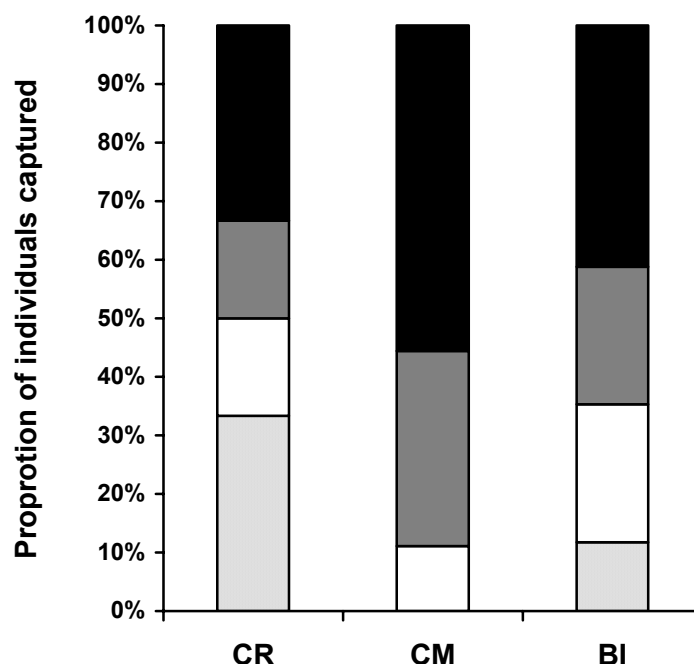
Figure 4.6. Spatial variation in eastern quoll demographics from the current study for CR - Cradoc (*n* = 6); CM - Cradle Mountain (*n* = 9); and BI - Bruny Island (*n* = 17). Trap effort of 100 trap nights (CR and BI) and 150 trap nights (CM) for July (CR and CM) and August 2010 (BI). Demographic classes identified as for Figure 4.4. and shown as a proportion of all individuals captured at each site.

Colour ratios

At Cradoc, colour ratios of eastern quolls in the current study showed a marked bias towards black-coated individuals, with the bias prevalent across all trapping sessions. When compared to historical studies, a highly significant difference in colour ratios was observed (χ^2 = 8.651, d.f. = 1, *p* = 0.003), with current ratios yielding a strong bias towards black quolls (1.75 black : 1 tan) compared to 1984 ratios that demonstrated a strong tan bias (0.29 black : 1 tan) (Figure 4.7). The magnitude of this change was predominantly attributable to significant swings in male coat colour (χ^2 = 7.429, d.f. = 1, *p* = 0.006), which changed from a 3:1 tan bias in 1984 to a 3:1 black bias in the current study. The low number of females captured in the current study didn't allow any statistical comparison of female colour ratios.

Colour ratios at Cradle Mountain were less biased, with black and tan colours evident in approximately equal numbers across all trapping sessions. As with Cradoc, the relatively low number of females captured at this site prevented any

analysis of colour ratios by sex. Historic data were not available to provide a long-term colour comparison for this site.

Whilst Cradoc yielded an obvious bias towards black-coated individuals, there was no significant difference in colour ratios compared to Bruny Island for either Cradoc ($\chi^2 = 0.834$, d.f. $= 1$, $p = 0.361$) or Cradle Mountain ($\chi^2 = 0.031$, d.f. $= 1$, $p = 0.860$), with Bruny Island displaying no obvious bias towards either coat colour (0.89 black : 1 tan). Colour ratios for the current study are illustrated in Figure 4.8.
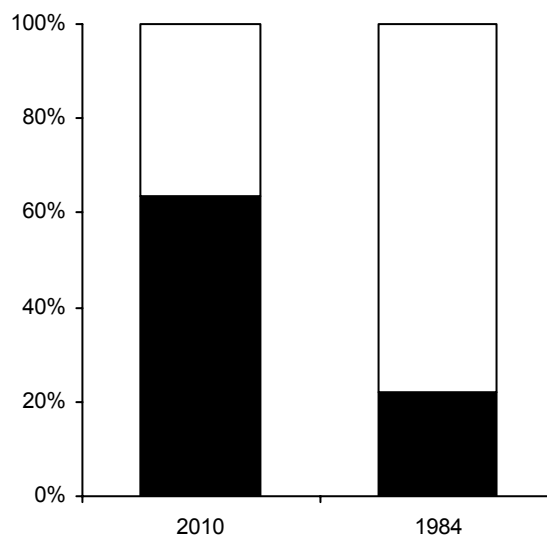
Figure 4.7. Long-term change in eastern quoll colour ratios at Cradoc from 1984 ($n = 27$) to 2010 ($n = 11$). Black shading represents black-coated quolls, white shading represents tan-coated quolls. Note the swing from a marked tan colour bias in 1984 to a strong black bias in 2010.
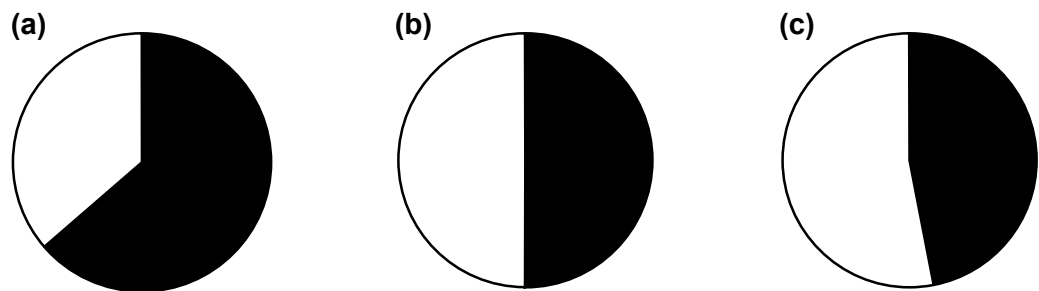
Figure 4.8. Spatial variation in eastern quoll colour ratios from the current study for (a) Cradoc ($n = 11$); (b) Cradle Mountain ($n = 14$); and (c) Bruny Island ($n = 17$). Black shading represents black coloured quolls, white shading represents tan coloured quolls.

4.3.2 Body condition

Whilst the BCI for adult males at Cradoc followed the typical seasonal trend (i.e. increasing prior to breeding then decreasing thereafter, see Figure 4.9), there was no significant difference in body condition between trapping sessions ($F = 3.814$, d.f. $= 2,9$, $p = 0.063$). As only one adult female was trapped during the current study, female body condition could not be assessed statistically for this site.

Body mass of adult males differed significantly between years ($F = 16.365$, d.f. $= 1$, $p < 0.001$) with males captured in the current study weighing more than those captured in 1984 for every trapping session ($F = 3.894$, d.f. $= 2$, $p = 0.029$), although differences were more marked in May and July (Figure 4.10). No significant difference was found in female body mass between trapping sessions between years ($F = 0.543$, d.f. $= 5,11$, $p = 0.741$).

The BCI for adult males at Cradle Mountain (Figure 4.11) revealed a significant difference in body condition between trapping sessions ($F = 7.397$, d.f. $= 2$, $p = 0.002$), with Tukey *post hoc* tests revealing a significant drop in body condition between May and July ($p = 0.001$). Body condition of adult males did not differ significantly between years ($F = 0.414$, d.f. $= 1$, $p = 0.524$).

The failure to capture adult females in March 2010 and July 1991 precluded any long-term statistical comparison of adult female body condition for these periods. However, the one adult female captured in May 2010 had a BCI (1.044) equal to or greater than the four adult females captured in May 1991 (mean BCI: 0.974, range: 0.898 - 1.044).

Significant spatial variation in body condition was evident during the current year ($F = 11.339$, d.f. $= 2,12$, $p = 0.002$) with adult males on Bruny Island during August having significantly lower BCIs than both Cradoc ($p = 0.006$) and Cradle Mountain ($p = 0.005$) for July. A similar variation was not seen in adult females ($F = 0.049$, d.f. $= 2,3$, $p = 0.953$). Spatial comparison of body condition across sites for this period is illustrated in Figure 4.12.
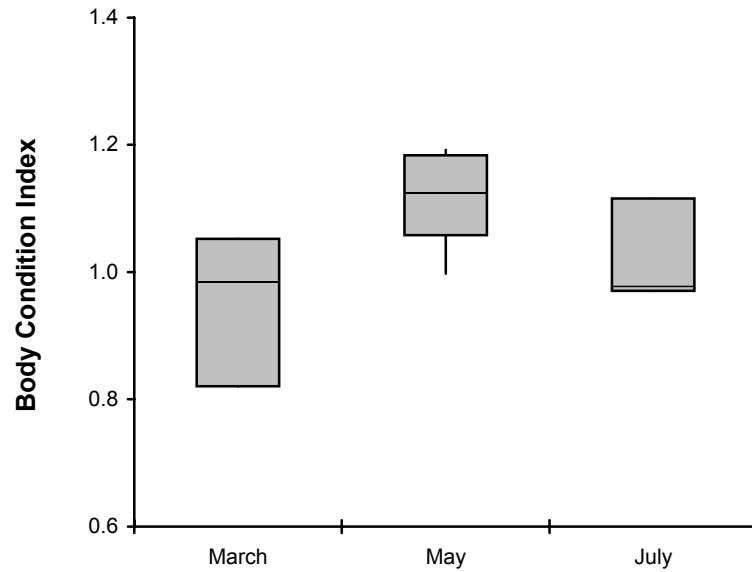
Figure 4.9. Body condition index for adult male eastern quolls at Cradoc during the 2010 trapping sessions (n = 3 (March), 6 (May), 3(July)). Box boundaries enclose the 25th and 75th percentiles, horizontal bar is median value, whiskers indicate maximum and minimum values. Note the seasonal trend, with increasing body mass during the breeding season (May) and subsequent loss of condition evident by July.
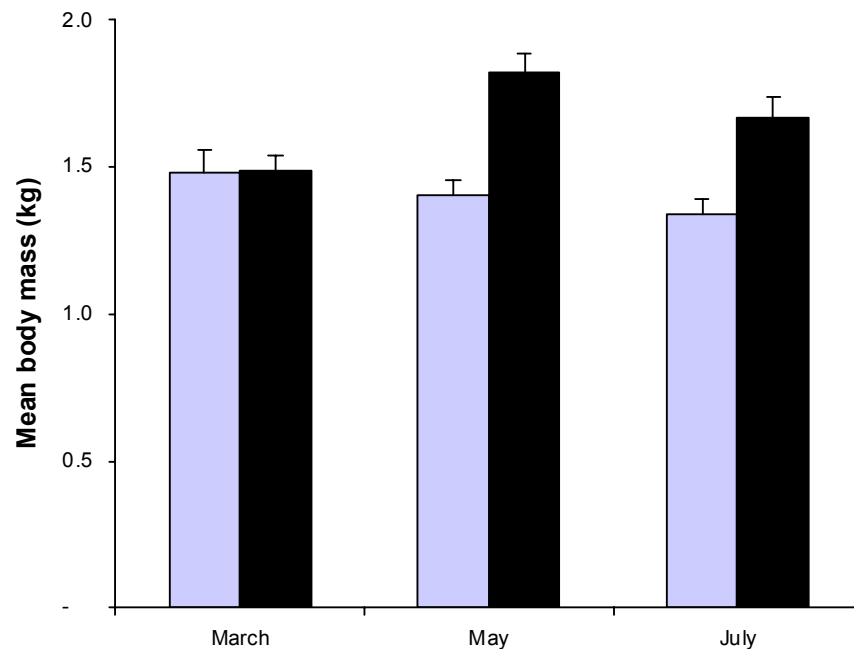
Figure 4.10. Mean body mass of adult males at Cradoc, showing increases in May and July from 1984 (grey bars) to 2010 (black bars). Mean shown with standard error bars.
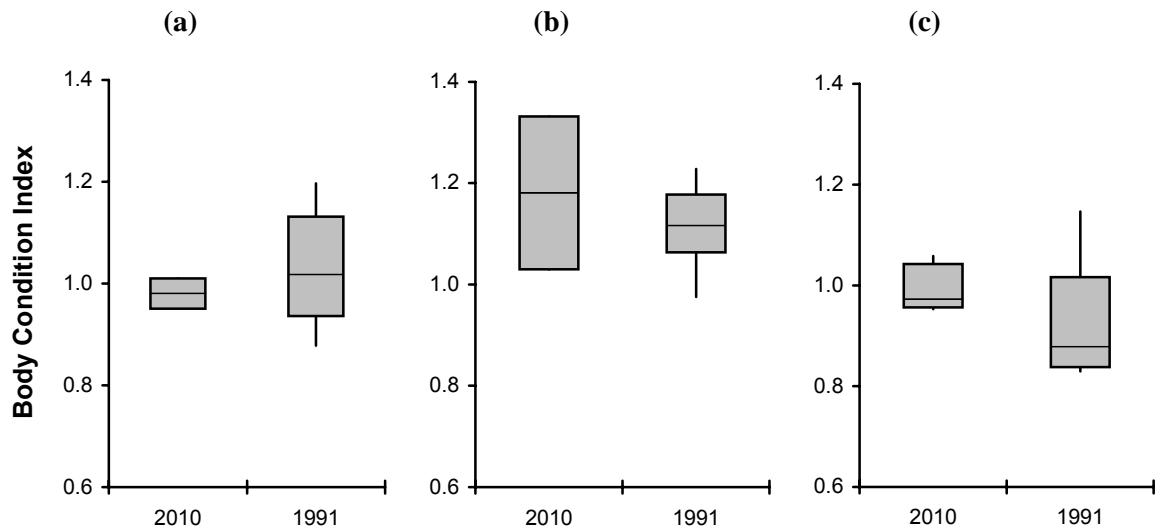
Figure 4.11. Body condition index for adult male eastern quolls at Cradle Mountain across (a) March, (b) May, and (c) July trapping sessions for the current study in comparison to 1991. Box boundaries enclose the 25th and 75th percentiles, horizontal bar is median value, whiskers indicate maximum and minimum values.
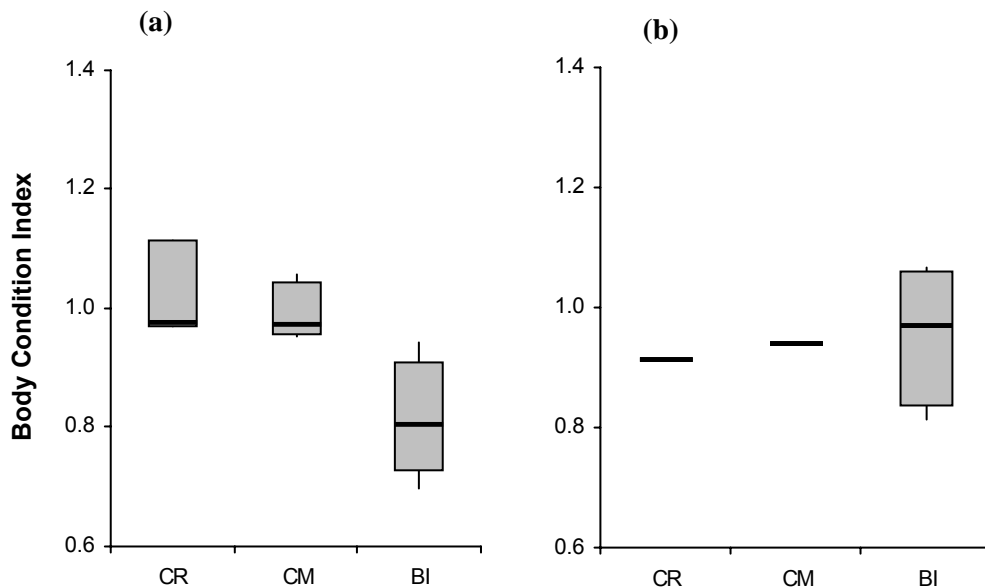
Figure 4.12. Body condition index for (a) adult male ($n = 3,5,7$) and (b) adult female ($n = 1,1,4$) eastern quolls for Cradoc (CR), Cradle Mountain (CM) and Bruny Island (BI) respectively during July/August 2010. Box boundaries enclose the 25th and 75th percentiles, horizontal bar is median value, whiskers indicate maximum and minimum values. Note: the apparent increase in BCI for females on Bruny Island would be predominantly a function of timing differences, with females on Bruny in August having much larger pouch young than the other two sites in July (pouch young not detached so included in mother's body mass measurement, hence giving the mother a higher body mass used in deriving the BCI).

4.3.3 Health

4.3.3.1 Gross assessment

Overall, captured eastern quolls examined in the current study appeared to be in good general condition. Whilst some minor wounds and scarring were evident on some quolls, there were no obvious abnormalities suggestive of debilitating disorders. General condition scores at Cradoc and Cradle Mountain ranged from 2 to 4 (median: 3), although quolls examined on Bruny Island during August had a median general condition score of 2 (range: 2-3).

A few quolls presented with pale gum colour consistent with anaemia, which was later confirmed with below normal PCVs (see section 4.3.3.2). CRT in all quolls ranged from < 1 second up to 3 seconds (mean: 1 second) with nothing to suggest problems with peripheral blood circulation. One quoll at Cradle Mountain in March had evidence of petechial haemorrhaging along the gums, whilst a further 3 quolls at Cradle Mountain took excessive periods of time (>15 minutes) for bleeding to stop after blood collection took place.

Gait was assessed as excellent (score = 5) in all quolls examined, with the exception of one elderly male quoll at Cradoc, which had a heavy burden of *Uropsylla tasmanica* larvae in May (discussed further in section 4.3.3.5).

4.3.3.2 Haematology

The haematological parameters observed in the current study are summarised in Table 4.4, with results by site and trapping session detailed in Appendix 6. All haematology data are reported as mean ± SEM.

Table 4.4. Summary of haematological parameters observed in eastern quolls in the current study. Values shown as mean ± SEM. Note some individuals were sampled in more than one trapping session, with minimum 2-month interval between trapping sessions.

	Males	**Females**	
Packed cell volume (PCV)	0.436 ± 0.012	0.464 ± 0.009	$L.L^{-1}$
Total plasma protein (TP)	65.5 ± 1.1	67.6 ± 1.1	$g.L^{-1}$
Total white cell count (TWCC)	6.6 ± 0.6	6.0 ± 0.7	$x\ 10^9\ L^{-1}$
Neutrophils (N)	2.4 ± 0.3	1.9 ± 0.4	$x\ 10^9\ L^{-1}$
Lymphocytes (L)	2.6 ± 0.2	3.0 ± 0.4	$x\ 10^9\ L^{-1}$
Monocytes (M)	0.5 ± 0.1	0.3 ± 0.0	$x\ 10^9\ L^{-1}$
Eosinophils (E)	0.5 ± 0.1	0.5 ± 0.1	$x\ 10^9\ L^{-1}$
Annular / ring forms (RF)	0.5 ± 0.1	0.4 ± 0.1	$x\ 10^9\ L^{-1}$
n (number of individuals)	*31**	*11*	
n (number of samples)	*42**	*16*	

* n = 30 individuals and 41 samples for PCV and TP

Packed cell volume (PCV)

Mean PCV in females (0.464 ± 0.009 $L.L^{-1}$) was slightly higher than in males (0.436 ± 0.012 $L.L^{-1}$), which contradicted relationships presented in reference values established for the species. Whilst males in the current study had a mean PCV within reference intervals (Ref: 0.301-0.557 $L.L^{-1}$), mean PCV for females exceeded the upper limit of the reference interval (Ref: 0.339-0.463 $L.L^{-1}$).

Across sites, mean PCV for males was highest at Cradoc (0.460 ± 0.020 $L.L^{-1}$) and lowest at Cradle Mountain (0.409 ± 0.024 $L.L^{-1}$), although differences were not significant ($F = 1.785$, d.f. = 2,38, $p = 0.182$). Site differences for females were significant ($F = 5.233$, d.f. = 2,13, $p = 0.022$) with mean PCV at Cradoc (0.491 ± 0.011 $L.L^{-1}$) significantly higher than on Bruny Island (0.440 ± 0.005 $L.L^{-1}$) (Tukey: $p = 0.024$).

There were no significant seasonal effects in mean PCV for males ($F = 1.619$, d.f. = 3,37, $p = 0.202$), however females demonstrated significant seasonal

fluctuations ($F = 3.688$, d.f. = 3,12, $p = 0.043$), with Tukey *post hoc* tests identifying mean PCV for May as being significantly higher than August ($p = 0.028$).

Nearly all male samples fell within the established PCV reference intervals (Figure 4.13). One Cradoc male showed a high PCV in March due to mild dehydration (supported by excessively dry scats at time of sampling), but returned within reference intervals for both May and July. Two Cradle Mountain males had below normal PCVs in July – both appeared anaemic at the time of sampling (pale gums and very watery blood). One of the two males had numerous small spike-like hairs inside his mouth, penetrating the mucous membranes, tongue, palette, gums and lips (see images at Figure 4.15). They appeared similar to those seen in cocoons of some anthelid caterpillars (P. McQuillan, pers. comm.) and may have become embedded when the quoll tried to eat the cocoon. The build-up of plaque on the molars and gums suggested that his ability to eat had been compromised and may have contributed to his anaemia. Notwithstanding the apparent anaemia in these males, both quolls appeared in good body condition with no other abnormalities detected.

Females deviated from the established intervals much more frequently than the males as illustrated in Figure 4.14, with most deviations occurring in May and July.

Total plasma protein (TP)

Mean TP was similar for both sexes, with females (67.6 ± 1.1 g.L^{-1}) being slightly higher than males (65.5 ± 1.1 g.L^{-1}). Significant site differences were observed for both males ($F = 8.500$, d.f. = 2,38, $p = 0.001$) and females ($F = 11.327$, d.f. = 2,13, $p = 0.001$), with Cradoc recording the highest mean site TP, and Cradle Mountain the lowest for both sexes (Tukey: $p = 0.001$).

No significant seasonal differences were found for either males ($F = 0.211$, d.f. = 3,37, $p = 0.888$) or females ($F = 1.634$, d.f. = 3,12, $p = 0.234$). Comparison to reference intervals for the western quoll indicated no abnormalities, with all samples falling within the specified intervals (Figures 4.16 and 4.17).
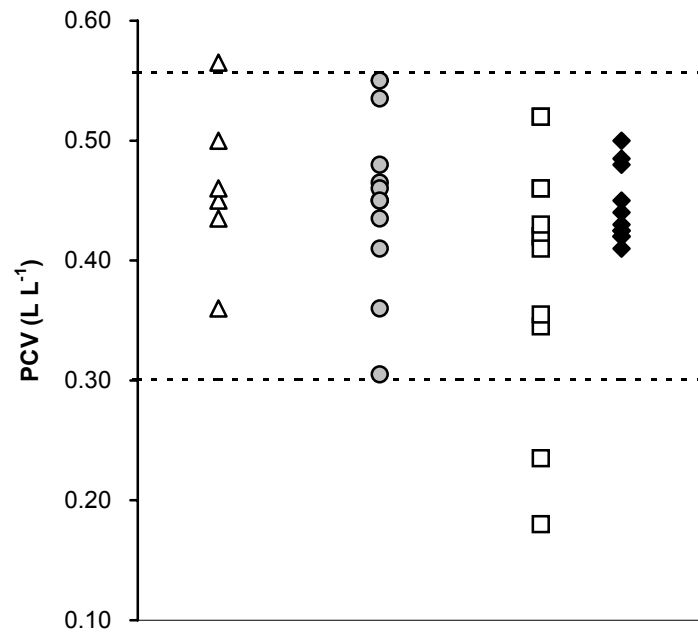
Figure 4.13. Packed cell volume (PCV) for male eastern quolls (*n* = 31 quolls, 41 samples) across all study sites. Samples collected during March (white triangles), May (grey circles), July (white squares) and August (black diamonds). Dotted horizontal lines represent upper and lower limits of reference intervals established for male eastern quolls by Melrose *et al.* (1987).
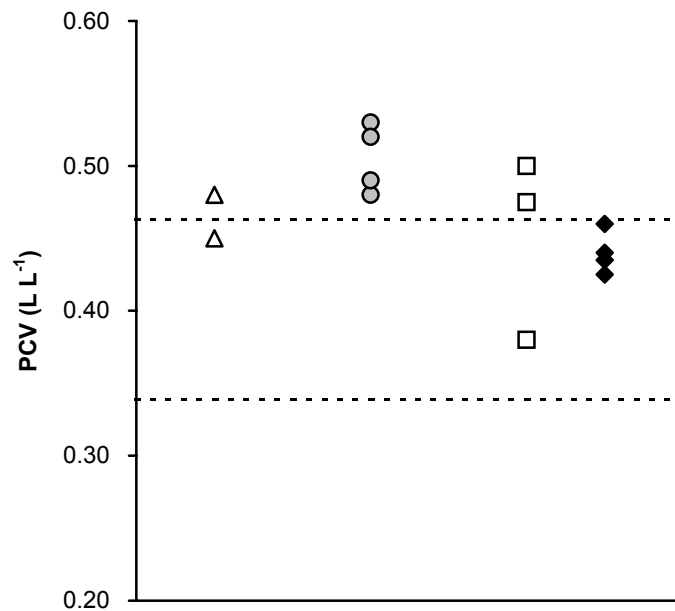
Figure 4.14. Packed cell volume (PCV) for female eastern quolls (*n* = 11 quolls, 16 samples) across all study sites. Samples collected across all trapping sessions (symbols as defined in Figure 4.13). Dotted horizontal lines represent upper and lower limits of reference intervals established for female eastern quolls by Melrose *et al.* (1987). Note the apparent seasonal deviation outside upper reference values.
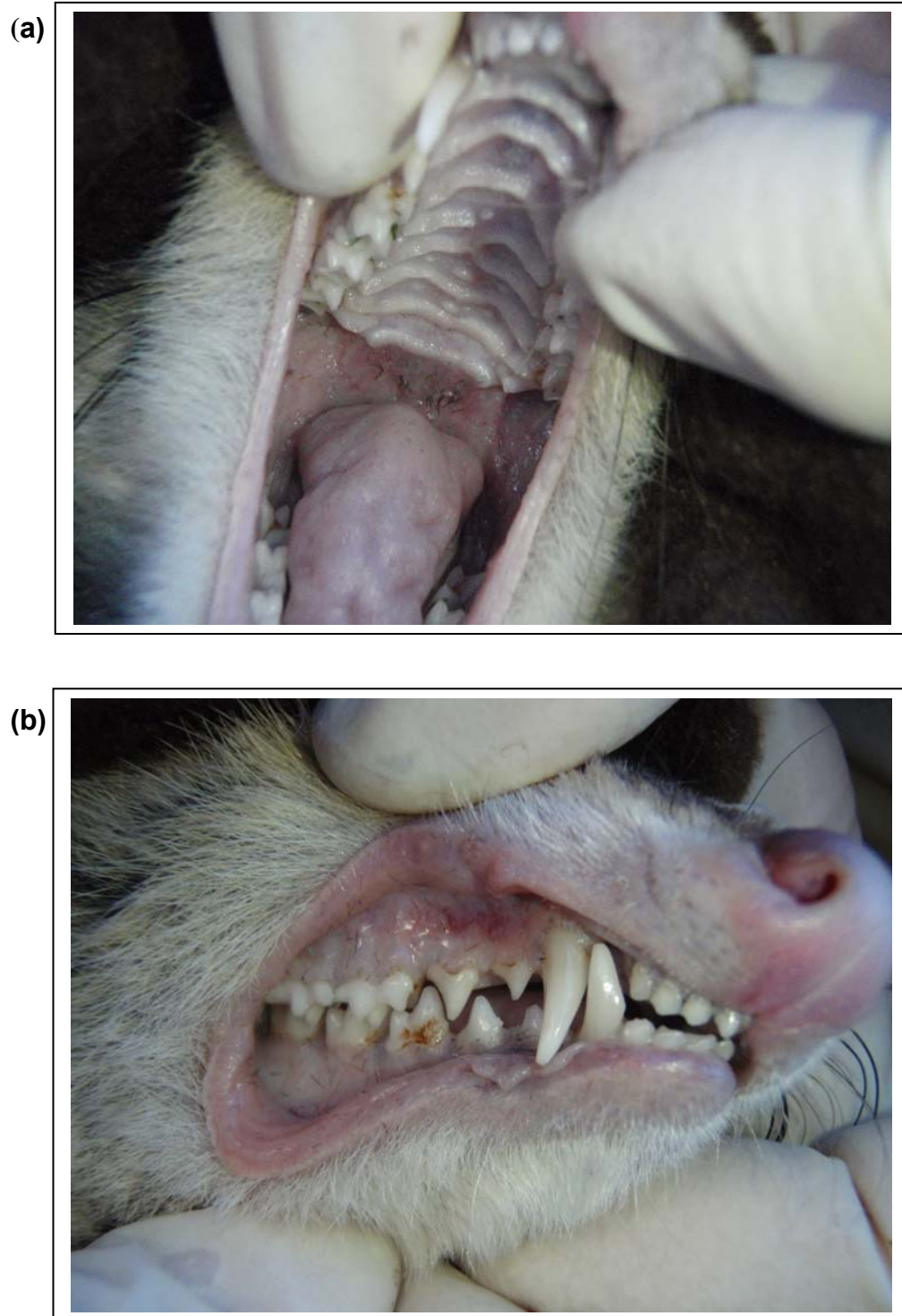
Figure 4.15. A one year old male eastern quoll at Cradle Mountain (July 2010) with grey gums indicative of anaemia (later confirmed with PCV of 0.23 L.L^{-1}). Photo (a) shows a patch of what appear to be small spikes embedded in the back of the quoll's throat and tongue, with photo (b) showing more spikes embedded under the surface of the gums and lips. Spikes were possibly embedded when the quoll tried to eat a caterpillar cocoon, possibly an anthelid moth larvae (*Photos: B. Fancourt*).
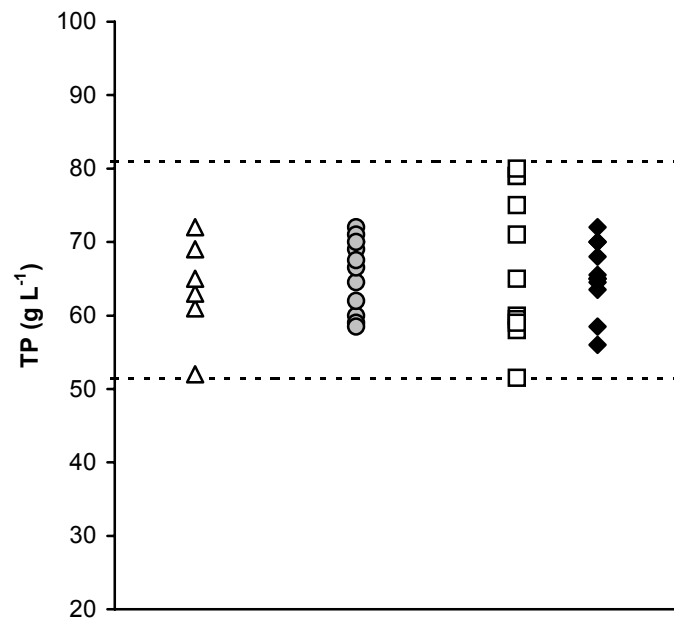
Figure 4.16. Total plasma protein (TP) for male eastern quolls (*n* = 31 quolls, 41 samples) across all study sites. Samples collected during March (white triangles), May (grey circles), July (white squares) and August (black diamonds). Dotted horizontal lines represent upper and lower limits of reference intervals established for congener western quoll by Svensson *et al.* (1998).
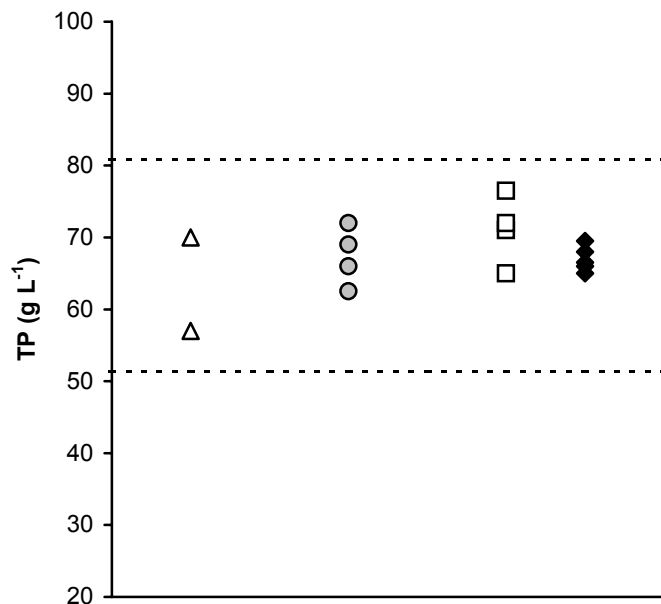
Figure 4.17. Total plasma protein (TP) for female eastern quolls (*n* = 11 quolls, 16 samples) across all study sites. Samples collected across all trapping sessions (symbols as defined in Figure 4.16). Dotted horizontal lines represent upper and lower limits of reference intervals established for congener western quoll by Svensson *et al.* (1998).

Total leukocyte count (TWCC)

Mean TWCC for males (6.6 ± 3.6 x 10^9 L^{-1}) was slightly higher than that observed in females (6.0 ± 2.7), which was consistent with established differences between sexes in reference intervals for the species. Whilst mean TWCC was higher at Cradoc than other sites, no significant site effects were found for either males (F = 1.788, d.f. = 2,39, p = 0.181) or females (F = 1.577, d.f. = 2,13, p = 0.244).

Mean TWCC for males increased in May, but no significant seasonal effects were found (F = 1.391, d.f. = 3,38, p = 0.260). Females showed an increased mean TWCC in both May and July, however differences between trapping sessions were not significant (F = 0.453, d.f. = 3,12, p = 0.720).

Mean TWCC for both sexes were within established reference intervals, although male eastern quolls frequently exceeded the upper limit of this interval (Figure 4.18). With the exception of one sample, TWCC for all female eastern quolls fell within the defined reference interval (Figure 4.19).

Differential leukocyte count (Diff WBC)

Significant differences were found in male diff WBC counts between sites for lymphocytes (F = 4.383, d.f. = 2,39, p = 0.019), eosinophils (F = 3.247, d.f. = 2,39, p = 0.050) and ring forms (F = 3.421, d.f. = 2,39, p = 0.043). Cradle Mountain was the source of most variation, with mean lymphocyte counts significantly higher than those at Bruny Island (Tukey: p = 0.021), and both eosinophils (Tukey: p = 0.041) and ring forms (Tukey: p = 0.035) having mean counts significantly lower than those at Cradoc (Figure 4.20).

Male eastern quolls showed significant seasonal differences for mean lymphocyte counts (F = 3.790, d.f. = 3,38, p = 0.018) with May counts significantly higher than those in July (Tukey: p = 0.009). No other seasonal effects were found for differential WBC counts for male quolls (Figure 4.22).

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Mean diff WBC counts for females showed no significant effects by either site (Figure 4.21) or season (Figure 4.23) (all WBC types: $p > 0.05$).

Leukocyte and erythrocyte morphology

The leukocytes examined from eastern quolls captured in the current study were consistent with those typically seen in many mammalian profiles (Canfield 1998), with the presence of lymphocytes, neutrophils, monocytes and eosinophils (Figure 4.24). There were two notable exceptions: the absence of basophils, and the presence of annular (ring form) leukocytes (Figure 4.24). Morphology of these cells was consistent with descriptions by Canfield (1998).

Erythrocyte morphology was difficult to assess in any systematic way due to the problems with stain contamination as explained in section 4.2.1.4. However, where cells could be clearly examined, all appeared to fit the erythrocyte profiles previously described for this species (Parsons *et al.* 1971; Melrose *et al.* 1987). Erythrocytes exhibited characteristics typically seen in mammalian species (Canfield 1998), being anucleate biconcave discs approximately 3-6 μm in diameter with a distinct area of cental pallor. Normal erythrocytes were commonly interspersed with varying concentrations of echinocytes and spherocytes, with occasional stomatocytes, polychromatophilic erythrocytes, Howell-Jolly bodies and Heinz bodies (see Figure 4.25).

4.3.3.3 Haemoparasites

No haemoparasites were detected from examination of peripheral blood smears in the current study.
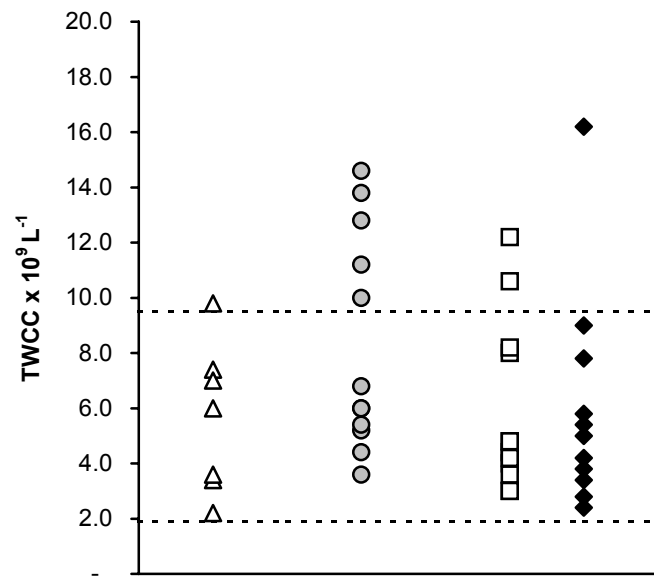
Figure 4.18. Total white cell count (TWCC) for male eastern quolls (*n* = 31 quolls, 42 samples) across all study sites. Samples collected during March (white triangles), May (grey circles), July (white squares) and August (black diamonds). Dotted horizontal lines represent upper and lower limits of reference intervals established for male eastern quolls by Melrose *et al.* (1987).
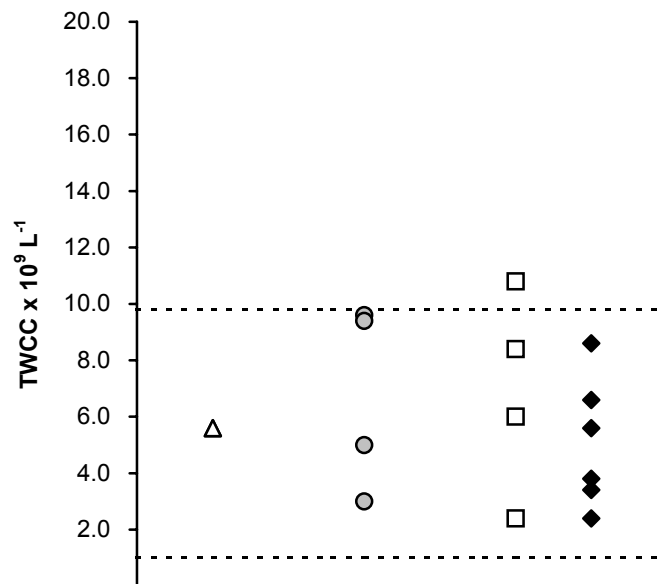
Figure 4.19. Total white cell count (TWCC) for female eastern quolls (*n* = 11 quolls, 16 samples) across all study sites. Samples collected across all trapping sessions (symbols as defined in Figure 4.18). Dotted horizontal lines represent upper and lower limits of reference intervals established for female eastern quolls by Melrose *et al.* (1987).
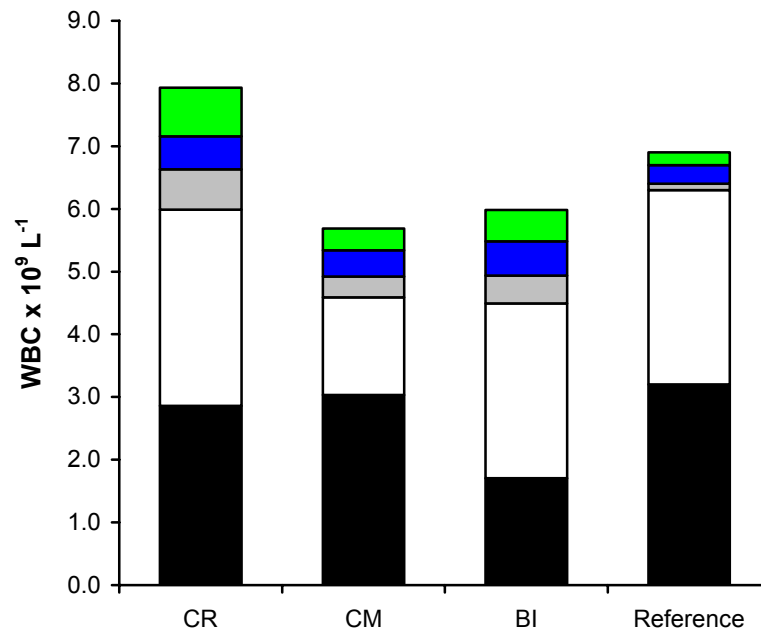
Figure 4.20. Mean differential white cell counts for male eastern quolls (*n* = 31 quolls, 42 samples) across all study sites (CR = Cradoc, CM = Cradle Mountain, BI = Bruny Island, Reference = reference values for male eastern quolls by Melrose *et al.* (1987)). WBCs differentiated into lymphocytes (black shading), neutrophils (white), ring forms (grey), monocytes (blue) and eosinophils (green). Data represent samples collected across all trapping sessions during the current study.
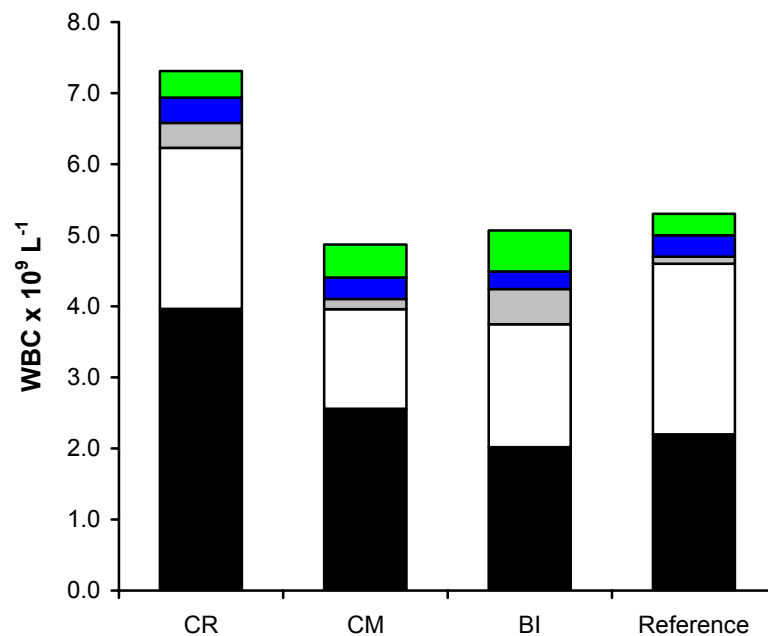
Figure 4.21. Mean differential white cell counts for female eastern quolls (*n* = 11 quolls, 16 samples) across all study sites (site symbols as per Figure 4.20). Reference = reference values for female eastern quolls by Melrose *et al.* (1987). Legend for site abbreviations and different types of WBCs as per Figure 4.20. Data represent samples collected across all trapping sessions during the current study.
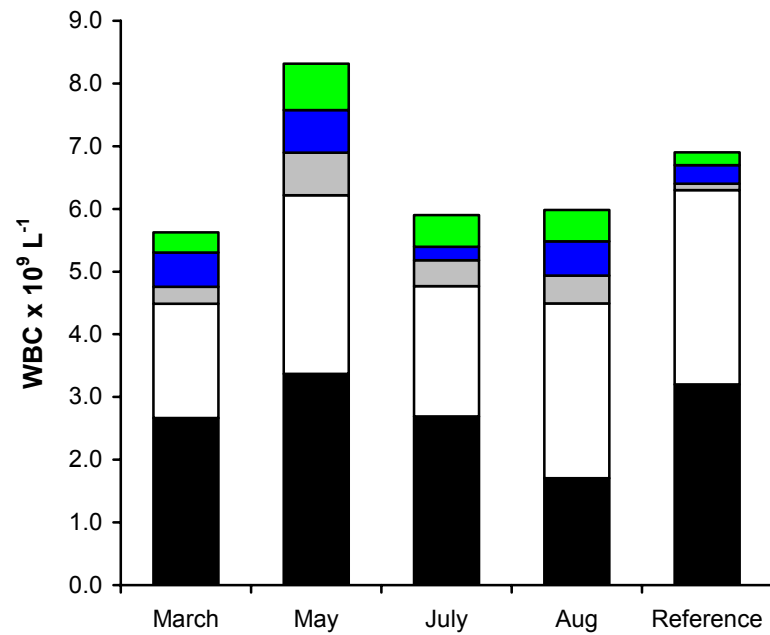
Figure 4.22. Mean differential white cell counts for male eastern quolls (*n* = 31 quolls, 42 samples) by trapping session across all study sites. Legend for site abbreviations and categorisation of each WBC type as per Figure 4.20. Reference = reference values for male eastern quolls by Melrose *et al.* (1987).
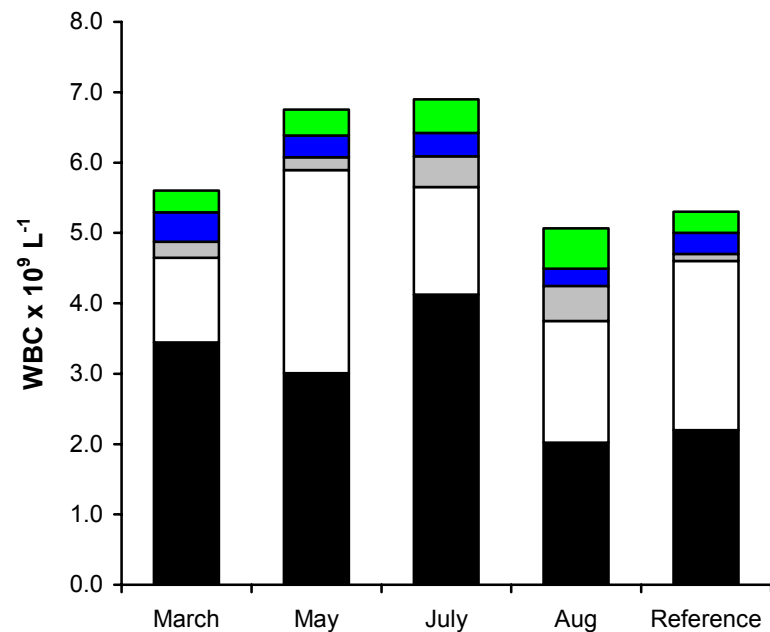
Figure 4.23. Mean differential white cell counts for female eastern quolls (*n* = 11 quolls, 16 samples) by trapping session across all study sites. Legend for site abbreviations and categorisation of each WBC type as per Figure 4.20. Reference = reference values for female eastern quolls by Melrose *et al.* (1987).
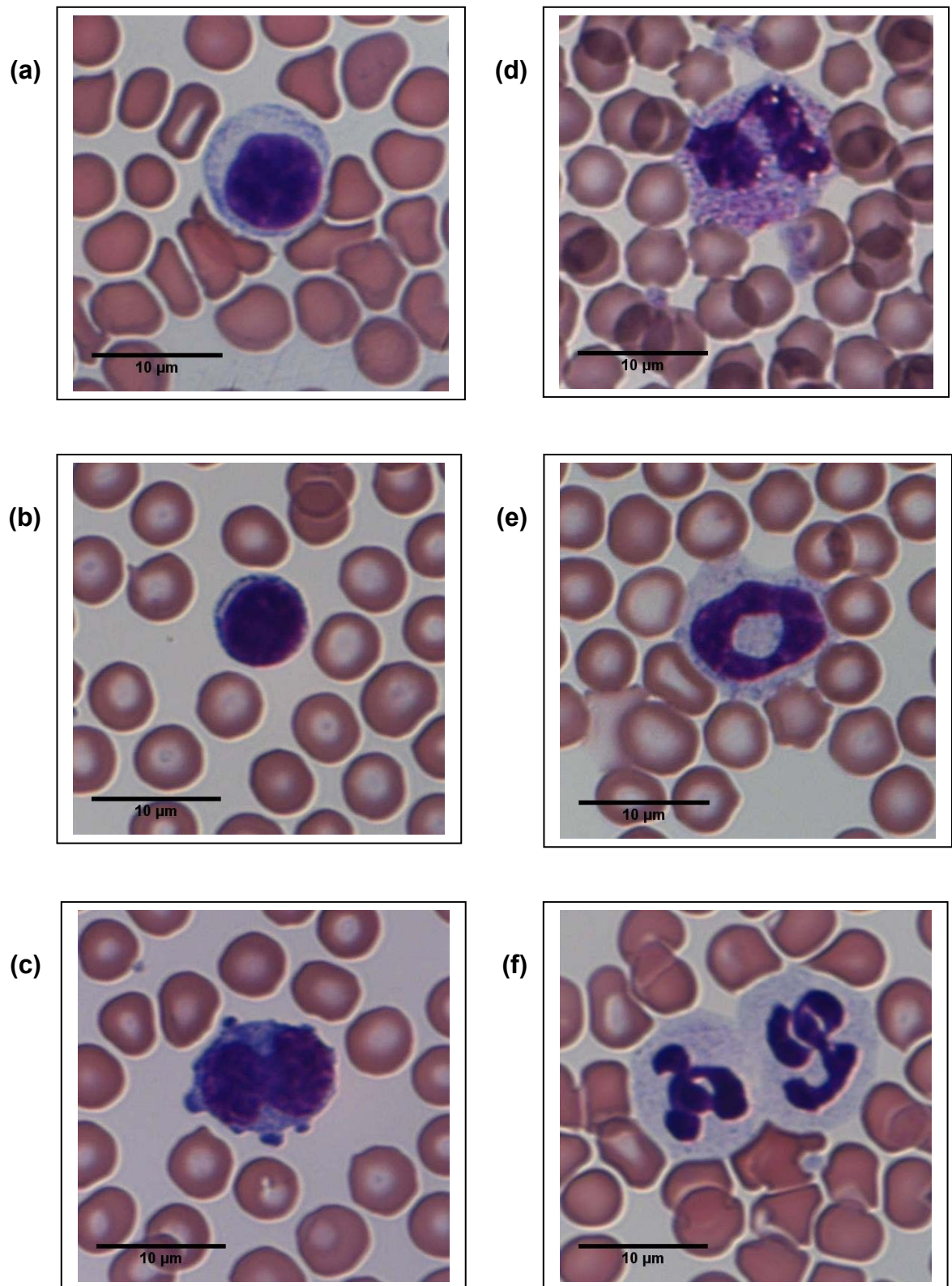
Figure 4.24. Images of different types of eastern quoll leukocytes from the current study; (a) large lymphocyte; (b) small lymphocyte; (c) monocyte; (d) eosinophil; (e) annular (ring) leukocyte; (f) segmented neutrophils. All images taken at x 1000 magnification (oil immersion) using Zeiss Axiocam HRC high resolution digital camera (Carl Zeiss MicroImaging GmbH, Jena, Germany) attached to an Axioskop 2 plus microscope (Carl Zeiss Light Microscopy, Göttingen, Germany). All images DQ stain.
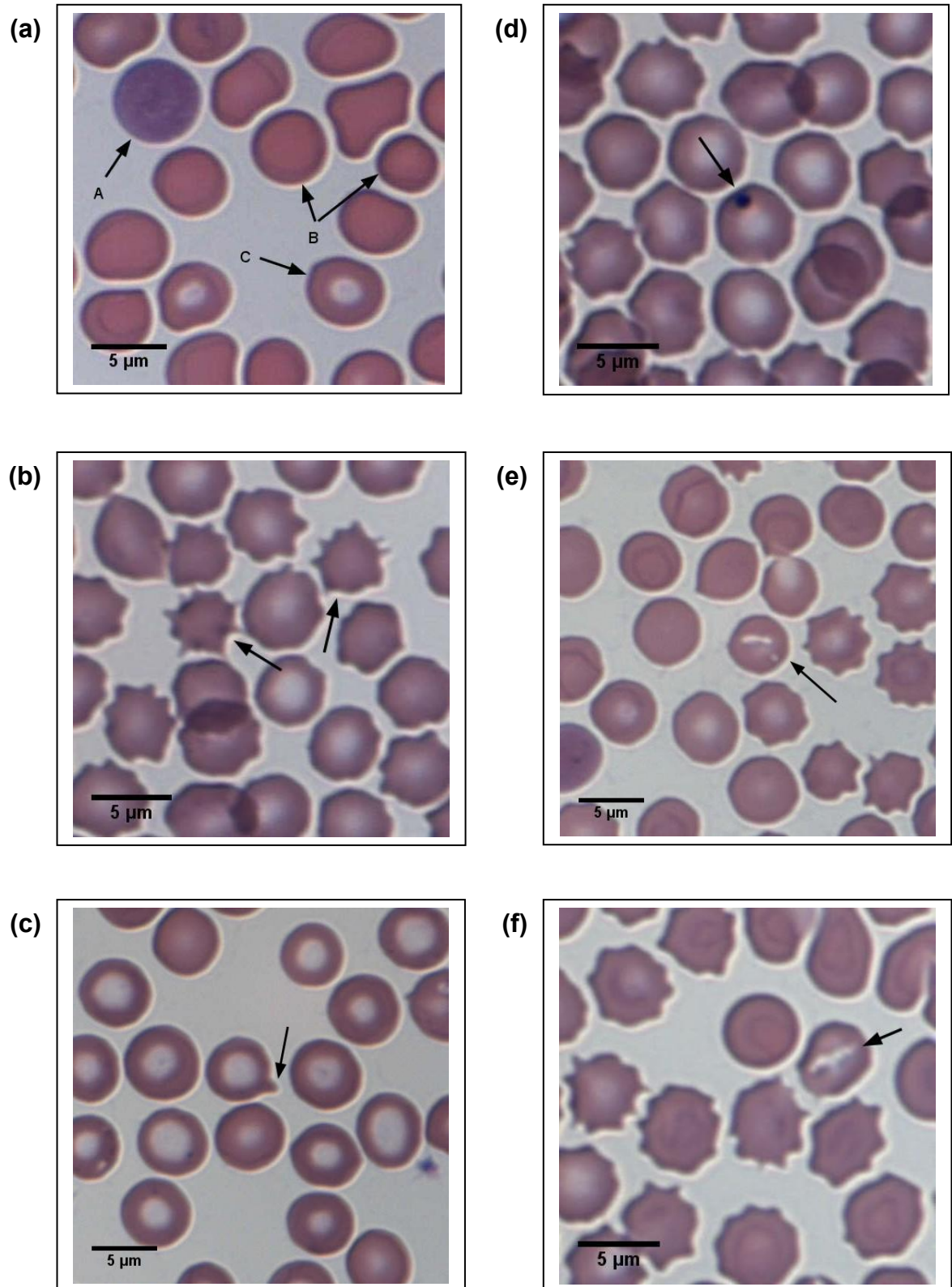
Figure 4.25. Images of different types of eastern quoll erythrocytes from the current study; (a) polychromatophilic erythrocyte (A), spherocytes (B) and normal erythrocyte (C); (b) echinocytes; (c) Heinz body; (d) Howell-Jolly body; (e) and (f) stomatocytes (arrows). Note the presence of additional echinocytes in images (d)-(f). All images taken at x 1000 magnification (oil immersion) using equipment as detailed in Figure 4.24. All images DQ stain.

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4.3.3.4 Toxoplasmosis

Of the 41 individuals tested, 16 (39%) were seropositive for antibodies to *Toxoplasma gondii*, with no significant differences between sexes (Fisher exact: $p = 0.265$).

Seropositive quolls were found at all three study sites, with significant differences observed between sites ($\chi^2 = 10.837$, d.f. = 2, $p = 0.004$). Prevalence ranged from 12% at Bruny Island up to 73% at Cradoc.

Significant differences were observed between age classes ($\chi^2 = 4.969$, d.f. = 1, $p = 0.026$), with prevalence amongst 1-year old quolls (13%) being much lower than 2+ year olds (54%). Site-specific results are summarised in Table 4.5.

Two male quolls at Cradoc (one 1-year old, one 2-year old) changed status from seronegative when tested in March and May to seropositive in July.

Table 4.5. Seroprevalence of *Toxoplasma gondii* antibodies in eastern quolls across all study sites in the current study (adapted from T. Hollings and B. Fancourt, unpublished raw data).

Site	Positive (n)	Negative (*n*)	Positive (%)	1 year olds positive (%)	2+ year olds positive (%)
Cradoc	8	3	73%	33%	88%
Cradle Mtn	6	7	46%	14%	83%
Bruny Island	2	15	12%	0%	17%
All sites	16	25	39%	13%	54%

4.3.3.5 Ectoparasites

Eastern quolls at Cradoc had the highest ectoparasite counts of all study sites, however all except two individuals carried only minor or no parasite loads. Marked fluctuations between trapping sessions were evident, with May and July producing much higher parasite loads than March. Low numbers of ticks were observed across all trapping sessions, but the most numerous parasites were fleas and *Uropsylla tasmanica* larvae seen throughout May and July. One male trapped in May was estimated to be at least 3 years old with a heavy burden of *U. tasmanica* larvae across most areas of his body (see Figures 4.26 and 4.27), with 20 larvae on the right ear alone. Numerous lesions contained multiple larvae within the one lesion, with evidence of extensive inflammation and infection. Whilst his body condition score had not dropped, his general fitness had deteriorated markedly since his last capture in March, with evidence of walking difficulties on release and apparent irritation from parasites. This quoll was not recaptured in July. A second male (estimated 2 years old) was captured in July with a medium burden of *U. tasmanica* larvae. Distribution of the larvae were more patchy (Figure 4.27) and it appeared that his younger age and better body condition had enabled him to endure the parasites with minimal effects.

Ectoparasites were notably absent at Cradle Mountain, with only one tick found on the ear of one quoll in July.

Bruny Island quolls had minor ectoparasite loads, with right ear counts producing one flea and five ticks over four quolls, with the remaining 13 quolls having no ectoparasites.

4.3.3.6 Post mortem findings

Ten roadkilled quolls (6♂, 4♀) were collected throughout the study. All bodies were collected from a range of locations throughout south-eastern Tasmania. No obvious abnormalities were detected from the post-mortem examination of these quolls.

Figure 4.26. Heavy infestation of *Uropsylla tasmanica* larvae observed on a 3-year old male at Cradoc in May. Infestation was evident over most of the body, but predominantly concentrated around the (a) rump/tail and (b) the cloaca/scrotal area. There was no evidence of any infestation when this individual was captured 2 months earlier *(Photos: I. Thomas and B. Fancourt).*
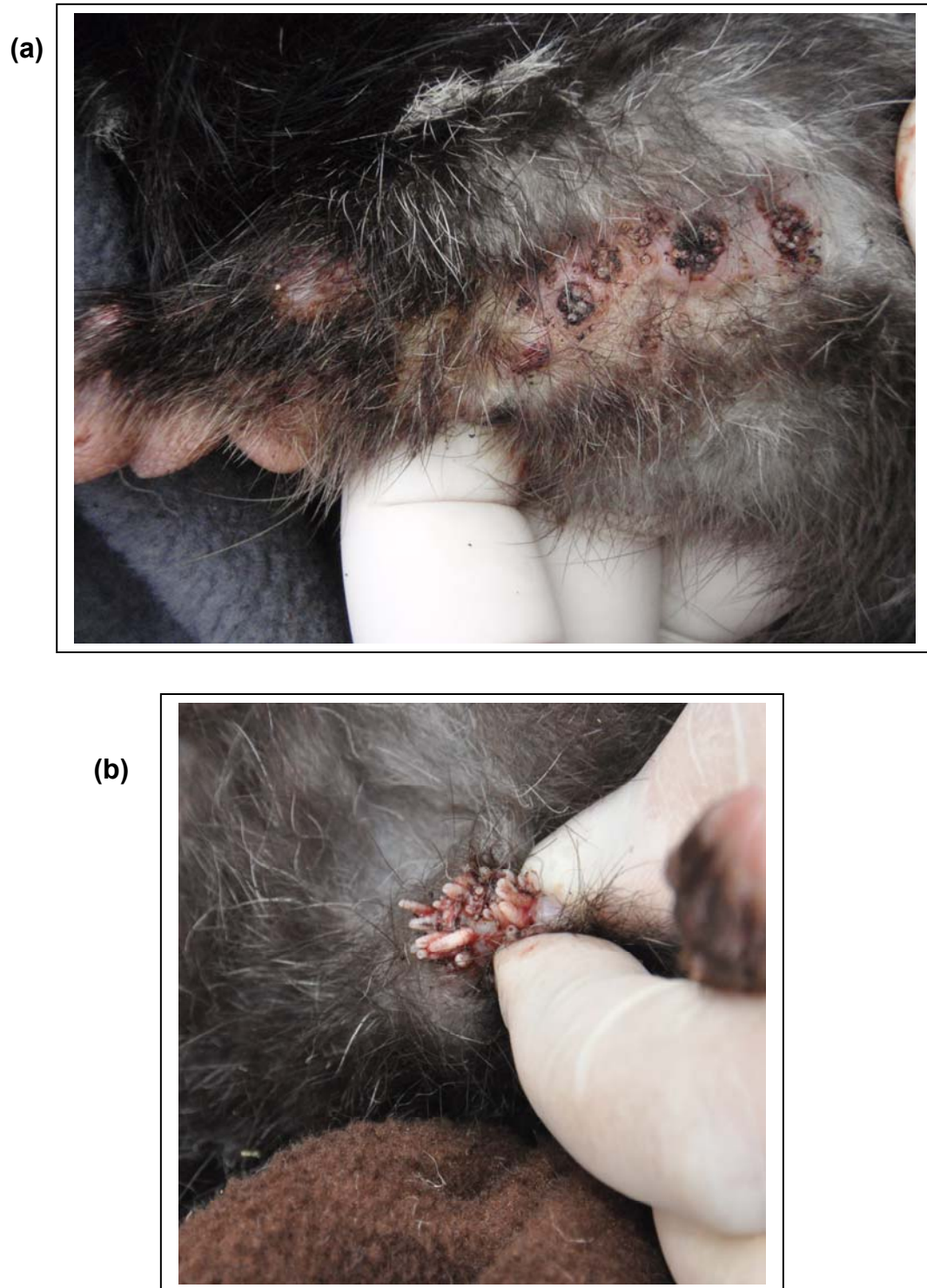
Figure 4.27. Infestation of *Uropsylla tasmanica* larvae (a) extended down the forearms, with multiple larvae within each lesion. Note the marked inflammation around the lesions. Distribution of lesions were more patchy (b) on this 2 year old male captured in July *(Photos: I. Thomas and B. Fancourt).*

4.3.4 Reproduction

4.3.4.1 Male reproduction

Testicular volume fluctuated seasonally with slightly different trends observed at each site, although seasonal effects were not significant ($F = 1.184$, d.f. = 2, $p = 0.323$). At Cradoc, mean testicular volume increased from March (3.28 cm^3) to May (3.39 cm^3), then fell in July (2.97 cm^3). At Cradle Mountain, mean testicular volume fell with subsequent trapping sessions, with a slight decrease from March (2.31 cm^3) to May (2.21 cm^3) but a more marked drop in July (1.85 cm^3).

Long-term temporal comparisons at Cradoc revealed significant differences between years ($F = 32.890$, d.f. = 1, $p < 0.001$), with testicular volume being much greater in 2010 than in 1984 across all trapping sessions as illustrated in Figure 4.28. Seasonal trends evident in the current year were also seen in the 1984 data, with testicular volume increasing slightly from March to May, but declining significantly in July ($p < 0.001$).

Significant spatial variation in testicular volume was evident in July 2010 ($F = 8.910$, d.f. = 2,20, $p = 0.002$) with Cradoc yielding significantly greater testicular volumes than both Cradle Mountain ($p = 0.002$) and Bruny Island in August ($p = 0.004$). Testicular volumes at Cradoc were significantly greater than those at Cradle Mountain in every trapping session ($F = 18.970$, d.f. = 1, $p < 0.001$).
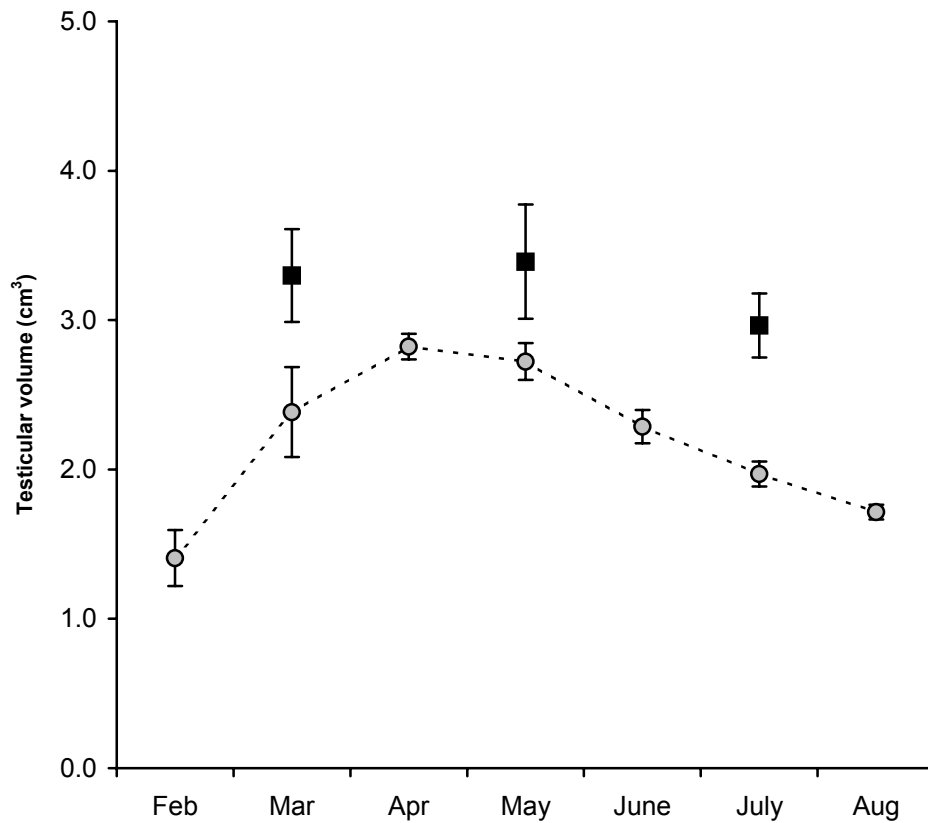
Figure 4.28. Long-term differences in eastern quoll testicular volume at Cradoc between 1984 (grey circles) and 2010 (black squares). Data points shown as means with standard error bars. Note that quolls in the current study appeared to follow the same seasonal trend seen in 1984, with significantly higher TV observed at each sampling period.

4.3.4.2 Female reproduction

Marked variation in breeding season was evident between sites, with Cradoc quolls breeding much earlier than those on Bruny Island and possibly Cradle Mountain.

All three females captured at Cradoc during July had 6 pouch young, ranging from 19.6-23.4 mm in length (CRL) on 14th July 2010. The age of these litters was estimated from growth charts at between 32 and 39 days respectively, giving mating dates of between 16th and 23rd May 2010. Prior studies at this site recorded slightly lower reproductive success, with 6 of the 7 females captured in July 1984 having

litters of between 2-6 pouch young (mean: 5). The seventh female had no pouch young in July, August or September so did not appear to have bred successfully that year. Estimated age of these pouch young were between 2 and 21 days, indicative of mating dates between 21st May and 6th June 1984. Whilst timing of breeding seasons for 1984 and 2010 appeared similar, breeding in 2010 appears to have started and finished slightly earlier in the year than 1984.

At Cradle Mountain, only one female was captured during July (20th July 2010). She had no pouch young at the time of capture, which indicated that she had not mated before July. The appearance of her pouch (deep red, swollen mammary glands) and cloaca (red and swollen) indicated that birth was due within days, suggesting a mating date around the first couple of days in July, however she was not re-captured on subsequent nights to confirm the birth date. Prior studies at this site recorded pouch young for both females captured in July 1991, with pouch young present on 13th and 16th July. Whilst no records were made of pouch young size on these dates, a 20 day gestation period suggests the latest possible mating date for these 2 females was 24th and 27th June respectively, however mating could have been anywhere in the 60 days prior to this date (as both quolls were captured 60 days earlier and neither had pouch young recorded at that time).

On Bruny Island, all six females captured in late August had pouch young (mean: 5.2, range: 3-6). CRL of pouch young ranged from 22.5 mm to 42.6 mm, giving estimated ages between 38 and 60 days respectively. Corresponding mating dates for these litters were estimated between 5th and 26th June respectively, falling somewhere between Cradoc and Cradle Mountain breeding seasons.

4.4 DISCUSSION

Whilst no obvious causative factors were identified in the current study that could explain the recent decline observed in eastern quolls, several areas highlighted trends that suggest potential areas of concern. These trends will be discussed below in a broader ecological context, taking into account the species' ecology and its potential agents of decline.

4.4.1 Population structure

Sex ratios

Whilst there were no significant differences between sex ratios observed in the current study and historic studies, this could be a function of the low sample sizes obtained in the current study, thereby increasing the risk of a type 2 error (Zar 1984).

The strong male bias of the species in the current study would *prima facie* cause some concern over the ability to reproduce at a sustainable level. However, the disproportionately low numbers of females appears to be a normal demographic relationship observed in this species, with varying degrees of male bias reported in previous studies (e.g. Green 1967; Godsell 1982; Bryant 1986; Jones and Barmuta 1998). Sex biased ratios have also been observed in many other carnivorous marsupials, including the northern quoll *Dasyurus hallucatus* (Oakwood 2000), agile antechinus *Antechinus agilis* (Davison and Ward 1998) and the common opossum *Didelphis marsupialis* (Austad and Sunquist 1986), indicating some ecological advantage to a skewed sex ratio. Many theories have been formulated concerning the evolution of altered sex ratios, taking in a range of factors including maternal condition (Trivers and Willard 1973), local mate competition (Hamilton 1967), local resource competition (Clark 1978) and cohort advantages (Wright *et al.* 1995). Whilst the male bias observed in the eastern quoll can readily be explained by several of these theories, it appears to be a normal part of this species' population dynamics. Accordingly, the observed sex ratios do not suggest any potential causative factors that may have contributed to the recent declines in eastern quolls.

Population demographics

The long-term changes observed in population structure were most evident as reductions in adult females and juveniles. This can be interpreted in several ways.

Firstly, as a female can only raise a maximum 6 young in any one year, a reduction in the number of adult females will reduce the reproductive potential of that population, with a corresponding decrease in juveniles entering the population. A decline in adult females and juveniles suggests that adult females may be more susceptible to a particular selective pressure than adult males. Such possibilities might include neoplasias of the female reproductive organs (e.g. ovaries, mammary glands). Members of the family Dasyuridae are particularly susceptible to the development of spontaneous neoplasms (Munday 1978; Twin and Pearse 1986; Canfield *et al.* 1990b), with mammary hyperplasias, adenomas, adenocarcinomas, and a variety of other proliferative lesions associated with either the teat or pouch skin (squamous cell carcinoma, sebaceous proliferations) commonly found in eastern quolls and other dasyurids (Canfield *et al.* 1990b). Whilst a thorough examination of pouches in the current study failed to yield any obvious signs of neoplastic proliferations, the low number of females captured precludes discounting this as a potential factor in the decline of adult females. Additionally, such afflictions may only present seasonally, possibly manifesting during lactation and becoming more prevalent during late lactation or weaning. The duration of the current study did not cover these periods and hence further examination of quolls should be performed during late lactation, weaning and post-weaning periods.

Secondly, nutritional stress associated with the recent drought could have had an adverse affect on quoll numbers due to a reduction in food availability. Tasmania has endured a sustained and persistent drought over the past 10 years, with drought-breaking rains first falling in mid-2009 (Tasmanian Planning Commission 2009). With limited food availability, nutritional stress would likely have affected those population classes with higher energy demands, such as adult females during late lactation when energy demands are almost twice that of non-lactating individuals (Green and Eberhard 1983). The more wide-ranging males (Godsell 1982) would be

less prone to such pressures, with the ability to range further to search for food. This could explain the disproportionate loss of adult females compared to adult males. However, the body condition and body mass of individuals examined at both Cradoc and Cradle Mountain was equal to or better than that observed in historical studies, with no evidence of emaciation observed in those individuals. This is not unreasonable given that rains received since mid-2009 would have increased food availability in the months that followed. Therefore, whilst many individuals may have died during the drought, those that survived would have been able to feed up and restore condition since mid-2009, thereby explaining the apparent good body condition observed during the current study. Given this post-drought recovery period, the excellent body condition observed in the current year does not eliminate drought and associated nutritional stress from being a potential causative factor that contributed to the recent decline up to 2009. To test this hypothesis, populations should continue to be monitored over the next few years to see if numbers start to recover in the post-drought period. Correlations between seasonal rainfall and eastern quoll observations in the spotlighting data over the past 20 years should also be assessed to identify if rainfall appears to be a driver of annual fluctuations in eastern quoll numbers.

Thirdly, the possible impact of sodium fluoroacetate (compound 1080) baiting on non-target eastern quolls should be considered. Whilst 1080 has been used throughout Tasmania since the 1950s, its use was historically targeted at browsing herbivores and was predominantly delivered as poisoned carrot baits that did not present a significant risk to non-target carnivores such as eastern quolls (Statham 2005). However, the Fox Eradication Branch (FEB) of DPIPWE commenced operational fox baiting programs in Tasmania in 2002 (Saunders *et al.* 2006), using both dried kangaroo meat baits and commercially prepared Foxoff® baits specifically designed to target carnivores (Fox Eradication Branch 2010b; Nick Bates, FEB, pers. comm.). Appendix 8 shows locations of eastern quoll sightings across Tasmania and the regions subject to 1080 fox baiting to the end of 2008. Laboratory trials have found the physiological tolerance of eastern quolls to 1080 (in the form of an LD_{50}) to range from 1.50 mg kg^{-1} to 3.73 mg kg^{-1} (McIlroy 1981; King *et al.* 1989). This

indicates an average 0.85 kg adult female (Godsell 1983) would only need to consume less than one half of one 35 g Foxoff$^®$ bait (containing 3 mg 1080) for it to be lethal to both her and any dependent young. Similarly, juveniles with their smaller body mass would require even less, whilst the larger adult males with their greater body mass would be less susceptible and need to consume more bait for it to be lethal. But whether this theoretical risk equates to a realised risk to eastern quolls in the landscape is poorly understood, with a range of variables such as: pattern and density of bait distribution; habitat structure; bait matrix composition; burial or surface presentation of baits; bait removal by other animals; availability of other foods; rate and extent of bait degradation due to biological and climatic factors; and ambient temperatures all affecting the likelihood that an animal will detect, dig-up, consume and die from consuming a bait (e.g. Oliver and King 1983; Saunders *et al.* 2000; Körtner *et al.* 2003; Gentle *et al.* 2007). Whilst limited field trials into the risk to non-target carnivores was carried out in parallel with initial operational baiting programs, studies focussed on the spotted-tailed quoll and the Tasmanian devil, with field-tests performed in areas outside the eastern quoll's core distribution (Mooney *et al.* 2005; Fox Eradication Branch 2010a). Accordingly, in the absence of conclusive field studies to assess the potential risk of 1080 fox baiting to eastern quolls, and given that fox baiting commenced around the time that eastern quolls started to decline, 1080 poisoning cannot be eliminated as a potential contributing factor to the recent decline. Whilst no 1080 fox baiting has been carried out on the Cradoc study site, around 18 km^2 was baited on adjacent properties (predominantly plantation) in September 2009 (K. Withers, FEB, pers. comm.), well within the home range of the quolls frequenting the study site. Given this baiting occurred at the time of year when females are in late lactation and energy needs are highest (Green *et al.* 1997), the possibility that this may have resulted in the loss of adult females and their dependent young can not be discounted. Fox baiting was also carried out in the vicinity of the Buckland study site in November 2005 (K. Withers, FEB, pers. comm.), although this occurred several years after the decline was first observed in the spotlighting data (Figure 2.8). Further field studies assessing the risk of 1080 baiting to eastern quolls in the landscape are required to either rule out 1080 baiting

as a key threat to eastern quolls, or to identify procedural changes that may be necessary to reduce the risk to eastern quolls from future baiting operations.

Colour ratios

The significant swing in colour ratios at Cradoc from a tan bias to a black bias warrants further discussion. Numerous accounts have referred to the relative colour ratios amongst eastern quoll populations, with all observing tan quolls (sometimes referred to as "greys", "light brown" or "fawn") in much higher numbers than black quolls. Historic accounts as far back as 1863 have all noted the predominance of tans in both Tasmania (e.g. Gould 1863; Weindorfer and Francis 1920) and on the mainland (e.g. Batey 1907; Sherrie 1910; Fleay 1940). Where colour ratios were recorded in studies over the past 50 years, ratios of tan : black ranged from 2.7:1 ($n = 269$) at Cradoc (Godsell 1983), 3.1:1 ($n = 49$) at Gladstone (Green 1967), up to 6:1 ($n = 21$) at Cygnet (Godsell 1983). For those studies where large sample sizes were obtained (e.g. Green 1967; Godsell 1983), colour ratios in both pouch young and adults approximated 3 tan : 1 black, indicating that the black coat colour may be an autosomal recessive gene.

The current study found a significant colour swing towards black quolls, contradicting ratios observed in all known historical accounts across both Tasmania and the mainland. If the black coat is indeed a recessive gene, this would suggest an increase in homozygotes in the current population. With the demonstrated decline in eastern quolls over recent years, the reduced population size increases the likelihood of inbreeding, which in turn can lead to an increase in the proportion of homozygotes in a population (Klug and Cummings 2005), thus accounting for the increase in black quolls. Whilst *prima facie* this appears to be a result of the decline rather than a contributing factor towards it, many deleterious alleles are expressed as recessive genes (Lacy 1993). Hence, an increase in the proportion of homozygotes in a population also increases the possibility that an individual may be homozygous for a deleterious allele, which may contribute to the decline. However, given the apparent reduction in tan rather than black, there is no evidence for the expression of a homozygous deleterious allele. Conversely, the tan quolls may be genetically

predisposed to some debilitating condition that has manifested through a recent mutation, although nothing was externally apparent in the small number of quolls examined in the current study. Whilst the low number of individuals captured in the current study prohibits any conclusive analysis of these potential genetic scenarios, the observed swing in coat colour suggests that further genetic work needs to be done to assess the extent of inbreeding depression and genetic variability within eastern quoll populations.

Notwithstanding this, the reduction in tan quolls highlights that other selective pressures may be acting on tan quolls in preference to black quolls. Being nocturnally active, eastern quolls are vulnerable to predators whilst foraging at night, suggesting that tan quolls may be easier to detect in the dark than black quolls. However, if different visibility at night resulted in different susceptibility to predation, this would have become evident long before the recent decline in eastern quolls. The main exception to this would be if a new predator had entered the ecological mix in recent years, preferentially selecting tan quolls over blacks. Recent attempts to re-introduce foxes to Tasmania around 12 years ago (Saunders *et al.* 2006) may be contributing to this. Studies have shown that foxes appear to have dichromatic colour vision (Jacobs *et al.* 1993) enabling them to detect different colours. This suggests that foxes may be able to detect tan coloured quolls more easily than blacks that blend in better at night, and may be a contributing factor to the decrease in the proportion of tan quolls. Further supporting this is the considerable overlap in areas where evidence of foxes has been collected, areas considered core fox habitat (see map in Appendix 7) and areas of core eastern quoll distribution.

Whilst historical colour ratios were not recorded for Bruny Island, Weindorfer and Francis' (1920) historical account of "light brown plentiful, black rare" was from the Middlesex Plains and Cradle Mountain areas, suggesting tan was historically dominant in that area. Roughly equal colour ratios were observed at both sites in the current study, representing a marked swing from the predominance of tans historically recorded for the species.

4.4.2 Body condition

At both Cradoc and Cradle Mountain, the seasonal fluctuation in male body condition followed that typically seen across the breeding season (Bryant 1986), with an increase in BCI from March (pre-breeding) to May (breeding), followed by a drop in condition in July (post-breeding).

The spatial comparison in male body condition revealed similarities between Cradoc and Cradle Mountain, with Bruny Island quolls in significantly poorer condition than the other two sites. Males generally reach their poorest post-breeding condition by August-September (Bryant 1986), therefore Bruny Island quolls examined in August would have been closer to their lowest seasonal condition whilst those at other sites in July would still have some condition to lose. Differences in body condition could also be a function of different population densities at each site (LeBlanc *et al.* 2001; Pettorelli *et al.* 2002; Pusey *et al.* 2005), with higher densities on Bruny Island possibly resulting in higher resource competition and poorer general condition than quolls in lower density populations, such as those at Cradoc and Cradle Mountain.

The significant increase in male body mass at Cradoc compared to 1984 may be due to less competition for available food resources and/or increased competition for mates as female numbers decline. Given that there was no corresponding increase in female body mass, the increase in male body mass does not appear to be a result of reduced competition for food. In most polygynous mammals, it is considered that larger males have the greater competitive ability (Andersson and Iwasa 1996; Ward 2003), with increased body size being more pronounced as numbers decline. If male eastern quolls compete for females as suggested by Godsell (1982), the observed reduction in females should increase competition amongst males. Hence, the long-term increase in male body condition appears to be a result of, not a contributor to, declines in eastern quoll populations.

4.4.3 *Health*

The procedures performed in the current study were not intended to be a comprehensive medical investigation, but rather to identify any abnormalities or trends that could suggest health concerns that may warrant more detailed targeted testing. Whilst no evidence was found to suggest any debilitating pathological condition affecting eastern quolls, many conditions will not be evident from external examination or from the limited sample collection carried out in the current study. Furthermore, limited sample sizes will restrict the ability to identify conditions less prevalent throughout populations. Despite this, some results did highlight areas that should be investigated further in order to conclusively identify potential causative factors that may or may not be implicated in the recent decline of eastern quolls.

Haematology

Whilst most haematological parameters fell within reference intervals, there were two exceptions: PCV for females, and TWCC for males. The high PCV observed in females could be symptomatic of dehydration or polycythemia. Persistent dehydration appears unlikely given that values returned to within reference intervals by August. Polycythemia cannot be diagnosed without additional tests such as haemoglobin levels, which were not performed as part of the current study. Whilst further tests would be needed to make any diagnosis, it does not appear imperative given that levels returned to within reference intervals in later months.

The PCV fluctuated seasonally (see Figure 4.14), reaching highest levels over the winter months. Seasonal fluctuations in PCV have been observed in other species such as the koala (Cleva *et al.* 1994), with increases over winter thought to be part of a metabolic response to increased energy demand associated with low environmental temperatures. This was also considered by Hallam *et al.* (1995), with the high PCV and high concentrations of circulating haemoglobin observed in female eastern quolls considered to be a strategy for coping with the requirements of a high metabolic rate. Whilst PCV levels in the current study dropped back within reference intervals by August, it did demonstrate an apparent seasonal variation not previously described for this species. Reference intervals were established without

indication of season (Melrose *et al.* 1987), so the extent to which this represents a natural seasonal variation is currently unknown. Hallam *et al.* (1995) recorded a mean PCV above reference intervals for four captive female eastern quolls from Taronga Zoo (time of year not specified), and whilst the haematological parameters of captive animals will not necessarily reflect those of their wild counterparts, it does support the possibility of seasonal variation in such parameters. Further haematological testing should be performed over an annual cycle to better understand the normal seasonal fluctuations in this species.

The TWCC for males followed the same trend as that seen in female PCV, increasing in May for the breeding season, then gradually dropping back within reference intervals by August (see Figure 4.18). The elevated levels in May and July could be a corticosteroid induced stress response (Buddle *et al.* 1992; Hajduk *et al.* 1992), with increased circulating cortisone observed during breeding in this species (Godsell 1983). Whilst stress in most mammals is typically characterised by neutrophilia and lymphopenia (Duncan and Prasse 1986), the leukocytosis observed in the current breeding season was due to a neutrophilia accompanied by a lymphocytosis not a lymphopenia. However, lymphocytosis rather than neutrophilia was the most commonly encountered leukocyte change in western quolls (Clark and Boardman 2005), with the function of lymphocytes in quolls poorly understood. Whilst the observations in the current study appear to reflect a seasonal variation for this parameter, seasonal changes in haematological values have not been recorded for this species. As noted for female PCV, reference intervals were established without reference to season (Melrose *et al.* 1987). Further haematological studies should be carried out across a full annual cycle to test for any natural seasonal fluctuations in bloods counts for the species.

With the exception of a retrospective analysis of haematological data from clinically ill western quolls in captivity (Clark and Boardman 2005), the haematological response to disease has not been reported for any species of quoll. However, as deviations from reference intervals in the current study appear to be more of a

seasonal fluctuation, there is no haematological evidence to suggest that any underlying disease has contributed to the recent decline in eastern quolls.

The absence of basophils and the presence of ring form leukocytes appear to be a normal part of the eastern quoll's haematological profile. Basophils were not identified in previous haematological studies of the species by either Parsons *et al.* (1971) or Melrose *et al.* (1987). However, Canfield (1998) and Clark (2004) have published images of eastern quoll basophils, indicating they do occur infrequently. Melrose *et al.* (1987) noted the presence of basophilic granules amongst some eosinophilic granules and postulated that eosinophils may form a dual function in this species, possibly accounting for the typical low prevalence of basophils. Ring form leukocytes have been previously reported in this species (Parsons *et al.* 1971; Melrose *et al.* 1987) as well as the eastern barred bandicoot, *Perameles gunnii* (Bettiol 2000) and are thought to be a form of metamyelocyte or immature neutrophil similar to the banded forms seen in humans and other species (Melrose *et al.* 1987; Bettiol 2000).

Similarly, low numbers of abnormal erythrocytes such as echinocytes, spherocytes, stomatocytes and polychromatophilic erythrocytes are typically seen in clinically healthy eastern quolls (Clark 2004). Echinocytes are often seen in samples where blood has had prolonged contact with anti-coagulant such as EDTA (Canfield 1998), however blood films in the current study were prepared immediately in the field from whole blood collected without the use of anti-coagulant and hence avoided any associated crenation. True echinocytes (or spicule cells) have been reported from eastern quoll peripheral blood films in all published historical studies (e.g. Parsons *et al.* 1971; Melrose *et al.* 1987; Clark 2004), together with erythrocyte inclusions such as Howell-Jolly bodies and Heinz bodies. Therefore, the observed cells appear to be a normal part of the erythrocyte profile for this species.

Haemoparasites

Whilst no haemoparasites were detected from blood films in the current study, the low sample sizes together with the problems relating to stain contamination (see

section 4.2.1.4) does not allow any conclusion regarding the presence of haemoparasites amongst eastern quolls and any potential contribution they may have made to the recent decline in eastern quolls.

Two haemoparasites were found in blood films from apparently healthy eastern quolls on Bruny Island during recent genetic studies, namely a *Hepatozoon* sp. and a piroplasm (M. Cardoso, pers. comm.). Similar haemoparasites were found in several eastern barred bandicoots (*Hepatozoon* spp. and *Trypanosome* spp.), with no statistical differences found in mean haematological parameters between infected and uninfected individuals (Bettiol 2000). This suggests that whilst little is known about the presence or affects of haemoparasites in eastern quolls, there is nothing to indicate any adverse effects on eastern quoll populations at any of the study sites.

Toxoplasmosis

The high prevalence of IgG antibodies in the eastern quolls examined raises concern regarding the eastern quolls' susceptibility to toxoplasmosis. Whilst the co-occurrence of susceptibility to *Toxoplasma gondii* and population decline does not establish causality (Freeland 1993), the apparent susceptibility combined with other factors such as nutritional stresses due to scarcity of food may result in reduced immunocompetence, and possibly recrudescence of any latent infection to manifest as acute disease (Obendorf and Munday 1983; Oakwood and Pritchard 1999).

The recent declines in devil populations due to the spread of DFTD (Hawkins *et al.* 2006) has raised speculation about the possible mesopredator release of species such as feral cats and spotted-tailed quolls formerly thought to be suppressed by devils (Jones *et al.* 2007). Such increases in feral cats could not only increase predation and competition pressures for eastern quolls, but also increase exposure to *T. gondii* for which the cat is the definitive host (Frenkel *et al.* 1970). However, despite an extensive review of the literature, no historical data for the prevalence of *T. gondii* specific antibodies could be found for eastern quolls, thereby precluding any assessment of whether the observed prevalence is normal for the species or whether it represents an increase from historic levels prior to the decline in devils.

The broader ecological consequences of the decline in devils are currently being investigated, including any correlation between declines in devils, increases in feral cats and spotted-tailed quolls, and any corresponding decrease in eastern quolls (T. Hollings, pers. comm.). Early results indicate a correlation between the emergence of DFTD and the timing of declines in eastern quolls, with areas of early DFTD emergence showing eastern quoll declines 2-3 years earlier than areas with later emergence of DFTD (T. Hollings, pers. comm.). However, this correlation does not equate to definitive causality, with other factors such as foxes, fox baiting and drought all correlating with the same period of eastern quoll decline. Further doubt arises when considering the competitive interactions of the sympatric spotted-tailed quolls and eastern quolls. Jones and Barmuta (1998) hypothesised the existence of intraguild competition, whereby young and female spotted-tailed quolls undergo dietary overlap with adult male eastern quolls due to their similar body mass and similar dietary composition. However, if the decline in devils has led to the mesopredator release of spotted-tailed quolls, reductions in adult male eastern quolls would be expected. As discussed in section 4.4.1, eastern quoll reductions were observed more in adult females and juveniles, not in adult males. Furthermore, neither devils nor spotted-tailed quolls were captured at Cradoc in historic studies spanning several years (Blackhall 1980; Godsell 1983; Bryant 1988b) and whilst spotted-tailed quolls were not captured at this site during the current study, two devils were captured within the first seven trap nights, indicating that devils may have actually increased in the area rather than decreased. This suggests that while mesopredator release may potentially contribute to declines in eastern quolls in some areas, other causative factors would appear to be responsible for declines at Cradoc.

The increased prevalence of IgG antibodies with age is not unexpected, as the likelihood of encountering sources of *T. gondii* would increase the longer the quoll lives. Similar age-related increases in prevalence have been seen in other species such as devils (Phillips 2009) and humans (Frenkel 1970) with no evidence of infection in a range of dasyurids less than 6 months of age (Attwood *et al.* 1975).

Whilst animals with overt toxoplasmosis can exhibit a range of symptoms including clouding of the cornea, lethargy, unnatural daytime activity, respiratory distress, incoordination, difficulty in walking and convulsions (Attwood *et al.* 1975; Obendorf and Munday 1983; 1990), often death is sudden without any outward evidence of infection (Attwood *et al.* 1975; Canfield *et al.* 1990a; Oakwood and Pritchard 1999). Animals afflicted with the described symptoms would be more prone to road mortality or predation, reducing the likelihood of observing any affected individuals in the landscape. This suggests that whilst no symptoms of overt toxoplasmosis were observed in the current study, it cannot be eliminated as a potential causative factor in the recent decline of eastern quolls. Post-mortem examination of recently dead eastern quolls could help in testing this hypothesis, however, recovering bodies before predation, decomposition or scavenging is often difficult and complicates this approach. Similar difficulties are currently being experienced by researchers investigating the potential contribution of disease to the recent woylie (*Bettongia penicillata*) declines in Western Australia, with predation preventing the examination of sick or dead woylies (A. Reiss, Perth Zoo, pers. comm.).

Ectoparasites

The main ectoparasite observed on eastern quolls was the larvae of *Uropsylla tasmanica* embedded subcutaneously over various parts of the quoll, with only minor numbers of fleas and ticks. This conforms with previous descriptions of the ectoparasite fauna of this species as described by Pearse (1981). Whilst a heavy burden was observed on one quoll at Cradoc in May, this quoll was estimated to be around three years old and possibly suffering from progressive debilitation that comes with old age. Hence, the parasitic infection was considered to be an opportunistic infection due to his debilitation, not a cause of it. Few parasites were found on quolls at Cradle Mountain, possibly due to the colder, wetter climate (Pearse 1981). Quolls on Bruny Island did not present with *U. tasmanica*, but carried slightly more ticks than other sites. Apart from the Cradoc quoll described above, no individuals presented with heavy burdens that could contribute to the debilitation of otherwise healthy quolls. Given that parasite loads observed in the current study appear consistent with (or lower than) the numerous historical accounts recorded in

this species (e.g. Pearse 1981; Godsell 1983; Bryant 1988b), there is no evidence to suggest that ectoparasites have contributed to declines in eastern quolls at the study sites.

4.4.4 Reproduction

Males

The seasonal fluctuation in testicular volume observed at Cradoc follows that previously reported for the species (Bryant 1986), although quolls in the current study had significantly higher testicular volume than quolls in 1984. This could be a form of sperm competition (Parker 1970; Parker *et al.* 1997; Schulte-Hostedde and Millar 2004) in response to increased male competition for declining numbers of females at this site (as similarly noted in body condition in section 4.4.2).

The seasonal fluctuation in testicular volume at Cradle Mountain is more concerning, especially given that individuals examined in the May and July trapping sessions recorded progressive decreases in testicular volume at a time when they are typically maximal for breeding (Bryant 1986). This may result in a mis-match in timing of optimal breeding condition between males and females and may account for the absence of pouch young observed in July. Whilst only one female was captured at Cradle Mountain in July, and in the absence of historical testicular dimensions for quolls at this site, there is insufficient evidence to explore this possibility further. However, it does highlight a phenomenon that should be investigated further in future years to establish if this was a one-off occurrence during the current year, or a concerning trend that may have adverse consequences for future reproductive effort at this site.

The markedly lower testicular volume observed at Bruny Island is again likely to be due to the later sampling at this site (August), by which time testicular dimensions are typically at a seasonal minimum (Bryant 1986).

Females

The only female captured at Cradle Mountain in July did not have pouch young, although her pouch appearance indicated that she was close to giving birth. This may have been due to a possible delay in breeding season during the current year at this site (as discussed in section 3.4.3).

As all other females captured at all other sites had between 3 and 6 pouch young, there does not appear to be any obvious reduction in reproductive output that may be contributing to the recent declines. The slightly lower number of pouch young per litter observed later in the season at Bruny Island appears to be a function of normal attrition, with females often losing some pouch young between birth and weaning (Godsell 1983; Bryant 1988b).

The estimated birth dates derived in section 4.3.4.2 suggest that mating at Cradoc in the current year occurred within the defined breeding season of late May to early June (Godsell 1982; Bryant 1986). Bruny Island appeared to have a slightly later breeding season, with estimated mating dates occurring around two weeks later than Cradoc, and extending later than the breeding period previously defined for this species. Whilst a two week delay does not appear to have resulted in lower reproductive success, it does raise questions about the cues that trigger mating. Given the close proximity of the Bruny Island and Cradoc study sites (approximately 25 km apart along the same latitude) and the similar climate and habitat, it suggests that these environmental cues may not be a major trigger for mating. However, given the isolation of quolls on Bruny Island from other populations throughout Tasmania, it is not unreasonable to observe a drift in ecological aspects such as time of breeding in island populations (e.g. Blondel 1985).

Whilst the results from the current study have highlighted some areas that warrant further research, there is no evidence to suggest that recent declines in eastern quolls are a result of reduced reproductive success.

4.4.5 Conclusion

The eastern quolls examined during the current study appeared to be in good overall health, with no obvious signs of debilitating illness, malnutrition or reproductive concerns. Whilst the current study did not identify any definitive causative factors responsible for the decline in eastern quolls, it has identified trends that suggest potential causative factors. Extended testing over a complete annual cycle will also be required to gain a better understanding of aspects that may only be seasonally evident, and hence were beyond the scope and timeframe of the current study. Recommendations for future research to test these hypotheses are outlined in chapter 5, with further investigations required to eliminate or attribute causal factors to the recent decline, and to identify key threats to the ongoing viability of the species.

Chapter 5: General Discussion

5.1 CONFIRMATION OF DECLINES AT STUDY SITES

This study has demonstrated a significant decline in eastern quoll populations at three study sites across Tasmania from which there are no immediate signs of recovery. The reduction is characteristic of a continuing decline, as defined by the eligibility guidelines for listing species under the Tasmanian *Threatened Species Protection Act 1995* ("the Act") as a "recent, current or projected future decline (which may be smooth, irregular or sporadic) which is liable to continue unless remedial measures are taken". As discussed in section 3.1.1, this differs from a mere fluctuation in that it is more sustained and it is unlikely that the species will recover without intervention.

The >50% reduction in eastern quoll sightings indicated in the spotlighting data over the past 10 years is supported by the long-term reduction observed in the trapping results. Therefore, the decline appears to meet the criteria for listing the species as endangered under the Act using criterion (A)(1), being a total population reduction in the form of an observed, estimated or inferred reduction of at least 50% over the last 10 years or within the past three generations of the species (whichever is the longer) based on (a) direct observation; and (b) an index of abundance appropriate for the taxon (DPIPWE 2008). Accordingly, it is appropriate that the eastern quoll be nominated for listing as a threatened species as soon as possible. This will confer greater protection and management of the species, with increased exposure and awareness of the species' plight.

5.2 POTENTIAL AGENTS OF DECLINE

Whilst identification of the causative factors is not necessary for listing the species, such information is crucial for assessing the nature, extent and urgency of recovery planning. The potential agents of decline for this species were outlined in section 1.2.3 and include: climatic factors such as rainfall and drought and the corresponding effects on food availability; persecution; road mortality; poisoning; disease; loss or

modification of critical habitat; and changes in key ecological interactions such as predation and competition. Identifying which of these agents have contributed to the recent decline in eastern quolls is complicated by several concurrent events that took place over the same 10-year period as the decline, including: recent attempts to establish foxes in Tasmania; commencement of 1080 fox baiting in Tasmania; decline of devils due to the rapid spread of DFTD; persistent and severe drought; and continued habitat modification and changes in land-use. Each one of these events could have potentially contributed to the decline, either alone or in combination.

Whilst the current study was unable to conclusively attribute the decline to any of these factors, it did highlight trends that suggest some factors may have been more likely to contribute than others, such as the development and timing of key reproductive stages, changes in population demographics and shifts in coat-colour ratios. It is unlikely that the decline could be attributed to a single causative factor, with two or more factors often interacting to cause such declines (Caughley and Gunn 1996; Hone *et al.* 2005).

5.3 FUTURE DIRECTIONS AND RECOMMENDATIONS

Based on the findings of this study, I recommend the following actions:

1. **Nominate the eastern quoll for listing as endangered** under the Tasmanian *Threatened Species Protection Act 1995*, the federal *Environment Protection and Biodiversity Conservation Act 1999*, and the IUCN Red List of Threatened Species.

2. **Consider the inclusion of additional spotlighting transects around Cradoc and Bruny Island in the annual DPIPWE spotlighting surveys**. Whilst the current study enabled collection of crucial baseline data for these local eastern quoll populations, spotlighting surveys are the only method by which eastern quolls are currently monitored on an ongoing basis. Inclusion of these key populations in future spotlighting surveys will enable future changes in eastern quoll populations to be detected at these sites.

3. **Consider future research in the following priority areas**:

(a) **Continue local monitoring at Cradoc and Cradle Mountain study sites to track ongoing population changes compared to baseline data collected in both the current and historic studies**. Bi-monthly trapping sessions over a minimum of two full annual cycles would facilitate better understanding of current population structure and fluctuations on a seasonal basis, and enable monitoring of conditions that may only manifest critical changes seasonally (e.g. haematology, juvenile survival and dispersal, diet, health and disease). Collection of crucial seasonal data will help identify whether key aspects of the species' ecology have changed with the declining population size. Correlation of any measured variables with declines at a local scale will assist in identifying potential statewide agents of decline and key threats to the ongoing viability of the species.

(b) **Assess the effect that changes in land-use have had on eastern quoll populations, and whether areas of core eastern quoll habitat should be protected as part of the future management and recovery of the species**. The modification or removal of core eastern quoll habitat may have contributed to recent declines, however, what constitutes "core habitat" for this species is poorly understood. Our current understanding is based predominantly on two ecological studies performed at Cradoc and Cradle Mountain (Godsell 1983; Jones 1995). Jones and Rose (1996) performed a preliminary assessment of broad forest habitat associations for eastern quolls to inform the Regional Forest Agreement for Tasmania, but concluded that their data were insufficient to identify which forest types eastern quolls are associated with. They could only conclude that eastern quolls are in low population densities in large, continuous areas of forest. They recommended that habitat associations be reviewed in areas where extensive clearance of native woodlands and grasslands has occurred, such as the Tasmanian midlands. Given the significant change in land-use on properties adjacent to the Cradoc study site (from a mosaic of agricultural land interspersed with areas of intact native forest to a monoculture of *Eucalyptus* plantations), further evaluation of habitat associations, possibly through explanatory

habitat modelling, should be performed in order to identify areas of core eastern quoll habitat.

(c) **Assess climatic factors as drivers of inter-annual fluctuations in population size.** Climatic factors such as rainfall, drought and temperature over the past 20 years should be compared with long-term spotlighting observations of eastern quolls across Tasmania, to identify any correlations between climatic factors and changes in eastern quoll numbers. While the amount of rainfall may be an important factor, the timing and seasonality of rainfall may also significantly affect the life cycles of key prey species such as pasture grubs. Climatic factors may also affect other aspects of food availability at crucial times of the year and thereby fluctuations in population size. This could be assessed through dietary analysis of scats collected throughout the year from a range of study sites experiencing different climates. Results will not only help identify potential causative agents for the recent decline, but will also provide a greater understanding of risks to the species with ongoing climate change.

(d) **Assess the impacts of 1080 fox baiting on non-target eastern quolls in the landscape**. Planned operational fox baiting programs provides an opportunity to monitor eastern quoll populations throughout the duration of a baiting operation. Radio collars with mortality indicators should be fitted to individual eastern quolls before, during and after baiting to enable daily monitoring of quolls, and to retrieve any dead quolls on a timely basis for post-mortem examination. In addition, the use of the non-toxic systemic tracer Rhodamine B in baits would facilitate vibrissae analysis to identify whether quolls have consumed fox baits and survived, as previously demonstrated in spotted-tailed quolls (Körtner 2007). Active field-based testing should be combined with a spatial analysis correlating historic fox baiting locations with long-term spotlighting data. This will help establish whether 1080 fox baiting poses a risk to non-target eastern quolls and whether it may have been a contributing factor to their recent decline.

(e) **Assess the impacts of changing ecological interactions on eastern quoll populations**. Given the recent attempts to establish foxes in Tasmania (Saunders *et al.* 2006) and the recent decline in devils due to DFTD, the dynamics of key ecological interactions between predators and competitors amongst marsupial carnivores and the introduced eutherian carnivores (foxes and cats) needs to be assessed. The direction of such research predominantly hinges on findings from research currently underway into the broader ecosystem impacts of DFTD.

(f) **Review the potential for reintroducing the eastern quoll to areas of its former distribution the Australian mainland**. Whilst intense fox baiting programs such as Project Deliverance in far East Gippsland in Victoria have been successful in enabling the recovery of numerous critical weight range species such as southern brown bandicoots and long-nosed potoroos, mixed or insignificant responses were observed in other species (Murray *et al.* 2006). Given the success of such recoveries is dependant upon ongoing fox control, the reintroduction of eastern quolls into such areas should be deferred until more conclusive testing has been performed on the potential risk of 1080 fox baiting to non-target eastern quolls in the Tasmanian landscape. Furthermore, consideration needs to be given as to what caused the demise of eastern quolls on the mainland during the last century. Whilst predation by foxes has been implicated by some (e.g. Wood Jones 1923; Johnson *et al.* 1989), disease and persecution may also have contributed to their disappearance (Wood Jones 1923; Lindsay 1962; Wakefield 1964; Bennett 1990). If foxes were not a major contributor to the quoll's mainland demise, then placing quolls in a high-risk environment frequently laden with 1080 fox baits will expose them to an unnecessary risk. Consideration of such options should be deferred until further testing as outlined in steps 3(d) and (e) be performed.

(g) **Review the possible expansion of existing captive populations to establish a broad-scale captive breeding program**. Precautionary measures to retain the genetic diversity of the species should be initiated before population declines reduce numbers to small isolated populations that face increased risk

of inbreeding and reduction of genetic variability necessary for maximising the species' likelihood of recovery. This may involve the expansion of eastern quoll populations in both zoos and fenced free-range enclosures. Whilst such measures may seem premature without having identified any agent of decline, recent rates of decline suggest that waiting for more information may be too risky, especially when planning such programs can take considerable time. Accordingly, the establishment of insurance populations to maintain genetic diversity may be a prudent precautionary measure.

4. **Preparation of a recovery plan for the future management of the species and its habitat**. Given that Tasmania represents the eastern quoll's last remaining stronghold, recovery actions should receive relative high priority. However, formulation of any plan and consequent management actions will require causative factors and agents of decline to be identified from step 3 above, and the extent of any such threat evaluated to assist in prioritising actions.

In conclusion, this study has demonstrated a significant decline in eastern quoll populations at three study sites across Tasmania. Whilst responsible causative factors were not identified, my results identified trends suggestive of potential contributors that warrant further investigation. I recommend that the eastern quoll be nominated for listing as a threatened species, and that further research be undertaken in a number of these areas to help identify causative factors. This information is crucial for the preparation of recovery plans necessary to identify and ameliorate key threats to the eastern quoll, and to facilitate rapid implementation of priority management actions.

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Appendices

APPENDIX 1. DPIPWE SPOTLIGHTING TRANSECTS

N
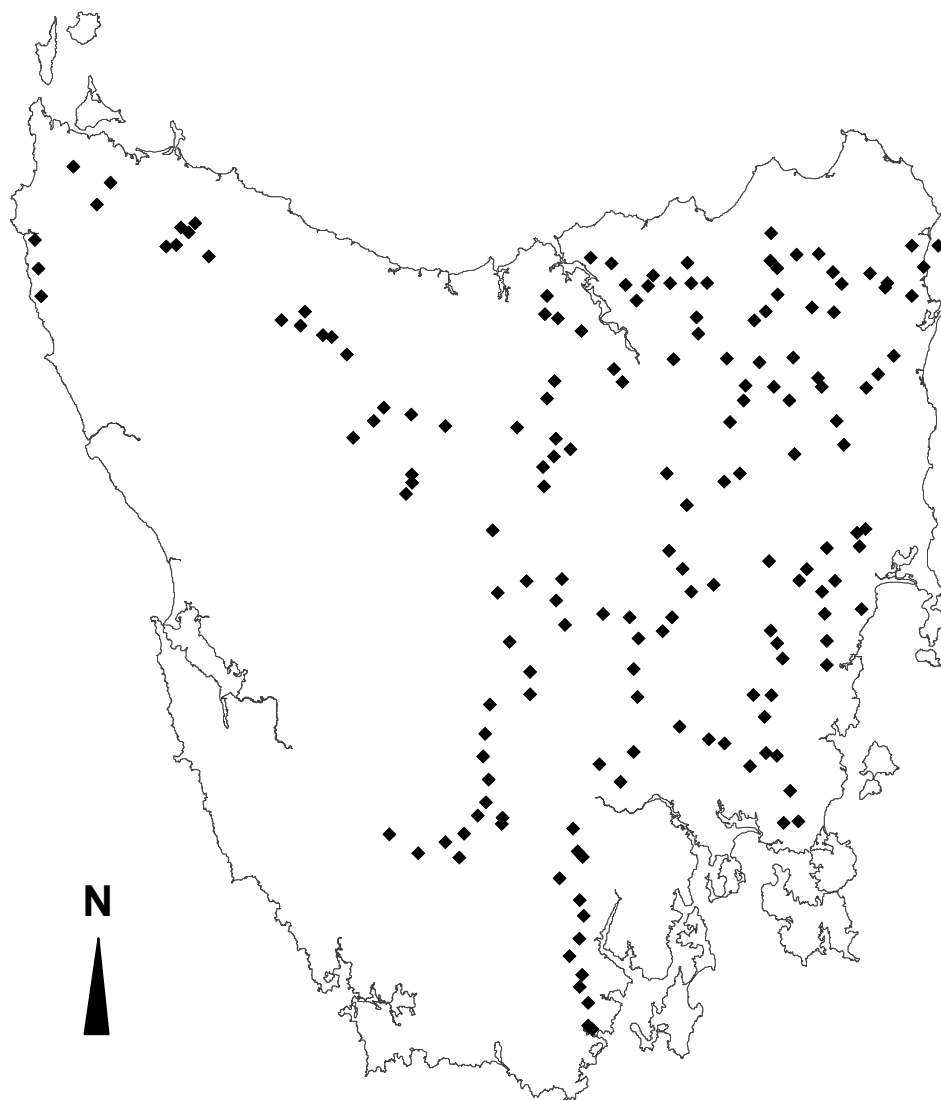
Map of transect locations used by DPIPWE in the annual spotlighting surveys across Tasmania. Each black diamond represents a 10 km transect (*Source: DPIPWE*).

APPENDIX 2. BY-CATCH

The following by-catch was captured during the current study.

Cradoc

Species	Sex	Individuals	Captures			Condition
			Mar	**May**	**Jul**	
Tasmanian devil (*Sarcophilus harrisii*)	F	1	1	-	-	Good condition
Tasmanian devil	F	1	-	1	-	Good condition

Buckland

Species	Sex	Individuals	Captures			Condition
			Mar	**May**	**Jul**	
Spotted-tailed quoll (*Dasyurus maculatus*)	F	1	1	-	3	Good (6 pouch young in July)
Tasmanian devil	M	4	2	2	1	3 in good condition, 1 DFTD (euthanased) in May
Tasmanian devil	F	2	-	2	-	1 Good (no pouch young). 1 DFTD (euthanased) in May (no pouch young)
Feral Cat (*Felis catus*)	?	2	2	-	1	Not assessed

Cradle Mountain

By-catch at Cradle Mountain included Tasmanian devils, spotted-tailed quolls and common brushtail possums, as outlined below. Two diseased devils were captured in March and released, however neither were recaptured in subsequent trapping sessions. Two microchipped devils were subsequently found as roadkill, each within 2 months of last capture. A 2009-born female devil "Cassandra" (ID:982009104873584) was trapped at the Cradle Mountain study site on 22nd July 2010. This devil was first microchipped by the STTDP at Woolnorth on the 19th March 2010, indicating that she had travelled over 128 km in 4 months, establishing the longest recorded distance travelled by a devil.

Species	Sex	Individuals	Captures			Sex
			Mar	May	Jul	
Spotted-tailed quoll	F	1	-	1	-	Good condition (no pouch young)
Spotted-tailed quoll	M	2	1	1	-	Good condition
Tasmanian devil	F	7	5	4	5	3 good cond (no py), 3 good cond (with py), 1 DFTD in March (with py)
Tasmanian devil	M	5	7	2	1	4 good cond, 1 DFTD in March
Common brushtail possum (*Trichosurus vulpecula*)			1	2	4	Not assessed

APPENDIX 3. POUCH STATUS

The stages of pouch development in the eastern quoll have been described by Bryant (1988b) based on captive and wild females and includes data from Green (1967). The classification of pouch status used in the current study modified previous descriptions to focus on those stages applicable to the trapping periods covered in the current study (e.g. weaning occurred outside the timeframe of the current study).

The following chart compares how the stages used in the current study compare to those described by Bryant (1988b).

Current study		Bryant (1988b)	
Pouch Status	**Description**	**Pouch Status**	**Description**
1	Immature • as for Bryant (1)	**1**	Immature. • shallow depression of bare skin (12-16mm diameter) • 6 exposed teats (2-4mm height) • no fur discolouration
2	Parous but not currently breeding • as for Bryant (2)	**2**	Parous but not currently breeding (Jan-Mar) • pouch formed (15-25mm diameter), shallow with wide loose rim of skin • teats dirty (5-12mm height) • fur surrounding pouch is brown-orange (Jan – March)
3	Entering breeding condition (Apr-May) • as for Bryant (3)(a) & (b)	**3 (a) & 3 (b)**	Entering breeding condition (Apr-June) • pouch deeper, wider, thick loose rim • red interior
4	Pre-oestrus / mating (May-June) • as for Bryant (3)(c) & (d)	**3 (c) & 3 (d)**	Entering breeding condition (Apr-June) • pouch fully developed, thick • crimson interior

Current study		Bryant (1988b)	
Pouch Status	**Description**	**Pouch Status**	**Description**
5	Prior to birth (mid June to early July) • as for Bryant (4) & (5)	**4** **5**	Prior to birth (late June) • pouch fully developed • red interior • moist, small glands visible beneath surface of skin Birth (early July) • pouch interior glandular, very moist and raised temperature on day of birth
6	Pouch young • as for Bryant (6) and early stages of (7)	**6**	Early lactation (July to Aug) • young tightly enveloped by increased pouch size • mammary glands visible, not swollen
7	Lactating, young in den (Aug-Nov) • no young in pouch • long, thin teats • milk secretion still active	**7**	Full lactation (Aug to Nov) • pouch diameter 30-40mm, depth 25mm) • individual mammary glands 27-34mm and protrude from pouch • depending on timing, young may still be in pouch or deposited in den
8	Lost pouch young (June-Nov) • long thin teats • no milk secretion during usual period of lactation		Not described
9	Post-reproductive • brown oil • old animal		Not described
	Outside timeframe of current study	**8**	Weaning (Dec to Feb) • pouch and mammary glands gradually decline in size and fullness • pouch diameter 24-30mm • lactating mammary glands ≤20mm • teats elongated (6-10mm) occasionally protruding from pouch

APPENDIX 4. HAEMATOLOGY STAINS

Preparation of Leishman's stain:

Mix 0.15 g Leishman's stain powder in 100 ml methanol. Do not use for 24 hours.

Preparation of Wright's stain:

Add 0.3 g Wright's stain powder in 100 ml methanol. Shake, heat on a water bath. Allow to cool, then filter.

Preparation of Leishman's-Wright's stain:

Mix equal parts (1:1) Leishman's stain and Wright's stain.

All stains stored away from heat and direct sunlight.

Staining of blood films using Leishman's-Wright's stain (modified from Mitruka and Rawnsley (1977)):

1. Air-dry blood slide.
2. Stain horizontally positioned blood slide with 7-10 drops Leishman's-Wright's stain. Leave 4-8 minutes.
3. Add 15-20 drops buffered water (pH 6.8) to slide and mix with stain. Leave 8-10 minutes.
4. Flush gently with buffered water (pH 6.8) until smear appears pink and translucent.
5. Allow slide to air dry before microscopic examination.

Staining of blood films using Rapid Diff (DQ) stain (as per Aspinall (2008)):

1. Air-dry blood slide.
2. Dip slide into DQ fixative 5 times, submersing for 1 second each time.
3. Dip slide into DQ stain solution I for 1 second, 5 times.
4. Dip slide into DQ stain solution II for 1 second, 5 times.
5. Flush with distilled water until smear appears pink and translucent.
6. Allow slide to air-dry before microscopic examination.

APPENDIX 5. GROWTH CHART
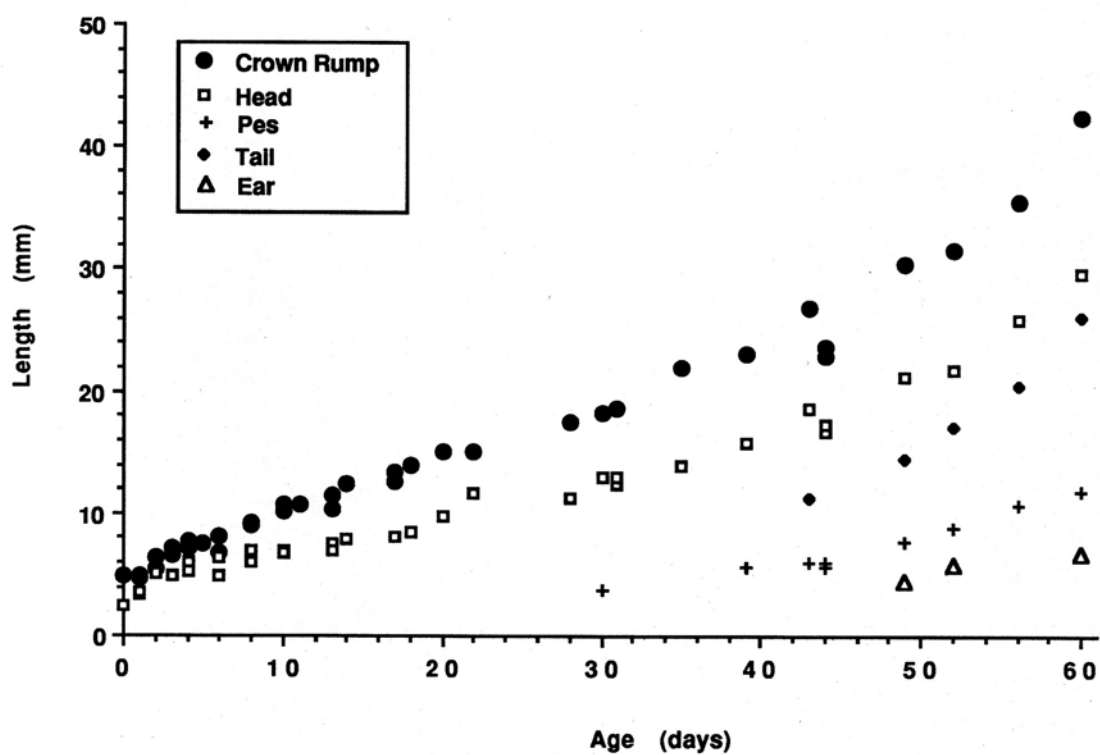
Age estimation curves using body measurements for ageing eastern quoll pouch young up to 60 days. Data based on measurement from 7 litters (*Source: Bryant (1988b)*).

	Males					Females				
Site	**March**	**May**	**July**	**August**	**All periods**	**March**	**May**	**July**	**August**	**All periods**
Cradoc	0.492 ± 0.037 (*n* = 3)	0.464 ± 0.031 (*n* = 7)	0.429 ± 0.034 (*n* = 4)	-	**0.460 ± 0.020 (*n* = 14)**	0.450 ± 0.000 (*n* = 1)	0.513 ± 0.012 (*n* = 3)	0.483 ± 0.008 (*n* = 3)	-	**0.491 ± 0.011 (*n* = 7)**
Cradle Mountain	0.432 ± 0.040 (*n* = 3)	0.441 ± 0.029 (*n* = 5)	0.380 ± 0.042 (*n* = 8)	-	**0.409 ± 0.024 (*n* = 16)**	0.480 ± 0.000 (*n* = 1)	0.480 ± 0.000 (*n* = 1)	0.380 ± 0.000 (*n* = 1)	-	**0.447 ± 0.033 (*n* = 3)**
Bruny Island	-	-	-	0.444 ± 0.009 (*n* = 11)	**0.444 ± 0.009 (*n* = 11)**	-	-	-	0.440 ± 0.005 (*n* = 6)	**0.440 ± 0.005 (*n* = 6)**
All sites	**0.462 ± 0.028 (*n* =6)**	**0.454 ± 0.028 (*n* = 12)**	**0.396 ± 0.030 (*n* =12)**	**0.444 ± 0.009 (*n* = 11)**	**0.436 ± 0.012 (*n* = 41)**	**0.465 ± 0.015 (*n* =2)**	**0.505 ± 0.012 (*n* = 4)**	**0.458 ± 0.053 (*n* =4)**	**0.440 ± 0.005 (*n* = 6)**	**0.464 ± 0.009 (*n* = 16)**

Eastern quoll packed cell volume (PCV) (L.L^{-1}) by sex for all sites and periods. All figures mean ± SEM. Number of samples shown in parenthesis.

APPENDIX 6. HAEMATOLOGY RESULTS

Site	Males					Females				
	March	May	July	August	All periods	March	May	July	August	All periods
Cradoc	66.7 ± 2.7 (*n* = 3)	68.4 ± 1.3 (*n* = 7)	76.3 ± 2.1 (*n* = 4)	-	**70.3 ± 1.4** **(*n* = 14)**	70.0 ± 0.0 (*n* = 1)	69.0 ± 1.7 (*n* = 3)	73.2 ± 1.7 (*n* = 3)	-	**70.9 ± 1.2** **(*n* = 7)**
Cradle Mountain	60.7 ± 4.9 (*n* = 3)	62.2 ± 2.0 (*n* = 5)	61.4 ± 2.8 (*n* = 8)	-	**61.5 ± 1.7** **(*n* = 16)**	57.0 ± 0.0 (*n* = 1)	62.5 ± 0.0 (*n* = 1)	65.0 ± 0.0 (*n* = 1)	-	**61.5 ± 2.4** **(*n* = 3)**
Bruny Island	-	-	-	65.3 ± 1.5 (*n* = 11)	**65.3 ± 1.5** **(*n* = 11)**	-	-	-	66.7 ± 0.7 (*n* = 6)	**66.7 ± 0.7** **(*n* = 6)**
All sites	**63.7 ± 2.8** **(*n* =6)**	**65.8 ± 1.4** **(*n* = 12)**	**66.4 ± 2.9** **(*n* =12)**	**65.3 ± 1.5** **(*n* = 11)**	**65.5 ± 1.1** **(*n* = 41)**	**63.5 ± 6.5** **(*n* =2)**	**67.4 ± 2.0** **(*n* = 4)**	**71.1 ± 2.4** **(*n* =4)**	**66.7 ± 0.7** **(*n* =6)**	**67.6 ± 1.1** **(*n* = 16)**

Eastern quoll total plasma protein (TP) (g.L^{-1}) by sex for all sites and periods. All figures mean ± SEM. Number of samples shown in parenthesis.

Site	Males					Females				
	March	May	July	August	All periods	March	May	July	August	All periods
Cradoc	6.6 ± 1.3 (*n* = 4)	9.4 ± 1.6 (*n* = 7)	6.7 ± 1.7 (*n* = 4)	-	**7.9 ± 0.9 (*n* = 15)**	5.6 ± 0.0 (*n* = 1)	8.0 ± 1.5 (*n* = 3)	7.2 ± 2.5 (*n* = 3)	-	**7.3 ± 1.1 (*n* = 7)**
Cradle Mountain	4.3 ± 1.6 (*n* = 3)	6.8 ± 1.5 (*n* = 5)	5.5 ± 1.1 (*n* = 8)	-	**5.7 ± 0.8 (*n* = 16)**	5.6 ± 0.0 (*n* = 1)	3.0 ± 0.0 (*n* = 1)	6.0 ± 0.0 (*n* = 1)	-	**4.9 ± 0.9 (*n* = 3)**
Bruny Island	-	-	-	6.0 ± 1.2 (*n* = 11)	**6.0 ± 1.2 (*n* = 11)**	-	-	-	5.1 ± 0.9 (*n* = 6)	**5.1 ± 0.9 (*n* = 6)**
All sites	**5.6 ± 1.0 (*n* =7)**	**8.3 ± 1.1 (*n* = 12)**	**5.9 ± 0.9 (*n* =12)**	**6.0 ± 1.2 (*n* = 11)**	**6.6 ± 0.6 (*n* = 42)**	**5.6 ± 0.0 (*n* =2)**	**6.8 ± 1.6 (*n* = 4)**	**6.9 ± 1.8 (*n* =4)**	**5.1 ± 0.9 (*n* = 6)**	**6.0 ± 0.7 (*n* = 16)**

Eastern quoll total leukocyte count (TWCC x 10^9 L^{-1}) by sex for all sites and periods. All figures mean ± SEM. Number of samples shown in parenthesis.

APPENDIX 7. FOX EVIDENCE

Map of Tasmania indicating location, type and amount of fox evidence collected by the Fox Eradication Branch to 28 May 2010 (*Source: Fox Eradication Branch (2010c)*).

APPENDIX 8. FOX BAITING COVERAGE
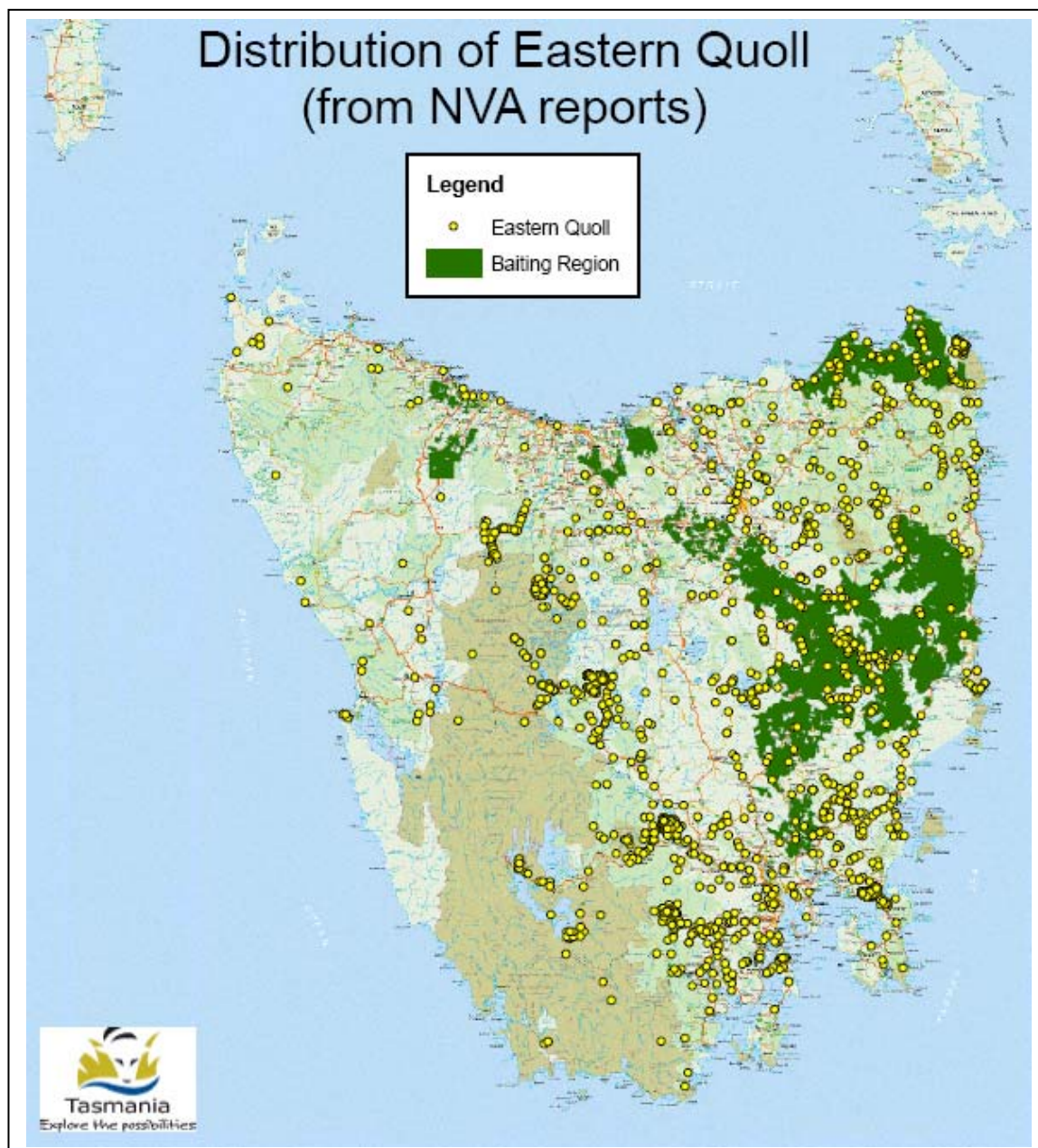
Map showing eastern quoll sightings (as per Natural Values Atlas database[©]) as yellow dots, with areas subject to fox baiting up to December 2008 shown in dark green (*Source: DPIPWE Fox Eradication Program*). © State of Tasmania.

APPENDIX 9. MEDIA COVERAGE

The following list outlines the media coverage of the research from the current study:

"Quoll decline" *ABC Tasmania Evening News*, Fiona Blackwood, 15 July 2010.

"Survival fears for quolls" *The Mercury*, Charles Waterhouse, 16 July 2010.

"Check on quoll numbers" *The Examiner,* Emma Webb, 16 July 2010.

"Quoll numbers declining" *ABC Online News*, 16 July 2010, available online from http://www.abc.net.au/news/stories/2010/07/16/2955349.htm

"Study to look at eastern quoll populations" *UTAS Communications and Media*, 16 July 2010, available online from http://www.media.utas.edu.au/general-news/all-news/study-to-look-at-eastern-quoll-populations

"Down but not out: spatial and temporal variation in declining eastern quoll (*Dasyurus viverrinus*) populations in Tasmania, *Australian Wildlife: Journal of the Wildlife Preservation Society of Australia*, Spring 2010.

"Eastern quoll populations have halved, surveys suggest", Research to Reality, UTAS, Edition 6, 2010.

Literature Review

Declining populations:

A review of recent declines in the eastern

quoll (*Dasyurus viverrinus*) in Tasmania

and the potential agents of decline

TABLE OF CONTENTS

1.0 INTRODUCTION

The Australian fauna has suffered numerous extinctions and declines throughout history. A downward trend in recent spotlighting data suggests that the eastern quoll (*Dasyurus viverrinus*) may be heading towards a similar fate. But population declines are difficult to measure and their causes may often be difficult to identify. In this paper I review the literature pertaining to historical Australian faunal declines and their correlated agents of decline. Declines in Australian marsupial carnivores are then reviewed in more detail to help establish whether eastern quoll populations are also in decline and what might be causing this. The ecology of the eastern quoll is then discussed, together with an assessment of the putative stressors and agents potentially responsible for its apparent recent decline in Tasmania.

2.0 HISTORICAL POPULATION DECLINES

Australia has experienced particularly high rates of terrestrial mammal extinctions over the past 500 years. Whilst the fossil record indicates that the extinction of species has occurred throughout geological time without any human intervention (Caughley 1994), Australian ecosystems have endured profound changes to the natural environment since European settlement around 200 years ago, leading to further changes in the richness and composition of Australian mammalian fauna (Bennett 1990). Terrestrial mammals have been particularly susceptible to extinctions and declines in both abundance and range (Burbidge and McKenzie 1989; Maxwell *et al.* 1996; Burbidge and Manly 2002), with Australia recording the largest concentration of mammal extinctions since 1500 AD (Short and Smith 1994; Baillie *et al.* 2004). Whilst the rate of mammal extinctions in Australia is unparalleled on any other continent (Short and Smith 1994), declines have not occurred evenly throughout the Australian fauna, with native medium-sized ground-dwelling mammals suffering at a disproportionately higher rate (Burbidge and McKenzie 1989; Short and Smith 1994; Maxwell *et al.* 1996; Johnson and Isaac 2009).

There are multiple factors associated with Australian faunal declines and extinctions, yet identifying the patterns of decline and the many processes that contribute to those declines is one of the most challenging aspects of wildlife ecology. In reviewing recent mammal declines in Australia, Burbidge *et al.* (2008) and McKenzie *et al.* (2007) found a strong, geographically based pattern of faunal attrition, with losses being greatest in arid regions and least in areas of high rainfall. Dickman *et al.* (2001) highlighted a marked disparity in the correlates of decline among different taxonomic groups of mammals, showing that while body weight and ground-dwelling habits may be good correlates of risk for macropodids (Johnson *et al.* 1989), they are not associated strongly with the high extinction-proneness of many native rodents (Dickman *et al.* 2000). Clearly there is no single factor responsible for all species declines, but rather a plethora of stressors and agents of decline, often working in combination to bring about the demise of a species.

With the notable exception of the thylacine (*Thylacinus cynocephalus*), Tasmania has remained unaffected by local mammal extinctions in recent history (Short and Smith 1994). However, many species have suffered significant declines in range and abundance, with twelve resident mammal species currently listed on State and Federal threatened species listings (DPIPWE 2010). Whilst the patterns of decline and extinction of marsupial carnivores accord with the general patterns for Australian mammals (Short and Smith 1994), the large carnivorous marsupials appear to have suffered more than other mammals in both Tasmania and continental Australia. The biology of these species and the agents implicated in their declines are reviewed in section 5.2.

3.0 MEASURING A DECLINE

To measure a population decline, the current population abundance must first be established and then compared to the population's historical abundance. Caughley (1977) outlined three ways of measuring population abundance: the number of individuals in a population, the number of individuals per unit area (absolute density), or the density of a population at a point in time relative to that at some other time (relative abundance). For many species an accurate estimate of population size or absolute density is difficult to obtain due to the considerable investment of time and resources (Witmer 2005) and the inability to meet assumptions necessary to estimate population size (Caughley 1977). For a species in decline, an index of relative abundance will often suffice to measure trends over time. Witmer (2005) argued that while population indices are generally easier to obtain, they are also influenced by many unknowns. For example, when relying on indices, it is necessary to assume that the index is proportional to the density and that this relationship is (relatively) constant (Caughley 1977), yet often the exact relationship of the index to the population density, or how that relationship may change over space and time, is unknown (Witmer 2005). Furthermore, there is little value in relying on an index if the precision is such that the results are biologically meaningless. For example, the home-range size of black-eared miners (*Manorina melanotis*) increases considerably between breeding and non-breeding periods, resulting in a decrease in survey precision due to the inability to find many birds when they occupy a larger home range (Clarke *et al.* 2003). In such cases, management decisions may inadvertently be based on "apparent" population trends when the estimates are uncertain and possibly even misleading.

So given the necessary assumptions and the plethora of indices adopted in wildlife surveys, which one do we use? Engeman (2005) lists the desirable qualities for an index as including practicality, sensitivity to differences in population size, precision and variance estimation and robustness. Detection success and precision for a particular taxon will vary considerably between survey methods (Witmer 2005; Garden *et al.* 2007), requiring different methods to be tested and compared in order to assess which is more appropriate for the target species. Selection of a method

should be influenced by a range of variables including the species or taxa of interest, their dietary and habitat preferences, home range size, distribution, behavioural attributes and body size (Clarke *et al.* 2003; Garden *et al.* 2007). Furthermore, different methods may prove better or worse under different conditions, at different locations and at different times (Southwell and Fletcher 1993; Edwards *et al.* 2000).

For example, top predators generally occur at low densities and as such are inherently difficult to monitor (Green and Young 1993). Edwards (2000) compared two methods of estimating relative abundance of two low density carnivore species (dingoes (*Canis lupus*) and feral cats (*Felis catus*)) and found passive-track surveys were more time-efficient and offered higher precision than spotlighting surveys. However, under suitable conditions with experienced personnel, spotlighting has been found to be an effective method for deriving a population index of certain higher density nocturnal mammals such as rabbits (*Oryctolagus cuniculus*) (Poole *et al.* 2003), squirrel gliders (*Petaurus norfolcensis*) (Goldingay and Sharpe 2004) and greater gliders (*Petauroides volans*) (Lindenmayer *et al.* 2001).

Depending on the ecological objective and the species of interest, a combination of methods may be necessary to measure a decline. For example, in attempting to demonstrate the spatial and temporal spread of the Devil Facial Tumour Disease (DFTD) devastating the Tasmanian devil (*Sarcophilus harrisii*) populations across Tasmania, Hawkins *et al.* (2006) incorporated a combination of spotlighting survey data, live trapping data, roadkill post-mortem data and anecdotal evidence, with the trapping and spotlighting data being used to assess the impact of the disease on devil populations. Whilst the relationship between devil spotlighting sightings and devil density has not been quantified, trends identified in spotlighting data appeared consistent with findings from other methods such as live trapping, suggesting that spotlighting surveys may be an appropriate method for detecting trends in this species. Whilst the statewide spotlighting data indicated an overall population decline, trapping data provided more detailed information on prevalence and dynamics at the local level, with both sources pointing to dramatic declines in areas where the disease was first observed (Hawkins *et al.* 2006).

4.0 WHY IS THIS SPECIES DECLINING?

If a species is declining, how then do we approach the questions: why is this species declining, and what might be done about it? In reviewing the literature into the causes of historic extinctions and evaluating whether this knowledge had assisted in slowing the loss of species, Caughley (1994) addressed this very question, suggesting that we proceed down the hypothetico-deductive path by following these four steps: (1) study the natural history of the species to gain a knowledge of its ecology, context and status; (2) based on this knowledge, list all conceivable agents of decline; (3) measure the levels of each agent where the species now is, and also where the species used to be, then test one set against the other to identify putative agent(s) of decline; and (4) test the hypotheses so produced by experiment to confirm the putative agent is causally linked to the decline, not simply associated with it.

The first two steps are considered in section 5.0 below in light of recent declines in the eastern quoll. Section 5.1 outlines the natural history of the species, followed by a discussion of the potential agents of decline in section 5.2, with particular attention to factors implicated in the decline of other large Australian marsupial carnivores.

5.0 DECLINES IN THE EASTERN QUOLL

Once widespread throughout Australia, the eastern quoll is now unofficially considered extinct on the mainland, with the last recorded sighting occurring in NSW in the 1960s in the Sydney suburb of Vaucluse (Dickman *et al.* 2001). Whilst the species is still considered widespread and locally common in Tasmania (McKnight 2008), annual state-wide spotlighting surveys performed by the Department of Primary Industries, Parks, Water and Environment's Wildlife Management Branch (DPIPWE) have suggested a significant decline in eastern quoll numbers (G. Hocking unpublished data). Over the past ten years, mean eastern quoll sightings per 10 km transect have steadily decreased across Tasmania, suggesting an overall reduction of around 50% statewide (Figure 1) with some areas showing more marked declines than others. If these suggested declines are correct, then such a reduction meets the IUCN's criteria for listing the eastern quoll as endangered on the IUCN Red List of Threatened Species (IUCN 2001).
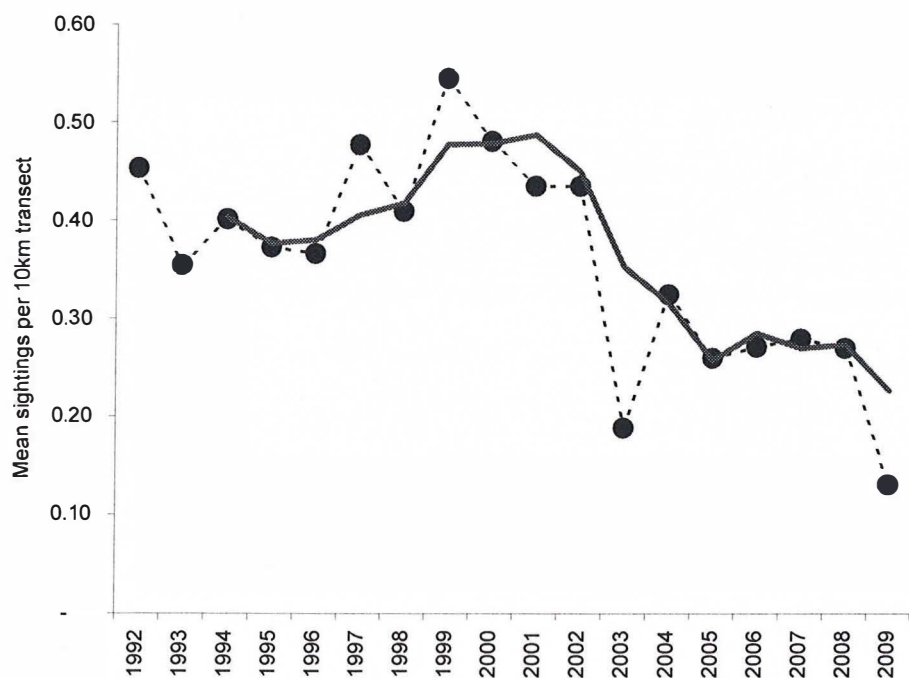
Figure 1 – Statewide spotlighting survey sightings: mean annual (˙˙●˙˙) and three year rolling mean (▬) sightings of eastern quolls per 10 km transect surveyed annually from 1992 to 2009 (G. Hocking unpublished data).

Whilst the factors contributing to this apparent decline are currently unknown, a review of the literature pertaining to historic fluctuations in the eastern quoll suggests that possible agents of decline might include predation by introduced European red foxes (*Vulpes vulpes*) and feral cats (Wood Jones 1923; Jones *et al.* 2004; Saunders *et al.* 2006), habitat modification through changes in land-use (Green 1967; Rounsevell *et al.* 1991; Taylor and Comfort 1993), road mortality (Jones 2000), direct killing by humans (Backhouse 1843; Green 1967), non-target poisoning (McIlroy 1981b; King *et al.* 1989), disease (Guiler 1961; Green 1967; Obendorf and Munday 1983) or even climatic factors such as drought (Abbott 2006; Levinsky *et al.* 2007). But given that agents of decline tend to interact to bring about population declines (Hone *et al.* 2005), a combination of these factors may be responsible. No investigation has been launched to determine the dominant cause of the current decline in the eastern quoll, nor the relative contributions of various agents of decline, yet such research appears crucial if declining trends are to be reversed before they can lead to the demise of the species in its last remaining stronghold.

5.1 Natural history of the eastern quoll

The eastern quoll is a medium sized sexually dimorphic dasyurid, with mean body weight of 1250 g (range: 900 – 2000 g) for males and 850 g (700 – 1100 g) for females (Godsell 1983; Jones and Rose 2001). Males are only sexually active during winter (Godsell 1983; Fletcher 1985), with females seasonally polyoestrous (Godsell 1983; Fletcher 1985). Individuals are sexually mature in their first year (Bryant 1988), with reproductive effort concentrated in their first two breeding years (Godsell 1983; Bryant 1988). The high synchrony of births in June suggests that most females conceive on their first oestrus from late May to early June (Godsell 1983; Fletcher 1985), although in rare cases where females do not initially conceive or subsequently lose their young, they may come into a second oestrus around 31 - 35 days later (Green 1967; Fletcher 1985). But females typically display high reproductive success and only one litter is supported each year (Godsell 1983). Mean gestation is 21 ± 2 days (Fletcher 1985) at which time up to 36 young are born, but only the first 6 young to reach the pouch and attach to one of the 6 teats survive, with most mothers observed to carry 5 - 6 young (Godsell 1983). The mother carries

the young in the pouch for around 8 - 9 weeks (Godsell 1983) at which time she deposits them in a den until fully weaned at around 20 - 30 weeks of age, depending on litter size (Merchant *et al.* 1984). Godsell (1983) found only half the number of young observed in winter were subsequently trapped in spring suggesting high juvenile mortality, although emigration may also be a factor. Populations fluctuate over an annual cycle, with peaks in summer due to juveniles entering the population and troughs in winter and early spring (Godsell 1982). Mean sex ratios bias males (1.25:1), but ratios fluctuate between seasons and years (Godsell 1982). Annual adult mortality appears high, increasing from between 17 - 50% mortality by their second mating season in May to between 67 - 91% by the following February, giving most individuals a life expectancy of around 3 - 4 years in the wild (Godsell 1983).

Eastern quolls are predominantly insectivorous, with pasture grubs such as corbies (*Oncopera intricata*) and southern army worms (*Persectania ewingii*) the predominant invertebrate prey (Blackhall 1980; Godsell 1983). Small mammals, birds, blackberries and plant matter are all eaten to varying degrees, depending on location and seasonal fluctuations in prey availability (Blackhall 1980; Godsell 1983; Jones and Barmuta 1998). They are commonly found in areas where open pastures used to feed by night adjoin areas of intact natural bushland used for denning during the day (Godsell 1983), but can also be found in sub-alpine buttongrass (*Gymnoschoerus sphaerocephalus*) moorlands (Rounsevell *et al.* 1991; Jones and Barmuta 2000), sedgeland (Taylor and Comfort 1993) and a mix of wet and dry schlerophyll (Hocking and Guiler 1983; Driessen *et al.* 1991), but are notably absent in large tracts of rainforest (Rounsevell *et al.* 1991).

Known predators include feral cats (Rolls 1969) and masked owls (*Tyto novaehollandiae*) (Mooney 1993), with foxes presenting a more recent predation risk (Mooney *et al.* 2005). Whilst Tasmanian devils are known to scavenge dead quolls (Jones 2000) and display competitive aggression towards them when feeding around carcasses (Jones 1998b), it is unclear whether devils prey on live eastern quolls.

5.2 Agents of decline

In investigating recent extinctions, Diamond (1989) found that their agents of decline (where known) could be classed under an 'evil quartet' of four headings: overkill, habitat destruction, impact of introduced species and chains of extinction. In a similar major review of the likely causes of extinctions of mammals and birds and of endangerment of extant species, Caughley and Gunn (1996) concluded that external agents such as habitat change, predators, competitors and pathogens were primarily responsible for population declines and that two or more agents of decline were often implicated. More recently, on reviewing global extinctions over the last two decades, Baillie *et al.* (2004) found the major drivers to be habitat loss and invasive alien species, although disease appeared to be a growing threat.

In order to consider which of the many factors may be potentially contributing to a decline in the eastern quoll, it seems prudent to first review declines in similar large marsupial carnivores and the factors implicated in their decline (see Table 1). The processes affecting the status of the Dasyuroidea have been inferred in many studies, however the magnitude and relative importance of most threats remains largely speculative (Dickman *et al.* 2001). Jones *et al.* (2003) outline the causes and correlates of decline most relevant to Australia's large marsupial carnivores as including loss, degradation and fragmentation of habitat (Orell and Morris 1994; Oakwood 2000; Burnett and Dickman 2008; Morris *et al.* 2008); introduced species (Orell and Morris 1994; Dickman 1996; Burnett 1997); and direct human-induced mortality (Green 1967; Jones 2000). The large Australian marsupial carnivores are outlined below, together with a brief summary of their associated agents of decline.

Thylacine

The thylacine was once the largest marsupial carnivore on Earth (Jones and Stoddart 1998). Formerly widespread across Australia (Mooney and Rounsevell 2008), the arrival of the dingo some 4000 years ago was implicated in its demise. The dingo's superior cooperative-hunting ability is thought to have out-competed the thylacine (Guiler 1985; Corbett 1995; Jones *et al.* 2003), possibly combining with hunting pressure from Aboriginal people (Johnson and Wroe 2003) to eventually culminate

in its extinction on the mainland. The absence of the dingo from Tasmania enabled the thylacine to persist beyond its continental extinction as Tasmania's top terrestrial predator until European settlement, when it was persecuted for killing sheep (Guiler 1985). Bounties were subsequently placed on the thylacine, resulting in it's near extermination by 1912 (Guiler 1985; Corbett 1995), although disease was also thought to contribute to the decline (Wood Jones 1923). After attempts to breed in captivity failed (Jones and Stoddart 1998), the last known individual died in captivity in 1936 (Mooney and Rounsevell 2008) and the thylacine was subsequently declared extinct later that century.

Tasmanian Devil

Like the thylacine, Tasmanian devils were once widely distributed across Australia, with their mainland demise primarily attributed to competition for food with dingoes (Guiler 1982) and possibly Aboriginal hunting pressures (Johnson and Wroe 2003). Whilst they mostly escaped the same degree of persecution as the thylacine in Tasmania, they were often culled by settlers for preying on domestic poultry and stock (Green 1967; Guiler 1982). Historic reports alluded to a number of fluctuations in devil numbers, with both disease and secondary poisoning suggested as agents of decline, interspersed between periods of devils reaching 'virtual pest proportions' (Guiler 1961; Green 1967; Statham 2005). Despite these fluctuations, devils persisted in the landscape in abundance until the latter part of the last century. In 2008, it was listed as endangered on the IUCN Red List of Threatened Species (Hawkins *et al.* 2008) due to the spread of an aggressive facial tumour disease (DFTD) (Loh *et al.* 2006). With signs typical of DFTD first reported in 1996, the disease has spread throughout much of Tasmania, with local population declines of up to 80% in some areas (Hawkins *et al.* 2006). The infectious cancer is invariably fatal, with affected devils usually dying within 3 - 6 months of first lesions appearing (Hawkins *et al.* 2006; Siddle *et al.* 2007). Whilst pathological investigations are continuing, there is no treatment or vaccine currently available, and the Tasmanian devil is facing a very real threat of extinction (Jones *et al.* 2007).

Spotted-tailed Quoll

The former distribution of the spotted-tailed quoll (*Dasyurus maculatus*) covered the coastal strip along eastern and south-eastern Australia, including Tasmania (Burnett and Dickman 2008). The northern subspecies *D.m.gracilis* is now confined to a small section of far north Queensland where it has suffered a 20% contraction in range, whilst the southern subspecies *D.m.maculatus* has suffered a range contraction of >30% and is now found in a patchy distribution from south-east Queensland through to Victoria and Tasmania (Burnett and Dickman 2008). Whilst listed as near threatened on the IUCN Red List of Threatened Species, the mainland populations are listed as endangered on the federal Environment Protection and Biodiversity Conservation Act 1999, and the Tasmanian population is listed as vulnerable. Population densities are naturally low throughout its range (Jones and Rose 1996) and the species' dependence on forest habitats (Jones and Rose 1996; Belcher and Darrant 2006; Belcher 2008) suggests habitat loss and fragmentation as a key threat for this species. Additional agents of decline include competition with foxes and feral cats (Taylor 1986; Jones and Barmuta 1998; Glen and Dickman 2005), predation by dogs and foxes (Glen and Dickman 2005; Körtner 2007) and non-target mortality associated with fox and dingo baiting programs (McIlroy 1981b; Belcher 1998; Körtner and Watson 2005). Further research is currently underway into the habitat requirements and landscape ecology of the Tasmanian population (S. Troy pers. comm.).

Northern Quoll

Once distributed across the northern parts of Australia from the Pilbara region in the west to south-eastern Queensland, the northern quoll (*Dasyurus hallucatus*) has suffered significant range contraction (Braithwaite and Griffiths 1994) and local population declines (Woinarski *et al.* 2001). Whilst the majority of its distribution lies outside core fox habitat (Oakwood 2008), it faces an equally devastating threat in the introduced cane toad (*Bufo marinus*) which fatally poisons quolls that try to eat (Burnett 1997). Feral cats and dingoes depredate quolls (Oakwood 2000), yet their long-standing co-existence suggests that they have not been a significant contributor to northern quoll mortality (Johnson *et al.* 1989). Habitat modification, however,

through changed fire regimes and associated removal of ground cover leaves quolls more susceptible to predators (Oakwood 2000). The northern quoll's status on the IUCN Red List of Threatened Species was upgraded from lower risk/near threatened to endangered in 2008 following a >50% decline in population over the previous ten years, with a projected similar rate of decline over the next ten years due to the effects of habitat modification and destruction, cane toads and introduced predators (Oakwood *et al.* 2008). Whilst a recovery plan is currently being prepared, management priorities revolve around captive breeding and translocations whilst securing island quoll populations from cane toads (Woinarski 2006).

Western Quoll

The western quoll (*Dasyurus geoffroii*) or 'chuditch' has a tumultuous history (Glen *et al.* 2009). Once relatively abundant across every state and territory on mainland Australia (Orell and Morris 1994), it has suffered significant population decline and range contraction since European settlement (Orell and Morris 1994). It is now confined to an area in the south-west corner of Western Australia representing around 5% of its former range (Serena and Soderquist 2008). It was previously listed as endangered on the IUCN Red List of Threatened Species, however this status was revised down to near threatened in 2008 based on a successful recovery program aimed at widespread fox baiting (Bailey 1996), captive breeding and translocations (Orell and Morris 1994; Morris *et al.* 2003). Whilst population trends are currently stable, the species' persistence is now dependent upon continuing conservation efforts (Morris *et al.* 2008).

The potential agents of decline discussed above have been summarised in Table 1, illustrating numerous agents in common across these species. Given the considerable overlap observed between these species, the potential agents of decline in eastern quoll populations will be considered under the following categories: (1) direct human-induced mortality; (2) habitat modification or destruction; (3) introduced species; (4) disease or pathogens. In the final section of this review I will discuss the potential interactions of these and other agents of decline.

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Table 1 – Summary of the six large Australian carnivorous marsupials, their IUCN conservation status and factors that have been implicated as being potentially causal agents of decline. Analysis commences around 4000 years ago with the introduction of the dingo to the Australian mainland, through to modern agents of decline that still operate across both the mainland and Tasmania.

		Species	Thylacine	Tasmanian devil	Spotted-tailed quoll	Eastern quoll	Western quoll	Northern quoll
		IUCN Classification	Extinct	Endangered	Vulnerable	Near Threatened	Near Threatened	Endangered
Agent of decline	Introduced species	Foxes			●12	●6,22,23,24	●29,30,31	
		Feral cats			●13,14	●6,14,24	●29,30,31	●34
		Cane toads			●15			●35
		Dogs / dingoes	●1,2,3	●5,7	●16	●5	●30,31	●34
	Direct human-induced mortality	Habitat modification	●37	●5	●17,18,19	●19	●31	●34
		Road kill		●8	●20	●8	●30	●36
		Poisoning (direct / indirect)		●9	●16,21	●5,9,25,26	●32	
		Persecution	●1,4,5	●4,5	●15	●5,27,28	●31	
		Disease	●6	●6,10,11	●6,11	●5,6,11	●33	

References

1	Guiler (1985)	21	Belcher (1998)
2	Corbett (1995)	22	Saunders *et al.* (2006)
3	Jones *et al.* (2003)	23	Burbidge and McKenzie (1989)
4	Johnson and Wroe (2003)	24	Jones et al. (2004)
5	Green (1967)	25	King *et al.* (1989)
6	Wood Jones (1923)	26	McIlroy (1981b)
7	Guiler (1982)	27	Bennett (1990)
8	Jones (2000)	28	Backhouse (1843)
9	Statham (2005)	29	Morris *et al.* (2003)
10	Hawkins *et al.* (2006)	30	Orell and Morris (1994)
11	Guiler (1961)	31	Glen *et al.* (2009)
12	Glen and Dickman (2005)	32	Soderquist and Serena (1993)
13	Taylor (1986)	33	Abbott (2006)
14	Rolls (1969)	34	Oakwood (2000)
15	Maxwell *et al.* (1996)	35	Burnett (1997)
16	Körtner (2007)	36	Oakwood and Pritchard (1999)
17	Belcher (2008)	37	Mooney and Rounsevell (2008)
18	Belcher and Darrant (2006)		
19	Jones and Rose (1996)		
20	Burnett and Dickman (2008)		

5.2.1 Direct human-induced mortality

Historically, the eastern quoll has been persecuted as an agricultural pest, both on the mainland (Bennett 1990) and in Tasmania (Backhouse 1843; Green 1967). Backhouse (1843) reported that in the days of early Tasmanian settlement, eastern quolls were thought to be so numerous that at one time 600 skins were brought in from hunting on one property in the southern midlands. Green (1967) argued that when predation on domestic poultry and stock became excessive, population control became a necessary part of "good pasture and stock management", although its feeding habits rendered it a lesser pest to primary producers than the spotted-tailed quoll and devil. The subsequent shrinkage in their range was later attributed to a combination of persecution and destruction of forest habitat associated with spreading settlement (Green 1967). Whilst the species is now legally protected, there may still be cases of eastern quolls being killed, however it seems unlikely that this historic agent of decline would contribute to a modern population-level decline in this species.

Road mortality has the potential to affect populations locally, recently accounting for the temporary extinction of the entire resident population of 19 eastern quolls (and half the resident 39 devils) along the northern entrance into the Cradle Mountain – Lake St Clair National Park (Jones 1998a; 2000). In 1991, the tourist access road into the park was widened and sealed to carry an increasing volume of heavy traffic such as tourist buses, resulting in increased traffic speed and a subsequent increase in the number of roadkills (Jones 2000). Traffic slow points and signage were later installed, with the local population re-establishing to 50% of its former level within two years, essentially due to transient quolls moving through the area (Jones 2000). Whilst this decline was only temporary, it highlights the susceptibility of the species to road mortality, often attracted to the road surface by the congregating insects during summer and the opportunity to scavenge roadkills throughout the year (Jones 2000). Compounding this risk is the eastern quoll's preference for open habitats (Jones and Barmuta 2000) and their use of roads and tracks for travelling long distances, with one individual observed to travel 5 km along the road in one night (Jones 2000). Whilst road mortality can have a dramatic impact on quoll populations in a relatively short period, it appears that the effects at Cradle Mountain

were only felt locally and recovery was reasonably quick due to the persistence of nearby source populations to replenish roadside sink populations. Given that sealed roads have been a part of the Tasmanian landscape for many decades and that declines in the eastern quoll are only recent, road mortality is not likely to be a significant agent of decline in recent statewide declines.

The former practice of controlling rabbits with strychnine may have resulted in secondary poisoning as eastern quolls scavenged on rabbit carcasses (Statham 2005), however there are no records of population levels from that time. Strychnine has since been replaced with compound 1080 (sodium monofluoroacetate), and this new compound now presents a novel risk to the eastern quoll through non-target poisoning. This is discussed further in section 5.2.3.

5.2.2 Habitat modification or destruction

Whilst up to 95% of Australia's woodland and shrubland habitats have been cleared since European settlement, no extinctions have been attributed solely to clearing, however the resultant fragmentation of habitat may have increased the risk of extinction from other causes (Short and Smith 1994). Tasmania has undergone considerable changes to its natural environment during this time (Tasmanian Planning Commission 2009) leading to reduction, modification and fragmentation in available habitat for many species whilst affecting the natural ecological processes that sustain biodiversity (McQuillan *et al.* 2009). Such changes have been particularly pronounced in areas used for agriculture, with continuous areas of natural vegetation being fragmented into remnant copses interspersed amongst crops and pastures dominated by exotic grasses (Bennett 1990). However, despite the effects such drastic landscape modification may have on many species, the eastern quoll appears to have benefited from much of this change in land-use (Green 1967). The establishment of pastures are typically accompanied by increases in pasture grubs and pests that form a substantial portion of the eastern quoll's diet (Blackhall 1980; Godsell 1983). Whilst these pastures may provide substantial feeding grounds for quolls to hunt by night, during the day they rest in underground dens or hollow logs located just inside the forest margin in adjacent areas of natural bush (Green 1967; Godsell 1983), although in some areas they have been known to den in open

grasslands where bush habitat was absent (Jones and Rose 1996). It would therefore appear that modification of the land for agricultural purposes is not a high risk to the eastern quoll, providing that remnant fragments of natural bushland persist nearby for denning during the day.

Despite their apparent affinity with pastoral lands, the eastern quoll is also associated with a wide variety of habitats, ranging from open sub-alpine buttongrass moorlands (Rounsevell *et al.* 1991; Jones and Barmuta 2000) and young areas of sedgeland (Taylor and Comfort 1993) through to wet and dry schlerophyll forests where their numbers have been shown to increase after fire, subsequently decreasing as the undergrowth re-establishes (Hocking and Guiler 1983; Driessen *et al.* 1991). However, Taylor and Comfort (1993) did not observe eastern quolls in fauna surveys of mixed forest in south-west Tasmania, and they were notably absent from large tracts of rainforest (Rounsevell *et al.* 1991). Furthermore, unlike the spotted-tailed quoll, they are not dependent on forests used for commercial timber-harvesting (Jones and Rose 1996; Belcher 2008). In essence, they are not a forest-dependent species (Jones and Rose 1996), and do not appear to be highly vulnerable to many forms of land modification, although further research into the effects of different types of land conversion may be necessary before habitat modification can be totally discounted as a plausible agent of decline in this species.

5.2.3 Introduced species

Introduced species have had a devastating effect on Australian ecosystems (Caughley 1994; Bergstrom *et al.* 2009), with foxes, feral cats and rabbits wreaking some of the greatest historic impacts on native mammals. Their effects predominantly manifest as increases in competition for food, shelter and resources, increased predatory pressure and the introduction of novel parasites and pathogens (Dickman 1996; Glen and Dickman 2005).

Feral cats have been a widespread part of the Tasmanian landscape since European settlement (Hocking and Guiler 1983), even being deliberately released by farmers in an attempt to control rabbit numbers (Bennett 1990). Whilst they are incriminated in the decline of numerous species (Short and Smith 1994) and are known to depredate

eastern quolls (mainly juveniles) (Wood Jones 1923; Rolls 1969), cats and quolls have not only co-existed but thrived together for hundreds of years without significant negative effects on either species. Similar co-existence relationships have persisted between mainland native species and feral cats (Johnson *et al.* 1989; de Tores *et al.* 1998; Abbott 2006), with many of these native species often only declining after foxes became established. Given their lengthy co-occupation in Tasmania and in the absence of any associated historic decline, it appears unlikely that the cat is a significant contributor to the quoll's apparent recent decline.

The threat posed by the incursion of foxes, however, is more disturbing. Foxes have caused devastation to both wildlife and agriculture on the mainland (Saunders *et al.* 1995), costing over $200 million annually in biodiversity and economic losses (McLeod 2004). Whilst the Australian mainland has recorded numerous species suffering at the hands of the fox, Tasmania has escaped such devastation by remaining fox-free until the late 1990's (Taylor 1986; Short and Smith 1994; Saunders *et al.* 2006). It has been controversially claimed that foxes have had a disproportionately negative effect on mammals within a critical weight range (CWR) i.e. those species with a body size between 35 – 5500 g (Burbidge *et al.* 1988; Burbidge and McKenzie 1989; Johnson *et al.* 1989; Johnson and Isaac 2009). Whilst some authors have sought to challenge this supposition (e.g. Cardillo and Bromham 2001; Fisher *et al.* 2003; Abbott 2006), it has been clearly demonstrated with several threatened species showing marked recovery following targeted fox-control programs (Friend 1990; Bailey 1996; Burbidge *et al.* 1997; de Tores *et al.* 1998; Kinnear *et al.* 1998; Morris *et al.* 1998) or following reintroductions into areas without foxes (Short *et al.* 1992). For example, Western Shield was an extensive fox-baiting program undertaken in the early 1990's across the south-western corner of Western Australia, an important biodiversity 'hotspot' that supports the last remaining relic populations of many CWR species (Bailey 1996). The subsequent increase in trap success for these CWR species demonstrated the negative effect foxes were having on these species prior to baiting, as illustrated in Figure 2. The brush-tailed bettong or 'woylie' (*Bettongia penicillata*) was one such species that recovered so well that it was subsequently removed from threatened species listings at the state, federal and international levels (Department of Environment and

Conservation 2008). Unfortunately, the recovery was relatively short lived and it is currently facing another recent population crash, the cause of which remains unclear (Wayne 2009). This case is discussed in more detail in section 5.2.5.

Chuditch at Batalling

Quenda at Batalling

Brush Tailed Possum at Batalling

Woylle at Batalling
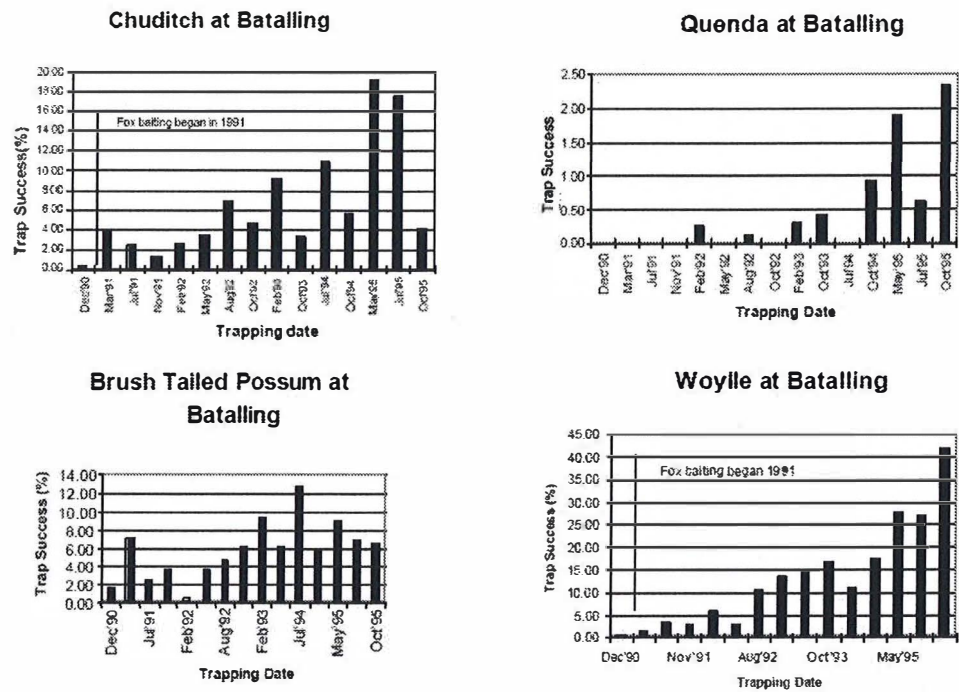
Figure 2 – Wildlife recovery at Batalling Forest, Western Australia in response to fox control undertaken four times per annum, commencing in March 1991 (taken from Armstrong and Batini 1998).

At present, foxes remain rare and elusive throughout Tasmania (Saunders *et al.* 2006; Berry *et al.* 2007), although their cryptic nature may contribute to their apparent low densities (Saunders *et al.* 1995). If foxes become established in Tasmania, numerous species that have persisted in the relative fox-free safety of Tasmania may soon suffer the same fate that many of their mainland counterparts have endured (Burbidge and Manly 2002). The eastern quoll is one of those species under threat (Mooney *et al.* 2005), with their decline in southern Australia coinciding with the arrival of foxes (Wood Jones 1923) and Tasmanian quolls demonstrating a lack of appropriate anti-predator response to acoustic cues of foxes (Jones *et al.* 2004), all suggesting their vulnerability to the establishment of foxes in Tasmania.

Compounding the threat of predation is the inference that competition for dens may be a limiting factor for the eastern quoll (Godsell 1982). This may be further exacerbated with the establishment of foxes, as previously illustrated by the arctic fox (*Alopex lagopus*) following invasion of its range by red foxes (Hersteinsson *et al.* 1989). Based on the available evidence, it appears that the establishment of the fox in Tasmania presents a very real and imminent threat to the eastern quoll and one that may already be a contributing agent to their recent decline.

Complicating this position further is the risk of non-target poisoning. Whilst foxes may be deadly to the eastern quoll, so too is the compound 1080 currently used to bait foxes (McIlroy 1981b; 1986; King *et al.* 1989). A major reason for the success of 1080 fox-baiting on the mainland is the high tolerance that many native non-target species have to this compound, evolving through their long-term exposure to fluoroacetate bearing plants of the genera *Gastrolobium* and *Oxylobium* which are widespread throughout south-western Australia (King *et al.* 1989). However this native exposure does not extend to Tasmania (King *et al.* 1989), with the eastern quoll being one of several non-target species having a considerably lower tolerance to 1080 and as such, being at much higher risk of poisoning than their mainland counterparts. For example, King *et al.* (1989) found that eastern quolls were five times more sensitive to fluoroacetate intoxication than both northern and western quolls. Two laboratory trials have been performed to establish the tolerance of eastern quolls to 1080 in the form of an LD_{50} value, representing the mean lethal dose required for 50% of individuals. McIlroy (1981b) established an LD_{50} of 3.73 mg kg^{-1} (95% CI: 3.18 - 4.38 mg kg^{-1}) whilst King *et al.* (1989) found their sensitivity to be much greater with an LD_{50} of 1.5 mg kg^{-1}. The wide disparity of these values appears in part to be a function of differences in their methods. For example, McIlroy (1981b) administered the dose orally whereas King *et al.* (1989) administered by intraperitoneal injection. Whilst McIlroy (1981a) found no significant differences in LD_{50} values for different routes of administration of 1080 in common brushtail possums (*Trichosurus vulpecula*) and galahs (*Cacatua roseicapilla*), oral administration probably more closely reflects the sensitivity of animals under actual field conditions, but this comparison was not tested on eastern quolls. Similarly, the temperature at which the animals were maintained for the

duration of the trial may have constrained the established LD_{50} values, with Oliver and King (1983) finding the susceptibilities of mice (*Mus musculus*), guinea-pigs (*Cavia porcellus*) and possums to 1080 varied considerably (differences between 2- and 5-fold) at different ambient temperatures between 4 - 33°C, with toxicity greater at both ends of the range indicating a greater population mortality might be expected at much lower or higher environmental temperatures. Both McIlroy (1981b) and King *et al.* (1989) conducted their trials under controlled laboratory temperatures between 19 - 22°C and 22 - 24°C respectively, but no testing was performed on the impacts that lower ambient temperatures may have on the sensitivity of eastern quolls to 1080. This would seem significant given the low ambient temperatures experienced in Tasmania, with mean annual maximum temperatures rarely exceeding 18°C (Bureau of Meteorology 2010).

The Tasmanian Fox Free Taskforce commenced its fox baiting program in September 2002 (Saunders *et al.* 2006), coinciding with the start of the decline in eastern quolls (refer Figure 1). Dried kangaroo meat (DKM) baits injected with 2.5 mg of 1080 (later increased to 3.0 mg) were used initially as they were considered hard for most wildlife, including quolls, to eat while dry (Mooney *et al.* 2005). Variability arising from the inconsistent distribution and concentration of 1080 within these baits (e.g. Twigg *et al.* 2000; Martin *et al.* 2002; Gentle *et al.* 2007) led to DKM baits being replaced with more consistent and convenient commercially prepared Foxoff® baits, using 35 g baits each containing 3 mg of 1080 (C. Hughes pers.comm.). Belcher (1998) found that captive eastern quolls could consume up to 90 g non-poisoned Foxoff® baits in a single meal and that they easily detected, dug up and consumed baits buried at a depth of 20 cm, suggesting that the buried-bait technique is not sufficient to avoid eastern quoll uptake of Foxoff® baits. Given these findings, the use of the higher LD_{50} of 3.73 mg kg^{-1} and the current bait burial depth of 10 cm adopted in Tasmania (Mooney *et al.* 2005) may not be sufficient to avoid or minimise non-target poisoning of eastern quolls. Where the risk of non-target species poisoning is high (especially a threatened species or one in decline), the conservative approach would be to adopt the worst-case scenario and ensure that the toxin dose presented to those species is kept below the lowest dose at which mortality occurs (Calver *et al.* 1989a; Calver *et al.* 1989b; Soderquist and

Serena 1993). For eastern quolls, the lower LD_{50} value of 1.5 mg kg^{-1} (King *et al.* 1989) would mean that an average 850 g female would only need to consume less than half of one 35 g bait for it to be lethal, much less than that assumed under the current Tasmanian fox baiting program (based on the higher LD_{50} 3.73 mg kg^{-1}) and considerably less than the 90 g eaten in the captive trials (Belcher 1998). Juveniles would require a much lower bait consumption and may even be more sensitive to 1080 than adult animals (McIlroy 1981a). Furthermore, McIlroy (1981a) also demonstrated that a 1080 dose that is sub-lethal to a mother may still kill her nursing young, while Sullivan *et al.* (1979) found that 1080 temporarily hindered spermatogenesis in male rats, although neither aspect has been tested in eastern quolls. Notwithstanding this high sensitivity, there are many variables that can affect whether a non-target species will actually be poisoned, including palatability or bait type (Calver *et al.* 1989a; Martin *et al.* 2002; Körtner *et al.* 2003), bait size (Batchelor 1982; McIlroy 1986), daily food consumption (McIlroy 1981b; Green and Eberhard 1983; Calver *et al.* 1989a), availability of alternative foods (Calver *et al.* 1989a; Martin *et al.* 2002; Körtner *et al.* 2003), rainfall levels and frequency (Fleming and Parker 1991; Saunders *et al.* 2000; Twigg *et al.* 2000; Gentle *et al.* 2007), health of the animal (Oliver and King 1983) as well as intraspecific and regional variation (McIlroy 1982; Calver *et al.* 1989b). Given these complexities and innumerable variables, it would appear that sensitivity trials conducted under controlled laboratory conditions are of limited use when predicting the likelihood of quolls dying after eating fox baits in the field (McIlroy 1982; Körtner *et al.* 2003). A more practical risk assessment would be achieved by performing field trials to monitor the effects of actual operational baiting campaigns on field populations of eastern quolls, such as those studies performed on radio-collared northern quolls (King 1988). Whilst capture-mark-recapture (CMR) studies have been performed in Tasmania on Tasmanian bettongs (*Bettongia gaimardi*) and brushtail possums before and after poisoning in both baited and control areas with no resultant change in size and persistence of individuals, operational baiting did not occur in large areas of moderate or high density quoll populations, thus CMR studies were inconclusive (Mooney *et al.* 2005).

5.2.4 Disease and pathogens

Disease is often considered a normal stabilising occurrence in animal populations (Abbott 2006; Hawkins *et al.* 2006), described by Colebatch (1929) as "one of those inexplicable calamities that now and again decimate wild animal communities." Freeland (1993) argued that the majority of Australian mammal extinctions since European settlement reflect the instability of ecosystems that lacked co-evolved host-parasite relationships with introduced species. Whilst parasites and pathogens do not always result in the host's death, the presence of other threats such as nutritional stress or adverse environmental conditions may amplify the effects, leading to population declines.

Abbott (2006) hypothesised that the early decline of many species in Western Australia between 1875 - 1925 was caused by an exotic disease, with up to 33 species suffering significant changes in distribution and abundance during that period. On a local scale, epidemic diseases have decimated whole populations in Tasmania and south-eastern Australia in the past (Wood Jones 1923), with a disease affecting the larger dasyurids believed to have caused a sudden decline in the early part of last century (Guiler 1961) and the DFTD currently devastating the Tasmanian devil population (Hawkins *et al.* 2006), although it is highly unlikely that this cell line will grow in other species such as the eastern quoll (McCallum and Jones 2006).

Dasyurids host a diverse fauna of helminth, arthropod and protozoan parasites, and whilst many parasites cause observable lesions, the full effects of parasitism often go beyond the visible effects where they have adverse effects on the metabolic processes and reproductive success of their hosts (Beveridge and Spratt 2003). Whilst several parasites have deleterious effects on their dasyurid hosts, no experimental studies have comprehensively investigated their full potential effects (Beveridge and Spratt 2003) so their possible role in declining eastern quoll populations cannot be eliminated at present.

Toxoplasmosis, caused by the protozoan *Toxoplasma gondii*, is common in marsupials as both a subclinical infection and an overt disease (Munday 1978). Animals may present with a range of external signs including clouding of the cornea

or lens, retinochoroiditis and numerous neurological signs including difficulty walking and paresis, with internal signs of encephalitis and meningomyelitis (Attwood and Woolley 1974; Attwood *et al.* 1975; Beveridge and Spratt 2003). *T. gondii* is a common intestinal parasite of cats, with intermediate stages occurring in the tissues of many birds and mammals (Frenkel 1970; Beveridge and Spratt 2003; Holz 2008). Attwood *et al.* (1975) found a high prevalence of *T. gondii* in eight of nine species of dasyurids investigated, however eastern quolls were not included in this investigation. Animals contract the disease through exposure to cat faeces, food or water that has been contaminated by cat faeces, or through eating the flesh of animals that contain the encysted parasite in its muscles (Frenkel 1970; Holz 2008). Whilst deaths from toxoplasmosis may constitute a major form of mortality for some native mammals (Obendorf and Munday 1983), animals often die suddenly without clinical signs of illness (Oakwood and Pritchard 1999), so the prevalence of afflicted animals may not be evident in the landscape. Likewise, individuals suffering neurological effects such as paresis may become more susceptible to predation and motor vehicles (Oakwood and Pritchard 1999), effectively reducing the apparent prevalence in wild populations. Whilst it does not appear to be a contributing factor to mortality in northern quolls (Oakwood and Pritchard 1999), the significance of toxoplasmosis in other dasyurids such as the eastern quoll and its contribution to their recent decline has not yet been investigated.

A number of neoplastic conditions have been described in marsupials, with dasyurids appearing to suffer more frequently than other groups (Munday 1978; Twin and Pearse 1986; Canfield *et al.* 1990). In a review of the Comparative Pathology Registry at Taronga Zoo, Canfield *et al.* (1990) found that mammary hyperplasias, adenomas and adenocarcinomas appeared common in eastern quolls, together with a variety of other proliferative lesions associated with either the teat or pouch skin (squamous cell carcinomas and sebaceous proliferations). Most cases reported were captive animals from zoological parks where the animal's life expectancy is greater than their wild counterparts given the ready availability of food and the timely treatment of incidental illnesses (Twin and Pearse 1986), hence these conditions may be a function of the animals' uncharacteristic old age and should not be assumed to mirror the general prevalence throughout wild populations. Whilst a small number

of cases have presented in wild eastern quolls (e.g. Twin and Pearse 1986), it appears unlikely that such conditions would be a significant contributor to declines in the eastern quoll, however this has not been investigated.

5.2.5 Interactions between agents

Agents of decline may act independently or interact (Hone *et al.* 2005), but it is often a combination of agents that bring about the demise of a species (McKenzie *et al.* 2007). Investigating potential agents of decline can be further complicated by this interaction, as demonstrated by the decline of the woylie in Western Australia. Whilst the success of the Western Shield fox baiting program resulted in a dramatic recovery in woylie populations (Armstrong and Batini 1998), numbers have subsequently crashed again, declining around 80% since 2001, with few or no signs of a subsequent recovery (Wayne 2009). Current evidence indicates declines are driven primarily by mortality with predation and scavenging by feral cats associated with most mortalities, but involvement of disease is also suspected, predisposing individuals to predation (Wayne 2009). The success of the fox baiting in reducing fox numbers may have inadvertently relieved the competitive and predatory pressures historically suppressing feral cats, enabling them to fill the niche previously occupied by foxes. An increase in feral cat numbers not only increases predatory pressure on woylies, but also increases their exposure to an array of diseases previously suppressed through the lower density of feral cats. Figure 3 illustrates the draft untested hypotheses currently postulated for the woylie's population decline, demonstrating the complexities associated with identifying responsible stressors and agents of decline.

The woylie's predicament illustrates how, despite the best intentions of wildlife managers, the loss or control of a vertebrate predator can lead to trophic cascades whereby the predator's removal can have wide-ranging inadvertent effects on the rest of the ecosystem (Sih *et al.* 1985). Another example can be seen with the control of feral cats on sub-Antarctic Macquarie Island, which was followed by a dramatic increase in rabbits, resulting in increased grazing pressures that have led to changes from complex vegetation communities to short grazed lawns or bare ground (Bergstrom *et al.* 2009). The contribution of feral cats to Australian faunal declines
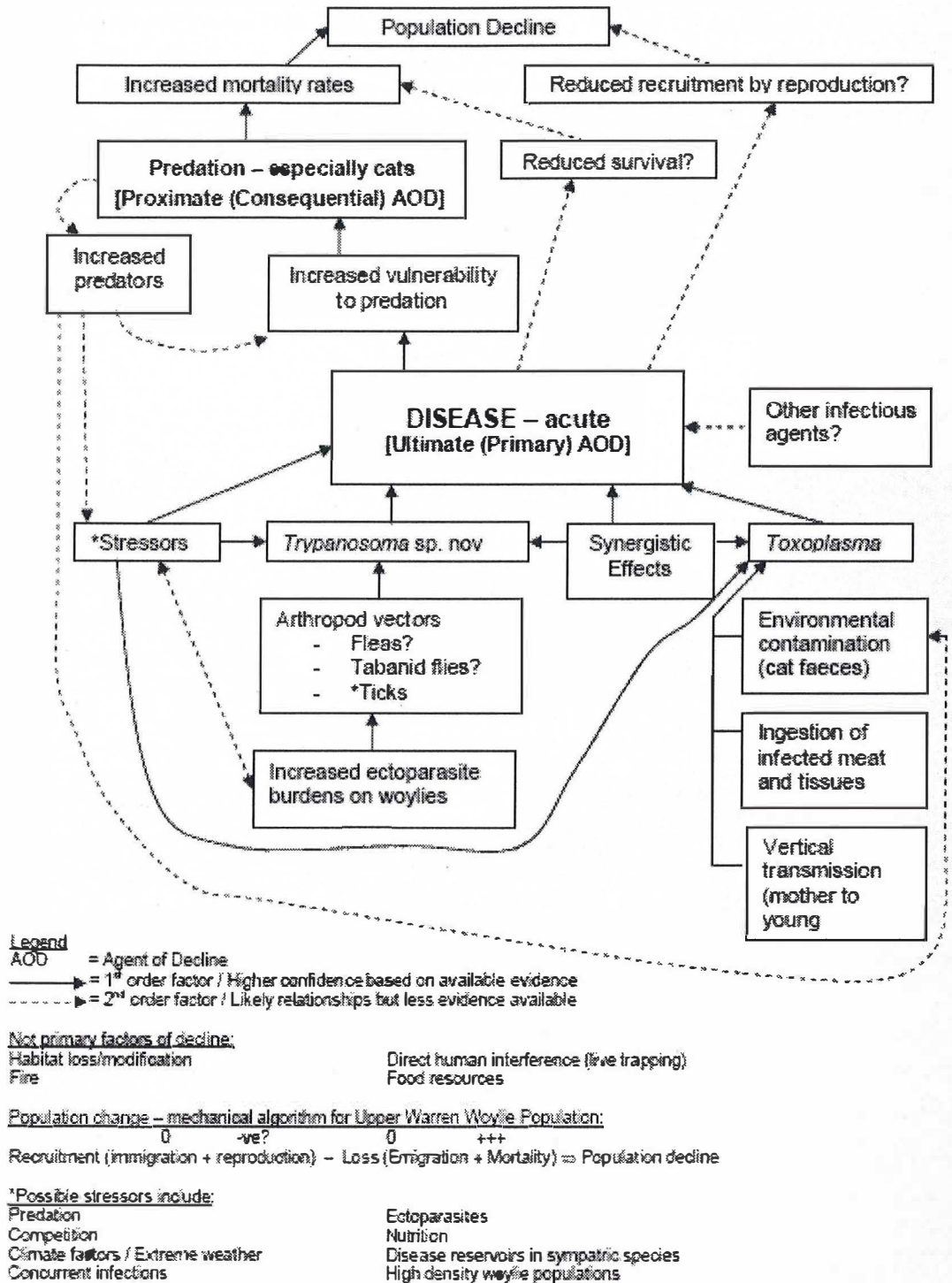
24

Figure 3 – The leading (untested) hypotheses of the causes of woylie declines in the Upper Warren region, Western Australia, based on preliminary and untested inferences (adapted from Department of Environment and Conservation 2008).

has been historically inconsistent, but they often act in concert with a range of other variables such as alteration of habitat, drought and disease, in some instances leading to the decline of native taxa (Oakwood 2000; Burbidge and Manly 2002; Abbott 2006).

Similar ecological interactions may have contributed to the apparent recent decline in the eastern quoll. One hypothesis is that the recent decline of devils due to the spread of DFTD may lead to mesopredator release (Jones *et al.* 2007). As spotted-tailed quoll densities rise, competition between male eastern quolls and the smaller spotted-tailed quolls (juveniles and females) may increase given the dietary overlap observed by Jones and Barmuta (1998) at certain times of the year. However, these observations were based on a sub-alpine ecosystem in the Cradle Mountain – Lake St Clair National Park, which may not reflect the dietary niches and overlap that exists throughout much of the eastern quoll's range in the drier, warmer parts of Tasmania. Given the limited overlap in their habitat preferences (Jones and Barmuta 2000) and their core distributions (Jones and Rose 1996), this postulated mesopredator release may have localised impacts on the eastern quoll in a limited number of locations, however it is unlikely to have statewide ramifications on eastern quoll populations.

Another hypothesis is that the loss of devils will enable feral cats and foxes to increase and subsequently exert increased predatory pressure on medium-sized prey species (Jones *et al.* 2007) as they have already done in mainland Australia (Burbidge and McKenzie 1989), with monitoring suggesting an increase in feral cats has already occurred (G.Hocking unpublished data). This could pose additional threats to the eastern quoll through competition for den sites and increased exposure to novel diseases and pathogens, but the likelihood of these complex interactions are currently unclear, with research currently underway into the broader ecological impacts of the DFTD on Tasmanian ecosystems and marsupial carnivores such as the eastern quoll (T. Hollings pers. comm.).

Alternative hypotheses involve the interaction of environmental variables, with recent long-term droughts possibly implicated in the eastern quoll's decline. Drought may have led to reduced pasture availability in areas lacking reliable irrigation sources and consequently a corresponding decrease in pasture grubs and

other invertebrates that form a substantial part of the eastern quoll's diet. Given the high energetic demands of lactating eastern quolls (Green and Eberhard 1983; Green *et al.* 1997), a lack of available food and the subsequent nutritional stress may result in a nursing mother being unable to support a full complement of six young, leading to increased mortality prior to weaning and a subsequent reduction in offspring entering the population thereafter. Assuming other sources of mortality such as predation and natural attrition remain constant, the resulting reduction in recruitment would possibly lead to a gradual population decline, a particular problem in a species with a short breeding life. But recurrent drought has been a feature of the Australian landscape for millennia (Abbott 2006) and it is difficult to comprehend why drought would bring about an apparent decline that to date has shown no sign of recovery. It is possible that the severity or duration of the recent drought may have exceeded those endured in the past, or that other interacting threats such as feral cats and foxes may be present at levels different to those experienced during previous droughts with cats known to have greater impacts in drier regions (Burbidge and Manly 2002; Johnson and Isaac 2009). But if drought is indeed the primary driver, subsequent periods of above-average rainfall will enable populations to breed-up and recover to pre-drought levels, but to sit back and 'wait and see' if populations bounce back may be catastrophic, especially if drought is not the main contributor. Further analysis is required on historic climatic patterns, their potential impact on food availability and the likely interaction of additional stressors and agents of decline.

6.0 CONCLUSION

This literature review has started down the path of Caughley's (1994) hypothetico-deductive approach to answering the inevitable questions – why is the eastern quoll declining and what can be done about it? The four key steps in this approach are: (1) study the natural history of the species; (2) based on this knowledge, list all conceivable agents of decline; (3) measure and compare levels of each conceivable agent where the species now is and where the species used to be to identify putative agent(s) of decline; and (4) test hypotheses so produced to confirm the putative agent is causally linked to the decline, not merely associated with it.

The first two steps have been addressed here. Whilst the literature on historic mammal declines in Australia and their associated agents of decline appears quite extensive, the magnitude and importance of the processes affecting the status of the dasyurids remain mostly speculative. A review of declines in the large Australian marsupial carnivores suggests several common agents of decline. However, their contribution to recent declines in the eastern quoll requires further testing.

Progression to the third and fourth steps requires that the suspected agents of decline highlighted in this review be investigated and measured in order to address some of the current gaps in the literature. Hypotheses can then be formulated and tested in order to identify, ameliorate and ideally reverse the casual factors contributing to the recent declines in the eastern quoll in Tasmania.

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