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Aerial baiting for wild dogs has no observable impact on spotted-tailed quolls (*Dasyurus maculatus*) in a rainshadow woodland

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Abstract. The short-term impact of 1080 aerial baiting for wild dogs (*Canis lupus dingo*, *Canis lupus familiaris* and hybrids of the two) on spotted-tailed quolls (*Dasyurus maculatus*) was investigated at a rainshadow woodland site in southern New South Wales, Australia. Sixteen quolls were trapped and fitted with radio-transmitters containing mortality sensors. Three feral cats were also opportunistically trapped and radio-collared. One week after trapping ceased, meat baits nominally containing 6 mg of 1080 poison and 50 mg of the biomarker rhodamine B were deployed aerially over a 10-km transect across the study area. Following bait deployment, collared quolls and cats were monitored daily over four weeks for evidence of mortality. During this time, one quoll and two cats died. The quoll did not die from 1080 but both cats showed clear signs of poisoning. Whisker samples were obtained from trapped quolls 5–8 weeks after baiting to determine whether they had been exposed to baits. Of the 15 remaining collared quolls, 12 were retrapped. Four of these tested positive for rhodamine B. Three individuals originally collared were not retrapped but confirmed alive at least seven weeks after bait deployment. A further six non-collared quolls were also trapped, with two of these positive for rhodamine B. Of the 19 quolls from which whisker samples were tested for rhodamine B then, 13 (68%) were negative and six (32%) were positive. Aerial baiting had no observable impact on the local radio-collared quoll population, a finding consistent with results from a similar study recently conducted in northern New South Wales.

Introduction

Considerable attention has been focused on the potential non-target impact of 1080 poison baiting for canids on a range of native mammals, particularly at-risk carnivores such as the spotted-tailed quoll (*Dasyurus maculatus*) (e.g. Belcher 2003; Glen and Dickman 2003*a*, 2003*b*; Körtner *et al*. 2004; Körtner and Watson 2005). This attention is warranted given the widespread nature of 1080 baiting across Australia, particularly for wild dogs that are known to kill and maim domestic stock (Fleming *et al*. 2001). Most recently, this has led to the development of the 'buried-baiting' technique, in which baits are covered, either within mounds of soil or sand, or buried below the surface of the ground (Glen and Dickman 2003*a*, 2003*b*). Doing this reduces uptake by quolls since they are less inclined to dig for food than are introduced canids (Belcher 1998; Glen and Dickman 2003*b*). Buried-baiting programs work best when there is a good system of access roads where bait stations can be systematically prepared and maintained. In forests with no tracks and trails, 1080 baits used for wild dog control are instead typically deployed from the air. This method results in baits resting on the surface of the ground, increasing risk of exposure to spotted-tailed quolls. Murray and Poore (2004) unequivocally demonstrated that a large proportion (65%) of a trappable population of quolls ate non-toxic baits loaded with the biomarker rhodamine B that were deployed aerially across a forested study site in southern New South Wales. More recent related studies by Claridge *et al*. (2006), in a different environment, illustrated similarly high exposure rates (47–60%) of quolls to non-toxic baits at lower baiting rates than that used by Murray and Poore (2004).

Although the simulated trials described above are instructive in assessing the potential risk that quolls face from aerial baiting programs for wild dogs, they do not provide information on mortality rates of animals if toxic baits were used (Claridge *et al*. 2006). Evidence for deleterious impact of 1080 baiting on spotted-tailed quolls in the wild is equivocal. Belcher (2003) reported significant declines among three separate populations of the species in southern New South Wales and far-east Gippsland, Victoria. He speculated that these declines were likely due to a combination of aerial baiting and illegal hand-baiting activities for wild dogs, or fox and rabbit baiting, respectively, that occurred before a crash in his study populations. In contrast, field trials with surface-laid and buried fresh meat baits showed a low impact on a quoll population in southern Queensland, with two confirmed 1080-related deaths among 76 radio-collared quolls (P. Cremasco, pers. comm. 2005).

Most recently, Körtner and Watson (2005) radio-collared a local population of quolls on the New England Tablelands in northern New South Wales ahead of a routine aerial baiting program on private and state forest tenures. Baits, injected with a nominal dose of 6 mg of 1080, as well as the biomarker

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rhodamine B, were deployed along transects across their study area. At the time of bait deployment, 31 quolls were radio-collared. Subsequent monitoring recorded only one quoll death that could be directly attributed to baiting. Critically, there were five live animals out of 35 sampled after baiting that tested positive for rhodamine B, indicating at least partial bait consumption but survival. These results indicated that baits used in wild dog control are not always fatal for quolls upon ingestion. Of further interest, the proportion of animals that encountered baits (6 of 35, or 17%) was less than that reported in the non-toxic trials conducted by Murray and Poore (2004) and Claridge *et al*. (2006). Körtner and Watson (2005) speculated that this difference may have been due to the inclusion of 1080 in baits, with animals either having a learned or innate aversion to the toxin since their trial was conducted in a location with a continuous history of once-yearly aerial baiting.

Overall, the results of Körtner and Watson (2005) indicated a very low level of impact of aerial baiting on their study population. However, to draw robust conclusions about the potential impact of aerial baiting on quolls *per se*, replicate trials in different sites are necessary. Moreover, the possibility of developed bait aversion needs testing. To partially redress these deficiencies, we investigated the impact of aerial baiting on a population of spotted-tailed quolls in southern New South Wales that did not have a recent history of aerial baiting. The survivorship and exposure rate of radio-collared animals was monitored before and after baiting. Since the focus of this current study was on non-target impacts, we did not assess the effect of aerial baiting on the local wild dog population.

Methods

Study area

The baiting trial was conducted within the catchments of the Jacobs River and Ingebirah Creek, in the Byadbo Wilderness section of Kosciuszko National Park in southern New South Wales, ~40 km south of Jindabyne (Fig. 1). General features of the 7000-ha study area, including topography, climate, vegetation and fire history, have been previously described in a series of related papers (Claridge *et al*. 2004, 2005, 2006).

Prebaiting trapping and transmitter deployment

For the present study, large cage traps (300 × 300 × 600 mm, Mascot Wire Works, Enfield South, New South Wales, Australia) were set at 36 known latrine sites in order to live-capture quolls and affix radio-collars (see Claridge *et al*. 2004 and 2005 for detailed descriptions of site selection). These were covered with a sheet of plastic to protect captured animals from rainfall. Traps were set for a maximum of five days and four nights, for each of four consecutive weeks during May 2005. The trapping effort was not equal for each of the latrine sites and reflected the effort required to locate individual animals. Traps were baited with chicken wings and checked between 0700 and 1100 hours each day.

Captured quolls were removed from traps and placed in a soft, thick cotton bag. Animals were then anaesthetised with isofluorane gas administered by a qualified vet, or via intramuscular injection of zoletil (6–8 mg kg^{-1}). On first capture, individuals were marked with a Passive Integrated Transponder (PIT) (Trovan Microchips Australia, Keysborough, Victoria, Australia) for unique identification, which was inserted into the tissue behind the neck. Quolls were then fitted with collars containing a VHF transmitter operating in the 150-MHz band and a mortality sensor (Faunatech/Ausbat Pty Ltd, Bairnsdale, Victoria, Australia). The mortality sensor was set for activation if the collar remained stationary for at least 12 h; after this time the pulse rate doubled. The collar was made of either suede or soft leather, designed in such a way as to stretch and wear over time, and eventually fall off. This negated the risk of having quolls with collars left in the field after the study if they could not be successfully retrapped. Total collar weight was ~27 g, or less than 2.5% of the bodyweight of the smallest females used in the study. Animals were also sexed, weighed and measured. Once fully recovered (typically ~10–15 min for isofluorane and 2–3 h for zoletil), animals were released at point of capture. During trapping we also caught a small number of feral cats (*Felis catus*). These were handled, sedated, radio-collared and released in the same manner as for the quolls, with the exception that tissue samples were not collected.

Aerial baiting

In total, 155 meat baits were prepared for the 1080 baiting exercise, 100 for deployment and 55 for a related 1080 degradation study (see Methods below). Each bait comprised a piece of boneless red meat weighing ~250 g. Baits were first air-dried for 48 h. After drying, 100 of these were injected separately with 0.2 mL of a solution containing 6 mg of 1080 (standard for dog baits in New South Wales) and then with 0.5 mL of solution containing at least 50 mg of the biomarker rhodamine B. Further details about the properties of rhodamine B and its field use are detailed in Fisher (1998). Baits prepared with 1080 and rhodamine B were deployed in the field exercise described immediately below. For the remaining 55 baits used in the 1080 degradation study, only the solution containing 6 mg of the toxin was injected.

In early June 2005 the meat baits with 1080 and rhodamine B were dropped from a helicopter at the rate of one every 100 m over a 10-km transect (Fig. 1). Total transect length was equivalent to that indicated in McIlroy (1999) for aerial-baiting proposals immediately adjacent to the study area. The transect used was chosen to represent the major topographic features usually targeted in aerial-baiting programs: drainage lines and ridges. The rate at which baits were deployed was consistent with what is operationally practised elsewhere within conservation reserves in New South Wales.

Monitoring of spotted-tailed quolls and feral cats

Systematic monitoring of the status of quolls and feral cats via radio-telemetry commenced two days before the baits were dropped and continued daily for 33 days. During the first two weeks after bait deployment the mortality status of quolls was checked every second day (weather permitting) via helicopter, using three yagi antennas fitted into a direction-finding system. This system allowed individual animals to be potentially located, as the signal strength increased with proximity to a transmitter and then passed through a ‘null’ (weak distorted signal) as the helicopter flew directly over the animal. After the first two weeks, helicopter-based telemetry to detect collars was

restricted to every third or fourth day. On intervening days, the mortality status of collars was checked either using a vehicle-mounted antenna (Faunatech/Ausbat Pty Ltd, Bairnsdale, Victoria, Australia) or on ground using a hand-held yagi antenna connected to an Australis 26K tracking receiver (Titley Electronics, Ballina, New South Wales, Australia). Ground-based telemetry provided some additional location fixes on individual animals together with that obtained from trapping and the helicopter-based telemetry.

In general, female quolls fitted with collars were monitored for locational fixes as well as for evidence of mortality. Male quolls and the three feral cats were typically monitored only for evidence of mortality since: (i) we had limited resources for aerial telemetry, and (ii) male quolls, in particular, are known to travel large distances, potentially adding flight time. However, in situations where a mortality signal was received from a collared male quoll or cat, the location was rapidly determined. Unique locations for each quoll, derived from a combination of trapping and telemetry points collected during the study, were entered into a tab-delimited (*.txt) file and imported into ArcView GIS 3.2a and displayed as an 'Event Theme'. Locations for individual quolls were then converted to point shapefiles and minimum convex home-range polygons (MCPs) created, where possible, using the extension 'Animal Movement' (Hooge and Eichenlab 1998). These were plotted against the location of the baiting transect to assess the likelihood that an individual quoll would have had the opportunity to encounter baits.

Carcasses or lost collars were retrieved as soon as possible after the detection of a mortality signal. Carcasses were subjected to a post-mortem within 48 h of collection. For quoll carcasses retrieved after the baiting, the stomach, liver and a muscle sample

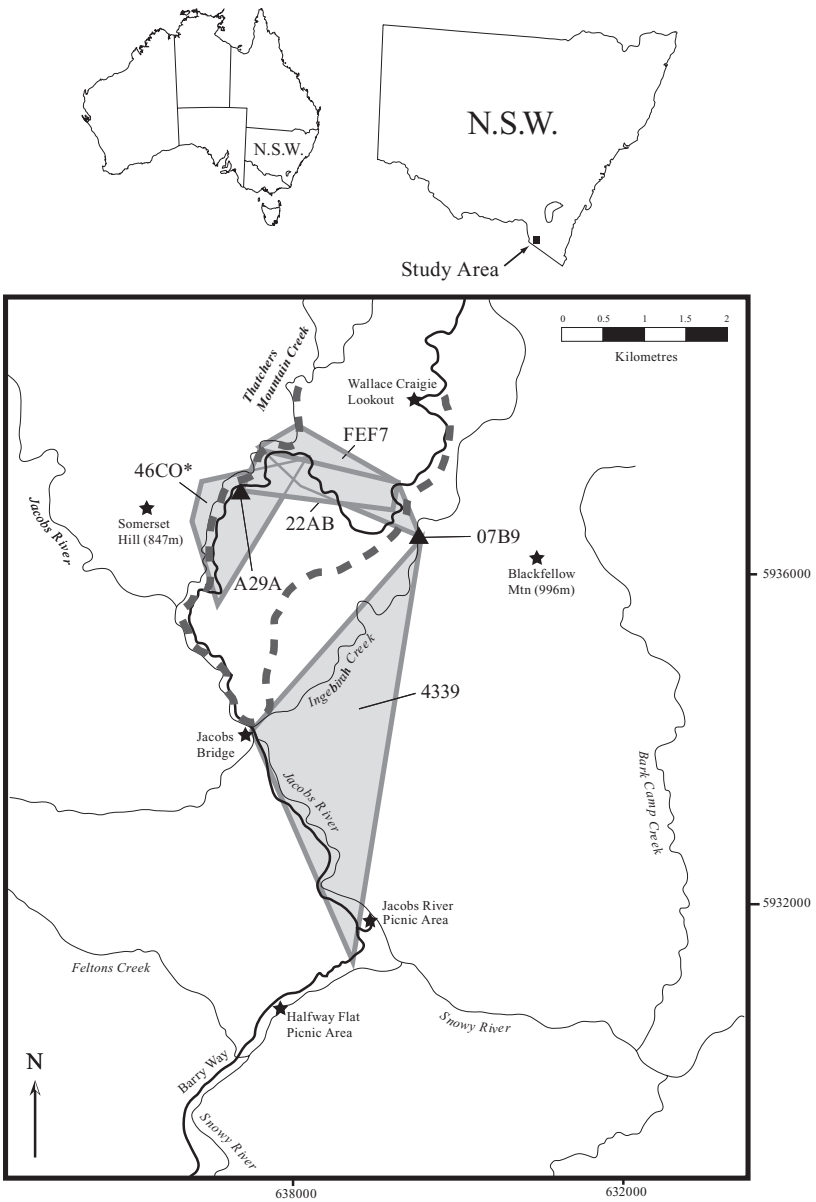

Fig. 1. Map of the study area, situated in the Byadbo Wilderness Area within Kosciuszko National Park, southern New South Wales. Minimum convex polygons for six quolls that tested positive for rhodamine B are also shown. Female quoll is denoted by an asterisk. Transects where baits were deployed are shown as dashed lines. Animals known only from one location (A29A and 07B9) are shown as small triangles. Grid references are based on Australian Geodetic Datum 66 (Zone 55).

were removed for 1080 analysis, the latter conducted at the Alan Fletcher Research Station in Sherwood, Queensland. These samples were kept frozen until the relevant assays were performed.

Post-baiting trapping and rhodamine assays of quoll whiskers

Trapping recommenced five weeks after the baiting event so that whisker samples could be obtained from individual quolls. This was considered enough time for the whiskers to have grown such that rhodamine B would be evident if animals had consumed baits (Fisher 1998). Trapping was conducted for a maximum of five days and four nights at the same sites, for each of three consecutive weeks during July 2005. Additional targeted trapping was variously conducted over a further three weeks in an attempt to retrieve radio-collars from individuals that were not encountered during systematic trapping.

Once sedated, 8–10 mystacial whiskers were plucked from captured quolls using tweezers and placed in labelled zip-lock plastic bags. In the laboratory, individual whiskers from each sample were washed in 70% ethanol to remove dirt and other debris. Once cleaned and air-dried, all of the whiskers from an individual animal were combined on to a glass slide, placed in mounting solution and a coverslip was applied. Once the mount had dried (24 h later), samples were observed under a fluorescence microscope and any distinctive banding of rhodamine B observed in whisker samples noted (see Claridge *et al*. 2006).

1080 deterioration rate

To assist in interpreting results from the aerial baiting trial, we also assessed the rate of deterioration of 1080 over time in 55 randomly selected meat baits on the day of deployment over the study area. Of these, 10 were bagged separately and frozen immediately after preparation. The remaining 45 baits were placed in a 3 m × 3 m wire enclosure within the study site. Each of five baits were then retrieved at random from the enclosure 5, 10, 20 and 25 days after initial placement, and a further 10 baits each after 30 and 40 days. All baits retrieved from the enclosure were frozen a few hours after collection, until analysed for 1080 (at the Alan Fletcher Research Station, Sherwood, Queensland). During the study, ambient temperature and rainfall were monitored daily since both climatic factors are known to influence the deterioration rate of 1080 in meat baits (e.g. McIlroy *et al*. 1988; Fleming and Parker 1991). Methods used for extraction of 1080 from baits are detailed in Körtner *et al*. (2003). Mean values for 1080 were calculated from individual samples at each time interval (±s.d) and then plotted. An exponential curve was fitted to the mean values using least-squares regression in the software program Microsoft Excel.

Results

Prebaiting trapping

In total, 69 captures of 16 individual quolls (seven female, nine male) and three captures of three individual feral cats (one female, two male) were made from 886 trap-nights during May 2005. The rate of capture of new quolls declined over the four consecutive weeks of trapping, with nine quolls trapped during the first week, five in the second week, and one each in the third and fourth weeks.

Monitoring of spotted-tailed quolls and feral cats

A single male quoll died 23 days after bait deployment. First captured and marked in the winter of 2004, this individual was thought to be an older animal (on the basis of a combination of bodyweight and the poor condition of its canine teeth). Post-mortem of the carcass indicated no traces of rhodamine B, which would have been consistent with recent ingestion of bait. Otherwise, there were no obvious signs of external trauma and the animal had good reserves of body fat. Parts of the stomach and lungs were filled with congealed blood and apparent secondary cancerous tumours. Later toxicology tests of the stomach, muscle and liver of the animal all tested negative for 1080.

Two of the three radio-collared cats were found dead within two weeks of bait deployment, both showing signs of being killed by 1080 baits. Two days after baiting the single female cat died. Scats of the animal, containing rhodamine B, were found immediately adjacent to the carcass. Post-mortem analysis revealed that the liver of the animal was unusually large and discoloured, consistent with toxic poisoning. Nine days after baiting the remains of a single male radio-collared cat were found hanging from a dead eucalypt tree. Much of the carcass, including the top half of the skull and the main body trunk had been stripped of flesh by a large raptor (likely a wedge-tailed eagle, *Aquila audax*), making full post-mortem impossible. The lower jaw of the cat, however, was stained bright pink with rhodamine B, indicating that the most probable cause of death was poisoning rather than predation. The remaining third cat (a large male) could not be retrapped, but its radio-transmitter was still functioning normally 30 days after baiting and it is assumed to have survived the baiting event and moved outside of the study area.

Three radio-collared quolls remained at large in the study area following the post-baiting trapping period. A single female quoll (553D), recorded entirely in the southern end of the study area well away from the baiting zone (see below also), was last located in mid-July 2005, some 48 days after baiting. Targeted trapping for the female in the vicinity of the last positive location failed. On the same day, the transmitter of a single male quoll (3ADD) was also detected and found to be operating normally (on the basis of pulse rate). However, no location for this animal could be obtained because the signal was too weak and intermittent, likely indicating antenna damage. Subsequent attempts to detect the same animal were made but with no success. The final radio-collared animal, also a male (1313), was last located in early August 2005, some 62 days after baiting. Attempts to retrap this animal at the last known location also failed.

Post-baiting trapping and rhodamine assays of quoll whiskers

Systematic trapping in July 2005 resulted in the capture of 18 quolls (6 female, 12 male) from 677 trap-nights. Of the 15 spotted-tailed quolls trapped before baiting that were still alive, 12 were retrapped. An additional six male quolls not previously trapped were caught during this period.

Of the 18 animals that were live-trapped and had whisker samples taken after baiting, six tested positive for rhodamine B and 12 tested negative (Table 1). The single dead male quoll, which was negative for 1080, was also negative for rhodamine B.

The number of individual whiskers marked in positive animals ranged from 2 to 7 out of 8, with most (n = 4) only having 2 whiskers marked. Single rhodamine B bands were seen in whiskers from five of the six positive animals, with two bands in whiskers from the remaining animal. Most of the rhodamine B bands viewed had weak fluorescence only compared with samples obtained from animals in non-toxic trials conducted at the same study site (Claridge *et al*. 2006).

Location of quolls in relation to baiting transect

The number of locality fixes for female quolls ranged from 13 to 25, and from 1 to 16 for males (Table 1). Of the six quolls that tested positive for rhodamine B, four were radio-collared. Three had ranges overlapping the baiting transect (22AB, FEF7 and 46CO), while the fourth (4339) occurred mostly adjacent to baits (Fig. 1). Two males that tested positive were known only from one location each, having been trapped adjacent to the transect only after baiting. Of the 13 animals that tested negative for rhodamine B, only two (E422 and 2017) were located away from the baiting zone and these were animals that were caught only after baiting (Fig. 2). Of the remaining 11 individuals, nine were radio-collared and two were captured only after baiting. Six of the nine radio-collared animals (1CA5, 1AE9, E2AF, 16A1, 07C9 and 3C3E) had ranges overlapping baits, while the remaining three radio-collared animals (5496, B4CA and 4518) had ranges adjacent to baits. The animals that were not radio-collared and tested negative to rhodamine B were trapped close to the baiting transect (3000 and 04E2). For the three remaining radio-collared quolls that were not sampled after baiting, two (553D and 3ADD) were located well away from baits (Fig. 3). The remaining unsampled radio-collared animal, an adult male (1313), was located near the baiting transect.

1080 degradation rate

The amount of 1080 in baits decreased at an approximately linear rate according to the equation:

$$y = 4.0332e^{-0.033x},$$

where y is the content in milligrams after x days (r^2 = 0.9808). The mean value at Day 0 was 3.79 ± 1.87 mg, less than the nominal dose of 6.0 mg expected from mixing the 1080 powder in solution as per label instructions. There was no apparent relationship between rainfall, temperature and 1080 content during the field trial (Fig. 4).

Discussion

Observed impact

The results of this study indicate that no radio-collared spotted-tailed quolls were killed by 1080 baits following their deployment, and that the number of quolls live-captured on-site was equivalent before and after baiting. Given this, we conclude that the baiting event had no short-term population-level impact. This finding contrasts with observations made by Belcher (2003), which identified local declines in populations of quolls against a background of various forms of 1080 baiting. Critically, in this latter study, only one dead quoll was found with 1080 in its tissues so the fate of other individuals in these populations can only be speculated upon. However, our findings are broadly consistent with those obtained by Körtner and

Table 1. Summary of rhodamine B assay results for spotted-tailed quolls (*Dasyurus maculatus*) trapped during this study

Status	PIT No.	Sex	Weight at first capture (g)	No. of locations	First location	Last location	Days
Rhodamine B +ve	4339	M	2800	8	4.v.2005	21.vii.2005	79
	FEF7[A]	M	2850	9	5.v.2005	19.vii.2005	76
	46CO	F	1600	20	6.v.2005	8.vii.2005	64
	22AB	M	3450	5	12.v.2005	13.vii.2005	63
	A29A	M	2200	1	5.vii.2005	5.vii.2005	1
	07B9	M	2250	1	7.vii.2005	7.vii.2005	1
Rhodamine B –ve	1AE9	M	1750	3	3.v.2005	20.vii.2005	79
	3C3E	M	1800	16	3.v.2005	20.vii.2005	79
	B4CA	F	1800	22	3.v.2005	22.vii.2005	81
	07C9	F	1200	25	5.v.2005	14.vii.2005	71
	5496	F	1650	13	6.v.2005	15.vii.2005	71
	ICA5	F	1950	16	11.v.2005	19.vii.2005	70
	4518	M	3000	5	11.v.2005	27.v.2005	17
	E2AF	F	1950	21	19.v.2005	2.vii.2005	76
	16A1	M	3700	2	27.v.2005	5.vii.2005	40
	3000	M	4150	3	6.vii.2005	8.vii.2005	3
	04E2	M	1800	1	6.vii.2005	6.vii.2005	1
	E422	M	1975	5	12.vii.2005	22.vii.2005	11
	2017	M	2100	1	20.vii.2005	20.vii.2005	1
Not sampled	553D	F	2300	15	3.v.2005	19.vii.2005	78
	1313	M	1800	4	11.v.2005	2.viii.2005	84
	3ADD[B]	M	3900	2	12.v.2005	18.v.2005	7

[A] Double bands were seen in the whiskers of this individual. All other animals marked for rhodamine B had single bands.
[B]Radio signal detected, operating normally on 19.vii.2005. No location was obtained but individual was in lower reaches of Bark Camp Creek.

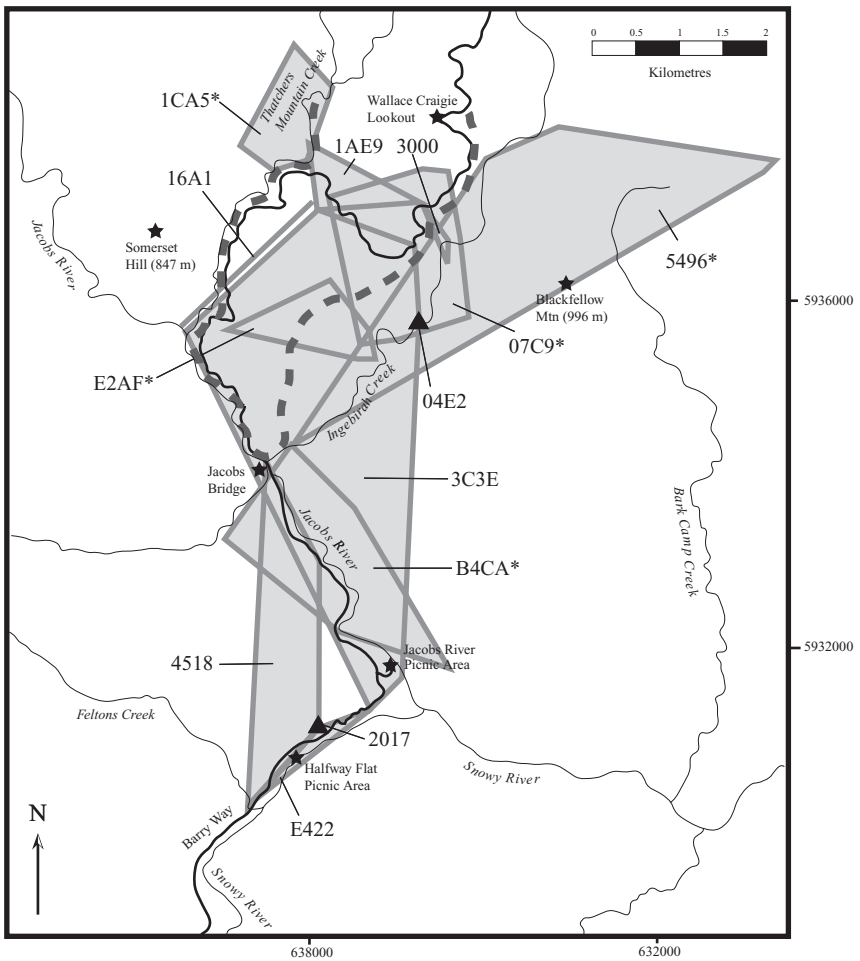

Fig. 2. Minimum convex polygons for the 13 quolls that tested negative for rhodamine B. Female quolls are denoted by an asterisk. Transects where baits were deployed are shown as dashed lines. Animals known only from one location (04E2 and 2017) are shown as small triangles. The animal known only from two locations (16A1) is shown as a solid line. Grid references are based on Australian Geodetic Datum 66 (Zone 55).

Watson (2005), who proactively monitored the fate of a radio-collared population of spotted-tailed quolls following aerial baiting on the New England Tablelands in northern New South Wales. Following bait deployment there, only one quoll death could be attributed to 1080 poisoning while several animals had been exposed to baits but survived. In our study, 6 of 19 quolls sampled (32%) tested positive for rhodamine B, reaffirming the result of Körtner and Watson (2005) that spotted-tailed quolls can be exposed to baits without being killed. In south-eastern Queensland, surface and buried-baiting control operations for wild dogs have also been shown to have a low-level impact on spotted-tailed quolls. In a series of experiments, only two quoll deaths could be attributed to 1080 poisoning from over 70 radio-collared individuals (P. Cremasco, pers. comm. 2005). However, since a biomarker was not used in baits, the level of exposure of animals could not be determined.

In comparison to quolls, baits apparently killed two of three radio-collared cats in our study. This finding is not surprising since cats are acutely sensitive to 1080 (McIlroy 1981*b*; Eason and Frampton 1991), although some studies have reported them to be bait shy (e.g. Risbey *et al*. 1997). Despite the small sample size the result illustrates one of the potential benefits of aerial baiting to spotted-tailed quolls. Cats very likely compete with the species for prey, including small birds, rodents and reptiles, which have been found to be common to the diet of both species (Belcher 1995). It has also been speculated that cats might compete for den sites with quolls (Jones *et al*. 2003).

Mechanisms for survival

It is difficult to establish why quolls are mostly able to survive exposure to baits since, upon deployment, the baits theoretically contained enough 1080 to have killed at least a proportion of the quolls (see McIlroy 1981*b*; Murray and Poore 2004). Unfortunately, the methods used here and in Körtner and Watson (2005) provide no information as to how much bait was consumed nor when animals encountered baits. This is critical since either factor may influence whether an animal has ingested a lethal or sublethal dose of 1080. While rhodamine B is a reliable and effective systemic marker in a range of different mammal species, including quolls (e.g. Fisher 1998; Fisher *et al*. 1999; Spurr 2002; Murray and Poore 2004; Claridge *et al*. 2006; present study), its use is limited to identifying exposure to baits. Rhodamine B banding in quoll whiskers provides no quantitative information about how much bait has been consumed since it is unknown how much of the dye needs to be ingested and then metabolised to produce marking. However, much of the banding that we saw in whisker samples was less striking than that seen in whisker samples taken from quolls during non-toxic baiting trials conducted at the same study site

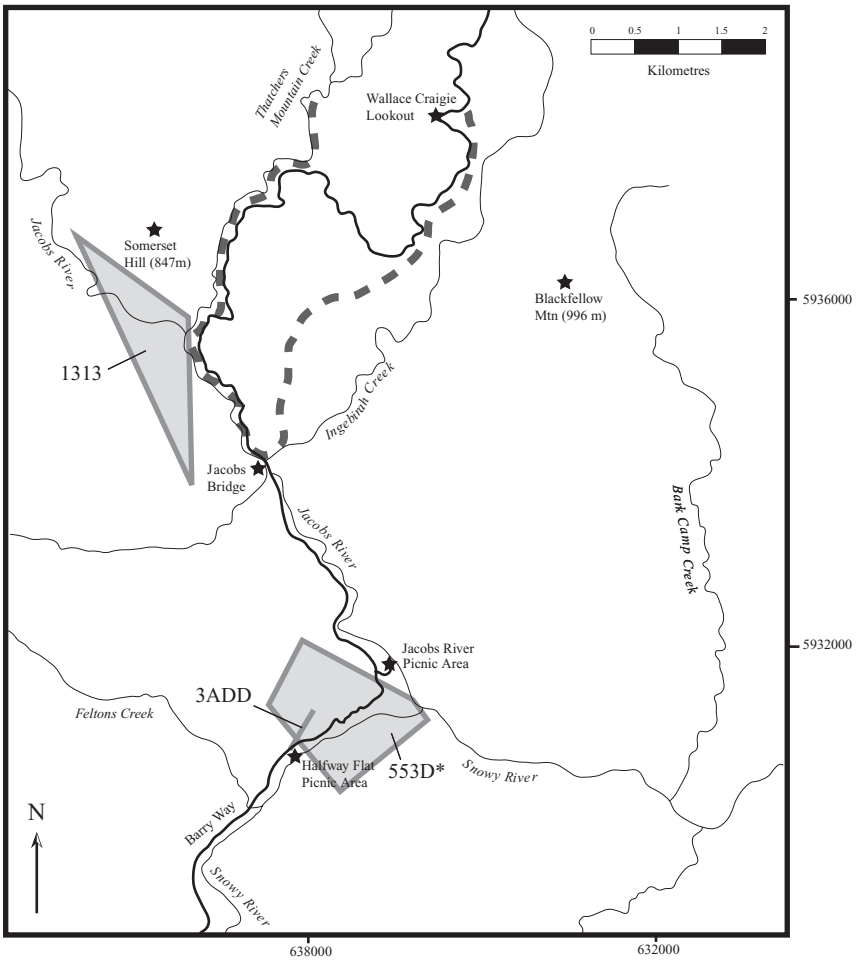

Fig. 3. Minimum convex polygons for the three quolls not assayed for rhodamine B. Female quoll is denoted by an asterisk. Transects where baits were deployed are shown as dashed lines. The animal known only from two locations (3ADD) is shown as a solid line. Grid references are based on Australian Geodetic Datum 66 (Zone 55).

(Claridge *et al*. 2006). Similar observations of faint marking in quoll whiskers were made by Körtner and Watson (2005), who used similarly prepared baits. This suggests that animals exposed to baits containing 1080 and rhodamine B may have only partially consumed baits, or ate lesser amounts of bait than those animals in the non-toxic trials.

Although 1080 is often reported as being odourless and tasteless, some authors have speculated that animals are capable of detecting it through either smell or taste, or both senses simultaenously (see Eason and Wickstrom 2001). In New Zealand, Morgan (1982) found that some wild possums (*Trichosurus vulpecula*) refused to eat a lethal quantity of toxic bait, or to eat any toxic bait at all, compared to animals exposed to non-toxic baits. He attributed this response to the ability of at least some possums to taste the 1080. In later laboratory trials, possums were observed to use a combination of smell then taste before rejecting toxic baits (Morgan 1990). Sinclair and Bird (1984) observed that laboratory-held fat-tailed dunnarts (*Sminthopsis crassicaudata*) either reduced food intake upon repeat exposure to 1080 baits, or refused to eat anything. This response was not an artefact of the bait type used since animals fed non-toxic baits continued to feed freely. In this case, the authors speculated that the response of the dunnarts was either due to a suppression of appetite caused by previous sublethal dosing, or because the animals could detect the 1080. Calver *et al*. (1989) similarly reported that rodents (*Mus musculus*, *Pseudomys hermannsbergensis*, *Rattus norvegicus* and *Zyzomys argurus*) preconditioned to eat non-toxic baits reduced intake when toxic baits were introduced to the diet. Whether quolls would display reduced feeding behaviour under the same circumstances remains to be tested.

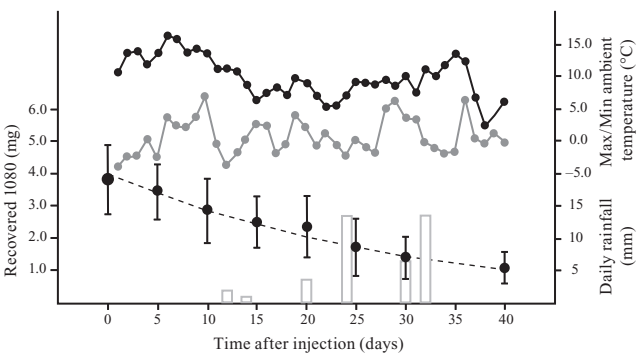

Fig. 4. Deterioration of 1080 with time since injection in meat baits used in the aerial baiting trial. Histogram columns denote daily rainfall. Grey dots denote minimum daily temperature. Small black dots denote maximum daily temperature. Large black dots denote mean amount of recovered 1080 for each time interval.

Other behavioural responses of quolls to ingestion of toxic baits may also account for the weak rhodamine B marking in whiskers. Vomiting is one of the first symptoms observed in animals after ingestion of 1080 (McIlroy 1981*a*). Sinclair and Bird (1984) observed that fat-tailed dunnarts routinely regurgitated part or all of toxic meat baits they were fed in captivity. In our study, pieces of regurgitated bait were found at a single location in the field, although the species that was responsible for this was unknown. If, however, quolls regurgitate meat baits in response to the initial stages of 1080 poisoning, then the amount of rhodamine B ingested and metabolised may decrease enough to produce only faint marking in whiskers. It is also possible that some animals may not get marked at all, despite encountering baits and ingesting at least a part of them. We therefore consider that the number of animals recorded as positive for rhodamine B in this study is a minimum estimate.

Diminished bait toxicity after deployment may also partially account for the survival of exposed individuals in our trial. In an operational situation, the amount of 1080 retained in baits declines after preparation due to a combination of factors, including seepage, defluorination by microorganisms or leaching by dew or rainfall (McIlroy *et al*. 1988; Fleming and Parker 1991). In the present case, seepage of 1080 was minimised by drying of meat baits before injection. However, in the field baits were potentially exposed to fluctuating moisture levels with some overnight frost and rainfall events following deployment.

Survival following bait consumption might also be explained if the efficiency of 1080 absorption in an animal gut decreases if the 1080 is in a bait matrix. Methods used to determine 1080 levels in baits usually result in incomplete extraction after dosing (McIlroy 1986; McIlroy *et al*. 1988; Fleming and Parker 1991; Körtner and Watson 2005; Fig. 4). This may be partially caused by some of the 1080 binding to proteins within the meat itself (see Fleming and Parker 1991). Whether this renders that portion of it 'unavailable' to an animal ingesting bait is unknown. However, Sinclair and Bird (1984) observed that fat-tailed dunnarts mostly survived the consumption of meat baits containing enough 1080 to have killed them. In contrast, most animals died when orally dosed with the same amount of 1080.

Previous exposure to baiting

The consistency in results between our study and that of Körtner and Watson (2005) suggests that previous history of aerial baiting may not influence the level of impact on quolls. In the latter study, aerial baiting had been carried out annually for over 30 years, enough time for selection for bait-shy individuals or bait aversion to have occurred. Learned bait aversions have occurred in wild possum populations in New Zealand subject to repeated baiting, making their ongoing control difficult (Morgan *et al*. 1996; O'Connor and Matthews 1999; Morgan 2004). There, individual animals are sufficiently long-lived to have encountered baits previously. In quoll populations, however, there is high annual turnover and individuals are shorter-lived than possums (Jones *et al*. 2001; Körtner *et al*. 2004), reducing the capacity for learned bait aversions when baiting is being conducted only once per year. At our study site, quolls would not have had previous opportunity to encounter toxic baits since aerial baiting had not been conducted there for over seven years (McIlroy 1999). Instead, it appears that a certain proportion of the population either do not encounter baits, or are not inclined to eat them if available, while those that do survive.

Parallels with other forms of canid control and future studies

The findings of this study and that reported by Körtner and Watson (2005) demonstrate broad parallels with the issue of 1080 baiting for control of red foxes. Studies by Belcher (1998) and Glen and Dickman (2003*a*, 2003*b*) have demonstrated that quolls are highly capable of detecting non-toxic Foxoff® baits presented in ways that simulate routine fox-control operations. The assumption was then made that baiting for foxes was highly risky to quolls. However, trials using radio-collared quolls demonstrated that individuals mostly discarded Foxoff® baits after locating them and mortality was rare (Körtner *et al*. 2003).

Despite the results presented here, there is a need for longer-term monitoring of spotted-tailed quolls in areas subject to aerial baiting. Such studies may be logistically difficult to carry out since aerial baiting is typically conducted in inaccessible areas. If possible, the population attributes of quolls should be measured against that of quolls in similar sites not subject to baiting. Similarly, our study provides no guidance in relation to the effect on spotted-tailed quolls when baiting is conducted at other times of the year. In spring, for example, adult female quolls may either have advanced pouch young or young may be independent (Jones *et al*. 2001). Under such energetic demand the foraging response of lactating females in the presence of baits may differ, as might their potential susceptibility. Juvenile recruitment into a local population may be important given apparent high turnover rates of adults reported elsewhere (Körtner *et al*. 2004). If this is impaired, viability of that population may be decreased. Nevertheless, the level of impact will again depend on the proportion of animals exposed to baiting versus those that are not.

Finally, there needs to be a thorough assessment of the effectiveness of aerial baiting in reducing the number of wild dogs in problem areas in south-eastern mainland Australia, using techniques similar to those used here for quolls. Although aerial baiting has been shown to be efficacious in more arid environments (e.g. Thomson 1986), its usefulness in mesic environments typical of the region in which we worked remains to be tested. The limited relevant research so far conducted places doubt on its utility as a control measure against the target species (McIlroy *et al*. 1986).

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