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Demographics of tiger quoll (*Dasyurus maculatus maculatus*) populations in south-eastern Australia

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Abstract

The tiger quoll is a large marsupial carnivore that occurs in forested habitat in south-eastern Australia. Three tiger quoll populations were trapped for up to six years and data on population parameters, including size, structure, sex ratio, adult:subadult ratio, weight, breeding characteristics, age and longevity were recorded for each population. Sex ratios (♂ : ♀) varied from 5:1 to 0:1. Population size and age structure reflected previous mortality events and social organisation traits, with all populations showing signs of instability due to disturbance events. Males did not reach full adult weight until three years of age and females until two years. Mean adult male weight was 2.81 kg ± 0.50 (s.d.) (range 2.0–4.2 kg) and mean adult female weight was 1.73 kg ± 0.22 (s.d.) (range 1.2–2.1 kg). Most females did not breed before two years of age and were recorded breeding up to four years of age. A proportion of females did not appear to breed in consecutive years. Matings were estimated to have occurred between late June and early August and births between mid-July and late August. Pouch litter size varied from 4 to 6 with a mean of 5.38 ± 0.65 (s.d.). The adult to juvenile ratio suggests that the mean number of young weaned per female is probably as low as one or two. Monitoring of four females found that the average number of young weaned was three with a range of 2–4. The maximum age recorded was five years. Population declines were found to correlate with 1080 poison baiting programmes, but not with selective logging.

Introduction

The tiger quoll (*Dasyurus maculatus maculatus*) is the largest extant marsupial carnivore on mainland Australia and the sole surviving member of the genus in south-eastern Australia. The species is sexually dimorphic for weight and is predominantly a predator of medium-sized vertebrates (Belcher 1995, 2000; Jones and Barmuta 1998), is crepuscular (Belcher 1994, 2000) and is found in a range of forested habitats, from rainforest to woodland (Mansergh 1984; Watt 1993; Edgar and Belcher 1995; Jones and Rose 1996; Belcher 2000). Two subspecies are currently recognised: *D. m. gracilis* in northern Queensland and *D. m. maculatus* from southern Queensland, New South Wales, Victoria and Tasmania. Recent genetic studies have suggested that the Tasmanian population should be recognised as a separate subspecies as it is phylogenetically distinct from all mainland populations (Firestone *et al.* 1999). *D. m. gracilis* is classified as 'Endangered' nationally (ANZEEC 2000) and *D. m. maculatus* is classified as 'Vulnerable' nationally (ANZEEC 2000), 'Vulnerable and rare' in New South Wales (TSC Act 1995) and 'Endangered' in Victoria (NRE 2000). The paucity of field research on the species has resulted in a lack of information on the demographics, morphometrics, breeding success and sex ratios of wild populations. The lack of information on its ecology and population dynamics has been recognised as a major impediment to developing appropriate management or recovery plans (Mansergh and Belcher 1992; Maxwell *et al*. 1996).

Details on reproduction, sex ratios and capture frequencies have been derived from captive breeding studies and reviews of museum and government agency records of tiger quolls (Fleay 1940; Settle 1978; Mansergh 1983, 1984; Green and Scarborough 1990). Lee

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et al. (1982) classified the tiger quoll as having a 'strategy III' life history, where females are usually monoestrous, but some females may enter a second oestrous if they fail to conceive or if they lose a litter. Fleay (1940) and Settle (1978) recorded details on breeding, litter size, sex ratios and the growth of young in captivity. Green and Scarborough (1990) provided information from Tasmanian museum records of the time of breeding and birth, pouch litter size, sex ratios of adults and pouch young and growth of young in Tasmania. Mansergh (1983, 1984) reviewed time of year of capture or collection of tiger quolls, from museum and government agency records. Males are over-represented in the datasets of both Mansergh (1983, 1984) and Green and Scarborough (1990). Mansergh (1983) found a sex ratio (♂:♀) of 11:1 for captured quolls. Fleay (1940) noted a similar preponderance of males in both tiger quolls and eastern quolls (*D. viverrinus*), each with a sex ratio of ~10:1. Settle (1978) recorded captive litters of close to 1:1. Green and Scarborough (1990) also found from Tasmanian museum specimens a male sex bias, but close to parity for pouch young. Green and Scarborough (1990) provided weight ranges and means for male and female quolls of 1.7–6.1 (2.62 kg) and 1.4–2.5 (2.0 kg) respectively from specimens held at the Queen Victoria Museum. Jones (1997) recorded mean field weights for male and female tiger quolls of 3.23 kg ± 0.39 (s.d.) and 1.67 kg ± 0.17 (s.d.) respectively.

Settle (1978) and Green and Scarborough (1990) believed that conclusions on population structure and sex ratios drawn from museum data may be misleading due to the behavioural differences between male and female tiger quolls. Demographic data from intensive field studies of tiger quoll populations over several years should therefore provide more reliable information on size, structure and dynamics of populations and body size (weight), sex ratios, breeding characteristics and longevity. Demographic data could also provide information on the impact of current management practices on tiger quoll populations. Such information is relevant when conservation management is required and where other management actions, such as logging and 1080 poison baiting for vertebrate pests have been suggested as causal factors in the species' decline (Mansergh and Belcher 1992; Watt 1993; Maxwell *et al*. 1996). Population structure and weight ranges of tiger quolls are also relevant when assessing 1080 poison dose rates for wild dogs and foxes and the potential impact on non-target species such as the tiger quoll.

This paper describes the size, structure and dynamics of populations of tiger quolls in south-eastern Australia and discusses the impacts of current land-management practices.

Methods

Study sites

Three sites were used during the study (Fig. 1). One site was on the escarpment in rain-shadow box woodland near Suggan Buggan in East Gippsland, Victoria. The other sites were in wet tableland or montane forest, near Pikes Saddle in Badja State Forest and at White Ash Road in Tallaganda State Forest, in south-eastern New South Wales.

Suggan Buggan

Trapping was undertaken around the base of a cliff face on the escarpment between Mt Stradbroke and Stradbroke Chasm, near a tiger quoll latrine (communal defaecation site) (Belcher 1994, 1995). The latrine is ~4 km west of Suggan Buggan (36°57′30″S, 148°16′45″E) at an altitude of 800 m.

The Suggan Buggan valley is in a rain shadow, with an average annual precipitation of ~600 mm with maximum monthly rainfall in November and December (Bureau of Meteorology). The main rain-bearing air streams (southerlies and south-easterlies) may bring rain at any time of the year. Snowfalls are regular from June to October above 1000 m and irregular down to ~700 m (LCC 1977).

The Wulgulmerang Plateau adjoins to the south, and the edge of the plateau forms a steep escarpment composed of Snowy River volcanics or rhyolites. The Suggan Buggan valley is composed of Lower

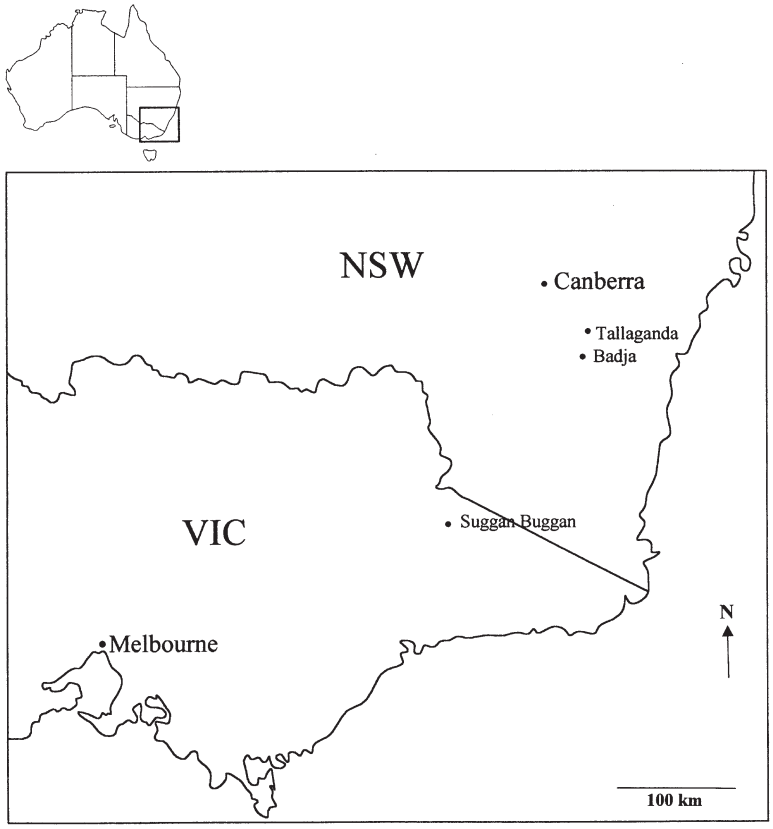

Fig. 1. Location of the three study sites in south-eastern Australia.

Devonian granites and the soils are typically shallow duplex and light red to brown. The vegetation in the vicinity of the Mt Stradbroke latrine varies from wet forest (with blue gum (*Eucalyptus globulus bicostata*)) at the base of the cliff face and the upper reaches of Stradbroke Creek, to open forest–woodland below the cliff face (with red stringybark (*E. macrorhyncha*), white box (*E. albens*) and cherry ballart (*Exocarpus cupressiformis*)) with a dense to scattered shrub layer and a sparse ground cover of native grasses.

Badja State Forest

The Badja site is near Pikes Saddle and is 3.5 km north-east of Big Badja (35°59′32″S, 149°33′20″E), in tableland forest on the western fall of the escarpment at an altitude of 1000–1200 m. Rainfall is ~900 mm per year and occurs as regular winter rains and occasional snow from the prevailing westerlies, while in summer the uplift of moist coastal air results in high rainfall and regular afternoon fogs (Anon. 1995).

The area comprises Ordovician metasediments with granitic outcrops. The soils at the Badja site are classified as having a moderate to high nutrient status (Anon. 1995). The vegetation in the study area is predominantly moist eucalypt forest on the lower slopes, flats and gullies is predominantly brown barrel (*Eucalyptus fastigata*), shining gum (*E. nitens*) and manna gum (*E. viminalis*) with a grassy to shrubby understorey. Mountain gum (*E. dalrympleana*), narrow-leaved peppermint (*E. radiata*), white ash (*E. fraxinoides*) and snow gum (*E. pauciflora*) occur on the higher slopes.

Tallaganda State Forest

The Tallaganda site is on White Ash Road on the eastern fall of the Great Dividing Range, ~22.5 km south-south-east of Captains Flat (35°49′25″S, 149°32′00″E). Annual rainfall is ~1000–1100 mm and occurs as regular winter rains and occasional snow from the prevailing westerlies, while in summer the

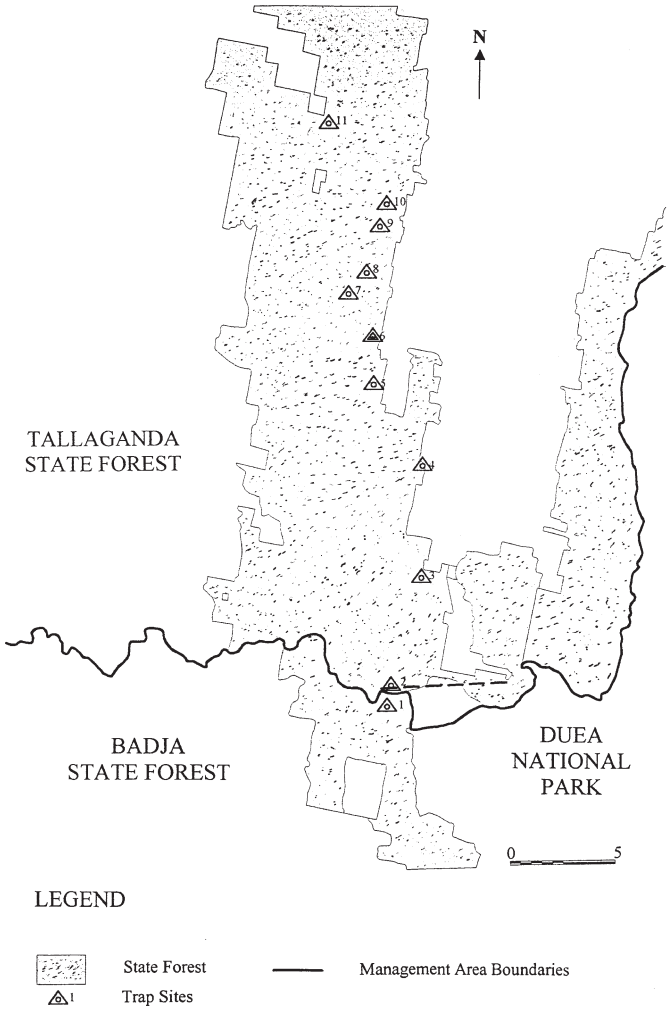

Fig. 2. Location of trap sites in Badja and Tallaganda State Forest.

uplift of moist coastal air results in high rainfall and regular afternoon fogs (Anon. 1995). The area comprises Regional metamorphics and Ordovician metasediments with granitic outcrops and tors, particularly along the eastern edge of the top of the Great Dividing Range. Soils are classified in the Palerang soil landscape unit (Anon. 1995).

Vegetation consists of white ash (*Eucalyptus fraxinoides*) and snow gum (*E. pauciflora*) at higher elevations, grading into brown barrel (*E. fastigata*), shining gum (*E. nitens*), mountain grey gum (*E. cypellocarpa*) and manna gum (*E. viminalis*) on the mid-elevation, nutrient-rich sites. Silvertop ash (*E. seeberi*) and narrow-leaved peppermint (*E. radiata*) occur on the lower-elevation nutrient-poor sites. The understorey is generally shrubby.

Remote photography and trapping

The Suggan Buggan site was monitored with a remote camera, a Canon Sureshot Supreme with a heat sensor trigger during the breeding season (May–November) in 1993. The camera was operated continuously and film was relaced every 2–4 weeks, depending on rate of use. The camera stopped operating for 1–2 weeks in June due to battery failure. The site was trapped for 7–30 days per month between May and August in 1994, 1995 and 1996. Badja State Forest was trapped for 8–14 days per month

between May 1996 and January 1998, with the exception of the period when females leave their young in a maternal den (mid-September to late November). Tallaganda State Forest was trapped for 7–10 days per month between January 1997 and May 1998 except for the period when females leave their young in a maternal den. The Badja and Tallaganda sites, plus a number of additional trap sites between these two main study sites, were trapped in June, August and December 1999, July and August 2000; and June, August and September in 2001 (Fig. 2). The southern end of Badja State Forest was also trapped in August/September and December 2001. Large wire cage traps (300 × 300 × 600 mm; Mascot Wire Works), baited with chicken or rabbit pieces, were used. Traps were normally set for 7–14 days, and checked each morning before being reset or rebaited. Traps were placed at 50–100-m intervals along each trap line, with 2–20 traps in each trap line. The number of traps and trap placement varied between sites and over time.

Each tiger quoll trapped was transferred from the cage trap to a catch-bag, weighed with 10-kg Salter scales, injected intramuscularly with a sedative, Zoletil (at a dose rate of 5 mg per kg bodyweight), and held until the sedative had acted. The animal was then removed from the catch-bag, and its sex and reproductive status recorded. It was also photographed and/or a microchip was inserted subcutaneously between the shoulder blades for later identification. Teeth were examined for wear, as a guide to the animal's age. The animal was held in the trap until it had fully recovered from the effects of the sedative (usually for about 2 h) and then released at the point of capture. Recaptured individuals were identified by their individual spot patterns and/or the presence of a microchip.

Age estimation

The age of individual tiger quolls was estimated from bodyweight, shape, condition, tooth wear and loss. These details were recorded for seven individuals that were re-trapped each year for up to four years. Age estimates were based on the following observations from known-age animals. Young were weaned at ~18–20 weeks and weighed 350–400 g. One-year-old females weighed 0.7–1.0 kg, and one-year-old males 1.2–1.6 kg. Specimens were finely built, unscarred and their teeth, particularly canines, were unworn and extremely sharp. Two-year-old females weighed 1.2–2.0 kg, and males 2.0–2.7 kg. Animals of this age class had a more robust build, their teeth were unworn and their canines were still very sharp. Three-year-old females weighed 1.4–2.1 kg, and males 2.5–4.2 kg. In this group, males were more developed around the shoulders, neck and head than females; canine teeth were intact but the tips were rounded and had lost the sharpness of the younger animals. Four-year-old quolls had either maintained their weight, or started to decrease weight. Their teeth, particularly the canines, were worn and rounded, and many had lost or broken one and sometimes two canines. Five-year-old quolls were generally lighter, had poorer body condition and had lost or broken two or more canines; the remaining canines were worn down and rounded, and some incisors were commonly missing as well.

Disturbance events

Selective logging

Tiger quolls in two compartments at White Ash Road were surveyed by trapping in 1997, before selective logging, which occurred in 1997 and 1998. The compartments were re-trapped in 1998 after logging. The sites were re-trapped in 1999, 2000 and 2001, to monitor the number of tiger quolls present and the reproductive status of the female quolls present.

1080 poison baiting

DNRE, Cooma and Braidwood Rural Land Protection Boards undertook baiting programs for vertebrate pests at the three study sites during the course of this study. Mound baiting for foxes (using Foxoff baits) and 1080 rabbit baiting (using chopped carrots) was carried out near the Suggan Buggan site between September 1995 and April 1996. Hand baiting with fresh meat baits for wild dogs was carried out at the Badja site between 1997 and 2000. Aerial baiting with fresh meat baits was carried out along a transect that extended from near the Badja site through Tallaganda State Forest and included the White Ash Road site in July 2000. Data were collected from a number of additional trap sites between the Badja site and Mt Tumanang, north of White Ash Road in Tallaganda State Forest (Fig. 2). The sites were trapped as part of an aerial baiting trial in 1999 and 2000 and monitored in 2001 (Belcher 2000).

Trapping data from each study site for each year was compiled in relation to these baiting events. Details such as age, sex, reproductive condition, weight and tooth wear were recorded for each individual tiger quoll trapped. Population trends and their correlation with 1080 baiting programmes were examined and the potential impact of baiting on populations assessed.

Table 1. Age and sex structure of tiger quoll populations at Suggan Buggan, Badja and Tallaganda State Forests between 1994 and 2001

Mound baiting using Foxoff baits was conducted at Suggan Buggan between September 1995 and April 1996. Rabbit baiting used chopped carrots was conducted at Suggan Buggan in spring 1995. Ground baiting using fresh meat baits thrown on the ground was undertaken between 1997 and 1999 along the freehold boundary of Badja State Forest and at Pikes Saddle in December 1999. Aerial baiting using fresh meat baits distributed from a helicopter was undertaken along the freehold boundary of Tallaganda State Forest in July 1998 and along a transect within Tallaganda State Forest in July 2000

Site and year	Sex	Age (years)					Baiting program
		1	2	3	4	5	
Suggan Buggan							
1994	Male	1	1	1	2	0	
	Female	0	1	0	0	0	
	Total	1	2	1	2	0	
1995	Male	0	1	1	0	1	
	Female	1	0	0	0	0	
	Total	1	1	1	0	1	Mound & rabbit
1996	Male	1	0	0	0	0	
	Female	0	0	0	1	0	
	Total	1	0	0	1	0	Mound
Badja							
1996	Male	1	1	4	2	0	
	Female	0	0	1	1	0	
	Total	1	1	5	3	0	
1997	Male	0	2	2	3	1	
	Female	1	0	0	0	0	
	Total	1	2	2	3	1	Ground?
1998	Male	0	2	1	0	0	
	Female	0	1	0	0	0	
	Total	0	3	1	0	0	Ground?
1999	Male	1	0	1	1	0	
	Female	0	0	1	0	0	
	Total	1	0	2	1	0	Ground
2000	Male	0	0	0	0	0	
	Female	0	0	0	0	0	
	Total	0	0	0	0	0	Ground
2001	Male	0	0	0	0	0	
	Female	0	0	0	0	0	
	Total	0	0	0	0	0	?
White Ash							
1997	Male	0	0	0	0	1	
	Female	2	1	1	0	1	
	Total	2	1	1	0	2	
1998	Male	0	1	1	1	0	
	Female	1	1	2	0	0	
	Total	1	2	3	1	0	
1999	Male	1	0	2	1	0	
	Female	2	1	1	0	0	
	Total	3	1	3	1	0	
2000	Male	0	0	0	0	0	
	Female	0	1	0	0	0	
	Total	0	1	0	0	0	Aerial

(*continued*)

Table 1. (*Continued*)

Site and year	Sex	Age (years)					Baiting program
		1	2	3	4	5	
2001	Male	0	1		0	0	
	Female	0	1	1	0	0	
	Total	0	2	1	0	0	
Badja–Tallaganda							
1999	Male	5	1	5	4	0	
	Female	2	4	3	0	0	
	Total	7	5	7	4	0	
2000	Male	0	0	2	2	0	
	Female	1	2	1	0	1	
	Total	1	2	3	2	1	Aerial
2001	Male	0	1	1	0	0	
	Female	0	1	0	0	0	
	Total	0	2	1	0	0	

Results

Trapping results

Suggan Buggan

At least seven tiger quolls were recorded by remote camera at the latrine in 1993 and identified by their unique spot patterns (Belcher 1994). One appeared to be a female and at least one of the males was re-trapped in 1994 and 1995. One male appeared to be a four-year-old, with a thick neck and bulbous nose.

Ten individual tiger quolls (eight males and two females) were captured between 1994 and 1996 (Table 1). Trap success varied from 25% (captures per 100 trap-nights) in 1994 to 4.5% in 1996 and the number of individuals captured fell from six to two after 1080-baiting.

Badja

Nineteen tiger quolls (16 males and three females) were captured at Badja State Forest between 1996 and 2001 (Table 1). One captured male was mistaken for a known individual and released in 1996 without any measurements being recorded. Four quolls were trapped in the southern end of Badja in 2001. Trap success at the Badja site varied from 10.6% in 1996 to 0% in 1999–2001, when the number of individuals captured declined from 11 to 0 after baiting. Trap success declined from 10.6% during the breeding season to 5.4% in early summer.

Tallaganda

Twenty-six tiger quolls (15 females and 11 males) were captured at the White Ash Road site. Six were trapped in 1997, seven in 1998, eight in 1999, one in 2000 and two in 2001 (Table 1). Trap success varied from 30% in 1999, to 3.6% (after 1080 baiting) in 2000, then to 5.4% in 2001.

Badja–Tallaganda

Trapping in 1999 resulted in the capture of 23 individual tiger quolls at nine sites, while trapping in 2000 (one month after aerial 1080 poison baiting) resulted in the capture of nine

Table 2. Mean body weights (kg) of 97 tiger quolls trapped between 1994 and 2001 at Suggan Buggan, Victoria, and Badja and Tallaganda State Forests, New South Wales

Sex	Age class	*n*	Weight range (kg)	Mean weight ± s.d. (kg)
Male	Adult	45	2.0–4.2	2.81 ± 0.50
	Sub-adult	12	1.4–1.9	1.63 ± 0.16
	All males	57	1.4–4.2	2.59 ± 0.66
Female	Adult	31	1.2–2.1	1.73 ± 0.22
	Sub-adult	9	0.7–1.2	1.0 ± 0.16
	All females	40	0.7–2.1	1.52 ± 0.38

individuals at four sites and three individuals at three sites in 2001 (Table 1). Trap success varied from 15.5% in 1999 to 6% in 2000 (after 1080 aerial baiting), then to 2.7% in 2001.

Sex ratios and adult : sub-adult ratios

The sub-adult category is defined as immature individuals and includes juveniles (animals up to one year old) and sub-adults (animals between one and two years old). Adults are defined as sexually mature and include all animals between 2 and 5 years. One female was recorded breeding at 1 year of age.

Suggan Buggan

The male : female ratio varied from 5 : 1 in 1994 to 3 : 1 in 1995 and 1 : 1 in 1996. The adult : sub-adult ratio varied from 5 : 1 in 1994 to 3 : 1 in 1995 and 1 : 1 in 1996 (Table 1).

Badja

Males outnumbered females every year, with the ratio varying from 9 : 2 in 1996 to 8 : 1 in 1997 and 3 : 1 in 1998 and 1999. The two adult breeding females disappeared in early 1997, and were replaced by a juvenile female in the same year. The adult : sub-adult ratio varied from 10 : 1 in 1996 to 8 : 1 in 1997, 4 : 0 in 1998 and 3 : 1 in 1999. No quolls were recorded in December 1999, June–August 2000 or June–September 2001 (Table 1).

Tallaganda–White Ash Road

Female tiger quolls outnumbered males each year, except for 1999 when the male : female ratio reached parity. The male : female ratio varied from 1 : 5 in 1997 to 3 : 4 in 1998, 4 : 4 in 1999, 0 : 1in 2000 and 1 : 1 in 2001. The adult : sub-adult ratio varied from 2 : 1 in 1997 to 5 : 2 in 1998, 5 : 3 in 1999, 1 : 0 in 2000 and 2 : 0 in 2001 (Table 1).

Badja–Tallaganda

Male : female sex ratios varied from 14 : 9 in 1999 to 4 : 5 in 2000 and 2 : 1 in 2001. The adult : sub-adult ratio varied from 16 : 7 in 1999 to 8 : 1 in 2000 and 3 : 0 in 2001 (Table 1).

Body weights

Weight measurements from 57 male and 40 female tiger quolls were used to calculate mean weights by age (adult and sub-adult) and by sex (Table 2). Males did not reach maximum weight until three years, while females reached maximum weight at two years (Fig. 3). The young weigh 300–500 g at weaning (unpublished data; R. Warneke, personal communication).

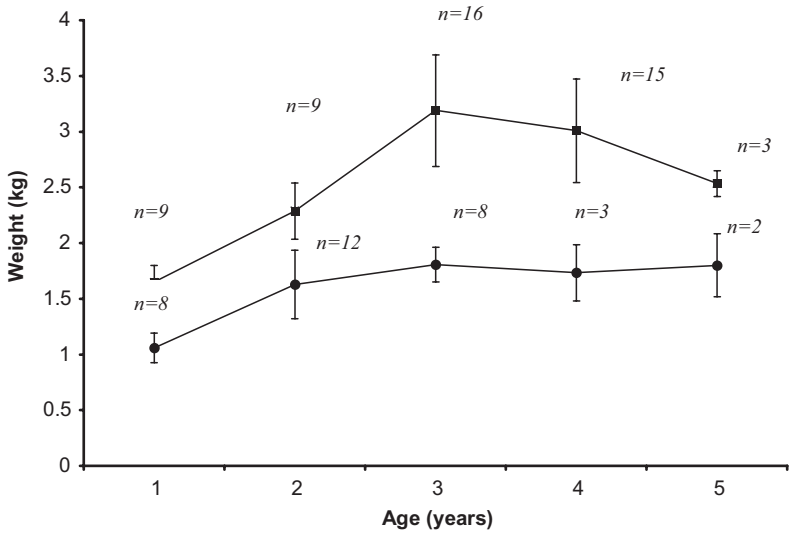

Fig. 3. Mean weights (±s.d.) of male (■) and female (●) tiger quolls recorded from Suggan Buggan, Badja and Tallaganda State Forests between 1994 and 2001.

Table 3. Comparison of tiger quoll weights by sex and age

Data are the results of a nested ANOVA. A summary of Tukey's pairwise comparison of sex (M, male; F, female) with age (1, 2, 3, 4 years), n = 80, is shown. Lines joining ages indicate non-significant comparisons. Weights are arranged from lowest to highest

Source	d.f.	m.s.	*F*	*P*	Summary of Tukey's comparison
Sex	1	15.004	120.890	0.000	F < M
Age(sex)	6	3.221	25.954	0.000	F_1 F_2 M_1 F_3 F_4 M_2 M_3 M_4
Error	72	0.124			

An analysis of variance of weights by sex and age found that there was a significant difference in weight between one-, two- and three-year-old males and between one- and two-year-old females (Table 3). Males were significantly heavier than females in every age class (Table 3).

Population age structure

An estimate of the age of each animal captured, based on weight, size, body condition and canine tooth wear was recorded to determine population age structure (Table 1). The age structure, sex ratio and adult:sub-adult ratio for each site fluctuated between most years, probably reflecting previous disturbance events. Male and female quolls between the ages of two and four years were normally re-trapped and considered to be resident, although some males were recorded shifting home ranges, usually when there were no adult females present (Belcher 2000). Most one-year-old male quolls were captured and recaptured during one trapping session, but not recaptured during the following months, suggesting that they were still dispersing. Juvenile and sub-adult females were regularly re-trapped in adult female quolls' territories. No five-year-old male and female quolls were recaptured from one month to the next, indicating that they were transients or had died.

Breeding

Most females did not breed until they were two years old. Only one of the eight females recorded breeding was a one-year-old. All of the two-year-old females captured were recorded breeding. A proportion of adult females were recorded breeding in a territory in one year, not re-trapped in that territory the next year and then recorded breeding in the same territory in the third year.

Mating

Data from 14 litters was used to estimate time of conception and birth based on correlations of age, growth rate and crown–rump length from Green and Scarborough (1990). Time of mating ranged from late June to early August (28 June – 4 August) and births from mid-July to late August (17 July – 25 August). Most matings were estimated to have occurred in early to mid-July and most births from late July to mid-August. Matings in any year were spread over 2–4 weeks.

Reproductive success

Development of the young of four females was monitored from early pouch-young stage to weaning, by monitoring each female's maternal den. Two females weaned two offspring from litters of six and two females weaned four offspring from litters of six.

Pouch young

All females examined had six teats. The litter size for pouch young was recorded from 14 females. The mean number of pouch young per litter was 5.38 ± 0.65 (s.d.), with a range of 4–6. Females were recorded breeding from one until four years of age. A one-year-old and a two-year-old were each recorded with four pouch young. All other females had either five or six pouch young.

Population correlations with selective logging

The trapping results at the White Ash study site between 1997 and 1999 (Table1) indicate that the selectively logged compartments continued to support resident females, which were recorded breeding each year after logging and the overall number of tiger quolls increased each year (6, 7, 8) until aerial baiting in 2000 (Table 1). Only one animal was trapped in 2000 and three in 2001.

Population correlations with 1080 poison baiting programs

Suggan Buggan

Fox baiting was carried out 5–6 km north of the Suggan Buggan site between spring 1995 and autumn 1996. Rabbit baiting was undertaken ~7–8 km to the south of the study area in late spring 1995. The number of adult males visiting the latrine during the breeding season of 1996 declined from five to zero.

Badja

The period of baiting for wild dogs in and adjoining Badja State Forest corresponded with the decline and eventual extirpation of the local tiger quoll population. The forest/freehold boundary had been baited since 1997 by landowners and the local Rural Land Protection Board (RLPB). In addition, illegal baits were found within Badja State

Table 4. Trapping results at 9 sites between Badja State Forest and Mt Tumanang in Tallaganda State Forest in 1999, 2000 and 2001

Site	1999			2000			20001		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Badja	1	0	1	0	0	0	0	0	0
Pikes	2	1	3	0	0	0	0	0	0
Jinden	2	1	3	0	2	2	0	0	0
Sweetwater	0	1	1	0	0	0	0	0	0
Bald Peak	3	1	4	1	2	3	1	0	1
WA, Latrine	2	1	3	0	1	1	0	1[A]	1
WA, south	1	1	2	0	0	0	1	0	1
WA, north	2	2	4	0	0	0	0	1	1
Tumanang	1	1	2	3	0	3	1	0	1

[A]A pouch young was recovered from a trap that had been set off, but the female had escaped.

forest in December 1999 (Jim Darrant, personal communication) and it would be reasonable to suspect illegal hand baiting in Badja State Forest prior to this time.

The two breeding female tiger quolls recorded in 1996 both disappeared in 1997, as did a number of male quolls present in 1996. Tiger quoll numbers at Badja State Forest remained low (4) in 1998 and 1999 and declined to zero by late December 1999 (Jim Darrant, personal communication) following the illegal baiting. Trapping during July and August of 2000 and 2001 failed to record any tiger quolls at the Badja study site.

Tallaganda

Information supplied by the local RLPB to State Forests of NSW indicated that, in 1996, baiting for wild dogs was undertaken on the western fall of the Great Dividing Range above White Ash Road, outside the known territories of the female tiger quolls at White Ash Road (Belcher 2000). In 1997, five females were trapped within the first 10 days' trapping while only one male (more than four years old) was captured during trapping over three months.

The eastern forest/freehold boundary of Tallaganda State Forest was aerially baited in July1998. Several days after baiting one male tiger quoll was trapped at the White Ash Road latrine site. The animal showed signs of 1080 poisoning (convulsions and vomiting). The quoll was released and followed to a hollow log, where it subsequently died. The animal was collected and an autopsy was carried out; it was found to be in good condition but no cause of death could be determined (Dr George Timmins, veterinary surgeon, Cooma, personal communication). Tissue samples were collected and analysed. The analysis found 1080 poison in the stomach and muscle tissue (John Wright, Landcare NZ, personal communication).

Badja–Tallaganda

Following the discovery of the poisoned quoll, no aerial baiting was undertaken by the RLPB in 1999. Tiger quoll numbers increased slightly at White Ash Rd, with males reaching parity with females (4:4). Breeding females were recorded at Sweetwater, Bald Peak, White Ash latrine, White Ash South, White Ash North and Tumanang trap sites (Table 4).

The local RLPB undertook aerial baiting in the area in July 2000. In 2000, the breeding females, their offspring from 1998 and 1999, and males were absent from Sweetwater, White Ash South and White Ash North trap sites (Table 4). Only one tiger quoll, a female,

was recorded from the White Ash latrine and, despite her pouch being developed, no young were present in August 2000. Numbers from the trap sites between Badja and Mt Tumanang dropped from 23 in 1999 to 9 in 2000 (Table 4). More specifically, numbers at White Ash North dropped from four to zero, White Ash South dropped from two to zero, White Ash latrine from three to one, and Sweetwater one to zero.

Discussion

Trap success

Apart from selecting suitable trap sites, two factors appeared to influence trap success. Trapping during the tiger quolls' breeding season resulted in higher trap success at all sites. Increased movement of males during the breeding season has also been recorded in other species of quoll (Godsell 1983; Serena and Soderquist 1989; Oakwood 2002). Trapping after 1080-poison baiting resulted in substantially lower trap success at all sites, suggesting a decline in the trappable population.

The spatial and social organisation largely determines the number of individuals and sex ratio of tiger quolls. Female tiger quolls are intrasexually territorial and female natal philopatry occurs (Belcher 2000), thus limiting the number of females that can be present at a site. Male tiger quolls are not territorial and have home ranges that overlap extensively with both females and other males (Belcher 2000). During the breeding season (May–August) males move back and forth between the territories of a number of females, monitoring the reproductive status of each female. If traps were set in a female's territory during the breeding season, it would therefore be expected that more males than females would be trapped. The results from Suggan Buggan and Badja suggest that the normal ratio of males to females captured in a female's territory is ~5 : 1.

Breeding

The adult : subadult ratio suggests that either reproductive success is low despite high pouch litter size, or juvenile mortality rates are high. Monitoring female reproductive success indicated that the mean mortality rate of young between first being left in a den and weaning was 50%, similar to the mortality rate of 64% recorded for young northern quolls (*D. hallucatus*) (Oakwood 2000). The female reproductive success rates should be viewed as tentative due to the small number of females monitored.

The data on mating and birth suggests that the tiger quoll is a seasonal rather than synchronous breeder, enabling males to potentially mate with a number of females. Reproductive output appears to be limited by the high mortality of young between being left in the maternal den and weaning and by most females first breeding when two years old. Two selective pressures are hypothesised to be operating on seasonally restricted breeding in dasyurid marsupials: reproduction is timed to ensure that the energetically demanding period of lactation coincides with a peak in food supply and that juveniles are weaned at a time when food is abundant, favouring continued growth (Wainer 1976; Braithwaite 1979; Lee *et al*. 1982). Tiger quoll young are weaned in late spring to early summer when their main prey (invertebrates, reptiles, small mammals and birds) are at peak abundance and/or activity (Belcher 1995).

Body weight

Male tiger quolls attained maximum body weight at three years and females at two years of age and had a maximum life expectancy of five years in this study. The other quoll species

reach full size and breed at the end of their first year and have a maximum life expectancy of 1–3 years (Godsell 1983; Serena *et al*. 1991; Oakwood 1997; Oakwood *et al*. 2001). Mean male body weights in this study were similar to the mean weights compiled by Green and Scarborough (1990) from 35 specimens in the Queen Victoria Museum, but lower than the mean male weight recorded by Jones (1997) from 31 Tasmanian quolls (2.81 ± 0.5 (s.d.) kg compared with 3.23 ± 0.39 (s.d.) kg). Mean female weights were similar to mean female weight recorded by Jones (1997), but was substantially lower than the weights recorded by Green and Scarborough (1990) (1.52 ± 0.38 compared with 2.0 ± 0.4 kg). Weight ranges for both sexes were also lower in this study than reported by Green and Scarborough (1990) for Tasmanian quolls; they recorded a male weight range of 1.7–6.1 kg compared with 1.4–4.2 kg in this study (Table 2). Similarly, they recorded a female weight range of 1.4–2.5 kg with information from the Tasmanian Museum of a 3.0-kg female compared with 0.7–2.1 kg in this study (Table 2). The mean adult male weight recorded by Watt (1993) from a small sample (n = 4) in southern Queensland was 4.55 kg (range 3.9–5.2 kg). The differences in maximum weights does not follow a latitudinal trend, with males recorded in south-east Queensland and Tasmania being heavier than those in south-east New South Wales and eastern Victoria. In a critique of ecological theory, Peters (1991) cited an exception rate of 68% to Bergmann's rule, suggesting that the theory that body weight follows a latitudinal trend is not valid. The differences in maximum weights may simply reflect resource abundance during the period of growth (Powell 1979; King and Moody 1982).

Population size and age structure

Age structure varied from year to year with no discernible pattern beyond reduction in the number of males (in particular) and females immediately after aerial and ground 1080 poison baiting (Table 1). Population size declined more gradually after 1080 poison ground baiting in Badja than after aerial baiting in Tallaganda (Table 1). The results suggest that each population declined in size after 1080 poison baiting and that is reflected in uneven and declining numbers in each age cohort.

Selective logging

The number of breeding female quolls remained constant after selective logging in late 1997 until aerial baiting in 2000 when the number of females declined to one and breeding females were lost (Table 1). The number of male quolls increased each year from 1997 until aerial baiting in 2000. The pre- and post-logging trapping results suggest that the decline from eight quolls to one, one month after 1080 poison aerial baiting, was not due to selective logging in 1997. The declines in tiger quoll numbers immediately after baiting at Suggan Buggan and Badja add further support to the suggestion that the decline at White Ash Road was not due to selective logging.

1080 poison baiting

One of the problems associated with determining the impact of 1080 poison baiting is the difficulty in locating poisoned animals, due to the length of time between ingestion, symptoms and death. Few, if any, carcasses of wild dogs, foxes or non-target species are found after a 1080 poison-bait program, probably because most animals retreat to a den when the symptoms of 1080 poisoning begin. As a consequence, indirect evidence, such as visits to bait stations or activity on sand pads are usually relied upon to evaluate the impact or effectiveness of 1080 poison baiting. Monitoring populations of tiger quolls by trapping before and after baiting provides more direct evidence of changes in populations and

Table 5. Susceptibility of the tiger quoll, by sex and age class, to 1080 poison baits
LD_{50} and LD_{100} values are from McIlroy (1981, 1982). Foxoff baits (60 g) contain 3.3 mg 1080, fresh meat baits (230 g) contain 4.5 mg 1080 in Victoria and 6 mg 1080 in New South Wales. McIlroy and Gifford (1992) found an average of 7.1 mg 1080 residue in rabbit carcasses after 1080 carrot baiting

Sex	Age (years)	Mean weight (kg)	mg 1080 for LD_{50}	mg 1080 for LD_{100}
Male	1	1.63	3.01	4.17
Female	1	1.0	1.85	2.56
Male	2–5	2.81	5.2	7.19
Female	2–5	1.73	3.2	4.43
Overall mean	1–5	2.15	3.98	5.70

therefore the possible impact of baiting on this species. The capture of a male tiger quoll displaying symptoms of 1080 poisoning in 1998 at White Ash Road, while clearly showing that full-grown male tiger quolls may find, eat and be killed by aerially deployed 1080 baits, was an unusual event. Monitoring populations before and after baiting, however, showed that most tiger quolls were likely to disappear after baiting, assumed dead. The density of tiger quolls at the southern end of Badja State Forest in 2001–02 was similar to the densities recorded at Suggan Buggan in 1994, around Pikes Saddle in 1996–97 and White Ash Road in 1997–99 prior to baiting (J. Nelson, personal communication), suggesting that the population declines recorded after baiting were not due to a natural population cycle.

As female tiger quolls are intrasexually territorial, they are unlikely to be exposed to baits unless baits are either deployed or cached within their territories (Belcher 2000). Male tiger quolls have significantly larger home ranges than females and their home ranges overlap extensively with both females and other males (Belcher 2000). The distribution of male tiger quolls is largely determined by the presence of adult females (Belcher 2000). Male activity peaks during the breeding season, with males moving back and forth between female territories, monitoring female reproductive status. Males are therefore more likely to encounter baits than females, due to their significantly larger home ranges and movement during the breeding season. Following baiting, no adult males were recorded, despite the presence of adult females at Suggan Buggan and White Ash Road.

On the basis of their mean weights, most tiger quolls in a population would be likely to receive a lethal dose from consuming one 1080 poison bait at ambient temperatures between 13° and 30°C (Table 5). At temperatures below 13°C, commonly experienced during baiting programmes, which are normally undertaken during winter, an even higher proportion of the population is likely to receive a lethal dose from consuming one bait.

An aerial baiting trial in 1999 found that at least 67% of the tiger quoll population and 86% of adult males and breeding females had consumed one or more baits (Belcher 2000). Results of trapping one-month after 1080 poison aerial baiting in 2000 indicated a 70% reduction in the population. The strong correlation between 1080 baiting and population crashes would suggest that the current 1080 poison baiting methods pose an unacceptable risk to a species listed as ‘Vulnerable’ nationally and in New South Wales and ‘Endangered’ in Victoria.

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