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Aerial baiting and wild dog mortality in south-eastern Australia

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Abstract

Context. Wild dogs, including dingoes and dingo cross-breeds, are vertebrate pests when they cause financial losses and emotional costs by harming livestock or pets, threaten human safety or endanger native fauna. Tools for lethal management of these animals currently include aerial baiting with poisoned baits. In New South Wales (NSW), Australia, aerial baiting was previously permitted at a rate of 40 baits km^{-1} but a maximum rate of 10 baits km^{-1} was subsequently prescribed by the Australian Pesticides and Veterinary Medicines Authority. The efficacy of these baiting rates has not been quantified in eastern Australia, undermining the value of the policy and rendering adaptive management efforts difficult, at best.

Aim. To quantify the mortality rate of wild dogs exposed to aerial baiting at historic and currently approved rates, i.e. 40 baits per kilometre and 10 baits per kilometre, respectively.

Methods. Wild dog mortality rates were measured at sites in mesic north-eastern NSW, where aerial baiting was applied to control wild dogs and contrasted with sites and individuals where no baiting was undertaken. In total, 132 wild dogs were trapped and fitted with GPS-VHF telemetry collars before annual aerial baiting programs. Collars were used to locate animals after aerial baiting and to determine the fates of individuals.

Key results. 90.6% of collared wild dogs exposed to aerial baiting at 40 baits km^{-1} died, whereas only 55.3% of those exposed to 10 baits km^{-1} died (Welsh's $t = 4.478$, $P = 0.004$, $v = 6.95$). All wild dogs that were not exposed to toxic baits survived during the same periods.

Conclusion. Managers using aerial baiting to maximise wild dog mortality in mesic south-eastern Australia should use 40 baits km^{-1} rather than 10 baits km^{-1}.

Implications. Wild dog population reduction for mitigation of livestock and faunal predation requires the application of efficacious control. The currently prescribed maximum aerial baiting rate of 10 baits km^{-1} is inadequate for controlling wild dog populations in mesic forest environments in NSW.

Additional keywords: *Canis familiaris*, Compound 1080, dingo, invasive species, pest control.

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Introduction

Until recently, the *Local Lands Services Act 2013* (and previously the *Rural Lands Protection Act 1998*) mandated control of wild dogs (*Canis familiaris*) on all lands in the State of New South Wales, Australia. This is primarily because wild dogs cause losses to agricultural production where they co-occur with livestock, particularly to sheep, goats and calves (Fleming *et al.* 2001; Allen and Fleming 2004; Fleming *et al.* 2014). Current NSW legislation (*Biosecurity Act 2015*) imposes a 'general biosecurity duty', to ensure the biosecurity risk posed by wild dogs is 'prevented, eliminated or minimised'.

Under these successive legislative frameworks, lethal control of wild dogs for agricultural and environmental protection is sought via several approved and regulated techniques, including aerial baiting, ground baiting, foot-hold trapping and shooting (Fleming *et al.* 2014). In the Eastern Division of NSW, especially in rugged areas located on or adjacent to the Great Dividing Range, aerial baiting is the dominant strategic lethal control option for managing wild dogs. Variants of the technique have been evaluated in Western Australia (Thomson 1986) and central Australia (Newsome *et al.* 1972), and, while ostensibly expensive, aerial baiting is regarded as a cost-efficient means of reducing wild dog attacks on livestock (Thompson and Fleming 1991). Other, seemingly non-lethal control methods, such as barrier fencing (McKnight 1969) and the use of guardian animals (van Bommel 2010), are also deployed to mitigate the negative impacts of wild dogs.

Aerial baiting for strategic lethal control of wild dogs in eastern Australia involves the distribution of meat baits from helicopters flown along pre-approved transects (for details of such operations, see Fleming *et al.* 1996). Managers aim to place baits as accurately as possible (within 10 m of the targeted line; Thompson *et al.* 1990) in locations selected to maximise the opportunity for wild dogs to find and consume them. A concurrent aim of these programs is to minimise uptake by non-target animals, primarily to minimise bait removal (Claridge *et al.* 2006) rather than because of threats to non-target animals' welfare. Despite early concerns based on captive LD_{50} trials of sodium fluoroacetate (Compound 1080, hereafter referred to as 1080; McIlroy 1981), field studies have consistently found no significant risk to south-eastern Australia's endemic spotted-tailed quoll (*Dasyurus maculatus maculatus*) populations from poisoned baiting programs using the chemical (Körtner *et al.* 2003; Körtner and Watson 2005; Claridge and Mills 2007; Körtner 2007), which likely benefit their populations (Fleming and Ballard 2018).

Aerial baiting for lethal control of wild dogs in north-eastern NSW was first trialled in by the Barnard River Dingo Destruction Association, aided by CSIRO, in 1957–58 (unpublished records of the Barnard River Wild Dog Control Association – B. Moore, pers. comm., 2010; F. Fenner, unpublished internal report to CSIRO, 1958). In the early 1960s, managers began aerial deployment of matchbox-sized meat baits rolled in powdered 1080 (Korn and Livanos 1986). Since then, aerial baiting rates have been quantified on multiple occasions, ranging between 20 and 120 baits of various size classes, per km, with an overall average of 35 baits per km (D. Robinson and P. Fleming, unpublished internal report to NSW Department of Agriculture, July 1984), but baiting efficacy was not measured.

A NSW review (G. Saunders, J. Giles, and T. Korn, *Review into wild dog control in eastern NSW*, NSW Department of Agriculture, unpublished report, c. 1985) resulted in only helicopters (rather than fixed-wing aircraft) being permitted for aerial baiting of wild dogs in the Eastern Division of NSW. At the same time, the maximum permitted aerial baiting rate was set at 40 baits km^{-1} for all lands. However, the NSW National Parks and Wildlife Service adopted a policy of using a lower maximum rate of 10 baits km^{-1} on their estate.

Following its national review of 1080 (Australian Pesticides and Veterinary Medicines Authority (APVMA) 2008), the APVMA determined that the 'higher rates of wild dog baiting (up to 40 baits per km) likely exceed the minimum effective rate, and 4 to 10 baits per km appear to work effectively in controlling wild dogs.' Although this was untested for efficacy in any environment, the APVMA set a new maximum allowable linear baiting rate for aerial application of 1080-injected meat baits for wild dog control at 10 baits km^{-1}. Thus, we investigated the mortality rates of wild dogs exposed to two aerial baiting rates and contrasted that with the mortality rate of wild dogs that were not exposed to aerial baiting. The two baiting rates represented the maximum rate set after the 2008 review (10 baits km^{-1}) and the previously used maximum rate (40 baits km^{-1}). Reducing local populations of annual breeders in the long term requires that annual population reductions are sufficient to stop population growth. Conservatively, a proportionate annual population reduction of 0.75 is required to stop the population growth of wild dogs (range 0.13–0.75; Hone *et al.* 2010). Therefore, 75% mortality of the target population was taken to represent efficacious control.

Methods

Experimental design elements and limitations

Ideal, total randomisation of treatments to sites was neither logistically possible nor feasible, because of: extant permit and policy constraints on where baits could be applied at 40 km^{-1}; the legal obligations of landholders to control wild dogs; and animal welfare responsibilities of livestock owners and their understandable reluctance to expose their animals to attack by uncontrolled wild dogs.

Instead, we used a quasi-experimental design (see Hone 2007 and Allen *et al.* 2013), where the treatments (0, 10 and 40 baits km^{-1}) were imposed non-randomly but the movements of wild dogs in relation to the treatments were not pre-allocated or known. Such a design provides only intermediate strength of inference (Hone 2007) but is the best possible, given the identified constraints. The key limitation here is that the results should not be generalised beyond similar temperate rangeland environments to semiarid or arid rangelands.

The experimental unit was the individual wild dog. *A priori* simulations using mortalities recorded in previous research (Thomson 1986; Fleming *et al.* 1996, 2001) suggested the trial would require a minimum sample size of 90 collared dogs, with 30 in each treatment. Increased replication was achieved by collaring additional wild dogs. It was not possible to capture, collar and track this number of animals in a single season, so data were collected over multiple years.

Efficacy of aerial baiting rates for wild dog control

Efficacy was evaluated using mortality of collared wild dogs. Exposure to aerial baiting was defined as an individual collared wild dog crossing one or more baited transects within a fortnight of the local aerial baiting program. This allowed a direct comparison of mortality rate for exposed animals at the two baiting rates. The fortnight-long exposure period ensured that baits were still toxic when encountered, which accommodated the natural decline in toxicity of 1080 that occurs in meat baits through biodegradation (APVMA 2008; Gentle and Cother 2014), and the usual rapid removal of baits (85–100% of baits taken by dogs or foxes by Day 5; Fleming 1996).

Individual dogs were considered to be unexposed if they did not cross or walk along a baited transect during the 2-week period or, for those purposely collared where aerial baiting did not occur (to guarantee a nil-treatment population), for the

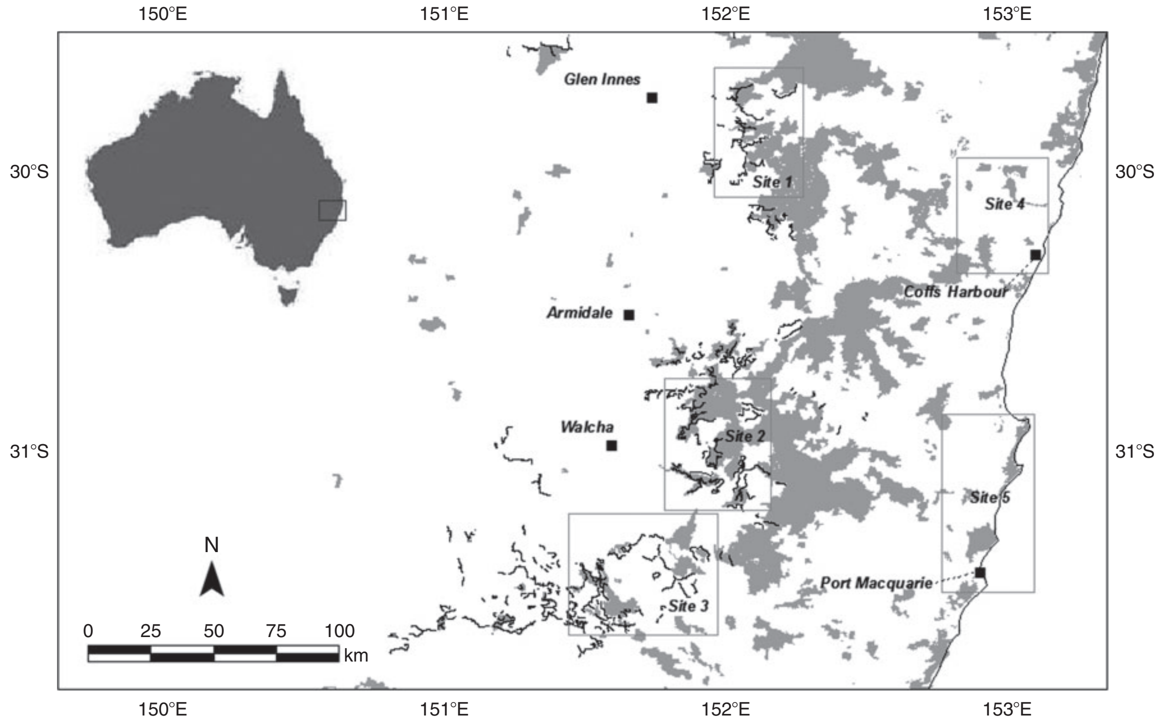

Fig. 1. Field sites where GPS-collared wild dogs were tracked in north-east New South Wales, Australia. Sites 1 to 3 were aerially baited. Sites 4 and 5 were not aerially baited. Aerial-baiting transects undertaken by land managers are shown as solid black lines. NSW National Parks and Wildlife Service estate (light grey shading) was baited at 10 baits km^{-1}. Aerial baiting on other tenures occurred at 40 baits km^{-1}.

period from the date of the first aerial baiting until 2 weeks after the last baiting at the sites with collared dogs. Mortality rates of wild dogs exposed to aerial baiting were contrasted with other collared wild dogs that were not exposed to aerial baiting during the same periods.

Experimental animals

Adult wild dogs were captured and released, at point of capture, in pre-selected study areas (Fig. 1) using approved foothold traps. These were Victor Soft-catch #3 traps (Woodstream Corporation, Lititz, Pennsylvania) with a single pair of jaw-springs, customised with after-market, in-line springs and heavy-duty swivels to further reduce injury risk. Trapping to obtain sufficient wild dogs before annual aerial baiting programs required agreement from neighbouring landholders. Each year, we began trapping as early as November and stopped trapping at least 2 weeks before planned commencement of aerial baiting (usually in April–May) to facilitate a return to 'normal' movement behaviour before any exposure to baiting. Most wild dogs were captured in 2011, 2012 and 2013, but data from GPS collars and aerial baiting transects enabled inclusion of wild dogs previously captured and collared for related work in 2007–10. To ensure adequate sample size for unexposed wild dogs, we also targeted trapping in sites where no aerial baiting was to be conducted.

Captured wild dogs were fitted with Sirtrack GPS-VHF collars (Lotek, Hastings, New Zealand) that were also satellite-system (Argos) enabled. Collars weighed 420 g, i.e. $\leq$4% of each collared dog's mass. A microchip and small, individually coded button-style ear tag were fitted to each wild dog. All collars were fitted with external release mechanisms programmed to activate several months after aerial baiting, and featured a mortality switch to ensure VHF signals changed from 40 to 80 pulses per minute when collars became stationary for >24 h, post-deployment.

Collars were programmed to store GPS locations on-board (either hourly or at 30-min intervals when satellite positions were optimal), and to upload a snapshot of recent data via the Argos satellite network each week. Successfully received Argos data enabled identification of dogs that had likely died, or released collars, from lack of movement between uploads. The most recent Argos locations from each collar were used to direct searches for VHF signals, which are line-of-sight and, in rugged conditions, commonly require close proximity (<1 km) for ground-based detection.

Aerial baiting and collar recovery procedures

Aerial baiting occurred at sites in north-eastern NSW in late April and May each year from 2008–13 along approved, pre-determined, mapped transects (Fig. 1). Sites included public and private lands, reflecting the across-tenure nature of wild dog management programs in NSW. The local area includes tableland plateau, gorges and lowland river flats, all of which are connected by spurs and ridges that are traversable by wild dogs. In accordance with NSW Government policy at the time, aerial baiting on NSW National Park estate was undertaken at 10 baits km^{-1},

Table 1. Sample sizes of wild dogs in the nil-treatment population (i.e. not exposed to aerial baits) and those exposed to aerial baiting at two currently permitted rates, 10 and 40 baits km^{-1}

'Lost' represents collars that were active at the time of baiting program but could not be retrieved because of equipment failure or inaccessibility of terrain

Nil-treatment	10 baits km^{-1}	40 baits km^{-1}	Lost	Total wild dogs
36	38	32	11	117

but baiting on private land and State Forest was undertaken at the specially permitted rate of 40 baits km^{-1}. Local managers tended to focus aerial baiting transects on travel paths that wild dogs have been observed to use, such as historic bridle trails along prominent features. A maximum permitted bait density of 25 per 100 ha for 40 baits km^{-1} areas and 16 baits per 100 ha for 10 baits km^{-1} areas effectively limited the proximity of adjacent baiting lines to generally no closer than 0.5 km apart.

Standard baits were prepared from boneless red meat, commonly horse or beef, cut into fist-sized chunks, ~250 g in size. One of the authors (GB) regularly attended bait preparation events, and used electronic scales to confirm baits were the nominal size. Each bait was injected by an Authorised Control Officer with 0.2 mL of standard 1080 solution, which delivered 6 mg of active ingredient, according to requirements of the Pest Control Order for control of wild dogs (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/602039/Wild-Dog-PCO.pdf, accessed 28 August 2018) and associated relevant permits.

Standard 1080 solution is dyed dark blue to assist operators, and this dye persists in the stomach until baits are completely digested. The requisite number of baits for each baiting transect ($n \approx 120$ transects across three sites) was loaded into the helicopter; then, as the aircraft flew along the mapped transects, an experienced navigator used an on-board GPS navigation system to accurately start and finish baiting, maintain placement accuracy and simultaneously record the flight path and baited transects.

Before and after aerial baiting programs were conducted, weekly positional data uploaded from collared wild dogs to Argos satellites were examined. Wild dogs were also tracked on the ground using collars' VHF signals. When locations did not change between weekly Argos updates, or when a VHF transmitter was in mortality mode, on-ground searches were made to retrieve collars and inspect carcasses for baits or signs of the blue dye in the gastro-intestinal tract. To determine whether or not individual animals had been exposed to aerial baiting, and at which rate, positional data from the fortnight following baiting were downloaded from GPS collars and reviewed against bait distribution flight logs.

Sample sizes

In total, 132 wild dogs were trapped and fitted with GPS-VHF collars between 2007 and 2013. Of these, some ($n = 15$) were not available for inclusion in the aerial bait rate trials because remote tracking did not coincide with baiting periods or because they died from natural causes, other management efforts or misadventure before the aerial baiting programs. Some wild dogs that were potentially exposed to baiting were actually unexposed because they were not in a baited area while baits were available (e.g. one had moved 90 km away). Some collars could not be recovered (Table 1), either due to equipment malfunctions or the interaction of stochastic events and extreme topographical conditions. For example, flash flooding in steep gorge country claimed some collars (although three submerged collars were retrieved from a river bed, waterfall and deep pool). Consequently, a sample of 102 wild dogs was potentially exposed to the annual aerial baiting programs (Sites 1, 2 and 3; Fig. 1). A further 15 wild dogs were deliberately trapped and released at sites where they would be unexposed (Site 4 and 5; Fig. 1) to secure a useful nil-treatment sample.

Subsequently, 117 wild dogs were available for inclusion in the analysis, and the minimum required sample was exceeded for all baiting rates (i.e. >30 individuals). In 2012, we trapped and fitted collars to 90% of wild dogs ($n = 29$) that had been individually identified from images photographed with camera traps set along trapping transects before baiting (Site 1; Fig. 1), indicating that our captured sample was likely to be representative of the populations of wild dogs in the study sites.

Every effort was made to recover collars, including re-trapping surviving, collared animals. Even so, 11 collars could not be recovered because of release failure, VHF signal failure, Argos upload failure, flash flooding or dispersal of the dog into inaccessible terrain. These 11 dogs were excluded from further analyses because we did not know about their exposure or fate.

Statistical methods for evaluating efficacy

We contrasted the differences in mortality rates for wild dogs exposed to each aerial baiting rate with those in the nil-treatment sample. Because the variance across samples was likely heterogeneous, Welch's *t*-tests (Welch 1947), which use un-pooled variance and degrees of freedom calculated with the Welch–Satterthwaite equation, were used to contrast mortality rates from the two aerial baiting treatments and the un-baited treatment. The significance level was set according to convention at 0.05.

Results

Aerial baiting rate efficacy

The efficacy of aerial baiting at 40 baits per km^{-1} was highly significantly greater than that achieved with 10 baits km^{-1} (Table 2).

Only the 40 baits km^{-1} rate killed more than the requisite 75% mortality. In contrast, the highest mortality recorded for the lower baiting rate was 67% of the collared dogs (Tables 2, 3).

The mortality rate of wild dogs did not differ significantly among years (Table 3) within the 10 baits km^{-1} treatment ($\chi^2 = 2.75$, d.f. = 4, NS), nor among those wild dogs exposed to 40 baits km^{-1} ($\chi^2 = 1.59$, d.f. = 3, NS).

Table 2. Overall mortality rates (%) and mean difference in proportional mortality from nil-treatment (*D*) for collared wild dogs in north-eastern NSW exposed to aerial baiting at two currently permitted rates, 10 and 40 baits km^{-1}, during 2007–13

ν = degrees of freedom approximation

	Nil-treatment (0 baits)	10 baits km^{-1}	40 baits km^{-1}	Welsh's *t*	*P*, ν
Overall mortality (%)	0	55.26	90.63	–	–
Mean *D* (95% CI)	–	0.52 (0.18)	0.90 (0.17)	4.478	0.004, 6.95

Table 3. Mortality of collared wild dogs in north-eastern NSW exposed to aerial baiting at two currently permitted rates, 10 and 40 baits km^{-1}, by cohort

'Lost' represents collars were active at the time of baiting program but could not be retrieved because of equipment failure or inaccessibility of terrain

Cohort	*n*	Nil-treatment		10 km^{-1}		40 km^{-1}		Lost
	Dogs	Exposed	Died	Exposed	Died	Exposed	Died	
Pre-2010	23	5	0	7	3 (43%)	4	4 (100%)	7
2010	16	4	0	12	8 (67%)	0	0	0
2011	32	11	0	6	2 (33%)	12	11 (92%)	3
2012	26	9	0	4	2 (50%)	12	11 (92%)	1
2013	20	7	0	9	6 (67%)	4	3 (75%)	0
Total	117	36	0	38	21 (55%)	32	29 (91%)	11

All dogs that were not exposed to baiting ($n = 36$) survived during the assessment periods (Table 3).

Discussion

Managers commonly use lethal control techniques, including aerial baiting, to mitigate the negative impacts of wild dog predation on livestock and wildlife (Fleming *et al.* 2014). When managers seek ongoing reduction of a wild dog population they must overcome an expected annual population growth of 0.13 to 0.75 (Hone *et al.* 2010). Conservatively, this equates to a requirement of >75% reduction of the wild dog population to achieve efficacious control in highly productive mesic environments.

Both of our aerial baiting treatments caused wild dog mortality but the two rates were not equally efficacious. The higher rate of 40 baits km^{-1} was more reliable and more efficacious than that of 10 baits km^{-1}, with the former achieving a proportional mortality >0.75 each year and achieving overall efficacy >0.9 (Table 3). Aerial baiting at 10 baits km^{-1} never achieved the conservative proportionate reduction necessary to limit wild dog population growth. The mortality rate associated with aerial baiting at 10 baits km^{-1} should not be considered sufficient to necessarily achieve wild dog population 'control' (see Allen and Leung 2014; Johnson *et al.* 2014). Rather, a better term for this outcome and similarly low population reductions (e.g. Allen and Leung 2014; Campbell *et al.* 2019) might be population 'disturbance'.

Bait availability, as influenced by competition for baits, both among wild dogs and from other fauna, may be a key reason for the lower rate being less efficacious. Some collared dogs, from 10 and 40 baits km^{-1} sites, were recovered with multiple baits in their stomach. Foxes (*Vulpes vulpes*), feral pigs (*Sus scrofa*) and birds, particularly ravens (Corvidae), can consume up to 100% of aerially deployed or surface-laid meat baits (Allen *et al.* 1989; Fleming *et al.* 2000). Removal of a large proportion of baits from management programs has obvious and significant implications on likely efficacy. For managers to maximise the efficacy of lethal control efforts, baiting rates, overall bait quantity and transect routes must account for probable consumption of baits not only by target animals, but by other affected vertebrate pests, e.g. foxes and cats (*Felis catus*), and unaffected fauna too, such as ravens (McIlroy 1984), spotted-tailed quolls (Claridge and Mills 2007; Körtner 2007) and feral pigs (Millar *et al.* 2015).

Even with the 90% mortality rate recorded here, previous findings suggest rapid repopulation can be expected: in the only previous assessment of aerial baiting efficacy in similar environments, Fleming *et al.* (1996) recorded reductions in wild dog abundance indices of 69–85% (following baiting at a nominal rate of 40 baits km^{-1}), but the indices returned to parity between annual programs. For managers who aim to mitigate adverse impacts of wild dog populations by lethal means, our outcome suggests that although annual aerial-baiting programs at 40 baits km^{-1} can have dramatic, immediate results on wild dog population size, maintaining a population at low levels will almost certainly require additional effort. This could be attempted either by expanding the initial aerial baiting program's area to account for likely immigration during the time between baiting efforts, maintaining annual programs, duplicating the programs at other times of the year or by integrating other techniques to limit repopulation by survivors and immigrants.

It is reasonable to question whether an aerial baiting rate greater than 10 km^{-1} but less than 40 km^{-1} would achieve the minimum >75% efficacy required to warrant description as 'control'. Similarly, managers might question whether a rate higher than 40 km^{-1} would produce an even greater population reduction. Unfortunately, although both questions are relevant to wild dog policy and management, this study was constrained by currently permitted rates and had insufficient resources to determine at what bait rate mortalities of 0.75 were achieved, nor the shape of the response curve describing aerial baiting efficacy. These questions could be the subject of further work.

It is important to note that our findings pertain to management programs in mesic south-eastern Australia, where aerial baiting has long been the predominant wild dog management technique. Without additional testing (e.g. Eldridge *et al.* 2000), one should not assume equivalence among bait types – we emphasise that these trials used only red-meat baits rather than commercial, manufactured baits. Finally, this study did not investigate non-lethal control (Fleming *et al.* 2001; Jenkins 2003; van Bommel and Johnson 2014), ground baiting, shooting or combinations of these with aerial baiting, so we could draw no reliable conclusions about the relative efficacy of aerial baiting compared with these alternatives.

Conclusion

Our series of trials revealed that 10 baits km^{-1}, the prescribed maximum aerial baiting rate for wild dog control, is insufficient to achieve efficacious lethal control of wild dog populations in mesic forest environments in NSW. However, in the present study aerial baiting at 40 baits km^{-1} was highly efficacious. Consequently, managers who seek to minimise wild dog populations via aerial baiting in mesic south-eastern Australia should use a rate of 40 baits km^{-1} rather than 10 baits km^{-1}.

Conflicts of interest

The authors declare no conflicts of interest.

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