AN EXPERIMENTAL EVALUATION OF LAMB PREDATION IN RESPONSE TO FOX (*VULPES VULPES*) CONTROL IN SOUTH-EASTERN AUSTRALIA

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ABSTRACT: Fox predation has long been suspected as a major cause of lamb death in southern Australia. The response of farmers has been to poison foxes using sodium monofluoroacetate (compound 1080). This has become more widespread in recent years due to a number of factors including the reduced returns from sale of skins which has made shooting foxes unprofitable. In a replicated experiment we investigated the effect of fox control on lamb survival. Fox baiting was implemented at three levels; no baiting, baiting once a year before lambing (the recommended practice), and baiting three times a year. This was carried out on sheep properties with ultrasounded flocks over three years. The experiment was conducted in central New South Wales, Australia, in an area where wild dogs and native dingoes had been eradicated. Foxes, an introduced species, were the major mammalian predators of lambs in the district, as estimated from previous post-mortems of lamb carcases. No significant difference was detected in lambing, as measured by the number of lambs per ewe at lamb marking 8 to 10 weeks after birth, however, there was a significant effect of fox control on the number of healthy lambs killed by foxes assessed by lamb post-mortems. The possible reasons for this result are discussed including features of the experimental design and the level of replication.

KEY WORDS: fox, *Vulpes vulpes* (L), lamb predation, pest management, compound 1080

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INTRODUCTION

General perceptions can lead graziers and farmers to believe that lowering predator pest numbers lowers the impact on prey and as a direct result, stock survival rates will improve. This is described as the functional response with the extent of predation assumed to be determined by the product of predator abundance and the per capita rate of eating prey (Begon, Harper and Townsend 1996). It is also assumed that carrying out recommended pest control measures will reduce impact by reducing predator numbers. Neither of these perceptions are necessarily true. For example, cattle mortality was reduced after wolf (*Canis lupus*) control in Alberta, Canada (Bjorge and Gunson 1985), but the number of sheep killed by coyotes (*Canis latrans*) was not correlated with kills of coyotes in California (Conner et al. 1998).

Predation control may not require killing of the predator. The slope of the functional response may be changed by alternative methods of predator control such as the use of guard dogs (Andelt 1992) although this is not a common practice in Australia.

Some predator control methods may not be effective for a variety of reasons. These can include the target species not being killed, the target species recovering by compensatory breeding or survival, or the population becoming healthier and remaining in high numbers after a cull reduces intraspecies competition.

Even if predator numbers are reduced, it does not necessarily follow that impact is reduced. Breeding success of the hen harrier (*Circus cyaneus*) was not apparently influenced by the presence or absence of foxes (*Vulpes vulpes*) (Green and Etheridge 1999). The survival of a small number of individuals habitualized to killing a particular prey species could be responsible for a large proportion of the pest impact and these individuals may not be affected by the pest control program. There is some limited evidence that individual foxes become habituated to the killing of lambs (Rowley 1970). Such foxes may cause serious lamb losses in individual flocks (Turner 1965). Other predators could increase their impact with a reduction of interspecific competition (e.g., removal of dingoes [*Canis familiaris dingo*]) may enhance the survival of foxes (Jarman 1986). The decrease in predation may also be detrimental to the impacted species in a variety of ways including inducing population crashes brought on by density dependent effects such as disease epidemics or over utilization of resources.

Similarly, the control program may not reduce pest numbers sufficiently or rapid reinvasion may occur. With territorial animals like foxes, coyotes and wolves, territories made vacant by the control program may be filled rapidly by immigrants or dispersing young that would normally have died. Home ranges could increase in both size and carrying capacity in response to the deaths of neighboring groups, leading to similar predation pressure despite the fact that an effective predator control program had been implemented. The problem here is that effect is measured by the numbers of predators dead, not the desired end goal which is reduction of impact on prey species. These extremely complex relationships between predator, prey, other species and their environment can only be explored experimentally if the true picture is to be revealed.

In Australia, the red fox which is an introduced predator, has rightly or wrongly received notoriety for its predation on lambs. They are also implicated in the reduction of many native mammal and bird populations (Saunders et al. 1995) and are thought to be pushing some species such as the malleefowl (*Leipoa ocellata*), towards extinction (Priddel and Wheeler 1990). Predator control may dramatically aid conservation efforts in these instances.

Cats (*Felis catus*), feral dogs (*Canis familiaris*), and feral pigs (*Sus scrofa*) are also introduced mammalian predators that are making an impact on the Australian environment although only dogs (Rowley 1970; Fleming and Korn 1989), pigs (Pavlov and Hone 1982; Choquenot et al. 1997), and foxes (Rowley 1970; Lugton 1993) are known to prey on lambs. There are no marsupial predators that kill lambs in NSW, but some birds such as crows and eagles are implicated (Rowley 1970). In the absence of larger predators like coyotes (Conner et al. 1998), wolves (Meriggi and Lovari 1996), and jackals (*Canis adustus*) (Yom-Tov et al. 1995) that kill stock throughout the rest of the world, foxes are among the top predators in mainland Australia (Walton and Richardson 1989).

Opinions on the level of impact fox predation has on lamb production has varied over recent studies. It ranges from around 1% (Rowley 1970) based on post-mortems of lamb carcases, up to 20% on some properties where predators were controlled (Lugton 1993). Single flocks or small areas of country can have unique circumstances such as poor mothering ability related to breed and proximity of optimal fox habitat (Moore et al. 1966), both of which can lead to higher predation rates (Coman 1985). Lambs also die for a variety of reasons other than predation. In Australia, where almost all lambs are born in the open, starvation, mismothering, exposure, and disease are common causes of death (Jordan and Le Feuvre 1989). The level of impact that foxes have on the survival of viable lambs has long been recognized as requiring further research.

With the range of results describing the impact of foxes on lambs, NSW Agriculture has developed fox control recommendations aimed at minimizing impact. The recommended "best practice for fox control" uses buried meat baits containing sodium monofluroacetate (1080) laid prior to lambing. This has become more frequent in NSW and other parts of Australia during the last ten years despite the lack of reported evidence evaluating the effects of fox baiting on lamb survival, especially under the recommended practice (Saunders et al. 1995; Saunders et al. 1999). Defining the extent of a pest problem and the effectiveness of pest control are key components of a strategic approach to vertebrate pest management (Braysher 1993; Hone 1994; Saunders et al. 1995; Olsen 1998). The recommended practice has not been tested to evaluate if it optimizes fox control or if it reduces impact most effectively at a reasonable cost to the land manager. This paper describes an experimental evaluation of the recommended practice of fox control in NSW. It also provides a chance to consider the response variables monitored and the scale of field experiments required to recognize a significant response and avoid a Type II error due to variability even with tightly controlled site selection criteria.

METHODS

The project involved a large-scale population management experiment. Six sites were selected on five sheep properties near Boorowa (34028'S, 148032'E) and Murringo (34018'S, 148032'E) in N.S.W., south-eastern Australia. These properties grazed self-replacing merino flocks, primarily for wool production, so lamb survival was vital to the economic operation of the farm. Sites were selected on over 50 site selection criteria including lamb survival rates, ewe fertility and bloodline, sheep management practices, climate and habitat features that affect lamb survival, past fox control practices, and prey species. Sites were representative of most sheep farming properties in the region, but were also extremely similar in factors that affected fox abundance and ewe and lamb survival, thus minimizing variance between replicate sites. Wild dogs, dingoes (*Canis familiaris dingo*) and wild pigs were not present in the area, leaving foxes as the only mammalian predator of lambs.

Foxes were poison baited with 3 mg of sodium monofluoroacetate (1080) in manufactured meat baits, Foxoff Econobaits (Applied Biotechnologies). Baits were buried approximately 3 cm underground to avoid poisoning non-target animals and checked twice weekly for three weeks. Baits that had been taken were replaced and those subject to heavy rainfall were also replaced to ensure their level of 1080 remained sufficient to kill a fox. McIlroy and King (1990) determined that 2.5 mg of 1080 in meat baits was a lethal dose for a fox. Baiting was carried out in 1995 and 1996 at one of three baiting strategies with two replicates of each treatment. These treatment levels were no fox control (experimental control); baiting once a year before lambing (recommended practice); and baiting three times a year (expected to be the maximum level farmers would carry out). Fox control programs were carried out over the experimental units and adjacent buffer zones covering approximately two fox territories around the lambing paddock under study. Fox territories sizes were based on mean home range (6 km^2) of foxes in similar habitats (Coman et al. 1991), and neighboring farmers took part in a group baiting program as part of the recommended fox control practice as described by NSW Agriculture (Korn and Lugton 1995). Synchronized lambing with neighbors was a further recommended practice to reduce fox predation that was carried out on these sites. Lambing occurred during a 6 to 8 week period in late winter on all sites and on many surrounding properties so a surplus of lambs was available to foxes over a relatively short time. Flocks of approximately 1000 mature ewes, having lambed previously, were ultrasounded on each site 8 to 10 weeks prior to lambing to determine the expected number of lambs. Lambs surviving to marking (tail docking and ear tagging), 8 to 10 weeks after lambing, were monitored.

The benefits of fox control were measured directly as enhanced lamb survival derived from differences in lamb marking rates between ultrasound scanned flocks. All forms of lamb mortality were also monitored so that fox predation could be differentiated from other causes. This involved intensive surveys of flocks at lambing using established techniques (Rowley 1970) for determining causes of lamb loss including other predators. Lamb deaths from all causes were recorded. Healthy lambs that had not utilized their fat stores, had milk in their intestines and no other contributing causes to death apart from evidence of fox attack were classified as type 1. Some lambs killed by foxes did not have any internal organs remaining so contributing factors like starvation or mismothering could not be determined. These were known as type 2 lamb deaths. Fox predation with contributing causes such as birth trauma, or the utilization of the lamb's fat stores as a result of exposure or mismothering, were recorded but are not considered in this paper. The response variables, lamb marking results and post mortem results, were examined using a Repeated Measures (REML) analysis (Genstat Committee 1993).

The response of the fox population to poison baiting was monitored by spotlight counts before and after the baiting period. Spotlighting was carried out over three nights as described by Weber et al. (1991) and Greentree et al. (In press). A one way ANOVA investigated changes in this index of the fox population. Initial fox density estimates, in July 1994 before fox baiting or lambing began on all sites, were calculated using DISTANCE (Buckland et al. 1993; Laake et al. 1994) as the density of foxes/km^2.

RESULTS

Fox densities in 1994 at the beginning of the study are presented in Table 1. There were no significant differences in initial fox abundance as measured by spotlight indices ($F=0.452$; df=2,3; $P>0.25$) between experimental sites. Similarly, there was no significant difference in the number of foxes counted by spotlight index as a result of fox baiting on the log transformed index of pre-baiting fox abundance in Spring 1995 and 1996 (Wald statistic=3.9, df=2, $P>0.25$).

Table 1. Initial fox density estimates 1994 calculated by DISTANCE (Buckland et al. 1993; Laake et al. 1994)

Level of Fox Control	Density of foxes/km^2	CV
None	4.0	14.3
	4.1	19.0
Once Per Year	4.0	17.2
	2.3	17.2
Three Per Year	6.0	15.2
(Maximum)	5.5	20.3

The number of lambs per 100 ewes at lamb marking in 1995 and 1996 are shown in Table 2. There were no significant effects of fox control on the number of lambs per 100 ewes at lamb marking (Wald statistic=1.3; df=2; $P>0.50$). Thirty-five replicates would have been needed to detect significance of the effect of fox control on lamb marking results between the maximum and no control treatments based on observed means and standard deviations as calculated from Krebs (1999, p. 235).

Table 2. The mean number of lambs alive at lamb marking as a percentage of the number of ewes at marking.

Level of Fox Control	1995	1996	Means
None	103.1	118.2	110.7
Once per year	119.6	98.8	109.2
Three per year (Maximum)	119.5	116.5	118.0

There was a significant effect of fox control on the percentage of carcases classified as killed by foxes, type 1 (i.e., potentially viable lambs) (Wald statistic=6.1; df=2; $0.025<P<0.05$). Adding together type 1 and type 2 deaths gives the maximum possible number of healthy lambs killed by foxes, although some of the type 2 deaths could have died even in the absence of fox predation. Again, there was a significant response to fox control in type 1 + type 2 deaths (Wald statistic=12.5, df=2, $P<0.005$). The mean minimum fox predation of potentially viable lambs, type 1 deaths, as a percentage of all carcases collected, for no treatment sites and maximum fox control sites is shown in Figure 1. The mean maximum number of lambs killed by foxes, type 1+2, under no treatment and maximum control strategies as a percentage of all carcases collected is presented in Figure 2.

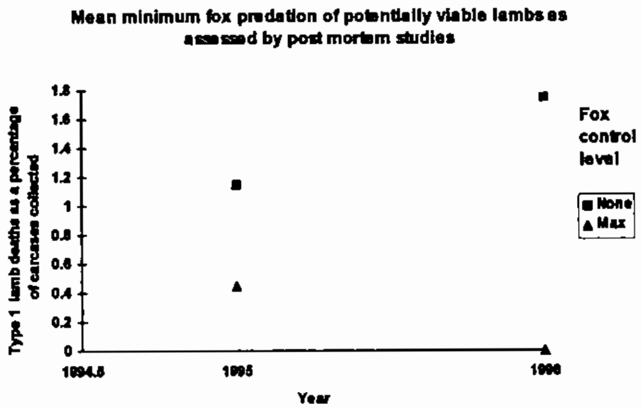

Figure 1. Type 1 lamb carcases as a percentage of carcases collected in 1995 and 1996 on maximum and no treatment sites.

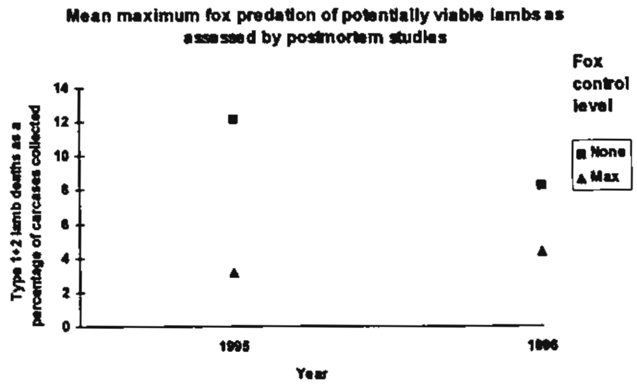

Figure 2. Type 1+2 lamb carcases as a percentage of carcases collected in 1995 and 1996 on maximum and no treatment sites.

DISCUSSION

Unlike sheep kills by coyotes (Conner et al. 1998) which showed no correlation between numbers of sheep killed and number of coyotes removed, the number of lamb kills did change in response to a fox baiting program in this study. Both the minimum and maximum number of lamb deaths attributable to foxes showed a significant effect of fox control, however, lamb marking results failed to show a similar response to fox control. There were no significant effects of fox control on the log transformed index of pre-baiting fox abundance in spring 1995 and 1996. This may have indicated that no long term effects of fox control on fox numbers occurred or possibly that the changes were not detectable in spotlight counts where not every fox is seen.

Fox numbers were not reduced sufficiently to influence overall lamb survival, but the significant post mortem results suggest that some response to fox control was occurring. It is considered likely that the impact reduction was masked by variations in lamb survival as affected by factors other than fox predation. Many more replicates or response variables may have detected a significant result or there may have been no response of the lamb population to fox baiting. Farm management practices, climate, and other variables probably had a larger effect on lamb survival than fox control. This is to be expected, but with over 50 site selection criteria standardized between sites and lambing synchronized to begin within two weeks on all sites it was expected that these other factors would have similar effect on all sites. In experimental field studies, variation even between otherwise similar sites can still be high.

Based on the results of this study, farmers should consider fox baiting within their complete farm management program. When flock management is good and lambs survive, fox control may return benefits at shearing, breeding, or sale. If flock management is poor, the lambs saved from foxes by a baiting program will probably not live to sale or shearing because of other causes. The outcomes of this experiment tend to support Rowley's (1970) findings of the impact of foxes on healthy lambs, and quantifies the response of lambing results to fox control when farm management is in accordance with the recommended practices. Variations in the application of these practices and the lack of an experimental control may account for the differences between these results and those of Lugton (1993). Small changes in pest impact, although difficult to detect, may be environmentally and economically significant. Highly productive farms or stud stock may benefit more from implementation of fox control. If predation is the major threatening process, then saving a threatened species from predation at a vulnerable period of life is vital. The need for increased replication and monitoring of multiple response variables, as identified in this particular experiment, could be applied to a variety of predation studies. In addition to allowing the pressure of predation to be detected, multiple response variables can indicate where an interaction of factors needs investigation. Priddel and Wheeler (1990) reported an increase in malleefowl survival after an intensive fox baiting program was undertaken, however, food became a similarly important limiting factor in chick survival when foxes were absent. This gives a clear indication that foxes are a cause of population decline, but other factors limit population growth when predators are absent. Similarly, this could explain why harrier hen breeding success was not apparently influenced by the presence or absence of foxes (Green and Etheridge 1999). Perhaps foxes are only one limiting factor to breeding success as was the case with malleefowl. Would examining a wider range of response variables help clarify the situation? In the case of lambs, the lack of a detectable response in lamb marking results when compared to the lamb post-mortem results, would indicate that other factors are also limiting population growth. Applying this to a threatened species such as the malleefowl, if direct measures of predation, like post-mortems, show a response, but population estimates do not respond when many replicates are used, then other threatening processes are indicated. This interaction is even more difficult to detect if just one response is measured and when replication is limited and it is almost impossible to determine if experimental controls are absent. In summary, we suggest that studies aimed at assessing the impact of predation may need to be carried out on a very large scale and assess a wide range of response variables in order to investigate relationships between predators and their prey and their responses to management decisions.

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