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Fox-baiting in agricultural landscapes in south-eastern Australia: a case-study appraisal and suggestions for improvement

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Summary In south-eastern Australia, the introduced Red Fox (*Vulpes vulpes*) is a major predator of native wildlife and livestock. Fox control in agricultural landscapes is heavily reliant on the laying of poisoned baits by private landholders, yet there have been few assessments of the application or success of landholder-baiting practices. We evaluated a community-based fox-baiting campaign, typical of programs employed throughout the agricultural regions of south-eastern Australia to control foxes. We recorded the spatial coverage of 1080 baits deployed by landholders, assessed baiting procedures, monitored the survival of six radio-collared foxes during and after baiting, and compared the spatial coverage and likely effectiveness of the baiting program with two alternative (theoretical) baiting strategies. Relative to other baiting programs, coordination among neighbours was reasonably high, with 37.5% of baited properties (n = 40) adjoining ≥3 neighbouring properties that also contained baits. Nevertheless, the maximum distance from the centre of a baited property to the nearest edge of an unbaited property was <750 m (mean = 380 m ± 147 m SD). On average, 33% (±17% SD) of each fox's home range overlapped with baited properties, but only two foxes died during the baiting program. The remaining four foxes were still alive 10 weeks after baiting ceased. Modelling of simulated fox home ranges showed that 13.5% contained no bait stations based on the community baiting program, whereas alternative roadside- and grid-baiting strategies (theoretically) delivered baits to all simulated home ranges. Some landholders employed practices that could reduce the effectiveness of baiting programs such as not removing decayed baits before deploying new ones or placing bait stations too close together. Our research illustrates the difficulties of managing a coordinated baiting program on private land that effectively controls foxes. Alternative baiting strategies such as roadside baiting need to be considered to improve fox control in agricultural landscapes.

Key words: *community involvement, conservation management, exotic species, monitoring and evaluation, pest animals.*

Introduction

The introduced Red Fox (*Vulpes vulpes*, Linnaeus 1758) is a major predator of native species and livestock in Australia (Saunders *et al.* 1995; Saunders & McLeod 2007). The annual cost of foxes to the Australian environment and agriculture is estimated at more than $227 million (McLeod 2004). Currently, the most widespread method of broad-scale fox control in south-eastern Australia is lethal baiting using sodium monofluoroacetate (hereafter, 1080) (West & Saunders 2007; Mahon 2009).

The effectiveness of 1080 baiting in reducing fox abundance is widely recognised (e.g. Dexter & Meek 1998; Thomson *et al.* 2000; Körtner & Watson 2005) and has resulted in increased abundance of native wildlife or improved reproductive output (e.g. Olsson *et al.* 2005; Murray *et al.* 2006; Kinnear *et al.* 2010). However, these baiting programs were mostly conducted by researchers or government agencies, and it is unclear to what extent published evaluations reflect the outcomes of landholder-baiting programs (Saunders *et al.* 2005; Saunders & McLeod 2007). Limited assessment of landholder-baiting strategies is problematic because fox management in the agricultural landscapes of south-eastern Australia is heavily reliant on ground baiting (i.e. baits buried by hand) by private landholders (*cf.* Greentree 2000; Gentle 2005; Saunders & McLeod 2007; West & Saunders 2007).

Establishing community-wide, fox-baiting programs is one strategy used to engage landholders and increase the coverage of fox-baiting (McLeod *et al.* 2010). The Broken–Boosey Conservation Management Network (hereafter, BBCMN) Community Fox-Baiting Program (hereafter, baiting program) was established with the principal aims of reducing the impact of foxes on native wildlife (primarily the Bush Stone-curlew, *Burhinus grallarius*, Latham 1801) through the coordinated use of 1080 baits and improving the cooperative management of biodiversity on private and public land (BBCMN 2005; Context Pty Ltd 2008). The BBCMN covers an area of approximately 350 000 ha across northern Victoria (see Fig. 1).

The BBCMN baiting program commenced during a month-long campaign in April 2005, with over 900 FOXOFF® baits deployed by 47 landholders managing a combined area of approximately 18 000 ha (BBCMN 2005; Kubeil & Castles

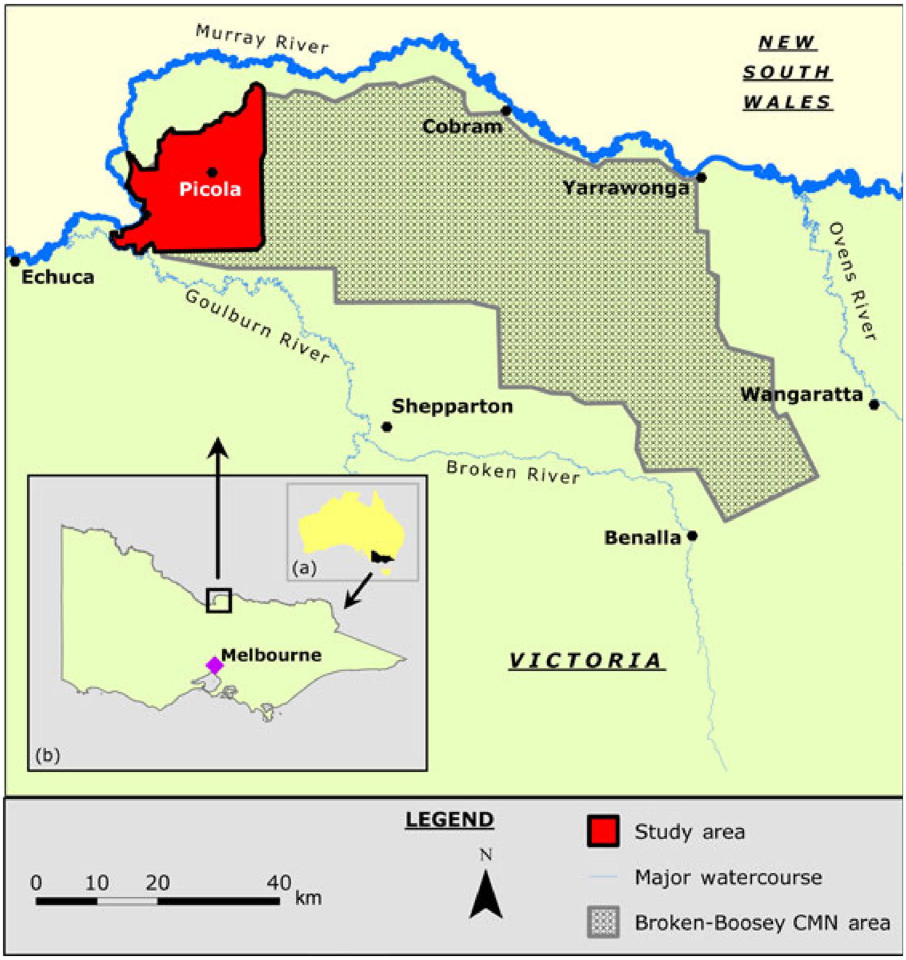

Figure 1. The location of the study area within Australia (inset a), Victoria (inset b) and the Broken–Boosey Conservation Management Network area (main figure).

2007). The annual baiting program gained additional community interest in subsequent years and was conducted during 4-week periods in February–March 2006 and February 2007. In 2007, approximately 10 000 baits were deployed by more than 100 landholders covering approximately 80 000 ha (BBCMN 2007).

Despite the potential contribution of landholder-baiting programs to fox control, there are few assessments of the application or success of these programs. Appropriate deployment and management of baits is particularly important in south-eastern Australia because aerial baiting is largely unsuitable in this region (Saunders & McLeod 2007). Moreover, efforts to protect some native fauna from fox predation (e.g. the Bush Stone-curlew) are almost entirely reliant on the participation of private landholders (Carter 2010).

We evaluated a month-long baiting program conducted by the BBCMN in 2008, typical of similar programs across south-eastern Australia. Our aims were to record the spatial coverage of 1080 baits, assess the baiting procedures of landholders, monitor the survival of radio-collared foxes during and after the program and compare the spatial coverage and likely effectiveness of the BBCMN program with two alternative (theoretical) baiting strategies.

Methods

Study area

The study area spanned approximately 43 000 ha of agricultural land in northern Victoria, encompassing the BBCMN baiting program's 'Nathalia/Picola Baiting Area' where 1080 fox baits have been deployed annually since 2005 (Fig. 1). The region consists mostly of privately owned farmland used for mixed enterprises including winter cereal cropping and livestock production (see Carter 2010 for further details).

The 2008 BBCMN baiting program

The 2008 BBCMN baiting program was conducted from March 3 to April 3 using 35 g FOXOFF® Econobaits (Animal Control Technologies, Somerton, Australia). Prior to the commencement of the program, we provided participating landholders with a data sheet to record the date that each bait station was established and the number of baits removed and replaced during each bait check, and an aerial photograph to record the location of bait stations on their property. We travelled to each bait station with landholders and observed their baiting procedures (e.g. method of bait station preparation). We also recorded the location of bait stations with a global positioning system (GPS) and subsequently imported this information into geographic information system software (ArcMAP™ 9.3, Environmental Systems Research Institute, Redlands, California, USA) for analysis.

The success of landholder-based fox-baiting programs is often measured by the area of land baited (Gentle 2005; Carter 2010). This is a questionable indicator of success, as the size of the baited area can be calculated in different ways (also, see Discussion). To illustrate this, we used the following three approaches to measure 'baited area' for individual properties: (i) incorporating the entire area of each property involved in the baiting program (i.e. all cadastral land parcels, including those without bait stations) (Fig. 2a); (ii) excluding cadastral land parcels that did not contain bait stations (Fig. 2b); and (iii) by placing a Minimum Convex Polygon (MCP) around all bait stations (i.e. the area encompassed by the outermost baits; see Kenward 2001) (Fig. 2c). The density of bait stations (per km^2) on individual properties was calculated separately for each method.

The degree of spatial coordination among neighbours was measured by determining the number of neighbouring properties that were baited simultaneously. For each property where baits were deployed, 'neighbouring properties' constituted land parcels (owned/managed by a different entity) located ≤500 m from the property boundary (following Gentle 2005). To assess the potential for foxes from unbaited properties to migrate onto baited properties, we measured the distance from the centre of each baited property to the nearest edge of an unbaited property using ArcMAP™ 9.3.

We also measured the proximity of bait stations to the nearest road, fence, tree, water and known fox den, as these landscape features may influence bait uptake by foxes (Carter 2010). Distances of <20 m were measured using pacing; all other measurements were made with a GPS. We compared differences in the average distance to landscape features from bait stations where baits were removed versus stations where baits were not removed using an unequal variance *t*-test (t').

During 2007 and 2008, radio-transmitter collars were attached to 14 foxes in the study area (see Carter 2010 for details of the radio-tracking procedures). At the beginning of the 2008 baiting program, six collared foxes remained in the area having been tracked for 3–35 weeks prior to baiting commencing to establish approximate home-range (hereafter, home range) areas. Landholders were not informed about fox locations or movements to avoid influencing bait station placement. Fox activity was monitored during each day and night of the month-long baiting program and periodically for 10 weeks after its completion.

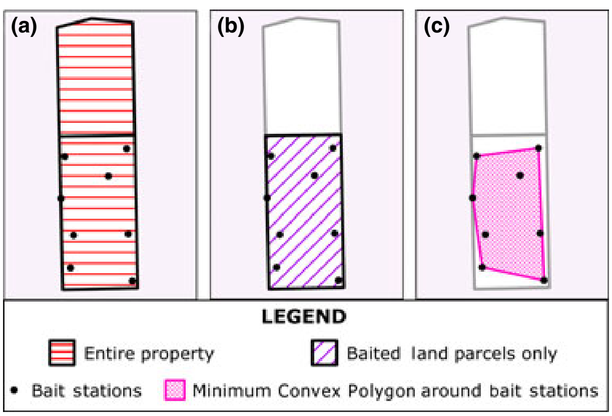

Figure 2. Schematic illustration of the three methods used to measure the extent of area baited on individual properties: (a) the area of the entire property involved in the Broken–Boosey Conservation Management Network baiting program (in this example, the property consists of two cadastral land parcels); (b) the cadastral land parcel that contains the bait stations only; and (c) the area of the Minimum Convex Polygon placed around the outermost bait stations.

Comparisons between the BBCMN baiting program and alternative baiting strategies

To evaluate the efficiency of the landholder-baiting strategy, we compared the distribution of bait stations placed by landholders with two alternative, hypothetical baiting strategies (i.e. no actual baits were deployed) and calculated the number of stations that occurred (theoretically in the case of hypothetical strategies) within the home range areas of foxes for each strategy (see below). Our analysis provided a counterpoint upon which the spatial coverage of baits during the actual baiting campaign could be compared, and whether this coverage could be improved if alternative baiting strategies were implemented.

The hypothetical grid-baiting strategy incorporated pseudo-bait stations placed in a uniform grid pattern at 1-km spacings across the entire study area regardless of land classification, property boundaries or distance to places of habitation (although in reality, these issues would affect bait station placement: Sharp & Saunders 2004). The grid-baiting strategy represented the 'best-case' scenario whereby baits are uniformly distributed across the entire landscape, as is possible with aerial baiting. We also developed a hypothetical roadside-baiting strategy whereby pseudo-bait stations were placed at 1-km intervals along public roadsides in the study area.

Although placement of 1080 baits along roadsides is generally prohibited in south-eastern Australia (Sharp & Saunders 2004), we explored this option for the following reasons: (i) Carter (2010) demonstrated that uptake of baits by foxes was higher at roadsides than at other landscape features (e.g. creek-lines and fence-lines); (ii) it is the most logistically feasible strategy that ensures comprehensive coverage; and (iii) it is more socially acceptable than aerial baiting owing to a lower probability of non-target effects. The use of 1-km intervals for bait stations along roads is consistent with large-scale baiting programs in several public conservation reserves in south-eastern Australia (e.g. Murray *et al.* 2006; Dexter & Murray 2009).

For each baiting strategy, we calculated the number of bait stations located within the home range areas of the six radio-tracked foxes. Home range areas were defined by the MCP (100%, 95%, 50%) and Kernel Contours (95%, 50%) methods and only foxes with >50 telemetry fixes were included in this analysis (see Carter 2010 for details). Because only a few foxes were radio-tracked, we also calculated the number of bait stations occurring within simulated home ranges to provide a more comprehensive assessment of the likely availability of baits to foxes under each baiting strategy. Four different, circular home range sizes were modelled (see Appendix S1), with the home range of each given size placed in the study area 1000 times at randomly determined locations. The number of bait stations occurring in each randomly placed home range was then calculated. The position of simulated home ranges was determined using 1000 random point locations (generated in ArcMAP™ 9.3 using Hawth's Analysis Tools for ArcGIS: Beyer 2004), with individual points designating the centre of each home range.

Results

The 2008 BBCMN baiting program

Twenty-four landholders participated in the 2008 BBCMN baiting program. The average area of land owned/managed by participating landholders was 568 ha (±788 ha SD, n = 24). Nine landholders distributed baits on >1 property, with 40 individual properties baited overall. The average size of individual properties was 341 ha (±609 ha SD, n = 40). If the entire area of each property was included in the calculation of area baited and bait station density, then 13 633 ha was baited with a mean density of 0.04 bait stations per ha (±0.03 SD, n = 40). If cadastral land parcels that did not contain bait stations were excluded, 9 203 ha were baited with a mean density of 0.05 bait stations per ha (±0.03 SD, n = 40). Using the MCP method, the combined area baited was 6 052 ha with a mean density of 0.29 bait stations per ha (±0.33 SD, n = 40).

In total, 391 bait stations were established with a mean of 16.3 (±20.3 SD, n = 24 landholders) bait stations per landholder. One landholder failed to record bait uptake (n = 102 bait stations), while data collected by two landholders (n = 19 bait stations) was deemed unsuitable for analysis. Of the remaining bait stations (n = 270), baits were removed from 48.5% (n = 131) with multiple uptake of baits recorded at 74 stations. Overall, 362 baits were taken (mean = 17.2 ± 21.0 SD baits per landholder). On individual properties, the maximum number of baits removed from a single bait station ranged from 1 to 15 (mean = 5.0 ± 3.7 SD, n = 131). Fox scats were present at 5.6% (n = 15) of the 270 bait stations.

During the month-long baiting program landholders checked bait stations regularly (mean = 11.4 occasions ±5.3 SD, range = 5–26) and the number of days between bait station checks ranged from 1 to 8 (mean = 1.8 ± 0.9 SD). Fourteen landholders (58%) located at least one fox carcass on their property during the baiting program.

Three landholders added new 1080 baits to bait stations without removing the existing baits that were visibly aged and decayed. One landholder placed a bait uncovered on a dead lamb carcass, while another landholder placed baits directly into hollow logs and fox dens. Two landholders dragged an animal carcass to form a continuous scent-trail between bait stations in an effort to increase bait uptake. Two additional landholders placed multiple baits at individual bait stations and deliberately placed several bait stations in close proximity to each other in the belief that such actions would help alleviate the problem of bait caching by foxes (see below). Additional details on landholder-baiting procedures are provided in Carter (2010).

Each property that participated in the baiting program adjoined, on average, 7.5 (±3.7 SD, n = 40 properties) neighbouring properties of which a mean of 2.2 properties (±1.7 SD) also contained 1080 baits. Eight properties were surrounded entirely by neighbours that did not conduct baiting, seven properties adjoined one neighbouring property that also contained 1080 bait stations, 10 adjoined two neighbouring properties that were baited, and 15 adjoined ≥3 neighbouring properties that were baited. The distance from the centre of a baited property to the nearest edge of an unbaited property ranged from 61 to 714 m (mean = 380 m ± 147 m SD, n = 40 properties).

Most bait stations were placed close to fences, with 80% (of 270) situated <50 m from a fence-line and approximately half located <1 m from a fence-line. Less than 4% of bait stations were situated <1 m from each of the other landscape features (road, tree, water or known fox den). There were no significant differences in the average distance to selected landscape features from bait stations where baits were removed versus stations where baits were not removed (Table 1).

The outer home range area (100%, 95% MCP; 95% Kernel) of each radio-collared fox overlapped with 1–3 baited properties

Table 1. Distance (m) from bait stations to selected landscape features according to bait uptake

Variable	Bait removed n = 131		Bait not removed n = 139		P*
	Mean (±SD)	Range	Mean (±SD)	Range	
Distance (m) to nearest road	248.3 (± 186.1)	0.5–815	250.5 (± 214.5)	1–834	0.928
Distance (m) to nearest fence	30.2 (± 69.3)	0–422	44.7 (± 85.2)	0–476	0.124
Distance (m) to nearest tree	68.9 (± 84.9)	0.3–361	58.7 (± 79.1)	0.3–404	0.307
Distance (m) to nearest water	304.2 (± 277.8)	2–1110	269.6 (± 245.2)	1–1075	0.280
Distance (m) to nearest known fox den	2348.4 (± 2671.2)	1–9006	2117.7 (± 2215.1)	9–9231	0.442

*Significance levels relate to comparisons of mean values and were calculated using an unequal variance t-test (t').

(mean = 2 ± 1 SD, n = 6 foxes). On average, 33% (±17% SD) of each fox's home range area (100% MCP) overlapped with baited properties. Two radio-collared foxes died during the baiting program; 23 and 29 days after the program commenced. The four remaining foxes were still alive 10 weeks after the baiting program finished on 03/04/2008.

Comparisons between the BBCMN baiting program and alternative baiting strategies

Between one and 16 bait stations (mean = 7 ± 6.1 SD) where located within the home ranges (100% MCP) of five collared foxes, while no bait stations were located in the home range of the remaining fox (Table 2). Information on bait uptake was available for only two home range areas. Fox MA 3's home range contained one bait station, but no baits were removed from this station (MA 3 was still alive 10 weeks after baiting ceased). Four bait stations were located within fox FA 1's home range, and baits were removed from three of these stations (FA 1 died 2 days before the baiting program ended). Under the hypothetical roadside- and grid-baiting strategies, bait stations (theoretically) occurred in the home range (100% MCP) of all six collared foxes (roadside, mean = 5 ± 2.7 SD bait stations per home range; grid, mean = 10 ± 2.7 SD bait stations per home range; Table 2).

There were substantial differences in the spatial distribution of baits between the BBCMN baiting program and the hypothetical roadside- and grid-baiting strategies (Fig. 3a–c). Landholder bait stations were highly clumped, whereas pseudo-bait stations deployed via the roadside or grid strategies were uniformly distributed throughout the study area. These differences were reflected in the results of the modelling exercise where a simulated fox home range of average area (704 ha; see Appendix S1), placed randomly 1000 times within the study area, contained a mean of 8.9 landholder bait stations (±7.5 SD, range = 0–39, n = 1000; Table 3), yet 13.5% of simulated home ranges contained no landholder bait stations. In comparison, the same home range area contained a mean of 4.2 pseudo-stations (±1.1 SD,

Table 2. The number of bait stations positioned within the home-range (HR) areas of six radio-collared foxes for the landholder- (L), roadside- (R) and gird-baiting (G) strategies

Fox ID	100% MCP† (ha)	Bait stations in home range			95% MCP (ha)	Bait stations in home range			95% Kernel (ha)	Bait stations in home range			50% MCP (ha)	Bait stations in home range			50% Kernel (ha)	Bait stations in home range		
		L	R	G		L	R	G		L	R	G		L	R	G		L	R	G
MA 3	1352	1	9	13	605	0	4	5	291	0	2	3	128	0	1	2	35	0	0	0
FA 1‡	544	4	3	6	467	4	3	4	187	2	1	1	76	2	0	0	19	0	0	0
MS 8‡	1436	10	7	13	1167	10	6	12	530	9	3	5	144	4	1	2	128	2	1	2
MS 9	788	16	3	9	728	16	3	8	215	5	1	2	64	2	1	0	19	0	0	0
MS 10	835	8	2	10	547	6	2	6	162	3	1	3	60	2	1	0	17	0	0	0
FS 4	1067	0	5	11	974	0	5	11	455	0	2	5	110	0	0	1	58	0	0	1
Mean ± SD		7 ± 6.1	5 ± 2.7	10 ± 2.7		6 ± 6.2	4 ± 1.5	8 ± 3.3		3 ± 3.4	2 ± 0.8	3 ± 1.6		2 ± 1.5	1 ± 0.5	1 ±1		0.3 ± 0.8	0.2 ± 0.4	1 ± 0.8
Minimum		0	2	6		0	2	4		0	1	1		0	0	0		0	0	0
Maximum		16	9	13		16	6	12		9	3	5		4	1	2		2	1	2

†Home-range areas were defined using the Minimum Convex Polygon (MCP) and Kernel Contours (Kernel) techniques. ‡Fox died during the Broken–Boosey Conservation Management Network baiting program.

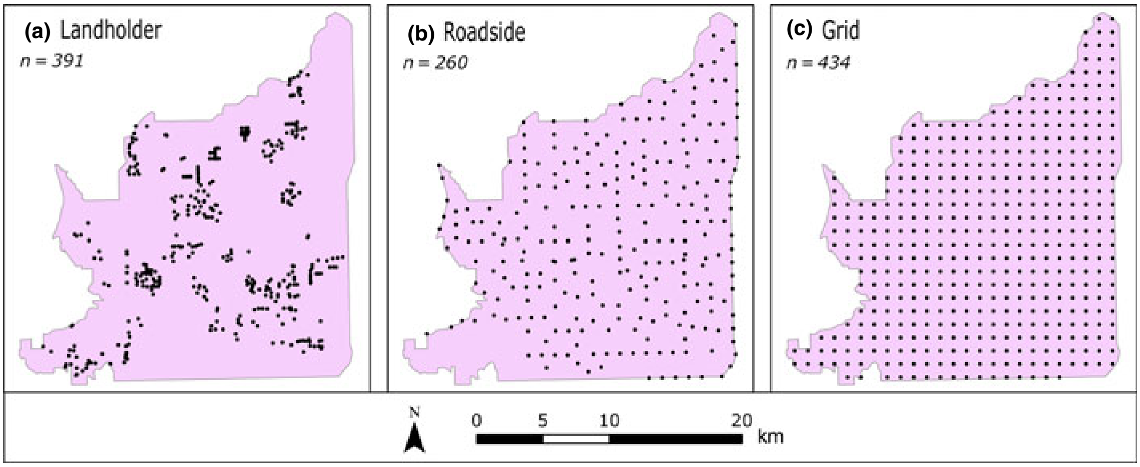

Figure 3. The location of landholder bait stations during the Broken–Boosey Conservation Management Network baiting program (a); and the location of pseudo-bait stations generated from the hypothetical roadside-baiting strategy (b); and hypothetical grid-baiting strategy (c).

Table 3. The number of bait stations occurring within simulated home-range (HR) areas according to the landholder-, roadside- and grid-baiting strategies

	Landholder-baiting strategy n = 391				Roadside-baiting strategy n = 260				Grid-baiting strategy n = 434			
Home-range areas (ha: 95% MCP)†	245	437	704	3033	245	437	704	3033	245	437	704	3033
Mean number of baits within home range ± SD	3.2 ± 3.9	5.6 ± 5.6	8.9 ± 7.5	36.0 ± 14.2	1.5 ± 0.7	2.6 ± 1.0	4.2 ± 1.1	18.1 ± 1.8	2.5 ± 0.8	4.4 ± 0.6	7.0 ± 0.8	30.3 ± 1.0
Range of baits within home range	0–26	0–35	0–39	4–64	0–4	0–6	1–7	12–24	1–4	4–6	4–9	28–33
Number of home ranges devoid of baits	353	213	135	0	64	6	0	0	0	0	0	0

†Results are presented for four different home-range sizes, each of which was placed at random 1000 times throughout the study area, and the number of bait stations that fell within each home range was counted. Home-range sizes relate to the average (704 ha), minimum (245 ha) and maximum (3033 ha) home-range areas of foxes radio-tracked in the study area during 2007–2008 (refer to Carter (2010) for additional details), and the average home-range area of 188 foxes (437 ha) radio-tracked in agricultural areas of NSW by Berghout (2000) and Saunders *et al.* (2002). MCP, Minimum Convex Polygon.

range = 1–7, n = 1000) based on the roadside-baiting strategy (n = 260 bait stations), and a mean of 7.0 pseudo-stations (±0.8 SD, range = 4–9, n = 1000) based on the grid-baiting strategy (n = 434 bait stations) and in both cases at least one pseudo-bait station was located in each of the 1000 simulated home ranges (Table 3).

Discussion

The BBCMN baiting program

Landholder approaches to baiting

The success of fox-baiting by landholders is generally measured by the number of baits deployed, number of participating landholders or the area of land baited (Gentle 2005). These approaches are inadequate compared to monitoring changes in fox populations, although the best measure of a baiting program's success is the response of prey species and/or changes in agricultural production (Saunders *et al.* 1995; Reddiex & Forsyth 2006; Saunders & McLeod 2007). Moreover, the area of land baited is almost always estimated by summing the entire area of each participating property, but our results demonstrate that this can substantially overestimate the actual baited area. Using the more accurate MCP method yielded an area baited of less than half that calculated from summing the area of each property. Failing to recognise this difference could result in the success of a baiting program being overstated or, alternatively, if success is measured through fox decline or prey species recovery, an overestimation of area baited may yield unrealistic expectations of the impact of baiting.

Landholders employed a number of practices that could compromise the effectiveness of the fox-baiting program, including placing new baits at bait stations without removing the existing, decayed bait. Following deployment, 1080 concentration in baits declines as a consequence of numerous factors such as leaching by rainfall or decomposition by insects (Saunders *et al.* 2000). Baits exposed for extended periods will eventually contain sublethal doses of 1080 (Saunders *et al.* 2000). The consumption of these baits by foxes could potentially increase the tolerance to 1080 of fox populations (as demonstrated for the European Rabbit (*Oryctolagus cuniculus*, Linnaeus 1758) in Western Australia: Twigg *et al.* 2002) or result in individuals eliciting symptoms of 1080 toxicosis that result in the development of an aversion to baits in the future (*cf.* Ogilvie *et al.* 2000).

Bait caching by foxes (i.e. moving baits from their original location and storing them elsewhere: Saunders *et al.* 1999) is likely to occur when landholders deliberately position several bait stations in close proximity to each other or place multiple baits at individual bait stations (Saunders *et al.* 1993; Gentle 2005), as caching is likely linked to the (over) abundance of food (Vander Wall 1990). When a fox dies or leaves an area, caches may be abandoned and this poses a risk to non-target species or may reduce the success of future baiting programs if other foxes consume cached baits that contain sublethal amounts of 1080 (Saunders *et al.* 1999, 2000; Gentle 2005). Attempting to lure foxes by creating a continuous scent-trail between baits (e.g. by dragging an animal carcass) may potentially encourage uptake of multiple baits by the same fox (Priddel & Wheeler 1997) or result in caching which would reduce access to baits for other foxes and leave many baits wasted (Gentle 2005).

These problematic baiting practices are likely to extend beyond the current study area as the BBCMN program is typical of many landholder-based fox-baiting campaigns in south-eastern Australia. It is crucial to eradicate these problematic practices, otherwise over time, many community baiting programs may simply be selecting for foxes that avoid baits. This would seriously undermine any benefits baiting programs provide to conservation and/or agriculture and also potentially increase the impact of foxes. Saunders *et al.* (2000) noted that not all landholders follow recommended practices during 1080-baiting programs. While some landholders in our study were aware that their practices are not recommended, the vast majority were unaware of the possible consequences of their actions. Therefore, improving the flow of information to landholders is crucial to improve the efficacy of baiting campaigns and eliminate problematic practices. This may be achieved best via direct communication (following Croft *et al.* 2002) at bait collection points or field days, as written information concerning baiting is often ineffective (A. Carter, pers. obs.).

The effectiveness of the BBCMN baiting program

To measure the effectiveness of fox-baiting, the BBCMN has previously employed spotlighting surveys pre- and post-baiting and recorded the difference in the number of fox sightings. These surveys found at least a short-term reduction in fox abundance immediately after baiting ceased (BBCMN 2007; Kubeil & Castles 2007). Community spotlighting surveys were not conducted during our study, but uptake of non-toxic baits showed a 15% reduction immediately after baiting, compared to pre-baiting levels (Carter 2010).

As changes in fox abundance were not measured, we assessed the effectiveness of the BBCMN baiting program through the participation of, and coordination among, landholders; bait placement and spatial coverage of baits; and the fate of the radio-collared foxes. Most landholders that participated in the 2008 baiting program did not undertake fox-baiting on their properties prior to 2005 when the BBCMN Community Fox-Baiting Program was established. Therefore, the program has been successful in fostering interest and involvement in biodiversity management on private land. During the 2008 program, 37.5% of baited properties were baited in conjunction with three or more neighbouring properties. This level of coordination among landholders is much higher than reported by Gentle (2005) who reviewed 5 years of baiting records in central New South Wales and found that only 8.5% of landholders coordinated baiting with three or more neighbours.

Despite the coordination among landholders, the average property size was reasonably small (341 ha) and the maximum distance from the centre of a baited property to the edge of the nearest unbaited property was only 714 m. This distance is insufficient to prevent dispersing foxes from migrating into baited properties following the baiting program (Coman *et al.* 1991; Marlow 1992; Robinson & Marks 2001). Moreover, re-colonisation of baited properties would have almost certainly occurred soon after the baiting program ceased, as large continuous areas of land remained unbaited throughout the study area. Many studies have documented rapid re-colonisation by foxes following substantial localised reductions in abundance (e.g. Short *et al.* 1995; Banks *et al.* 1998; Kinnear *et al.* 2010).

In our study, bait stations were mostly located close to fences, consistent with results from other agricultural areas in south-eastern Australia (e.g. Saunders *et al.* 1999; Greentree *et al.* 2000). This may reflect convenience (e.g. farm tracks often follow fence-lines), the widespread belief that foxes follow fence-lines while travelling (Saunders *et al.* 1995; Slater 1998), or that fences are likely sites of fox activity (Vine 2004). However, we found that bait uptake was not higher closer to fences. Moreover, in controlled experiments testing bait uptake at different landscape features, Carter (2010) found that fewer baits were removed along fence-lines than at roadsides, creek-lines, remnant vegetation or open paddocks. These results suggest that fence-lines may not provide the most favourable sites for eliciting bait uptake by foxes, and bait station placement, an issue that has largely been overlooked in analyses of fox-baiting, may affect substantially the efficiency of 1080-baiting campaigns.

Five of the six collared foxes had at least one bait station within their home range, yet four foxes survived the baiting program. In a study similar to ours, Dexter and Meek (1998) recorded the death of all of their six radio-collared foxes within 10 days of baiting commencing, during a ground-based 1080-baiting campaign in coastal New South Wales. In a much larger investigation using aerial baiting, Thomson *et al.* (2000) radio-collared 45 foxes in semi-arid Western Australia and found that 60% of collared foxes died within 3 days of 1080 baits being deployed and 100% were dead within 44 days. While relatively few foxes were radio-collared during our study, the results raise concerns over the effectiveness of the fox-baiting program and emphasise the need for detailed research on the foraging behaviour of foxes and more careful selection of bait locations (Trewhella *et al.* 1991).

The simulated fox home range modelling also reflected this, where a relatively high proportion of home range areas was devoid of landholder bait stations compared with the hypothetical roadside- and grid-baiting strategies. These results strengthen the argument that the spatial coverage of bait stations during the BBCMN baiting program was insufficient to result in widespread fox population reductions throughout the study area. The most likely outcome is short-term reductions in fox abundance on individual properties. Given the timing of the baiting program (February–April), this may benefit participating landholders wanting to protect new-born lambs during March–April, but is unlikely to fulfil the program's overriding objective of reducing the impact of foxes on native fauna.

Another important issue in assessing the effectiveness and impact of community-based fox-baiting programs is the potential response of interacting pest species. For example, following reductions in fox populations, the Feral Cat (*Felis catus*, Linnaeus 1758) may increase in abundance (Christensen & Burrows 1995; Risbey *et al.* 2000) or modify its habitat use and diet (Molsher 1998, 1999), and rabbit populations may significantly increase (Banks *et al.* 1998; Banks 2000). Monitoring and managing multiple pest species is inherently difficult, but a holistic approach to pest management is vital to minimise impacts to native and agricultural ecosystems.

A roadside-baiting strategy

Reducing the impact of foxes on native fauna in the study area would almost certainly require the duration of the BBCMN baiting program to be increased considerably (e.g. 3–4 months) or for baiting to be performed more frequently (e.g. at alternating 1-month intervals for several months; Robley (2010) also recommended increasing the duration and frequency of baiting). Achieving such intensive baiting regimes based entirely on landholder involvement is highly unlikely (*cf.* Greentree 2000).

Evidence from our study and past research (Greentree 2000; Greentree *et al.* 2000; Gentle 2005) suggests that the way foxes are currently managed in agricultural areas requires re-evaluation and consideration of alternative strategies. One potential alternative that is gaining popularity on farming properties is the use of guardian animals (e.g. alpacas, donkeys, Maremma dogs) that are kept with livestock to protect them from predators (van Bommel 2010). However, this approach has relatively limited applicability and should be viewed as a complementary technique, rather than as a substitute for other broad-scale control methods (Saunders & McLeod 2007). Another proposed alternative is the reintroduction of the Dingo (*Canis lupus dingo*, Linnaeus 1758) to parts of its former range, with the view that as the top predator, the dingo will out-compete foxes and cats. This approach, nevertheless, is more suited to the less-populated rangeland areas (e.g. semi-arid western NSW: Dickman *et al.* 2009) and it is probably unrealistic in the closely settled temperate agricultural landscapes of south-eastern Australia.

Our results indicate that distributing fox baits along roadsides may be a viable alternative to supplement baiting on private land, especially considering the limitations of aerial baiting in Eastern Australia (Saunders & McLeod 2007) and the current lack of practical alternative approaches to baiting. The hypothetical roadside-baiting strategy we employed required considerably fewer baits (n = 260) than the grid-baiting strategy (n = 434), yet the number of simulated fox home ranges that (theoretically) received baits was relatively even between the two strategies (Table 3). Moreover, roadsides appear to be commonly used by foxes. Numerous studies have found that foxes consistently use roads for movement and/or hunting (e.g. Lumsden *et al.* 1991; Meek & Saunders 2000; Ramp *et al.* 2006; Gosselink *et al.* 2007; Silva *et al.* 2009) possibly owing to resource abundance on or near roads (e.g. roadkill or roadside vegetation) that enables foxes to optimise foraging success (Meek & Saunders 2000; Silva *et al.* 2009). This is supported by controlled experiments by Carter (2010) who demonstrated that 69–73% of baits placed at roadsides (n = 420) were removed by foxes within 8 days of deployment. While a roadside-baiting strategy has great potential in landscapes with extensive road networks (e.g. agricultural regions of northern Victoria), it is limited as a sole strategy in regions with few roads (Carter 2010). In these instances, roadside baiting must be conducted in conjunction with baiting on private land and public reserves.

Owing to the risk of poisoning domestic pets, a roadside-baiting strategy would require strict guidelines including adequate notification to residents, clear identification of bait stations, burial of baits to reduce non-target exposure and stringent distance restrictions (e.g. baits placed >500 m from residences). Pest control officers would need to be employed to manage the baiting, and this represents a significant shift in fox management policy in Australia. Yet baiting in areas accessible to the general public and domestic pets is not without precedent. The Sydney-North Regional Fox-control Program is a 1080-baiting program in bushland bordering high-density housing in the northern suburbs of Sydney, with baits placed within 150 m of dwellings (Mason & Olson 2000; Olsen *et al.* 2005). The program has been running for 10 years and has an excellent safety record with only one case of a domestic dog being poisoned (Saunders & McLeod 2007).

The BBCMN baiting program we evaluated is typical of most landholder-based baiting programs in south-eastern Australia. Such programs face substantial challenges in reducing the impact of foxes on native fauna or livestock. We argue that the inadequacy of these programs demonstrates that fundamental change is required in the way fox-baiting is conducted in the agricultural regions of Eastern Australia. Without such change, current fox-baiting efforts will contribute little to ensuring the conservation of threatened native fauna such as the Bush Stone-curlew.

Implications to Management

- Greater emphasis should be placed on the spatial coverage of baits during fox-control programs in agricultural landscapes. Across landscapes, it is crucial to limit the number of properties devoid of baits. These properties can reduce the overall effectiveness of baiting programs by acting as sources for foxes that can rapidly recolonise baited properties where other foxes have been removed. On individual properties, it is important to distribute baits across the entire property, rather than only at sites that are most accessible or convenient to check.
- Baiting operators need to be better informed about correct baiting practices and the potential negative consequences of inappropriate methods such as not removing old baits or placing baits too close together. This may be achieved best by direct communication and active demonstrations at field days or bait collection points.
- Coordinating effective fox-baiting among multiple, adjacent landholders is problematic and management agencies must consider alternative strategies such as roadside baiting that can potentially deliver better fox control.
- Caution should be exercised when interpreting figures on the 'area of land baited' as this can be calculated in different ways and in most instances will overstate considerably the actual baited area.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Description of home-range areas used for simulated home-range modelling.

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