Final Report to the Australian Pest Animal Research Program

Demonstrating the potential resilience of fox populations to coordinated landholder baiting programs for agricultural protection

Andrew Bengsen

New South Wales Department of Primary Industries

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Project summary and recommendations

Current best practice for mitigation of the impacts of the European red fox (*Vulpes vulpes*) throughout Australia recognises that large-scale cooperative management programs provide the greatest benefits. Poison baiting using 1080 is generally the most effective and cost-efficient means of achieving this. Experimental, large-scale evaluations of population reductions from lethal baiting show that baiting programs can achieve high success rates. However, the resources, duration and care that go into experimental control programs are generally much greater than occurs during routine fox control operations conducted by landholders. Bait distribution patterns are often highly clustered within properties, and the lack of spatial continuity means that many conventional poison baiting programs are likely to reach only a fraction of the resident fox population, even when coordinated across neighbouring properties. In these situations, the removal of some foxes by baiting is likely to be almost immediately compensated for by adjustments in the home ranges of other resident foxes. Consequently, potential economic returns on fox control investment are not being realised.

This study assessed the resilience of fox populations to coordinated baiting programs by tracking the fate of individual GPS collared foxes and by monitoring changes in fox activity across the landscape using camera trap surveys. Baiting programs were conducted by existing cooperative fox management groups, using conventional baiting practices, with the main aim of reducing fox predation on lambs.

Graphical overlay and simulation of fox movements over property boundaries and bait locations highlighted the importance of coordinating baiting programs among neighbouring properties. Baited properties comprised 47 and 28 % of the two sites studied. However, surveys of fox activity across the landscape showed no decline in activity after baiting. Furthermore, 70% of collared foxes on baited properties survived baiting.

Greater coordination of baiting activities would increase the proportion of the fox population exposed to baits, which is a necessary first step to increasing the impact of baiting programs. However, it may be unrealistic to expect landholder participation to approach 100 % because some landholders will avoid participating for a variety of reasons. Nonetheless, the high survival rate of collared foxes on baited properties suggests that substantial improvements can be achieved within existing baiting groups. Bait distribution densities observed in the study were low, relative to expected fox densities. An increase in baiting intensity above levels observed in this study should therefore produce greater fox mortality by ensuring that all foxes have access to baits.

Based on these results, it is recommended that fox baiting groups aiming to protect lambs and other stock from fox predation should:

1. maximise coordination of bait distribution timing and spatial extent among neighbouring properties, and
2. ensure that sufficient baits are distributed within individual properties to provide multiple opportunities for each fox present to encounter a bait.

The results and recommendations of this study will be disseminated to end users via communication channels targeting landholders, pest management officers and pest animal researchers, to help land managers maximise their return on fox baiting investment. The results will also be used to guide future research efforts directed towards the same aim.

The major findings of this paper have been published as a peer-reviewed journal article (Bengsen 2014) which should be used as the definitive reference for this material.

Bengsen, A. J. (2014) Effects of coordinated poison baiting programs on survival and abundance in two red fox populations. *Wildlife Research*. online early http://dx.doi.org/10.1071/WR13202

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Landholders from the Mogriguy, Eumungerie, Wongarbon and Ballimore fox baiting groups provided access to properties for fox capture and monitoring; data on baiting activities; and accommodation during extended fieldwork periods.

Comments from Peter Fleming improved the presentation and discussion of the project results.

Project information

Project name

GMS1510 - Demonstrating the potential resilience of fox populations to coordinated landholder baiting programs for agricultural protection

Applicant details

Project Officer and primary contact

Dr Andrew Bengsen
New South Wales Department of Primary Industries
Orange Agricultural Institute
Locked Bag 6006
Orange NSW 2800
Ph: (02) 6391 3991
andrew.bengsen@dpi.nsw.gov.au

Secondary Contact

Dr Glen Saunders
New South Wales Department of Primary Industries
Locked Bag 21
Orange NSW 2800
glen.saunders@dpi.nsw.gov.au

Collaborators

The study was a close collaboration between the New South Wales Department of Primary Industries, the Central West Livestock Health and Pest Authority (CW LHPA) and the Mogriguy, Eumungerie, Wongarbon and Ballimore Fox Baiting Groups. Landholders and pest management facilitators were directly involved in the study implementation, data collection and interpretation.

Project duration

February 2012 to June 2013

Objectives

The main goal of this project was to evaluate and demonstrate the ability of conventional baiting practices to suppress fox populations. This was to be achieved through the following objectives:

1. Estimate changes in fox population densities in response to coordinated baiting programs.
2. Estimate the extent to which individual foxes within populations are exposed to baiting.
3. Communicate results and implications to public and private land managers through extension networks of partner agencies, as well as scientific and management fora.

This project was aligned with Goal 3 of the Australian Pest Animal Strategy (manage the impacts of established pest animals), and Objective 4 of the Commonwealth Fox Threat Abatement Plan (improve the effectiveness, target specificity, integration and humaneness of control options for foxes). Foxes are a priority pest species addressed by the ABARES 'Managing Vertebrate Pests' guidelines. The project also addressed the following specific recommendations in the ABARES document 'Improving Fox Management Strategies in Australia' (Saunders and McLeod 2007):

Continual assessment of 'real world' management programs.

Evaluating the efficacy of conventional baiting programs.

Developing reliable methods for estimating fox densities.

Background

The European red fox (Vulpes vulpes, hereafter fox) is an important predator of livestock and small native fauna throughout much of Australia and is one of the country's most serious pest animals (Saunders et al. 2010). Current best practice for reducing the impacts of fox predation on livestock in Australia recognises that large-scale cooperative management programs provide the greatest benefits (Saunders and McLeod 2007; McLeod et al. 2010; Fleming et al. accepted). Poison baiting using compound 1080 (sodium fluoroacetate) is generally the most effective and cost-efficient means of achieving this. Experimental, large-scale evaluations of population reductions from baiting programs show that intensive baiting operations can achieve high success rates (e.g. Thompson and Fleming 1994; Dexter and Meek 1998). However, the resources, duration and care that go into these operations are generally much greater than occurs during routine fox control operations conducted by landholders (Saunders and McLeod 2007).

In contrast to experimental studies, assessments of actual baiting practices by private landholders or conservation organisations in Australia suggest that many baiting operations may be unlikely to achieve meaningful reductions in fox densities or impacts. Bait distribution patterns can be highly clustered among and within properties, and baits are often distributed over small areas or at low densities (e.g. Gentle 2005; Reddiex et al. 2006; Carter et al. 2011; Towerton et al. 2012). Poor spatial continuity means that many conventional poison baiting programs are likely to reach only a fraction of the resident fox population, even when coordinated across neighbouring properties. In these situations, the removal of some foxes by baiting is likely to be almost immediately compensated for by adjustments in the home ranges of other resident foxes, or rapid incursions by foxes from nearby areas (Carter et al. 2011).

The present study assessed the ability of two coordinated baiting programs conducted by private landholders to reduce the density of foxes in a mixed agricultural landscape. We used camera trap surveys to test whether fox activity decreased noticeably after baiting, and we monitored the fates and movement patterns of GPS collared foxes to estimate their exposure to baits in the landscape. We offer suggestions to improve the efficacy of future baiting programs.

Study area

Two study sites were established near Dubbo in central New South Wales (Figure 1). Both sites were part of a broader coordinated fox baiting program administered by the Central West Livestock Health and Pest Authority, which aimed to have as many landholders as possible in the area surrounding the Goonoo National Park (GNP) baiting cooperatively twice per year, in Autumn (March) and Winter (July) (Robinson and Thomas 2008; Anonymous 2012). The National Parks and Wildlife Service (NPWS) conducted a monthly baiting program within GNP and some adjacent State Conservation Areas to protect native fauna, principally the malleefowl (Leipoa ocellata).

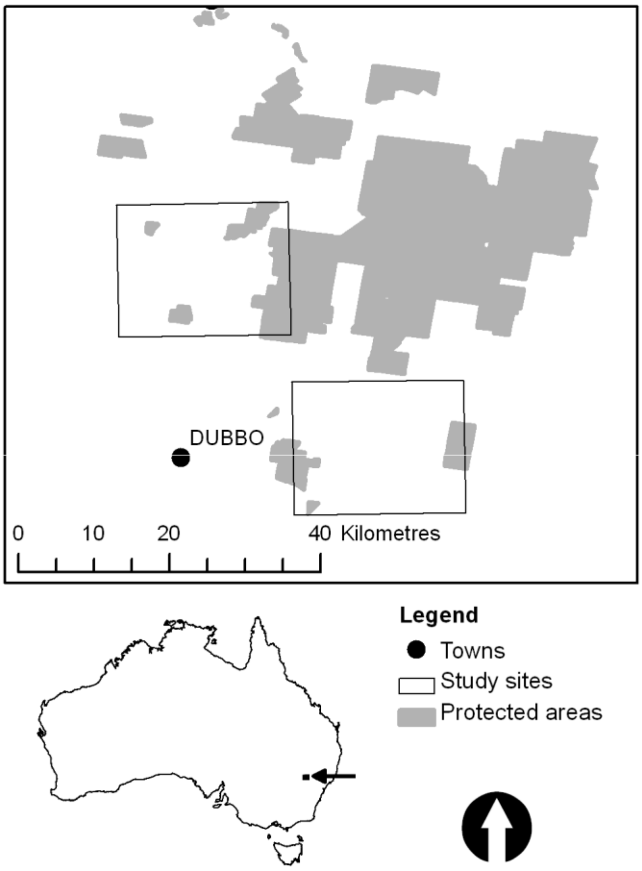

Figure 1: Map showing the location of two study sites near Dubbo, New South Wales.

Both sites covered approximately 336 km^2, comprising mixed agricultural enterprises including prime lamb production, beef cattle and cropping, as well as small areas of State Forest or National Park. The first site (Site 1: 32.02 S, 148.66 E) was centred between the localities of Mogriguy and Eumungerie, to the west of GNP. Fieldwork was conducted here during winter 2012, coinciding with the distribution of baits to landholders in July. The second site (Site 2: 32.24 S,148.85 E) was centred between the localities of Wongarbon and Ballimore. Fieldwork was conducted here the following summer and autumn, coinciding with coordinated baiting in March 2013.

Methods

Baiting

All baiting was conducted by landholders on their own properties using fresh meat baits (mainly sausages, livers, fowl heads, chicken wingettes or beef chunks) containing nominally 3.0 mg of 1080. To illustrate the distribution of baits across the landscape, landholders were asked to mark the locations of bait stations on aerial photographs of their properties, and to provide information about when baits were removed by animals or replaced. These data were entered into a GIS (ArcGIS 10, ESRI, Redlands, USA) for description and spatial analysis.

I used the Average Nearest Neighbour function in ArcGIS, specifying Euclidean distance and the area of each property, to produce a nearest neighbour index for each property that provided spatial information about bait locations. The nearest neighbour index was calculated as the ratio of observed to expected mean distance between nearest neighbouring points. The test statistic ([observed mean distance – expected mean distance] / standard error) was compared against a z distribution to test for statistically detectable deviations from a random spatial pattern. Index values not significantly different to 1 represent a random distribution of points, values < 1 represent spatial clustering and values > 1 represent greater than expected dispersion.

Movement and survival of foxes

Foxes were captured with foothold traps (soft catch # 1.5, Oneida Victor, Ohio, USA), baited with a variety of proprietary and opportunistic olfactory lures, in winter 2012 at Site 1 and autumn 2013 at Site 2. Carcasses were sometimes used opportunistically as a calling lure to draw animals to an area for trapping. Captured foxes were restrained and subdued with a hessian bag placed over the head and eyes while a physical examination was conducted to check for injuries and physical condition, and a GPS tracking collar was fitted (G2C171B, Sirtrack Ltd, Havelock North, New Zealand). Collars weighed about 180 g, and were only fitted to animals heavier than 3.6 kg so that collars weighed < 5% of body weight. Collars were programmed to attempt a location fix every 2.5 hours, and to release from the animal at predetermined dates. Collars were recovered after the animal died or the timed-release mechanism operated as programmed. Foxes were only trapped on properties that were participating in the baiting programs, so the collared sample was representative of the population of foxes on baited properties, not the broader population of the sites.

The fate of each collared fox was categorised using the following classes: 1) died or lost before baiting, 2) died after baiting from poisoning, 3) alive > 20 days after baiting, 4) died after baiting from other causes. I applied the Kaplan-Meier estimator to a dataset comprising all collared individuals to estimate the proportion of the population that was killed by baiting programs. Data were pooled across both sites due to small sample sizes and similar bait-induced mortality levels. The entry and exit dates for each animal were standardised by subtracting the date at which baits were distributed on the property where they were most frequently detected.

Bait exposure

Based on the estimated lethal dose of 1080 for foxes (McIlroy and King 1990), the predicted decay curve for 1080 in fresh chicken meat baits (Gentle et al. 2007a) and the median weight of foxes captured at our sites (5.1 kg, IQR = 1.35), baits were expected to remain consistently lethal to foxes for no more than 7 days. I therefore estimated an average 7 day home range for foxes at each site by calculating 95% minimum convex polygons (MCP95s) from all fixes recorded for 168 hours after a randomly selected location fix for each fox. Location fixes with a horizontal dilution of presence (HDOP) value > 9.0, indicating potentially low precision, were excluded (following Bengsen et al. 2012). I repeated this 99 times for each fox and calculated the median, and then used the median of these values across all foxes as our expected 7 day home range.

To estimate the extent to which the resident fox populations were exposed to baits, I randomly located 500 simulated circular 7 day home ranges across each study site, and calculated the proportion of home ranges that intersected with a baited property. This method is expected to overestimate exposure to actual baits, because bait stations were not uniformly distributed across properties, so contact with a baiting property did not automatically equate to contact with baits (see also Carter et al. 2011).

Camera trap surveys

At Site 1, a single passive infra-red triggered camera (HC600, Reconyx Inc., Holmen, WI, USA) was deployed in each of 20 cells randomly selected from a 9 x 10 grid superimposed over the site. A fresh chicken neck was buried in a metal cage, about 3 m in front of each camera to attract foxes to the site. All cameras were deployed by the same operator, mounted horizontally with the lens about 30 cm above ground, and programmed to record five images in quick succession for each trigger event. Two consecutive 12 day surveys were conducted immediately before bait distribution, and three consecutive surveys commenced five days after baiting. Lures were replaced at the start of each survey. A similar process was used over seven consecutive surveys at Site 2, except the lure comprised a small, perforated tin of tuna and a piece of cotton wool bearing an olfactory lure (Carman's Canine Call Lure, Russ Carman, New Milford, USA) nailed to a tree in front of the camera (Figure 2). The survey conducted during the baiting period at Site 2 was discarded because the assumption of population closure was violated as a result of foxes being killed. The mean distance between cameras was 2.91 km at Site 1 and 2.71 km at Site 2. No camera was closer to its nearest neighbour than the expected diameter of an average fox home range (2.32 km), estimated from 117 foxes in nearby areas (Saunders et al. 2002).

Figure 2: Camera trap photos of a GPS-collared fox investigating a lure at a monitoring station at Site 2.

I created daily detection/non-detection histories for foxes at each camera station during each survey, such that each day was given a code of 1 if a fox was detected on that day or 0 if no foxes were detected. It was not possible to consistently identify individual foxes. For each combination of site and survey period, I applied the Royle-Nichols abundance-induced heterogeneity method (Royle and Nichols 2003) to the detection histories to estimate local fox abundance at each camera station. These estimates were then averaged across all camera stations for each survey period. Therefore the abundance estimate for each survey period represents the average number of animals that were expected to have used monitoring sites during that period, whether or not they were actually detected. To describe variation in detectability and occupancy, I used second order information-theoretic model selection procedures to estimate model parameters for each survey across a 95% confidence set of models. Models were implemented using the 'unmarked' package (v. 0.9-9, Fiske and Chandler 2011) in Program R (v. 2.15.1, R Development Core Team 2012).

Results

Baiting effort

At Site 1, baits were distributed on 18 separate private properties during winter 2012 as well as three NPWS properties. These properties covered 157.5 km^2 (47 %) of the study site, including 44.4 km^2 of National Parks estate. Nine properties at Site 1 provided detailed information on bait station locations. Median bait density across these properties was 2.96 baits km^{-2} (IQR = 1.03) (Table 1). At Site 2, baits were distributed on 17 private properties, covering 93.9 km^2 (28%) of the site. Median bait density across the seven properties at Site 2 that returned detailed bait location data was 4.37 baits km^{-2} (IQR = 4.02). The only deviation from a random pattern of bait distribution across all properties that provided data was towards a more even dispersion pattern (Table 1).

Table 1: Density and spatial dispersion characteristics of fox bait stations at two sites. P values < 0.05 represent a detectable deviation from a random distribution, i.e. from an index value of 1.00.

Property ID	Baits km^{-2}	Nearest neighbour index	*P*	Spatial pattern
Site 1				
E3	1.67	1.68	< 0.001	dispersed
E4	2.80	1.35	< 0.001	dispersed
E2	2.81	1.02	0.90	random
E6	2.85	1.39	0.001	dispersed
M3	2.96	0.71	0.08	random
E1	3.05	1.37	0.01	dispersed
M1	3.84	0.92	0.51	random
M2	4.82	1.26	0.04	dispersed
E5	6.18	0.91	0.43	random
Site 2				
W1	1.97	0.92	0.48	random
W4	2.15	1.65	< 0.001	dispersed
W3	2.25	1.46	< 0.001	dispersed
B3	4.37	0.90	0.26	random
W2	6.13	1.37	< 0.001	dispersed
B2	6.31	0.81	0.19	random
B1	10.30	1.25	0.001	dispersed

Fox movements

Seven foxes were captured and collared at Site 1, but the VHF signal of one fox was lost three days prior to bait distribution, so no data were recovered from this animal. Post-hoc appraisal of movements revealed that two foxes had no opportunity to encounter baits because their home ranges did not traverse any properties where baits were distributed during the expected lethal period (Figure 3). The median expected 7 day home range estimated across all foxes at Site 1 was 1.50 km^2 (IQR = 0.43) (Table 2). Twenty seven per cent of simulated circular 7 day fox home ranges at Site 1 did not intersect with properties that baited.

Twelve foxes were instrumented at Site 2, but one animal died of indeterminable causes four weeks before baiting commenced. The home ranges of the remaining 11 foxes traversed at least one baited property during the seven day lethal period. The collar on one of these foxes did not record any location fixes, but all six attempts to locate the source of its VHF signal after baits were distributed indicated that it was consistently using a woodland area that had been baited. The median expected 7 day home range of foxes at Site 2 was 2.79 km^2 (IQR = 4.70) (Table 2). Forty five per cent of simulated circular 7 day fox home ranges at Site 2 did not intersect with baited properties.

Figure 3: Estimated seven day post-baiting home ranges of foxes (95% MCP) at two sites near Dubbo, New South Wales. Home ranges delineated in red represent individuals killed by baits. The broken line (M1SW) represents a 100% MCP around six VHF position estimates for a single fox.

Table 2: Characteristics of 19 GPS-collared foxes and their tracking observations at two sites near Dubbo, New South Wales.

ID [A]	Wgt (kg)	Start date	Finish date	Location fixes	Seven day home range (km^2) [B]	Bait stations in 7 day home range	Fate 20 days after baiting
Site 1							
F1m	4.8	23/06/2012	11/08/2012	424	1.62	unknown	Alive
F2e	4.9	5/07/2012	11/08/2012	189	1.10	0	Alive
M3m	7.1	26/06/2012	2/07/2012	75	0.15	1	Alive
M4m	7.5	7/07/2012	11/08/2012	305	1.28	0	Alive
M5e	5.9	7/07/2012	11/08/2012	306	1.30	0	Alive
M1m	5.8	19/06/2012	11/07/2012	196	na	≥ 1	Dead, baited
M2m	5.1	22/06/2012	11/07/2012	na	na	na	Missing
Site 2							
F3w	4.0	27/01/2013	27/04/2013	505	0.43	1	Alive
F4w	4.4	30/01/2013	1/05/2013	521	0.68	2	Alive
F5w	4.7	31/01/2013	30/03/2013	340	1.04	3	Alive
F6w	4.7	2/02/2013	31/03/2013	406	11.11	18	Alive
M1w	6.5	28/01/2013	1/05/2013	0	na	unknown	Alive
M4b	5	14/02/2013	9/04/2013	457	0.35	0	Alive
F1w	3.6	24/01/2013	13/03/2013	236	8.70	17	Dead, baited
M3w	5.5	3/02/2013	21/03/2013	338	1.03	3	Dead, baited
M5b	6.2	15/02/2013	20/03/2013	235	0.09	1	Dead, baited
M6b	5.1	15/02/2013	25/03/2013	246	0.26	1	Dead, baited
M2w	7	3/02/2013	23/03/2013	367	10.65	6	Dead, unknown
F2w	4.5	25/01/2013	5/02/2013	71	na	na	Dead, before baiting

[A] F = female, M = male

[B] 95% MCP home range estimate for the seven day period commencing on the date that baits were distributed on the property that the animal was most frequently recorded on.

Survival

Five of the 17 foxes whose post-baiting fate was known died within four days of bait distribution; one at Site 1 and four at Site 2 (Figure 3). The remainder survived for at least 20 days, except one male at Site 2 which was presumed to have died 12 days after bait distribution when its collar, which had been cut off by an unknown person, was discarded. The carcass of this animal was not recovered so cause of death could not be established. The Kaplan-Meier estimate of the post-baiting survival rate across foxes that used baited properties at both study sites was 0.69 (95% C.I. = 0.494, 0.957, n = 16) (Fig. 4).

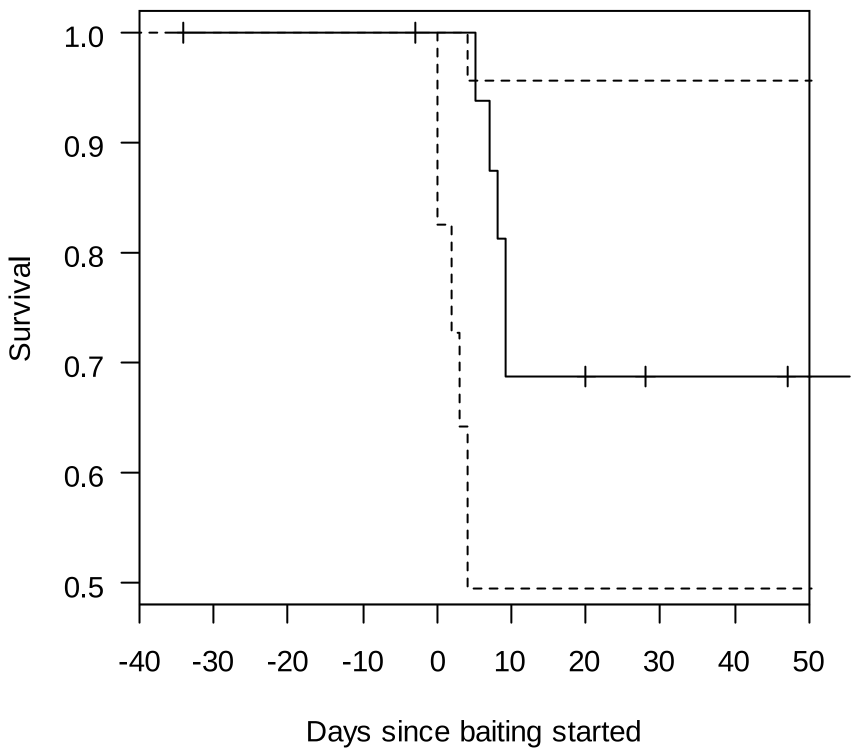

Figure 4: Kaplan-Meier survival function estimated from 16 radio-collared foxes subjected to poison baiting programs at two sites near Dubbo, New South Wales. Dashed lines represent 95% confidence intervals, and ticks represent points at which animals were removed from the study for reasons other than being killed by baits.

Camera surveys

Camera trap surveys revealed no consistent response of fox abundance to baiting. There was no detectable decline in fox abundance, averaged across all camera stations, at either site (Fig. 5). At Site 1, abundance averaged across all stations on baited properties was significantly lower than abundance averaged across stations on unbaited properties for the survey period immediately after baiting (Fig. 6) (t_{18} = 2.66, P = 0.007). However, this was due to an increase in average abundance at unbaited sites, rather than a decrease at baited sites. There were no differences between abundances from baited and unbaited properties for any other period at Site 1, or any period at all at Site 2 (Fig. 6).

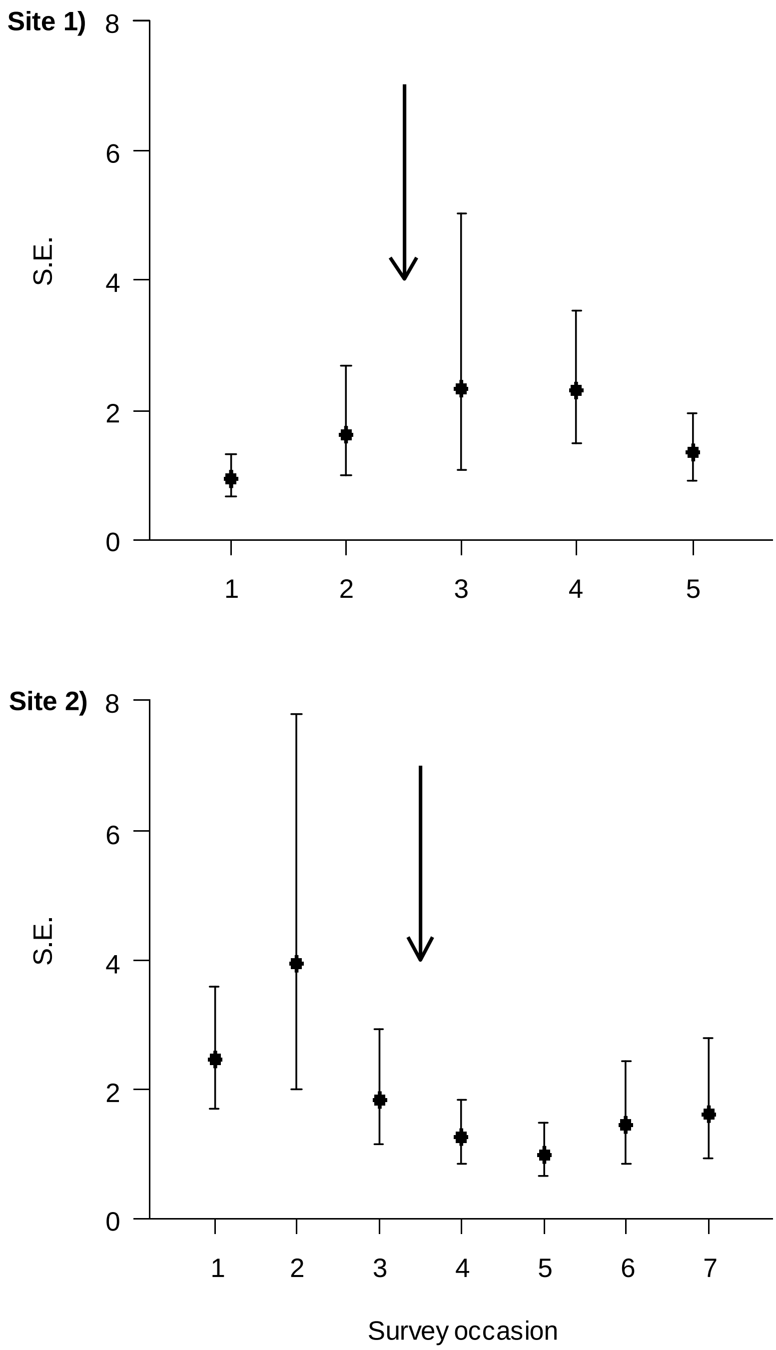

Figure 5: Average number of foxes (λ) using camera trap monitoring stations at two study sites, estimated over repeated 12-day surveys. Arrows indicate the commencement of coordinated fox baiting programs. Estimates and standard errors are back-transformed from a Poisson distribution.

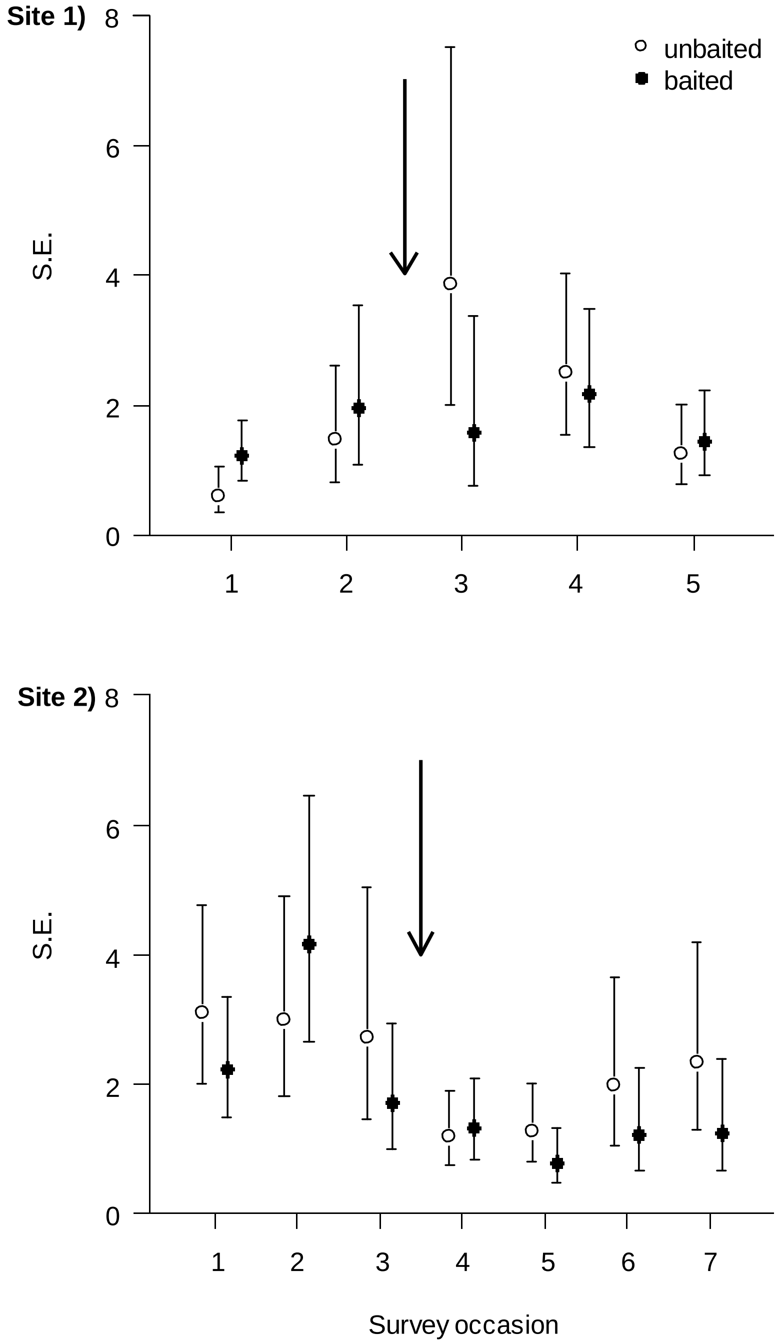

Figure 6: Average number of foxes (λ) using camera trap monitoring stations at baited and unbaited properties on two study sites, estimated over repeated 12-day surveys. Arrows indicate the commencement of coordinated fox baiting programs. Estimates and standard errors are back-transformed from a Poisson distribution.

Discussion

In many parts of Australia, baiting programs to protect lambs and other vulnerable resources from fox predation are conducted on an ad hoc basis by individual landholders with little coordination among neighbouring properties. However, the effects of isolated, infrequent programs on local fox populations are likely to be fleeting at best, because any individuals removed by baiting are likely to be quickly replaced by foxes from surrounding unbaited areas (Gentle et al. 2007b). The aim of coordinated baiting programs, such as those examined in this study, is to provide longer-lasting and more widespread population reductions by exposing a greater proportion of the local population to the risk of being killed as a result of bait consumption.

It is clear from a visual examination of the distribution of baited properties and the short term home ranges of collared foxes (Figure 3) that coordination among neighbours increases the numbers of foxes that would be exposed to baits, relative to individual properties baiting in isolation. However, 25 and 48 per cent of simulated fox home ranges did not intersect with baited properties. Morevoer, two foxes at Site 1 were unlikely to have been exposed to baits because their home ranges did not include baited properties during the seven days after baiting, even though they were originally trapped on properties that later baited. Consequently, substantial proportions of the fox populations at both sites were likely to have been insusceptible to the baiting program, despite the relatively high level of coordination among properties.

While it is important that baiting programs achieve a high level of coordination among neighbours, it is also desirable that bait coverage within properties is sufficiently dispersed to allow all foxes on those properties to access baits. This is highlighted by the small home range sizes of some foxes. Nearest neighbour analysis indicated that no properties exhibited clustered bait distribution patterns that could be expected to leave large unbaited gaps in properties. Nonetheless, the estimated seven day post baiting home range of two foxes whose home ranges were constrained within baited properties did not contain any bait stations. Consequently, these foxes probably had little opportunity to encounter baits, even though they resided entirely on baited properties during the period over which baits were expected to remain lethal.

In addition to an even spatial distribution of baits within properties, baits should be distributed at sufficient intensity to allow all foxes access to at least one bait, in the presence of competition for baits from other foxes (Thompson and Fleming 1994; Fleming 1997). Baiting intensity, in this sense, refers to the number of baits available per fox, and is a function of the density of foxes and of baits, as well as time. Ideally, each fox using a baited property would be able to encounter multiple baits, so that the cumulative probability of consuming a bait increases with the number of baits encountered. It was not possible to estimate baiting intensities during this study because we could not estimate absolute fox densities. However, previous studies in temperate farmlands during late winter and spring, when fox populations are expected to be close to their annual nadir, have produced fox density estimates of 1.3 to 1.9 foxes km^{-2} (Fleming 1997) and 4.6 to 7.2 foxes km^{-2} (Thompson and Fleming 1994). Using these estimates, the baiting densities observed in the present study would have provided multiple baits per fox only at the lowest population densities. At intermediate and high fox densities, there would be fewer than one bait available per animal (Table 3). Consequently, it is likely that even on baited properties, many foxes may not have had the opportunity to encounter and consume baits. This is particularly important at Site 2 which was studied in autumn, when fox population densities are expected to be greater than the lower estimates used here due to the seasonal nature of fox reproduction and population dynamics (McLeod et al. 2004; Saunders and McLeod 2007).

Table 3: The expected number of baits available per fox at each study using fox densities estimated from previous studies in similar landscapes. The intermediate fox density of 4.3 represents the median of the two cited studies.

Site	Median bait density		Fox density		
			1.3 [A]	**4.3**	**7.2 [B]**
1	3.0	baits per fox	2.3	0.7	0.4
2	4.4		3.4	1.0	0.6

[A] (Fleming 1997); [B] (Thompson and Fleming 1994)

The exposure of a large proportion of the targeted population to the risk of consuming a bait is a necessary first step towards achieving a meaningful population reduction. However, exposure alone is not sufficient. For an animal to be killed as a result of consuming a bait, it must: 1) encounter the bait; 2) choose to consume the bait; 3) be physically able to access and consume the bait; and 4) consume sufficient bait to ingest a lethal dose of toxin. A failure to complete any step in this sequence will prevent an animal from being killed (Bengsen et al. 2008). The present study has shown that many foxes that had bait stations within their home ranges failed to consume a lethal dose, and that well-coordinated and resourced baiting programs did not produce substantial, lasting reductions in the local fox populations.

In addition to the previously discussed low bait densities, other possible causes for the failure to convert high rates of potential bait encounter into substantial population reductions include: foxes not being attracted to bait sites, foxes not being enticed to eat baits once they discovered them, or the toxin content of baits degrading too rapidly for foxes to find baits and consume a lethal dose. It is impossible to estimate the extent to which these factors may have contributed to the survival of foxes on baited properties. Nonetheless, it is unlikely that baits were consistently unattractive or unenticing to foxes, because several landholders reported high rates of bait-take (> 80 %), particularly at Site 2. Bait attractiveness and toxin degradation may, however, have been a problem at a small number of properties where fresh meat baits were apparently not distributed until after several days of unrefrigerated storage. In these cases there is an additional risk that foxes may consume a sub-lethal dose of 1080. Many species appear to experience post-ingestive malaise after consuming sub-lethal doses of 1080, and individuals can subsequently develop persistent bait aversions (e.g. Sinclair and Bird 1984; Morgan et al. 1996). Foxes are capable of developing conditioned aversions to other substances presented in baits (e.g. Massei et al. 2003; Gentle et al. 2004; Baker et al. 2007), so ingestion of sub-lethal doses of 1080 might also induce persistent bait aversion that could render sub-lethally dosed animals behaviourally immune to future baiting programs.

Management implications

Theoretical studies suggest that lethal fox control programs need to achieve annual population reductions of about 65 per cent, on average, to prevent the surviving population from recovering at its maximum potential growth rate (Hone 1999). The failure of camera trap surveys at both sites to detect a meaningful decrease in the numbers of foxes using monitoring stations indicate that neither of the baiting programs was able to achieve this level of control. This is not surprising, given the high survival rate of collared foxes on properties that baited and the fact that baited properties represented less than 50% of each study site, which resulted in 25 and 45% of simulated fox home ranges having no access to baited properties. It may be unrealistic to expect baiting programs such as these to achieve sustained control of fox populations, i.e. a large reduction in population density followed by ongoing control to prevent recovery to pre-control levels. However, coordinated baiting has been conducted at these study sites for several years, and it is possible that the current twice yearly baiting regime is constraining fox densities below the environmental carrying capacity. This could only be tested by abandoning baiting at a number of sites and checking for increases in increases in fox densities over time, which is highly undesirable.

The results of this study graphically demonstrate that coordinated baiting programs involving groups of neighbouring properties have greater potential to achieve meaningful reductions in fox densities than programs conduction on individual properties. We therefore reiterate previous recommendations that landholders aiming to reduce the impacts of foxes on their enterprise should strive to involve as many of their neighbours as possible in simultaneous baiting operations (e.g. McLeod et al. 2010; Carter et al. 2011). Many producers already recognise this (Southwell et al. 2013), but in reality, some landholders will always be unlikely to participate in baiting programs for various reasons including the nature of their own enterprises or previous negative experiences with baiting (Allen 2008; Southwell et al. 2013).

It is also apparent that the full benefits of coordinated baiting may not always be realised, despite relatively high landholder participation rates. In particular, low bait densities and high rates of bait-take suggest that many landholders may not be deploying enough baits to target all foxes using their property. Optimal baiting densities will depend on many factors, most notably the density of foxes, but a density of 5 to 10 baits km^{-2} is likely to be suitable for most situations in Australia (Saunders and McLeod 2007). Observed average bait densities on most properties in the present study were lower than this recommendation, and well below the maximum of 20 baits km^{-2} allowed under current state regulations (NSW Government 2010). Given estimated fox densities on similar landscapes in eastern Australia (Thompson and Fleming 1994; Fleming 1997), and the small home ranges of some foxes in the present study, most properties in the present study would probably benefit from increasing the number of baits deployed. However, this remains to be tested. Finally, neighbouring properties should aim to deploy baits at the same time and refrain from distributing baits that have degraded and may contain a sub-lethal dose.

Conclusions

From this examination of the movements of individual foxes, and the responses of those foxes and broader fox populations to baiting programs, it can be seen that coordination of baiting actions across neighbouring properties is necessary to ensure that a large and contiguous proportion of the population is vulnerable to control. However, the timing and spatial distribution of baits within properties is also important, and even where it is impossible to increase the number of landholders participating in coordinated programs, substantial improvements in fox control might be achieved by improving baiting practices on those properties that do participate.

Success in meeting objectives

The project has met two of its three milestones. Progress towards the third is continuing.

Milestone 1: Estimate and describe responses of fox populations to baiting programs

This milestone was achieved with the analysis of camera survey data in June 2013. The survey methods used here provided a useful method of collecting data on site visitation by foxes. These methods have not previously been used to survey fox populations. The analytical methods provided a useful method for converting the survey data to an informative and flexible index of relative abundance. Future surveys in similar situations would benefit from using a greater number of monitoring stations to improve precision. This would allow surveys to detect smaller changes in abundance than was possible in the present study, although this study was mainly concerned with large, demographically meaningful changes.

Milestone 2: Estimate responses of individual foxes to baiting programs

This milestone was achieved with the retrieval of the final tracking collar in autumn 2013. The use of tracking collars to monitor the fates of individual foxes was very labour intensive, but provided the best means of achieving the objective and also provided a great deal of extra information on fox movements in the landscape relative to baiting activity. Survival analysis allowed extrapolation from the collared sample to the broader community, but a large number of foxes would be required if the aim of the project was to estimate small changes in survival with a high level of confidence.

Milestone 3: Communicate results and implications to public and private land managers

Communication of results to lamb producers, protected area managers and fox management facilitators has commenced with presentations to several fox baiting groups in the Dubbo region, as well as articles in the ‘Goonoo Fox Tales’ newsletter which is sent to over 100 landholders (Annex A).

More detailed communication and directed extension material will be possible once a peer-reviewed paper has been accepted for publication. Production of enduring extension material prior to peer review is undesirable because aspects of the analysis or interpretation of the results may change during this process. A peer-reviewed paper will also provide a definitive reference for extension material. A manuscript is currently being developed for submission to a journal, and a communication plan targeting producers, pest management facilitators and researchers has been prepared.

Assets created or acquired

Twenty GPS tracking collars and 20 remote cameras were acquired for the project. Cameras were purchased using funding from Meat and Livestock Australia.

Project materials created

Project materials created or arising include:

- Camera survey datasets from two sites, comprising 99,412 and 74,598 digital photos
- GPS tracking data from 19 foxes
- Tinn-R files detailing analyses used for the above data
- Hard copy bait distribution maps
- A field notebook detailing relevant information collected during fieldwork

All digital materials are stored on a desktop PC used by the senior author and a portable hard drive stored in the author's project file at NSW Department of Primary Industries. Hard copy material is stored in the project file.

Statement of expenditure

An audited statement of expenditure will be provided as soon as it is available.

Receipt of other contributions

The following direct contributions have been received from Meat & Livestock Australia, through NSW DPI:

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Annex A: Communication activities

Communications activities to date include:

Presentations to Central West LHPA District Fox Baiting Groups:

- February / March 2012
- June / July 2012
- February / March 2013
- June / July 2013

Interactive presentation and demonstration on foxes and their control to Conservation and Land Management students at Gilgandra TAFE campus, July 2012

“Tracking foxes to demonstrate the benefits of cooperative baiting” Newsletter article, Goonoo Fox Tales, July 2012. Distributed to over 100 landholders in the Goonoo region, near Dubbo.

“How many foxes are killed by baiting?” Newsletter article, Goonoo Fox Tales, June 2013. Distributed to over 100 landholders in the Goonoo region, near Dubbo.

“Predators brought down with baiting” Newspaper article, Daily Liberal June 2012