National Feral Animal Control Program

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DEPARTMENT OF AGRICULTURE, FISHERIES AND FORESTRY

EFFECTIVE IMPLEMENTATION OF REGIONAL FOX CONTROL PROGRAMS

LYNETTE McLEOD, GLEN SAUNDERS, STEVE McLEOD AND MICHELLE WALTER

VERTEBRATE PEST RESEARCH UNIT
NSW DEPARTMENT OF PRIMARY INDUSTRIES

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PART A: PROJECT OUTLINE

1. PROJECT INFORMATION

1.1 Project Name
Effective implementation of regional fox control programs

1.2 Details of Applicant
(a) Organisation Details

Vertebrate Pest Research Unit (VPRU),
NSW Department of Primary Industries (DPI)
Orange Agricultural Institute
Forest Road, Orange NSW 2800

(b) Project Officers

Michelle Walter — Project Officer (Jan 04 – Feb 05)
Lynette McLeod — Project Officer (Feb 05 – Jun 07)
Tel: 02 6391 3953
Fax: 02 6391 3972
Email: lynette.mcleod@dpi.nsw.gov.au

(c) Project Supervisors

	Glen Saunders	Steven McLeod
Tel:	02 6391 3890	02 6391 3810
Fax:	02 6391 3972	02 6391 3972

Email: glen.saunders@dpi.nsw.gov.au
steven.mcleod@dpi.nsw.gov.au

(d) Other Project Staff (NSW DPI)

Neil Harrison — Technical Officer
Remy van Ven — Statistician

1.3 Collaborators / Third Parties
Collection of data for this project involved constant involvement with individuals and organisations responsible for land management and in particular vertebrate pest control, including the Rural Lands Protection Boards, National Parks and Wildlife Service and Forests NSW. The shooting aspects involved collaboration with the Game Council of NSW and Sporting Shooters Association of NSW.

1.4 Period of Project
Commencement date: 1/7/03 Completion Date: 30/12/06

1.5 Project Objectives
- Monitor the effectiveness of the 'Outfox the Fox' baiting program using combinations of landholder perceptions and detailed measurements of production values and fox populations.
- Determine the appropriate levels of fox control (baiting strategy) which will achieve production benefits which can in turn be used to derive control effort/damage relationships.

- Evaluate/model likely outcomes from the combined effects of bait caching and bait degradation.
- Conduct field evaluations of shooting as a means of reducing agricultural impact and compare with 1080 baiting for cost/benefit purposes.
- Conduct desktop feasibility studies on alternative fox management strategies.
- Based on outcomes, further refine best practice fox management strategies on agricultural lands.
- Through participatory learning and education, ensure adoption of modified strategies by relevant organisations and land managers.

1.6 Acknowledgements

Thanks to all the landholders and fox shooters who took the time to fill in and return their questionnaires. Sincere thanks to the rangers and office staff from the five participating Rural Lands Protection Boards of Dubbo, Forbes, Molong, South Coast and Young – especially Lisa Thomas, Rhett Robinson, Brad Hazell, Colin Somerset, Andrew Miners, Marne Wood, Ron Duggan and Michael Hayes - for their cooperation, assistance with collection of questionnaire data and identification of properties for the spatial mapping. Thanks also to Damien Monahan and Jason at South West Slopes Noxious Weeds for the use of their mapping database. Jason Neville from NSW National Parks and Wildlife Services, Matthew de Jongh from Forests NSW and Barbara Mathie from Landcare Illawarra provided data and assistance. Adam Leto and Boyd Mackinnan from Sporting Shooters Association NSW, and Nikki Tremain, Stacey Ellice and Brian Boyle from the Game Council NSW helped with the promotion and distribution of the fox shooting questionnaire.

1.7 Conclusions from this study

- Fox baiting on neighbouring properties has a significant impact on a property's lamb production. As the proportion of near neighbours who bait with a group increases, so to does lamb survival on the individual property.
- Baiting twice a year, approximately six months apart (to impact on fox breeding and dispersal), by either a property and/or its near neighbours also significantly enhances that property's lamb production.
- It is more beneficial for a property to time its baiting with a group of near neighbours up to a few months prior to lambing than baiting alone just before lambing.
- Group baiting programs such as 'Out-fox the Fox' increase the number of landholders baiting with a group and can increase landholder involvement outside of their lambing period.
- Continual and effective promotion of group programs is required to maintain the landholder support required to be successful.
- Bait replacement, especially in the initial stages, and collection of baits not taken at the end of a baiting campaign are important procedures to follow to minimise the number of sub-lethal baits in the environment, and hence reduce the risk of development of bait aversion in foxes.
- 1080 ground baiting is generally more cost effective than shooting in terms of the cost per fox killed. Although shooting by both recreational and professional shooters, can be a successful alternative in areas where

foxes will not succumb to baiting, 1080 baiting is not feasible, or where baiting is not a preferred option.

- Group shooting programs can be just as successful as group baiting programs. The key to success involves incorporating as large an area as possible and conducting regular (twice a year) control programs to maximise the effectiveness.
- Lethal techniques look set to retain their importance in fox management in Australia in the foreseeable future, especially for broadscale application.
- There is no alternative to 1080 as a toxin in the short-term, however para-aminopropiophenone (PAPP), may be an alternative in the longer-term.
- The importance of non-lethal techniques will increase if the techniques can be improved and refined. Ongoing research is mandatory if these additional methods of fox control are to be adopted.

2. PROJECT DESCRIPTION

2.1 Background

The European red fox (*Vulpes vulpes*) is a major pest in Australia threatening a range of native fauna and preying on livestock, in particular lambs (Saunders et al. 1995). Despite intensive efforts to control this pest, it remains numerous and widespread. Land managers aim to control the impact of foxes primarily through lethal baiting (using sodium fluoroacetate, hereafter referred to as 1080), shooting, trapping den fumigation, den destruction exclusion fencing, and using guard animals such as alpacas and dogs (Saunders et al. 1995). There has been an exponential increase in fox control, particularly through lethal baiting in the past decade (Saunders and McLeod 2007).

It is well documented that the fox is a major threat to a range of native fauna but although it is known to prey on livestock the economic impact of fox predation on agricultural production is not clear. Fox predation has been reported on piglets, calves, cows in birthing difficulties, deer, ostrich and emu chicks, and free-range poultry, including chickens, ducks, geese and turkeys, however the principle losses are believed to involve newborn lambs and kids. The predation rate on otherwise viable lambs is subject to controversy. Past surveys (e.g. Rowley 1970, Holst et al. 2002) indicate that the biggest single factor in lamb loss is associated with the birth process or as a result of poor maternal care; predation causing the death of an otherwise healthy lamb is of only minor significance. Rowley (1970) points out that most of the important factors involved in poor lambing percentages are inconspicuous, whereas damage inflicted by predators is usually highly visible, commonly leading the sheep-owner to overestimate the importance of predators. Loss of lambs due to foxes scavenging on lambs that died from other causes confounds the effect of lamb predation by foxes.

Studies into the effect of fox predation on lambs in Australia show a range of results from a minimum 0.8% of lambs in south-eastern Australia (Greentree et al. 2000), up to 30% of lambs affected in western NSW (Lugton 1993).The study by Greentree et al. (2000) was the first replicated experimental manipulation of fox populations aimed at deriving the extent of fox predation on lambing flocks at a property scale. The study was conducted around Boorowa in the central ranges of NSW and demonstrated that lamb production may not necessarily be improved by current fox management strategies. There were no significant effects of fox control (no control, and baiting conducted once and three times a year) on lamb marking percentages. However, significant reductions in the incidence of predation were related to higher levels of control. The effect of fox control on lamb marking percentages may not have been detectable due to the other more frequent causes of lamb mortality such as starvation, or because the study was on a relatively small scale and foxes were reinvading the sites. Gentle (2005) modelled the potential for fox immigration after typical group baiting campaigns in central NSW and found that the spatial coverage and frequency of baiting were inadequate to prevent fox re-invasion. These results raise concerns about the current conventional methods of baiting programs and their efficacy.

Another study by Linton (2002) on fox control was conducted in South Australia throughout different agricultural regions using 500 km^2 cells. She used questionnaires to collect data from landholders and found that sheep producers with low lamb marking percentages (50-80%) achieved gains of up to 35% after group fox control while producers with high lamb marking percentages achieved negligible gains (<10%) after fox control. Linton (2002) found that lamb marking percentages were high on properties that did not bait if neighbours baited: she therefore hypothesised that fox control was having an effect at a scale larger than a property. There was also a linear distribution between baiting distribution and lamb marking percentages (Henzell pers. comm. 2002). Where there was no bait usage over a 500 km^2 cell in any year, lamb percentages were 79. When bait usage was approximately 1400 baits per 500 km^2 (or 2.8 baits km^2) lamb percentages were 95. There are limitations to the inferences that can be made from the study due to inadequate replication.

A possible explanation for the discrepancies between the studies by Greentree et al. (2000) and Linton (2002) is the scale at which they were conducted and analysed. The Greentree et al. (2000) results were based on short-term data collected on a property-size scale, whereas Linton (2002) was based on a regional scale, and data collected over a longer time frame. Although both studies identified factors other than fox predation that could influence lamb marking percentages (ewe nutrition at joining, dystocia, exposure, starvation and mismothering), these would have had more influence in the short term (and thus more influence in the Greentree data) than on the longer term data. Other explanations are that the studies had different approaches (experimental versus adaptive management), there were differences in the response between sites, or other factors influencing lamb marking percentages confounded results.

The evaluation of fox control on agricultural lands in Australia still mainly relies on anecdotal or unpublished information to sustain the notion that ongoing control campaigns produce positive cost-benefits. Monitoring of the outcomes of management programs is an important aspect that is often overlooked (Braysher 1993, Walker 1998), mainly because of the difficulties in collecting and quantifying data, such as lambing percentages, on the impact of foxes in agricultural enterprises. Monitoring methods currently used in agricultural programs measure variables such as participation rates, number of baits laid, and area baited (mapping) (e.g. Pollard 2000), and often includes some measure of the change in relative abundance of foxes over time, (e.g. spotlight counts or bait uptake), despite there being no known consistent relationship between fox densities and the amount predation on livestock (Saunders and McLeod 2007).

A number of studies evaluating the instantaneous efficacy of fox control on reducing fox abundance have been published (Saunders and McLeod 2007, and references therein). In summary, most successful aerial baiting campaigns require a baiting rate five times that of fox density, and ground-baiting programs were successful in conjunction with long free-feed periods. There have been examples of intensive baiting programs conducted over long-periods which have significantly reduced fox populations. It is not clear whether conventional agricultural fox baiting programs sufficiently reduce fox abundance, or more importantly whether there is sufficient reduction on the impact of foxes on lamb production.

Owing to the difficult nature of quantifying the benefits of fox control, cost effectiveness analysis has been used as a measure of efficiency of fox control (e.g. Hone 2004, McLeod et al. 2004, Moberly et al. 2004, Gentle 2005). The economic evaluation of Jones et al. (2005) was the first attempt to evaluate a large scale fox baiting program (‘Outfox the Fox’), using benefit–cost analysis. The lamb industry was identified as the main beneficiary of this group fox control program (it was assumed that lamb production increased between one to five percent as a result of this fox control) and, according to the results from the economic surplus model, the change in annual economic surplus due to this program was $3.4 million. The benefit–cost analysis showed that the project provided a significant return on public investment with a mean net present value of $9.8 million and a mean benefit–cost ratio of 13:1. Probability analysis indicated there was a very low probability that this group fox control program would provide a negative economic return.

Most of the scientific evaluations on control impact and efficacy on agricultural lands are based on the results from trials focussed on lethal 1080 baiting. It is questionable how much these evaluations reflect the outcomes of the majority of agricultural fox control programs as they are conducted mostly by government agencies using high levels of resources and non-representative techniques. Although the use of lethal 1080 baits is the most common control action used against foxes (77% of all control actions in NSW during 2004 – West and Saunders, unpublished data), shooting can also play an important role (13% of control actions), but so far has not been included in any scientific evaluation of fox control strategies.

Shooting is becoming an increasingly popular control strategy employed by landholders. Large numbers of animals are being shot with little or no documentation of how it is being done or the impact on production values. Most shooting is being conducted at a property level where outcomes could be potentially similar to those of the Boorowa experiment. The effectiveness of this control technique needs to be further evaluated in line with other methods of control.

2.2 Project Outcomes

- Improved effectiveness of existing and ongoing fox management programs particularly where group control is promoted.

- Identification of potential alternative fox management strategies and a research protocol for the evaluation of these strategies.
- The continued environmentally sound and safe use of 1080 for fox control.
- Publication of suitable extension material.

2.3 Methodology

The main components of this project involved observational studies of ongoing fox management projects. No direct manipulation or experimental field work was involved. Data was collected from participants using legislative records and postal questionnaires. The other components of this project involved desktop reviews of available literature (alternative strategies), and the modelling of existing experimental data (bait caching and bait degradation).

2.3.1 Questionnaire Design

Questionnaires or surveys are a popular method for collecting data from a specific target population and are becoming increasingly popular in ecological studies (White et al. 2005). The selection of sampling procedure depends on the research hypotheses, the characteristics of the target population and what information needs to be collected. Most commonly a subset of the target population is approached to provide information which can be analysed to test the research hypotheses.

There are several different methods of data collection with postal questionnaires one of the most popular. Postal questionnaires are a cost effective way of reaching a large number of participants however they are susceptible to low response rates and sampling bias (White et al. 2005). There are many techniques in the literature to reduce the errors inherent in the use of these types of questionnaires including improving questionnaire design, combination of survey methods, offering incentives, gaining the trust of the respondents and cross-checking response data (e.g. Asch et al. 1997, Edwards et al. 2002, Anon 2007).

The data required for this project; agricultural production figures such as lambing percentages, and fox shooting figures, can be most simply collected from participants using questionnaires. The sampling technique involved calling for participants from the target population (volunteer sampling). Volunteer sampling in questionnaires has many inherent problems. One major problem is determining how representative the respondents are of the larger population (List 2002). There are several methods to check or reduce this uncertainty including doing random surveys or ensuring the response rate is high from all sections of the target population. Stressing the importance of the study with a persuasive covering letter, making the participants feel their contribution is valued and gaining the trust of the participants were all important to ensure a high response rate.

A postal questionnaire was the survey method chosen for both the collection of lamb production data and fox shooting data, because it is a cost effective way of reaching a large number of participants across a large geographical area (White et al. 2005). The questionnaires were carefully designed to eliminate measurement and non-response errors. As most of the information required was of a factual nature, the questionnaires contained mainly closed-format questions to eliminate uncertainty. The collection of factual type data can be susceptible to respondent's biases so the accuracy of data collected from both questionnaires was assessed against data collected by alternate means where possible.

Non-response bias was quantified in both cases by demonstrating non-respondents were not substantially different from respondents. As follow-up surveys of non-respondents were not feasible in both cases, the degree to which the respondents were representative was assessed by comparison of relevant characteristics with those of the target population.

To further improve the design of both the questionnaires, they were piloted on a sub-sample of participants. This allowed the opportunity to gauge the responses, and correct any questions that were ambiguous or open to misinterpretations. From these pilot studies it was possible to gain an idea of the variance that would be expected and to in turn calculate the sample size needed for the main survey that would be sufficient for statistical analysis.

PART B: EFFECTIVENESS OF CURRENT BAITING STRATEGIES

1. INTRODUCTION

Large-scale fox control programs have been advocated to give more chance of long-term respite from predation damage while maximising the efficiency and cost-effectiveness of the control program (Saunders et al. 1995). During the 1990s, large-scale fox-baiting programs, involving liaisons and cooperation between private and government agencies, were promoted and embraced in all areas of Australia, for both conservation and agricultural purposes. In NSW, large coordinated group fox control programs have become popular in both agricultural and conservation areas. These group programs are structured to the strategic goals of minimising agricultural production losses caused by invasive agricultural pests; promoting responsible and timely chemical usage; developing working liaisons with Rural Lands Protection Boards (RLPBs), other agencies and landholders; forming regional pest management groups; and promoting agricultural sustainability and protecting the natural environment. One such program is the ‘Outfox the Fox’ program.

1.1 Outfox the Fox

‘Outfox The Fox’ is a strategic, coordinated fox-baiting program promoted and operated through the NSW RLPB system. The program began in September 1999, with 700 landholders from six boards participating. Since then Board and landholder participation has increased, along with involvement from NSW National Parks and Wildlife Services, State Forests, and the Crown Land and Reserve Trust. In 2007 twelve Boards participated, with an estimated 25% of the state’s pastoral regions being covered. Because foxes are not declared pest animals in NSW (no legal requirement to control), the RLPBs see their involvement as a service to all ratepayers.

The main aim of the program is to get as many landholders strategically fox baiting over as large an area as possible, to protect young stock by reducing fox numbers and the rate of fox immigration. The program aims to improve the efficiency and cost-effectiveness of landholder 1080 fox-baiting practices by promoting best practice techniques. These techniques are specifically to:

- synchronise baiting within a control group
- bait at least twice a year
- bait during periods when the fox is most susceptible
- regularly check and replace baits that are taken
- continue the baiting program until bait take declines.

‘Outfox the Fox’ targets two set times of the year when foxes are thought to be susceptible to bait placement: March–April, when juvenile foxes disperse from their natal dens to seek their own territories, and August–September, when vixens require additional food (pre- and post-whelping). Both these times also coincide with critical lambing periods; important for lamb producers.

Initially, monitoring of the program involved participating landholders completing a questionnaire to assess the adoption of the best practice techniques and any gaps in extension (Balogh et al. 2001). The landholders were surveyed at the commencement of the program (September 1999) and then again in autumn of the following year. Results from this questionnaire showed that the baiting program had been successful in raising awareness and participation, particularly in group baiting. However several deficiencies were highlighted in the adoption of the best practice baiting techniques, demonstrating the need for improvement in the extension information provided to the participants (Balogh et al. 2001).

In more recent years, promotion and monitoring of the program has been left up to the individual RLPBs and their rangers. Most boards measure the success of the program by the number of participants, or groups involved in baiting, along with landholder comments and personal observations. Some boards also conduct fox population counts in small areas. These are usually associated with local conservation projects (e.g. mallee fowl in Dubbo RLPB—de Jongh et al. 2005; bush stone-curlew in Forbes RLPB—Hazell 2005). Monitoring of best practice baiting techniques has not been continued. The outcomes of the program, in terms of changes in production values have never been adequately monitored.

2. OBJECTIVES

The objectives for this component of the project were to:

- Monitor the effectiveness of the 'Outfox the Fox' baiting program against its aims of promoting group baiting and baiting twice a year during periods when the fox is most susceptible.
- Determine the appropriate levels of fox control (baiting strategy) which will achieve production benefits which can in turn be used to derive control effort/damage relationships.

3. METHODS

3.1 Study Area

The study area was located in the central west of New South Wales focussing on the four Rural Land Protection Boards (RLPBs) of Molong, Forbes, Young and Dubbo (see Figure B3.1), who all are participants in the Outfox the fox program. This region falls within the 'Uniform Rainfall- Temperate Climatic Zone' (Bureau of Meteorology 1986), which is characterised by mainly reliable rain and warm to hot weather in summers, and mainly reliable rain and cool to cold temperatures in winter. The Great Dividing Range is in the east and extends into lower plains in the west. Median annual rainfall increases heading west to east and is generally between 400-800 mm but higher in some areas in the east. Elevation ranges from about 200–900 m above sea level with a few higher peaks up to 1350 m in the east. The main agricultural enterprises in the region are merino wool, prime lamb, beef cattle production, and cropping. Vegetation consists of open improved pastures with remnant vegetation mainly consisting of dry sclerophyll forest and woodland. The study area covered 5.6% of the area of NSW (4,694,607 ha) and in 2005, contained 20% of the sheep in NSW (5,448,787 out of 26,698,537 sheep) (Rural Lands Protection Board 2005).

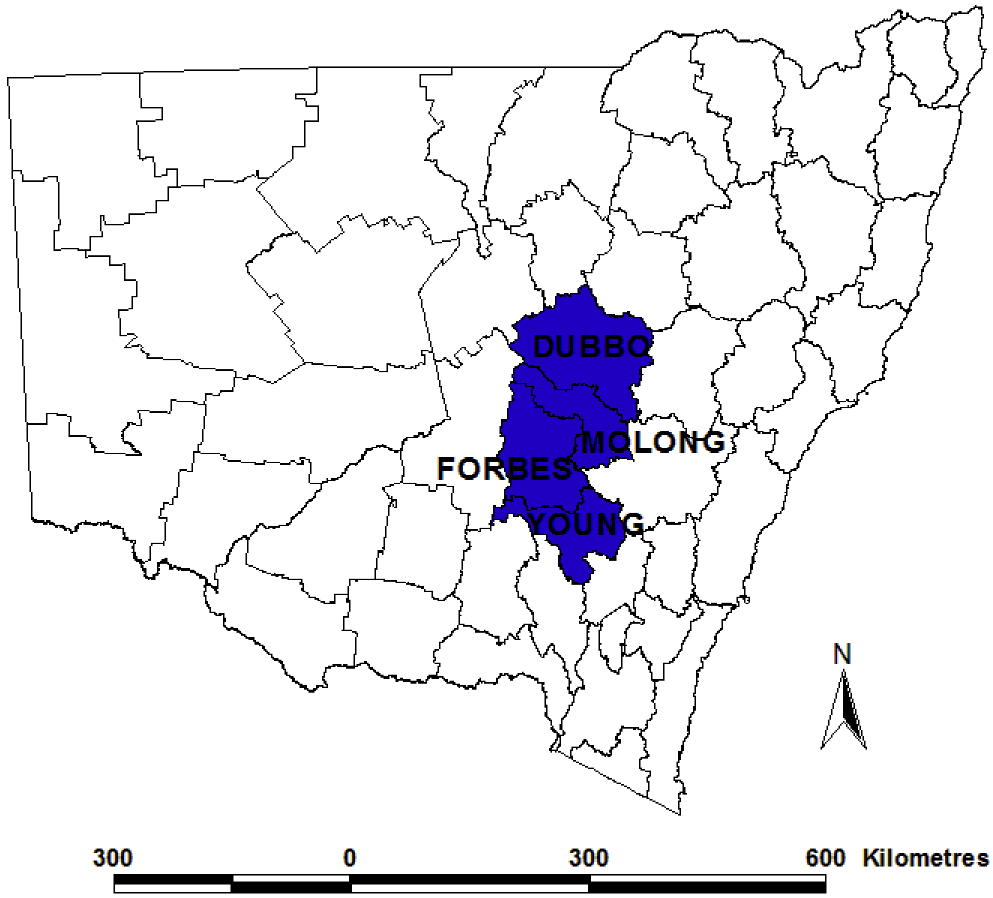


Figure B3.1: The study area showing Dubbo, Molong, Forbes and Young Rural Lands Protection Boards boundaries.

3.2 Data Collection

3.2.1 1080 Poisons Register

In NSW, 1080 is tightly controlled under the *Pesticides Act 1999*, as well as by Commonwealth legislation. Only Authorised control officers, usually employees of RLPBs or government agencies such as NSW DPI and NPWS, are allowed to obtain, handle, prepare and supply 1080 prepared baits. A 1080 Poisons Register must be kept by each agency that handles 1080. This register contains the names and property identifier of all landholders or agencies who have collected 1080 baits for the use on their land. It also records the bait type, quantity of baits, target species and date collected. Landholders who baited in a group are also indicated.

With the cooperation of each of the participating boards, all of the data from the NSW poison register of 1080 use was collected for the experimental period between 1998 to the end of 2005. The Boards also made available their ratepayers' property information including cadastral information and property identifiers so that bait users could be linked to the GIS mapping program. This GIS information was used in the analysis to ascertain the proximity of properties to each other. As information was unavailable as to what sections of the property were actually baited, it was assumed that baits were laid across the entire property.

3.2.2 Lamb Production Data

A standard measurement of lamb production that is recorded by producers is the lamb marking percentage; defined as the number of lambs that survive to lamb-marking, divided by the number of ewes joined. At the large scale that this study was operating, this figure was the only feasible variable of lamb production that was able to be collected across the four participating boards.

The most economical method to collect the large amount of lamb production data from lamb producers across the four boards was by means of a simple questionnaire (see Appendix I). The project did not have direct access to landholders contact details from the RLPB because of privacy issues, so the questionnaire (with postage paid return envelope) was included in the annual RLPB stock returns mail out. Initially it was hoped to mail these questionnaires just to lamb producers but obtaining a separate list was difficult, so the questionnaire was distributed to all ratepayers in the Dubbo, Forbes, Molong and Young RLPBs in June 2004. Promotion of the questionnaire took place in the local media (Appendix I).

Since the questionnaire was being sent to all ratepayers it was decided to collect not only the lamb production data required but also general information on fox control methods and perceptions of fox management programs. Lamb producers were asked to provide numbers of ewes joined and numbers of lambs marked as well as additional information such as breed of sheep, dates of lambing, ewe condition and age, and nutritional information which are known to have an impact on lambing rates, and were needed as covariates in the final analysis. Extra information such as ultrasounding figures was also collected where available. Landholder's willingness to participate in the project in 2005 was sought, and their contact details collected for future mail outs.

In the questionnaire sent out in June 2004 lamb production figures were collected from that autumn lambing in 2004 and from previous years. A follow-up questionnaire to gather lamb production figures from winter and spring 2004, as well as any 2005 figures, was distributed in June 2005 to all landholders who had indicated their willingness to participate (Appendix II). Extra copies of the questionnaire were also made available at all four RLPB offices for lamb producers who had missed the initial questionnaire and wished to participate. A media release (Appendix II) and cooperation by the rangers at all boards assisted in the promotion of the questionnaire. A prize incentive ($250 worth of agricultural products) was offered to all landholders (one prize per Board) who returned the questionnaire by a set date, to encourage the timely return of questionnaires. Reminder notices were sent out one month prior to the close off date for the draw of this incentive prize.

Properties that supplied lamb production data were also linked to the GIS mapping program using the cadastral information and property identifiers supplied by each of the participating Boards. This GIS information was used to identify the location of the individual properties during the analysis of baiting strategies.

3.2.3 LambAlive Model

There are many important factors other than fox predation that influence lamb survival (Holst et al. 2002). These covariates were adjusted for using the LambAlive component of the GRAZPLAN decision support system.

LambAlive contains a predictive model that estimates the level of mortality of new born lambs in relation to chill index, ewe breed, ewe condition and percent of lambs that are twins (Donnelly et al. 1997). It requires the start date of the lambing period and averages the mortality risk over a lambing period of 17 days (length of oestrous). Chilling factor, CH (kJ m^{-2} h^{-1}) is related to mean daily wind velocity, v (m s^{-1}), mean daily temperature, T_{mean} (°C), and total daily rainfall, R (mm) by the equation (Donnelly et al. 1997):

$$CH = 481 + (11.7 + 3.1v^{1/2})(40 - T_{mean}) + 418(1 - \exp(-0.04R)).$$

The proportion of young that die in the first three days after birth from exposure, XR, can be predicted from the functions below given relative body condition of the ewe at lambing BC, chill index, CH, and litter size, Y, as explanatory variables (Donnelly et al. 1997):

$$XR = \frac{\exp(XO)}{1+\exp(XO)}$$

where

$$XO = C_{D8} - C_{D9}BC + C_{D10}CH + C_{D11,Y}$$

A higher proportion of lambs from Merino ewes die than lambs from crossbred ewes; the parameter values for the two genotypes are listed in Table B3.1.

Table B3.1: Parameters used for predicting mortality rates in newborn lambs from merino and crossbred Ewes in LambAlive (after Donnelly et al. 1997).

Parameter	Description	Units	Merino Ewes	Crossbred ewes
C_{D8}	Constant term	–	-9.95	-8.90
C_{D9}	Effect of body condition	–	1.71	1.49
C_{D10}	Effect of chill index	$kJm^{-2}h^{-1}$	0.0098	0.0081
$C_{D11, Y}$	Effect of lamb number (Y)	–		
	1	–	0.0	0.0
	2, 3	–	1.10	0.82

Sheep data such as the number of ewes joined, ewe body condition, ewe and lamb breed and the number of lambs marked, was collected using the questionnaire. Historical weather records at a district level, were obtained from the Bureau of Meteorology. Daily temperature and rain data was downloaded from the SILO website, and monthly average wind speed from the Bureau's own web site.

The proportion of twin data was obtained from experimental and demonstration flocks from within the study area (Merino: S. Hatcher, NSW DPI, Orange unpublished data; Crossbred: Fogarty et al. 2004 and D, Stanley, NSW DPI, Cowra unpublished data). There was no significant difference in the proportion of Merino twins between age classes ($F=0.18$, $df=1$, $p=0.69$) and lambing season ($F=0.09$, $df=1$, $p=0.77$), so the average figure of 0.35 was used for all Merino flocks. There was a significant difference in the proportion of twins between age classes of crossbred ewes ($F=42.3$, $df=1$, $p<0.001$) with maidens averaging 0.31, older ewes 0.66, and mixed aged flocks 0.51. There was no significant difference between lambing seasons (F=1.40, df=1, p=0.27).

Two breed categories, merino and crossbred (which included all other breeds and crosses) were used. Goats were excluded. Ewes with missing body condition scores were allocated the average score of ‘2’. The start date of the lambing period was calculated from 150 days (average gestation length) from the given joining date.

3.2.4 Drought and Locust Data

Two major environmental variables to affect the study area during the period between 1998 and 2005 were the ongoing drought conditions and plague locust swarms. Information for these two events was collected from the NSW DPI website. The NSW DPI drought maps are prepared from information provided by the 48 Rural Lands Protection Boards around the state, rainfall details from the Bureau of Meteorology and reports from Department of Primary Industries regional staff.

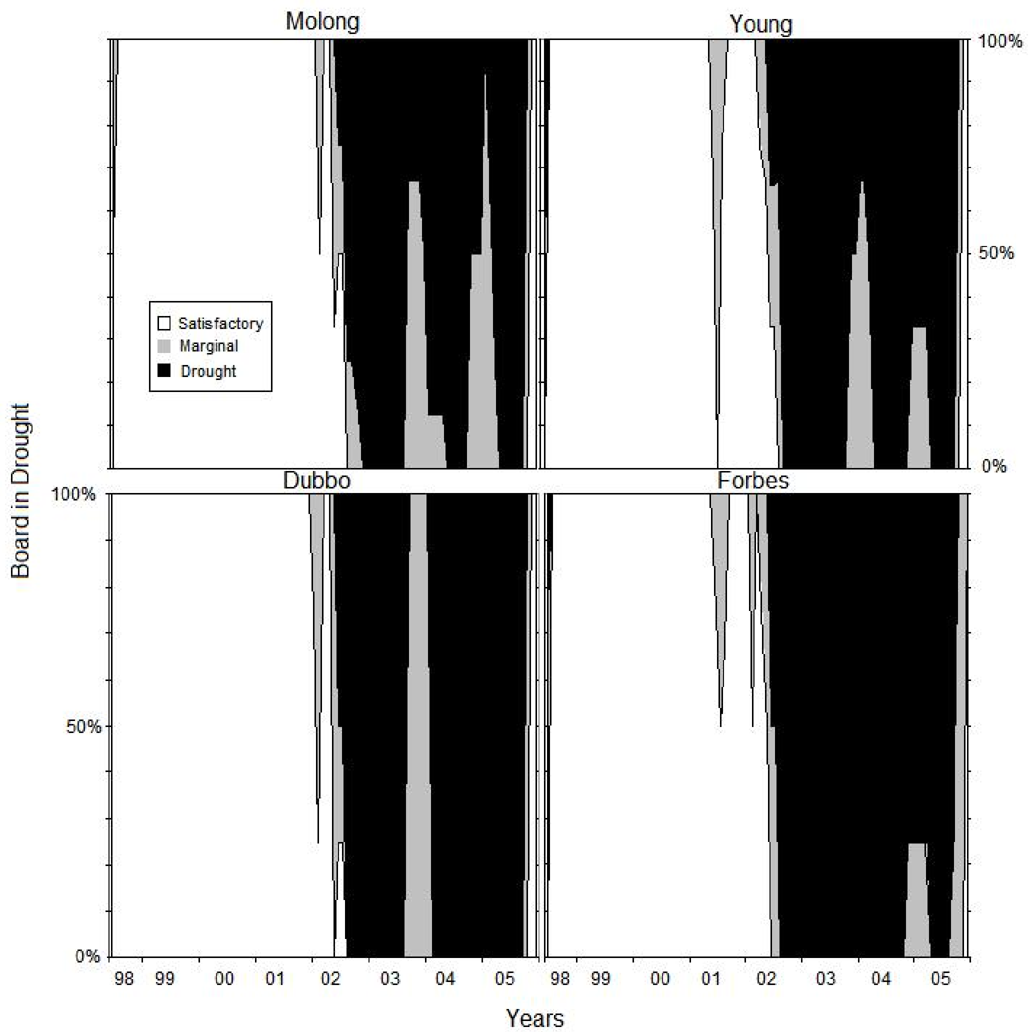


Figure B3.2: Percentage of each of the four participating RLPBoards drought declared throughout the years 1998 to 2005 (source NSW Department of Primary Industries).

Drought classification of an area takes into account the following factors:

- a review of historic rainfall records for the area

- pasture availability
- climatic events such as frosts
- seasonal factors such as pasture growing seasons.

Drought conditions were declared in all four participating boards during the last four years of the study (i.e. 2002 – 2005). The severity of the drought conditions varied only slightly between boards and within boards over this time (see Figure B3.2).

Under the *Rural Lands Protection Act 1998*, landholders are required to report the presence of plague locusts on their land to their local Rural Lands Protection Board. They are also required to use insecticide to control locust nymphs when the nymphs band together. This information is collated by the NSW DPI and is available to the public on their website.

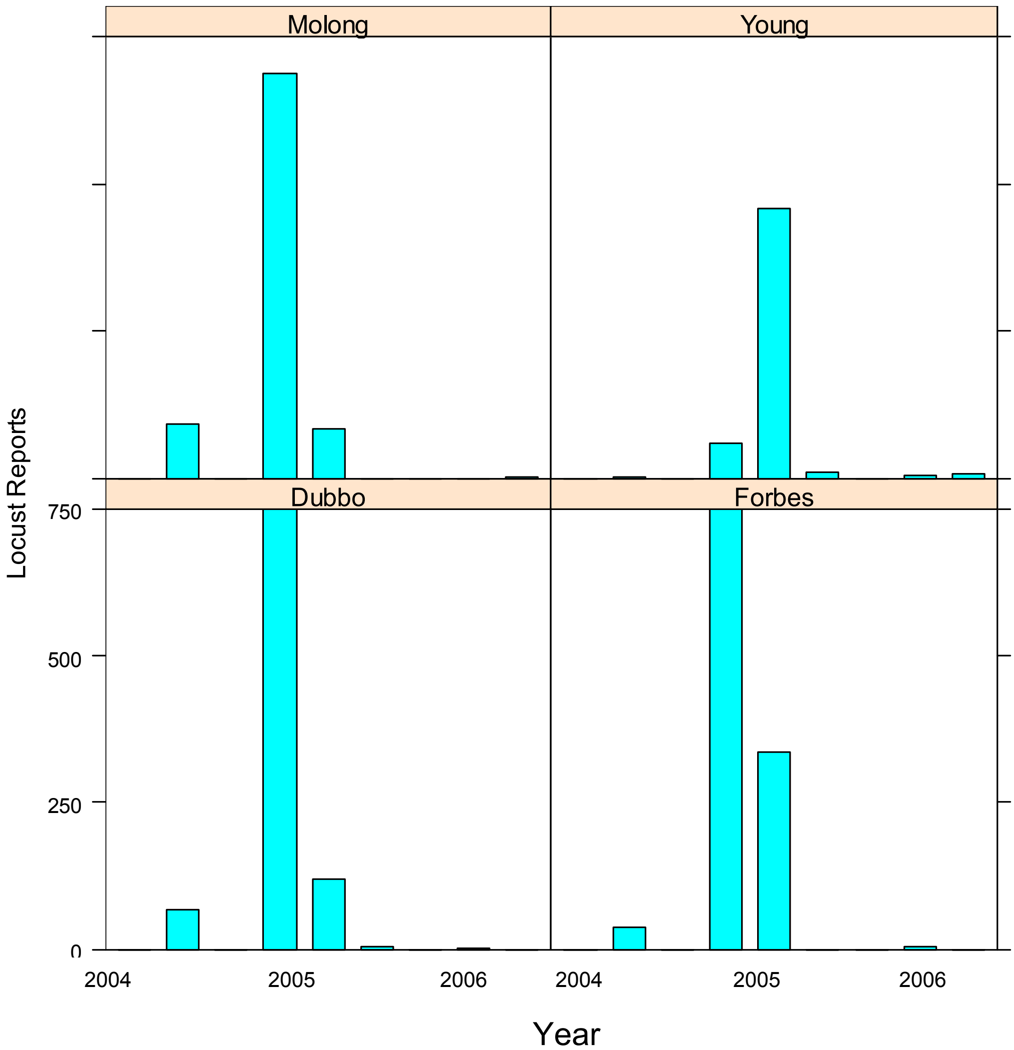


Figure B3.3: Locust reports in the four RLPBoards during the study period (source NSW Department of Primary Industries).

Locusts were reported during the last two years of the study. The presence of locust swarms in each of the four participating boards highlights the progress of the swarms southwards across the state over time, with Dubbo and Molong reporting sightings before Forbes and Young (see Figure B3.3).

3.2.5 Cost Effectiveness Calculations

Saunders and McLeod (2007) published a cost structure for determining the cost of a 1080 ground baiting program using various strategies of bait checking and replacement on an average 2000 hectare property on the tablelands in NSW. A typical program with baits checked and replaced twice was costed at $373.70 in total. The labour and vehicle costs used for this calculation were considered out of date with current price increases so were modified accordingly. Labour costs were increased to $13.47 an hour. Vehicle operating costs were increased to $0.55 per kilometre, based on average running and standing cost figures of a typical 4WD vehicle as used by farmers (NRMA 2007). Incorporating these new values, the total cost of a ground baiting program on an average 2000 hectare property on the tablelands in NSW, with baits checked and replaced twice was calculated to be $397.91.

Gross margins are commonly used to compare similar resourced enterprises on a farm, and are defined as the gross income from a particular enterprise less the variable costs incurred in achieving the particular enterprise. NSW DPI has developed a range of typical Merino and first cross enterprise gross margins based on a theoretical flock of 1000 ewes or wethers. Included in these figures are sensitivity tables which can be used to determine the effect of weaning percentage on gross margins (NSW DPI 2007a and b).

3.2.6 Fox Population Monitoring

To monitor the effectiveness of management programs, the impact of foxes needs to be measured. Quantifying such impacts is usually difficult and costly for most agricultural programs, so fox abundance is often used as an approximate indicator. Obtaining absolute counts of secretive animals such as foxes is impossible so the easier option is to measure an index of abundance which is assumed to be somehow correlated with the true abundance.

A common method used by many programs in Australia is that of spotlight counting along fixed transects. If a constant proportion of animals is counted across time and space, then there is a reasonable chance that the index will detect the true trend of a population, although the trend statistic may still be biased (see Barker and Sauer 1992). A typical standard method is for counts to be conducted over three consecutive nights from a vehicle travelling at five to ten kilometres/hour along set tracks and using a 100 Watt spotlight (e.g. Greentree et al. 2000), despite Field et al. (2005) suggesting that, because of the low detectability of foxes, at least five (and as many as nine) repeat visits might be required.

An attempt to determine an index of abundance for foxes which could be compared before and after baiting programs was initiated in the Goonoo State Forest area within Dubbo RLPB. Two ten kilometre transects (one baited, one not baited) were spotlighted before and after the baiting programs in winter 2004 and autumn 2005. Each transect was counted by the same observer over three consecutive nights using the standard method as described above. These counts were conducted in conjunction with a mallee fowl conservation project in the area.

3.3 Statistical Analysis

3.3.1 Questionnaires

The chi squared test for homogeneity was used to test if the respondents from the 2004 questionnaire were representative of the ratepayers in their boards with respect to lamb production and fox baiting.

3.3.2 Program Effectiveness

The data collected from the 1080 registers was used to monitor the performance of the Outfox the fox program in respect to its objectives: i) increase landholder participation in group baiting, ii) increase the frequency of landholder baiting and iii) increase baiting in times of fox vulnerability (Mar/Apr and Aug/Sep). Two response variables were analysed; the number of landholders baiting, and the proportion baiting as a group in each of four boards during each month for the eight years 1998 to 2005.

The number of landholders baiting data were analysed on the square root scale to improve variance homogeneity. Figure B3.4 gives a trellis plot of the square root landholders baiting (sqrtN) versus month, with separate lines for each year and data for each board on a separate sub-plot. There are cyclical trends within each year with a possible cyclical trend also working over a six month period, in some Boards.

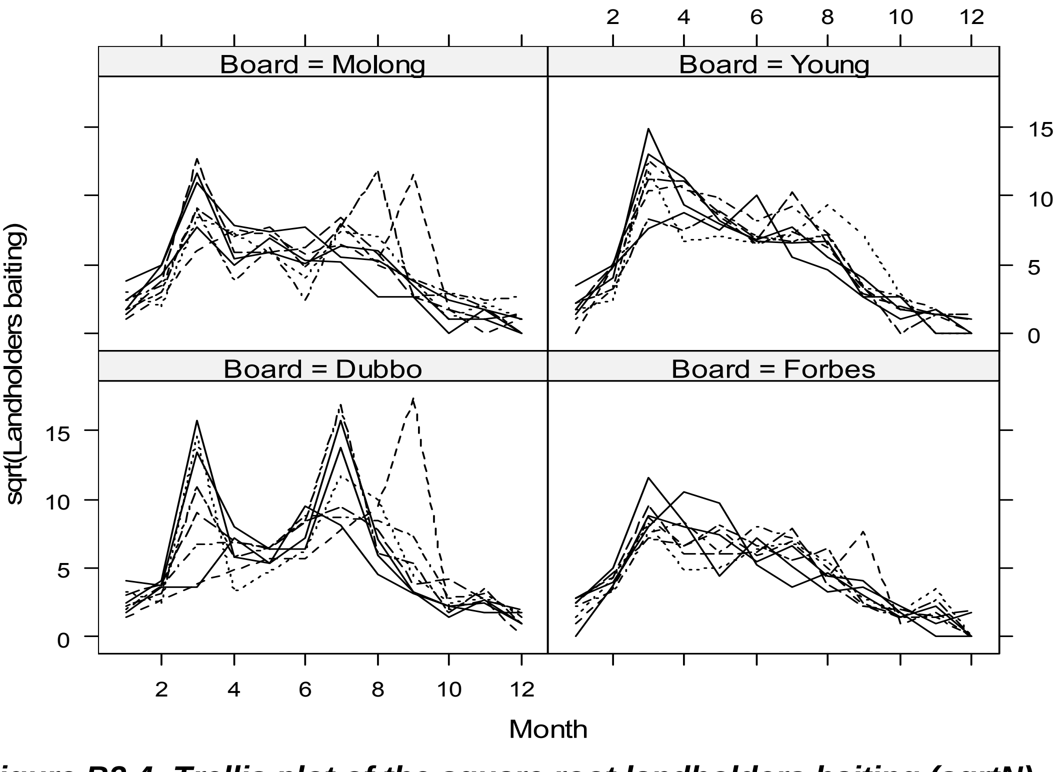


Figure B3.4: Trellis plot of the square root landholders baiting (sqrtN) versus month, with separate lines for each year.

To model the data (using ASREML (Gilmour *et al.* 2002)) the following linear mixed model was fitted

sqrtN = mean + Board + Time + Board:Time +

cos(Time,1) + sin(Time,1) + Board:cos(Time,1) + Board:sin(Time,1) +
cos(Time,0.5) + sin(Time,0.5) + Board:cos(Time,0.5) + Board:sin(Time,0.5) +
Drought + Locusts + Drought:Locusts +
Board:Drought + Board:Locusts + Board:Drought:Locusts +
spl(Time) + Board:spl(Time) + ***fac(Time) + error***

Time is a variable measured in years and ranging from 0 to 8. The terms cos(Time,1) and sin(Time,1) taken together allow for a cyclical trend with unspecified magnitude over a one year period. This cyclical trend is allowed to interact with Board. A similar cyclical effect but operating over a half yearly cycle is also included. Effects for level of Drought (No, Marginal, Yes), presence of Locusts (No and Yes), interaction of these two effects and their interaction with Board are also included. Also included is an overall smoothing spline spl(Time), and an additional smoothing spline for each board. The terms in bold / italic are fitted as random effects. These are random effects associated with each unique sampling month (i.e. fac(Time)) and a random error component. The random error is modelled to have different variance within each board.

The corresponding trellis plot for the proportion baiting as a group versus month is given in Figure B3.5.

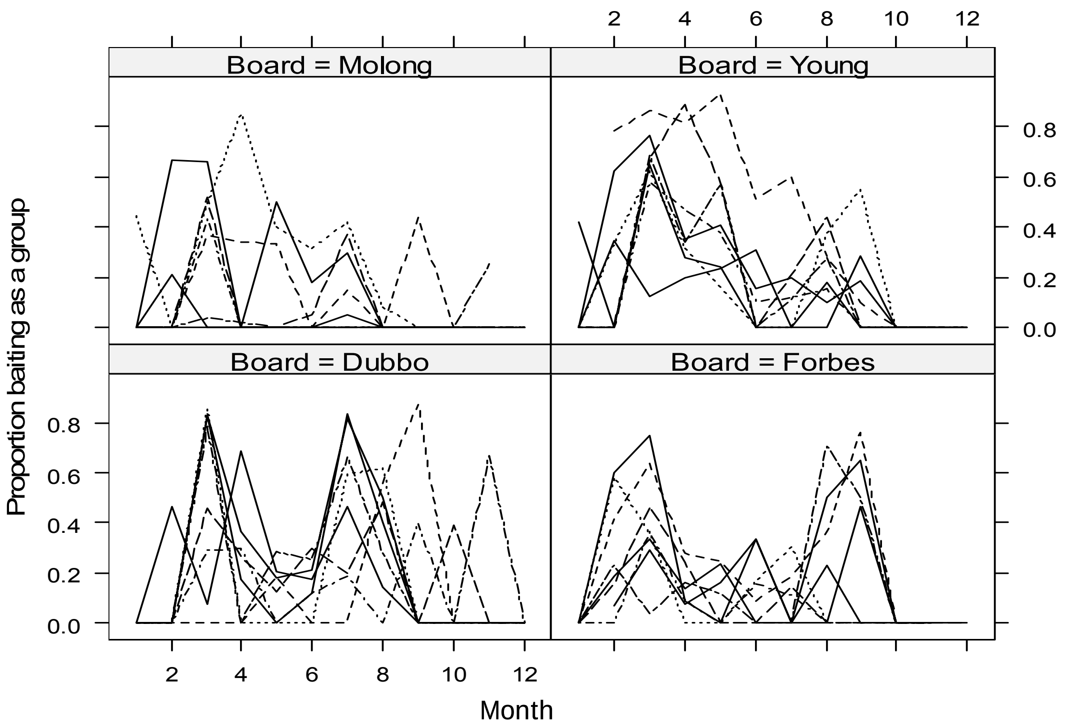


Figure B3.5: Trellis plot of the proportion of landholders baiting in a group versus month, with separate lines for each year.

To model the proportion of landholder baiting as a group (P) within any board at a given Time a generalized linear mixed model (GLMM) was fitted, with mean E (P) given by

E (P) = mean + Board + Time + Board:Time +

cos(Time,1) + sin(Time,1) + Board:cos(Time,1) + Board:sin(Time,1) +
cos(Time,0.5) + sin(Time,0.5) + Board:cos(Time,0.5) + Board:sin(Time,0.5) +
Drought + Locusts + Drought:Locusts +
Board:Drought + Board:Locusts + Board:Drought:Locusts +
spl(Time) + Board:spl(Time) + ***fac(Time)*** + mv

and variance proportional to a binomial variate based on N (number of landholders baiting in that board at that time) with the proportionality constant depending on board.

The terms in the model for E(P) are as for the model for sqrtN given above except for mv. This is an omnibus term allowing for estimation of the missing data corresponding to times when zero landholders baited and the proportion baiting as a group is undefined.

3.3.3 Baiting Strategy

The objective was to determine if lambing percentages on a particular property were affected by fox baiting effort on neighbouring properties prior to the lambing event, and then determine the appropriate levels of fox control (baiting strategy) which would achieve production benefits with respect to total area baited and frequency of baiting. Effort was described as baited or not baited as baiting density could not be determined for each property.

To summarise the fox baiting history in the neighbourhood of each lambing event we calculated the following summary statistics (covariates) (Table B3.2). In brief these correspond to the proportion of those properties, within a given distance range from the property having the lambing event, that baited in the given time interval prior to the lambing event. For example, if D2T3 = 0.75 this implies that three quarters of the properties that are a distance 0.2 – 2.5 km from the lambing property baited 6 – 9 months prior to the lambing event.

Some comments are worth noting on the above choice of distance and time intervals.

- As no two properties were within 0.2 km apart, summary statistics D1T1, D1T2, D1T3 and D1T4 are either 1 or 0, depending on whether the lambing property baited or did not bait respectively in the given time interval.
- The second distance range, 0.2 – 2.5 km, was chosen so as not to have too many missing values in this statistic. This statistic will be missing if there are no baiting properties within this distance from a property having the lambing event. Also, we did not want to make this interval too large as it would be assumed that effectiveness of baiting on a lambing event declines with distance. As calculated we have 522 missing values for each of D2T1, D2T2, D2T3 and D2T4. These missing values are set to zero in the analysis.
- Baiting beyond 5 km from a lambing event within the previous year was found not to affect the lambing rate.

Table B3.2: Summary of covariates used in analysis. See text for explanation of terms.

Summary statistic	***Distance (D)***	***Time (T)***
D1T1	< 0.2 km	0 – 3 months prior
D1T2	< 0.2 km	3 - 6 months prior

D1T3	< 0.2 km	6 - 9 months prior
D1T4	< 0.2 km	9 - 12 months prior
D2T1	0.2 – 2.5 km	0 – 3 months prior
D2T2	0.2 – 2.5 km	3 - 6 months prior
D2T3	0.2 – 2.5 km	6 - 9 months prior
D2T4	0.2 – 2.5 km	9 - 12 months prior
D3T1	2.5 – 5.0 km	0 – 3 months prior
D3T2	2.5 – 5.0 km	3 - 6 months prior
D3T3	2.5 – 5.0 km	6 - 9 months prior
D3T4	2.5 – 5.0 km	9 - 12 months prior

To model the lambing percentages (LMP) to examine if fox baiting distance and timing has an influence on the outcome we use the following linear mixed model, which is given in ASREML (Gilmour *et al.* 2002) notation and is explained below.

```
LMP ~ mu Breed Drought Breed:Drought FYear FSeason ,
  D1T1 D2T1 D3T1 D1T2 D2T2 D3T2 D1T3 D2T3 D3T3 D1T4 D2T4 D3T4 ,
!r Breed:FSeason Breed:FYear ,
 FYear:FSeason Breed:FYear:FSeason FacPKey
2 1 0
 459 0 ID
1110 0 ID
```

The first two lines of the above model indicate that we allow the response variable (LMP) to be a linear combination of the following fixed effects:

Breed effect allows for different lambing rates for crossbreed and merino
Drought effect allows for different lambing rates in drought and non-drought
Breed:Drought interaction allowing the possibility of one breed handling drought better than the other
FYear allows for different lambing rates across the three years
FSeason allows for different lambing rates across the five seasons

D1T1 to *D3T4* covariates already explained in Table B3.2.

The next two lines of the model, with terms following the !r symbol, are terms fitted as random effects. Except for *FacPKey* these are interaction terms between fixed effect terms already explained. The term *FacPKey* corresponds to individual property effects and thus allows for variation across properties. The last three lines of the model set up the error model. Here we have assumed the random error terms are independent but with possible different variances for crossbreds and merinos.

4. RESULTS

4.1 1080 Poisons Register

For the period 1998 to 1995, 1733 register records were available to enter in the database, recording over 14,000 instances when baits were issued for fox control (a total of 833,863 baits – see Figure B4.1). The types of bait issued were predominantly Foxoff (64%), followed by fresh meat (including liver) (24%) and chicken heads (8.9%). Other baits were chicken wingettes (2.7%) and unknown (0.3%). The use of different bait types varied between RLPBs and between years (Figure B4.2).

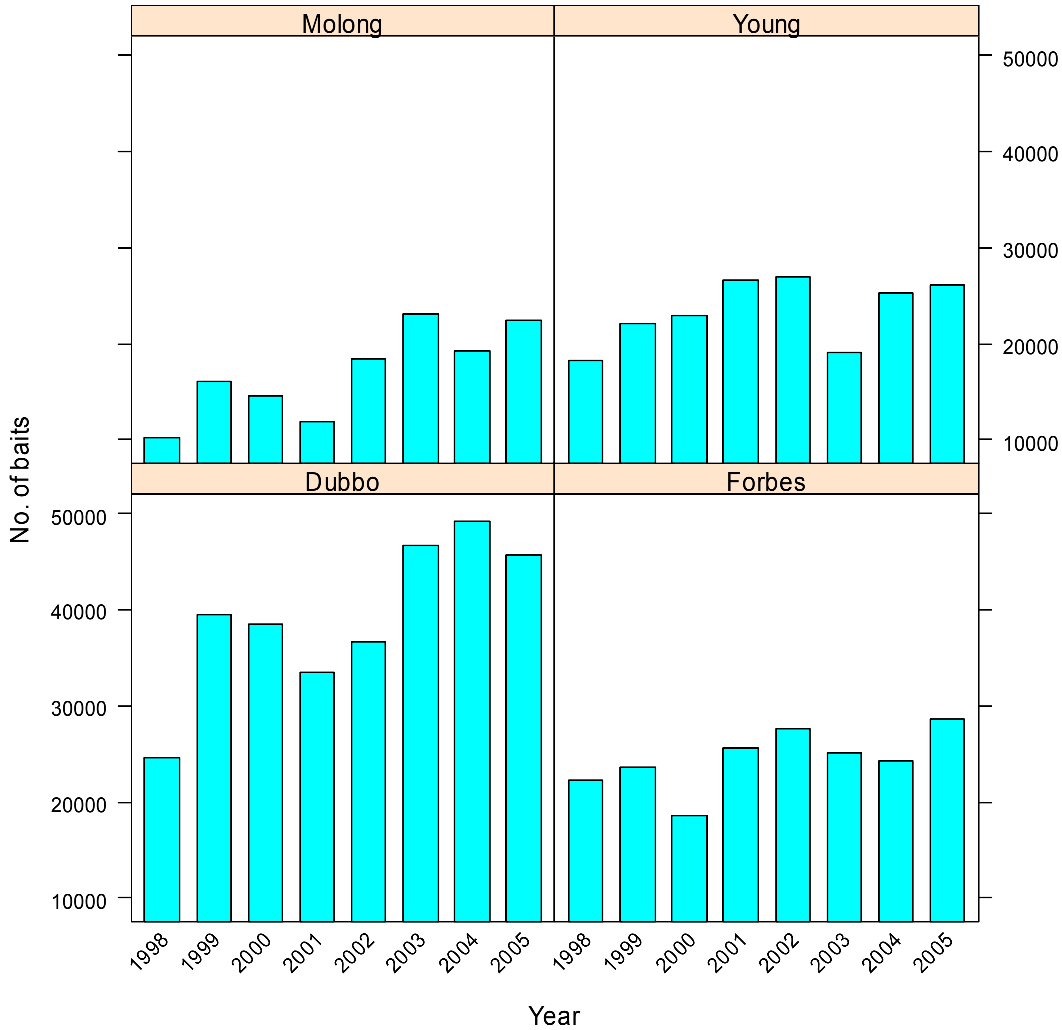


Figure B4.1: Number of 1080 fox baits issued from 1998 to 2005 collected in the register for 1080 use for Dubbo Molong, Forbes and Young RLPBs.

From the property cadastral information supplied by the RLPBs a high proportion of individual properties listed in the 1080 register could be identified and linked to the GIS mapping program (93% of Dubbo, 95% Molong, 94% Forbes and 95% Young). The small proportion that could not be linked represented only 7% of the actual baiting incidents over the eight year study period. Reasons why properties could not be linked included incomplete information recorded, incomplete cadastral information held by the RLPB records, change in ownership and/or name of property, change in circumstance (e.g. subdivision, amalgamation) and property not listed as a rateable property on the database (and hence no cadastral information available).

Properties that used 1080 fox baits in each of the four participating boards in the years 1998 to 2005 are indicated in figures B4.3a-d.

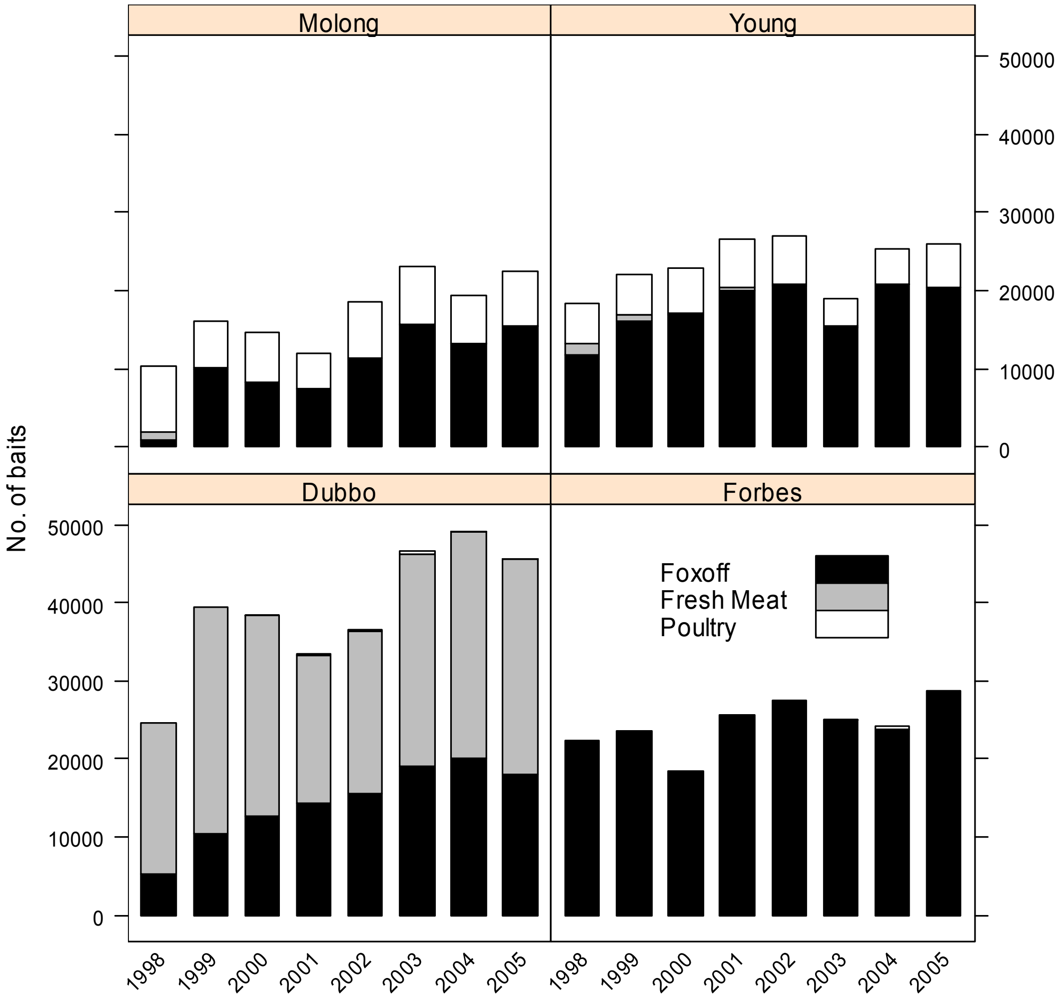


Figure B4.2: Three main types of 1080 fox baits: the manufactured Foxoff, fresh meat (red muscle meat and liver), and poultry (chicken heads and wingettes) issued from 1998 to 2005 from Dubbo Molong, Forbes and Young RLP Boards.

4.2 Lamb Production Data

In June 2004 over 12,000 questionnaires were distributed to the ratepayers in the Dubbo, Forbes, Molong and Young RLPBs (see Table B4.1 for break down). Although 22% of the envelopes were returned, only 13.6% contained the questionnaire, with the others containing the RLPB stock return or other board related paperwork. From the stock return information collected by the boards, it is estimated that of the 12,226 ratepayers, approximately 4,800 were sheep producers. From these producers we received 959 responses (20%), representing over 1400 flocks and 700,000 lambing ewes. A further 702 questionnaires were received from non-lamb producers (9.5% of non-lamb-producers).

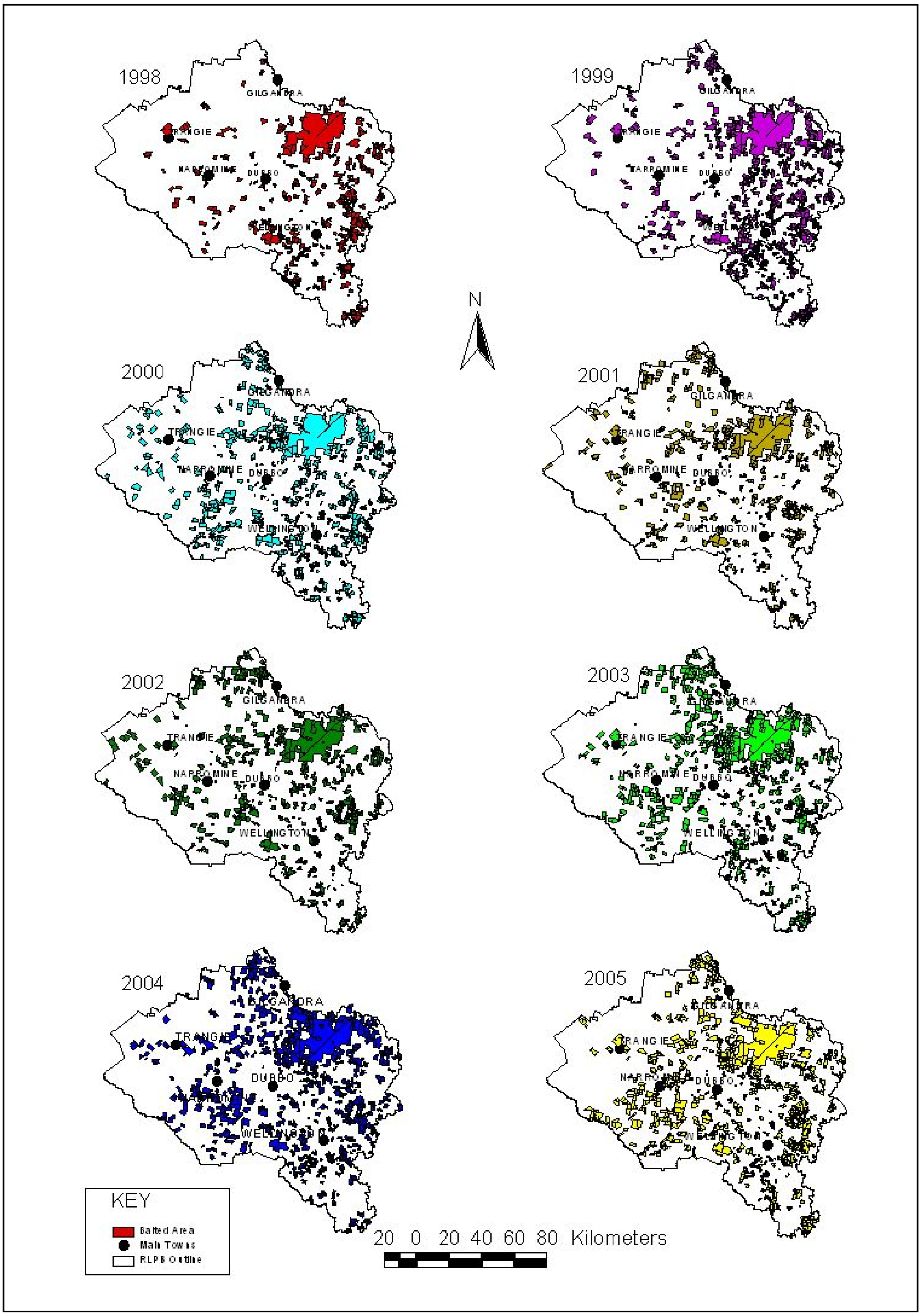


Figure B4.3a: Properties that used 1080 fox baits in Dubbo RLP Board in the years 1998 to 2005.

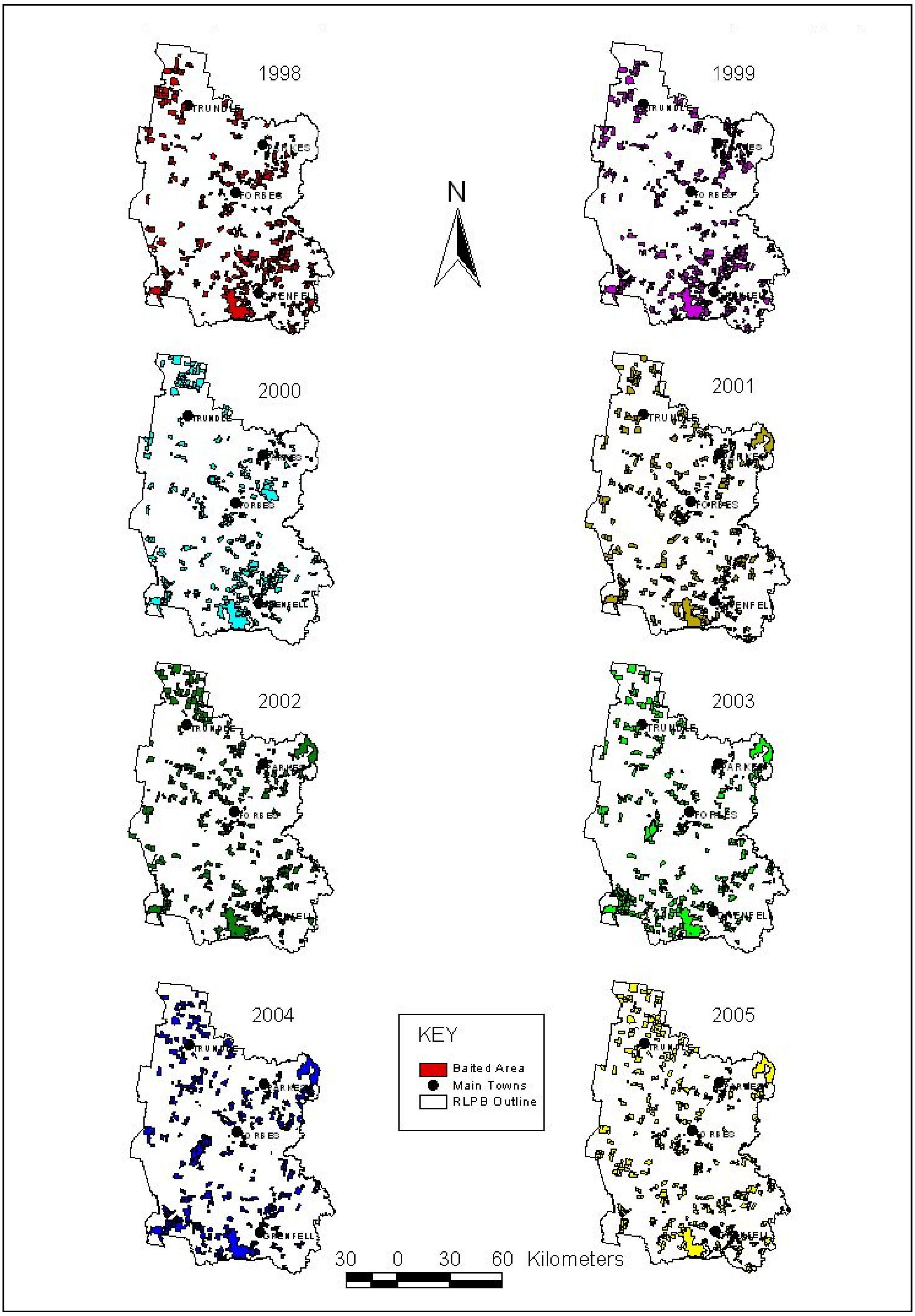


Figure B4.3b: Properties that used 1080 fox baits in Forbes RLP Board in the years 1998 to 2005.

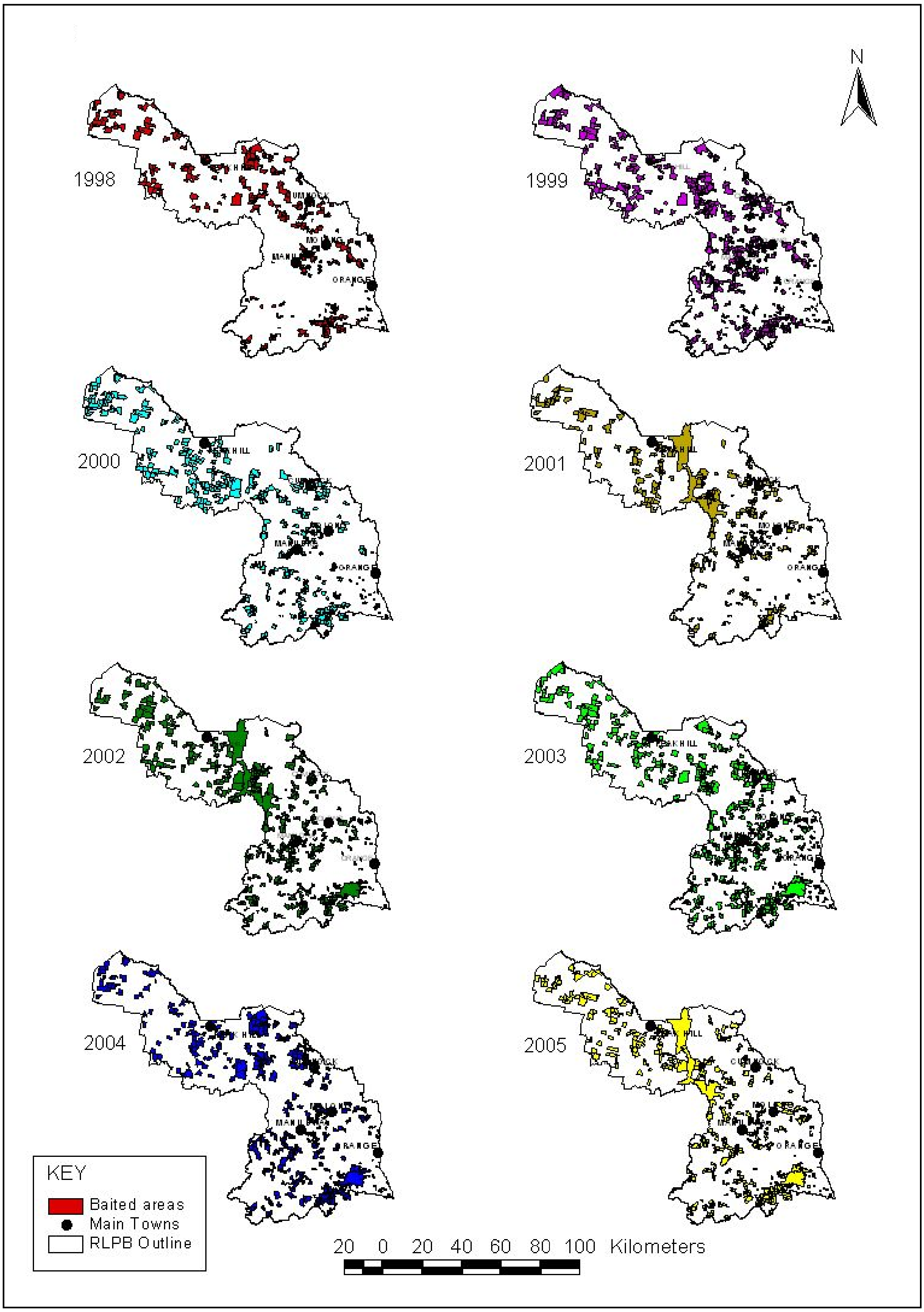


Figure B4.3c: Properties that used 1080 fox baits in Molong RLP Board in the years 1998 to 2005.

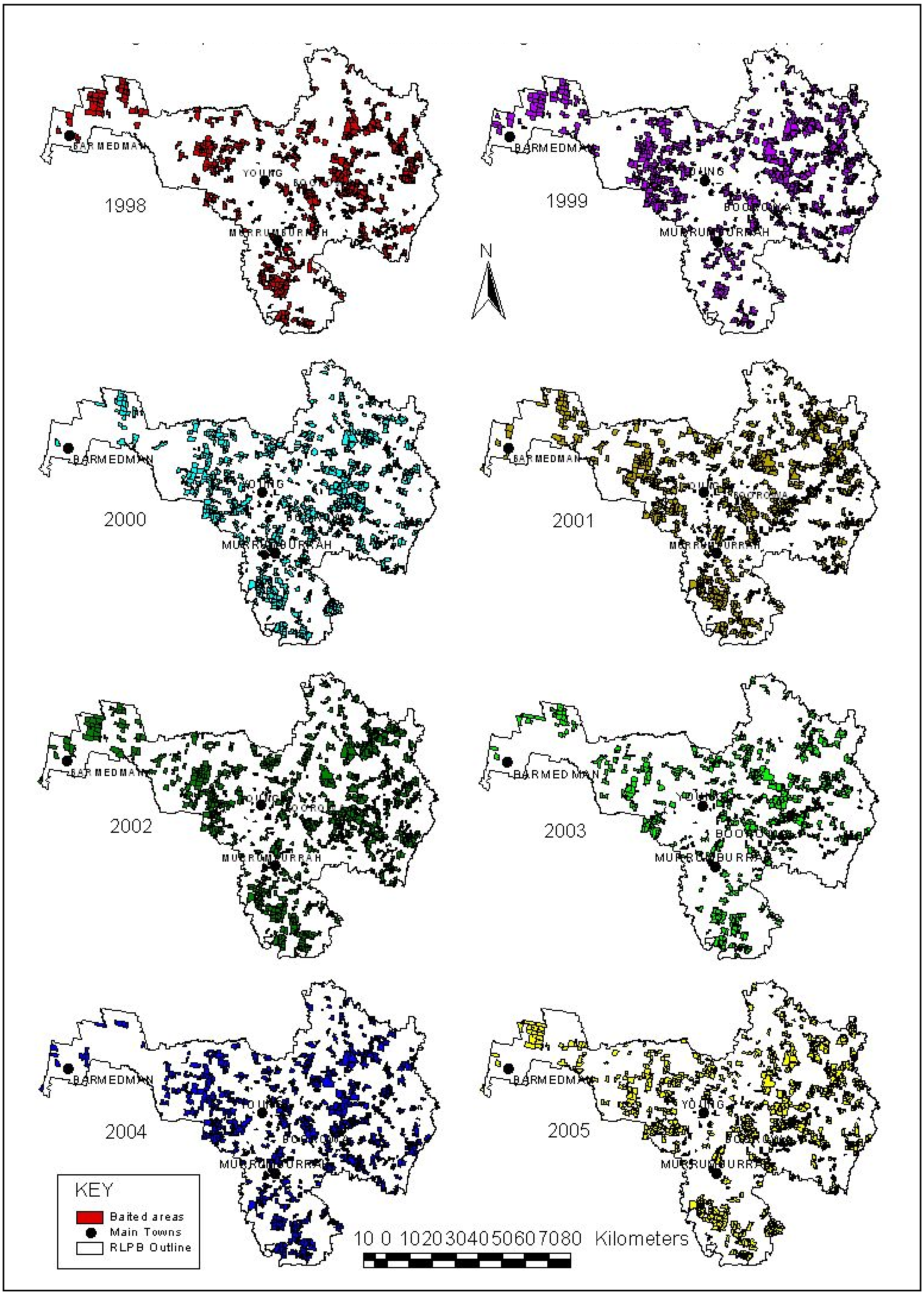


Figure B4.3d: Properties that used 1080 fox baits in Young RLP Board in the years 1998 to 2005.

Table B4.1: Break down of respondents from the 2004 questionnaire into lamb / non lamb producer groups (LP = lamb producers, NLP = non lamb producers).

	Questionnaire Responses			Total in Board (2004)	
RLPBoard	LP	NLP	Total	LP	Ratepayers
Dubbo	303	312	615	1 216	4 286
Forbes	200	95	295	~1109	2 597
Molong	185	173	358	925	2 549
Young	271	122	393	1 550	2 794
TOTAL	959	702	1661	~ 4 800	12 226

In all boards a higher proportion of lamb producers responded to the questionnaire than non lamb producers (X^2=204.9, df=1, p<0.0001). This was not surprising as the questionnaire's main function was to collect lamb production information. There was also a higher proportion of landholders who used 1080 fox baits that responded to the questionnaire, as opposed to landholders who did not bait (X^2=230.4, df=1, p<0.0001) (see Table B4.2). Even though other forms of fox control could not be accounted for in this analysis, it is clear that the responses to the 2004 questionnaire were heavily biased towards landholders who had an interest in the lamb production and fox control issues. This bias influenced the general representativeness of the responses to the questions on fox control methods and perceptions of fox management programs.

Table B4.2: Break down of respondents from the 2004 questionnaire into fox / non fox baiters.

	Questionnaire Responses			Total in Board[1]	
RLPBoard	Baiters	Non Baiters	Total	Baiters	Non Baiters
Dubbo	189	426	615	689	3 597
Forbes	88	207	295	303	2 294
Molong	92	266	358	443	2 506
Young	136	257	393	513	2 281
TOTAL	505	1156	1661	1 948	10 678

[1] From the period 1st July 2003 until 30th June 2004.

From the 959 lamb producers who responded to the 2004 questionnaire, 831 indicated they would consent to participate again in 2005. Fourteen of these landholders did not provide adequate contact details and \ or had moved from their property by June 2005, leaving 815 questionnaires to be distributed. A further 400 questionnaires were handed out through the four RLPB offices. The reminder notices that were sent out one month prior to the close off date for the draw of the incentive prize, prompted seven landholders to request another copy of the questionnaire.

Three hundred and fifteen responses (39%) were received from the lamb producers who had already participated in 2004, and a further 39 lamb producers who had not participated before, representing lambing data for a further 753 flocks and 390,000 lambing ewes. A number of landholders indicated on their returned questionnaires that, due to the continuing drought, they had decided to reduce the number of ewes lambing, or had not joined at all. It is unclear if the worsening dry conditions, or the presence of plague locusts in the study area played a part in the low return rate of the questionnaires, as producers did not have any further information to report or had other priorities and concerns.

In total nearly 1000 separate lamb producers responded to our questionnaire, providing information for over 2100 lambing flocks for the years 1998 to 2005. Data from 347 flocks were culled because of insufficient or incomplete information and a further six flocks were based outside the study area. Given that the majority (96%) of the lambing records were available for years 2003 – 2005 (see Figure B4.4) analysis of the lambing percentages were restricted to these three years. Further, as the 1585 lambing records for these three years correspond to 459, 1110 and 16 records for crossbreed, merino and unknown breeds respectively, analysis was further restricted to the crossbreed and merino breeds only. This left 1569 records for analysis. Of these lambing flocks used in the analysis, 54% lambed in the autumn months, 33% lambed in the winter months, with only 8% lambing in spring and 5% in summer.

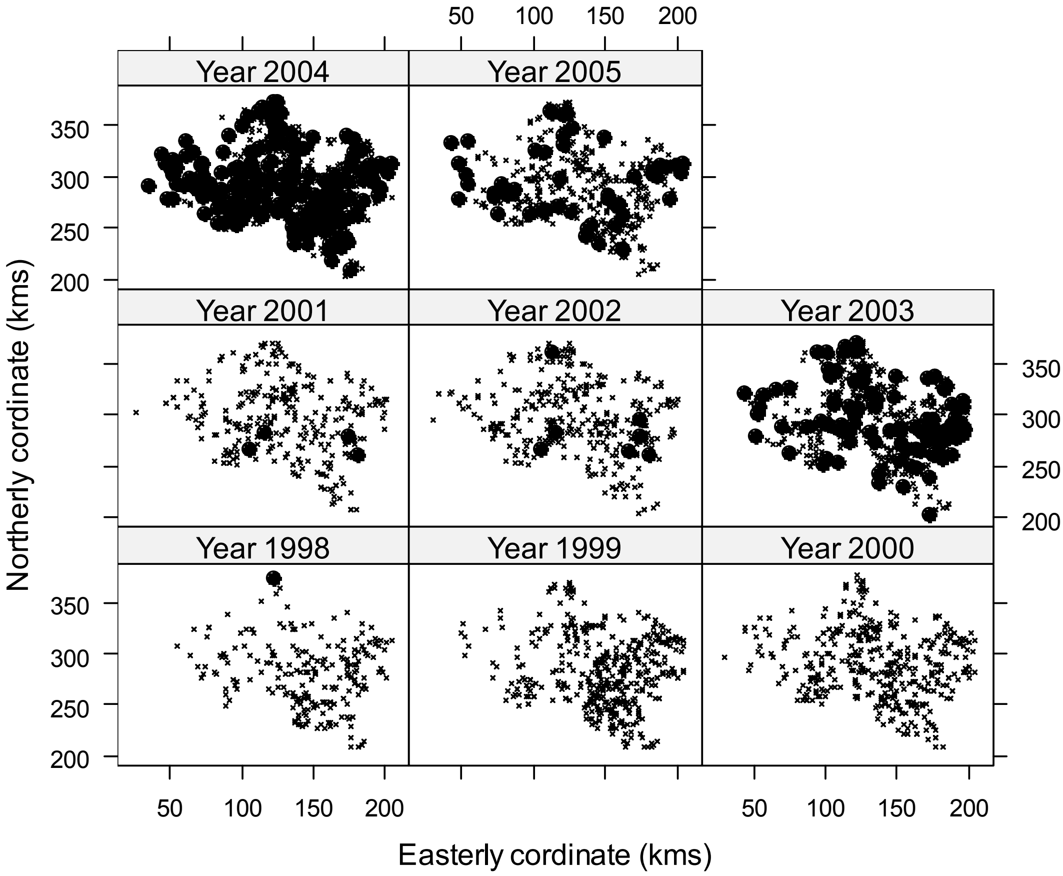


Figure B4.4: The distribution of baiting events and lambing percentage records for years 1998 – 2005 (solid points represent available lambing data, small crosses represent available baiting data.

4.3 Program Effectiveness

4.3.1 Landholder Baiting

There were no significant effects on the number of landholders baiting associated with drought or locusts, nor interactions between these two, and no significant interactions with any of these with Board. There are significant cyclical effects within years and within six monthly cycles, and these differ significantly across boards.

Of primary interest is that there are no significant linear or smoothing spline trends with time after removing cyclical trends, either overall or within any board (i.e there were no significant change in the total number of landholders baiting over time).

There was a significant difference in the random variation across boards, with variation largest for the Dubbo board. The random variations within the remaining three boards (Forbes, Molong and Young) were not significantly different.

4.3.2 Group Baiting

There was no significant effect associated with Locust but in some boards drought significantly affected the proportion baiting as a group. In Forbes, Molong and Young Boards the proportion baiting as a group is estimated to be the lowest under drought conditions. At Molong this is significantly less (p-value < 0.05) then under marginal conditions or no drought conditions whereas at Young the proportion baiting as a group under drought or marginal conditions are not significantly different but are less than under no drought conditions. At Dubbo the proportion baiting as a group is not significantly different across the three drought categories (drought, marginal conditions or no drought).

As might be expected, there are cyclical trends within a year. First there is a yearly cycle that differs across Boards. In addition this is a cycle that operates on a half yearly interval and this cycle is not significantly different across the boards.

After adjusting for the cyclical trends and the effects due to drought there remains significantly different trends over time in the proportion baiting as a group across Boards. This is identified in significant effects for both an overall spline plus an additional separate spline component for each board. This trend is illustrated in Figure B4.5 where the predicted proportion baiting as a group is plotted against the time for each Board together with approximate 95% confidence bounds for each predicted point. Here the trend indicates two peaks in the proportion baiting as a group, one at approximately Time 2 (end of 1999 and beginning of 2000) and another at approximately Time 6.5 (mid 2004). The proportion baiting as a group appears least across the Molong board.

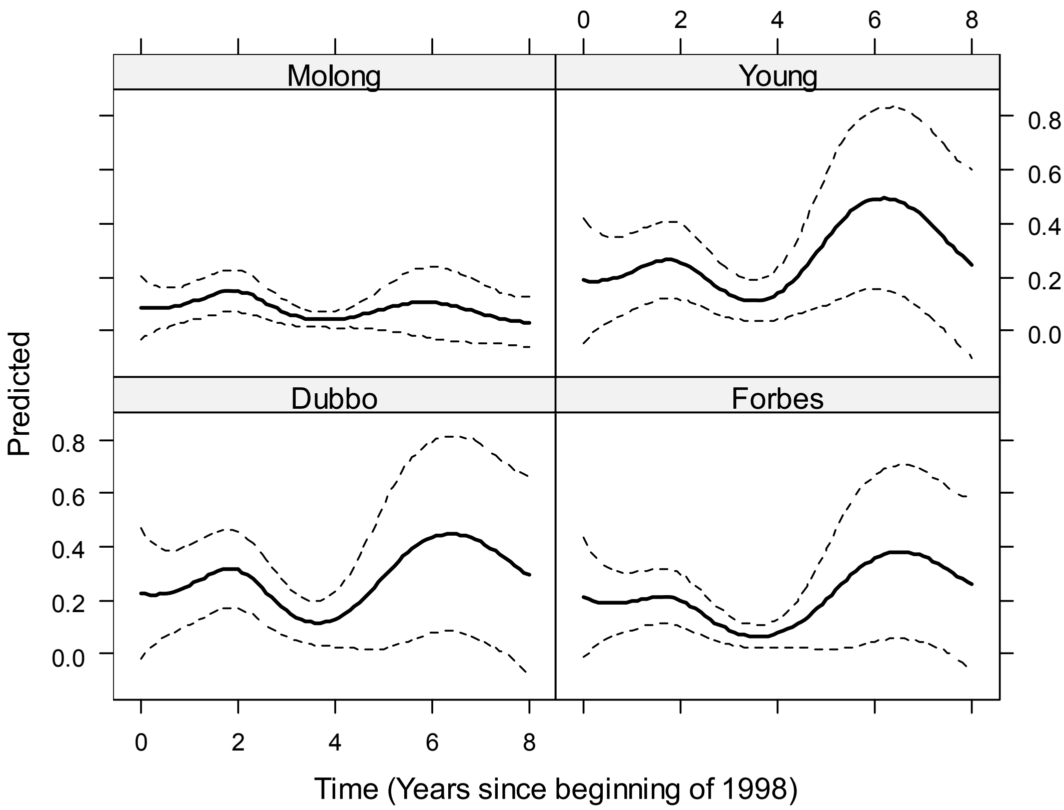


Figure B4.5: The predicted proportion of landholders baiting as a group for each RLPB. The predictions given are after removing cyclical trends within a year and assuming no drought.

4.4 Baiting Strategy

The described model was fitted and fixed effects terms not significant at the 0.05 level sequentially removed. Random terms with zero variation were also removed leaving the final model

LMP ~ mu Breed D2T3 !r FYear:FSeason FacPKey
2 1 0
459 0 ID
1110 0 ID

The estimated lambing percentages for the crossbreds and merinos breeds based on the above final model (D2T3 = 0.1) were 102.4% (s.e. = 1.7%) and 78.5% (s.e. = 1.2%) respectively. The Breed effect was highly significant (p-value < 0.001), whilst the only significant covariate, after adjusting for Breed, was D2T3 (p-value = 0.044) with lambing percentages increasing as D2T3 increased (i.e. lambing percentage increased as the proportion of near neighbours baiting 6-9 months prior to the lambing increased).

A surprising omission was the covariate D1T1 (i.e. baiting 0-3 months prior to own lambing) as it would be expected that baiting at this time (which is the most common practice) would have some effect on the resulting lambing percentages. On closer inspection of the data the sample size of landholders who did not bait but provided lambing data was far outweighed by those that did bait, therefore allowing no statistical significance of this covariate to be found.

In the above analytical approach there were many ways of including bait timing / distance covariates in the model, for example by simply modifying the distance and time intervals. In other analyses of this data different choices were considered and in some of these none, one or two of the covariates came out significant. However there was no consistent pattern.

The initial model above was kept reasonably simple. Interactions of the covariates with themselves, or with other fixed effects were not included. When the model was extended to include interactions of the covariates with themselves and fixed effects terms not significant at the 0.01 level (*a more stringent criteria is used for selection given the extra number of tests*) were sequentially removed and then random terms with zero variation removed, the resulting model was:

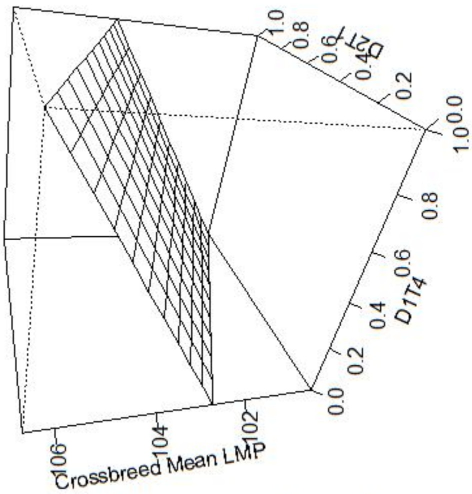
LMP ~ mu Breed D1T2 D1T4 D2T1 D2T3 D1T2.D2T1 D1T2.D1T4
D2T1.D2T3,
!r FYear:FSeason FacPKey
2 1 0
 459 0 ID
1110 0 ID

Table B4.3 gives the results from the Analysis of Variance for the above model, with p-values adjusted for other terms in the model. Again Breed effect was highly significant along with the three covariate interactions D1T2.D1T4, D1T2.D2T1 and D2T1.D2T3, representing an interaction between lamb production and baiting twice a year (six months apart) as well as interactions between neighbour baiting just prior and six months prior to lambing time.

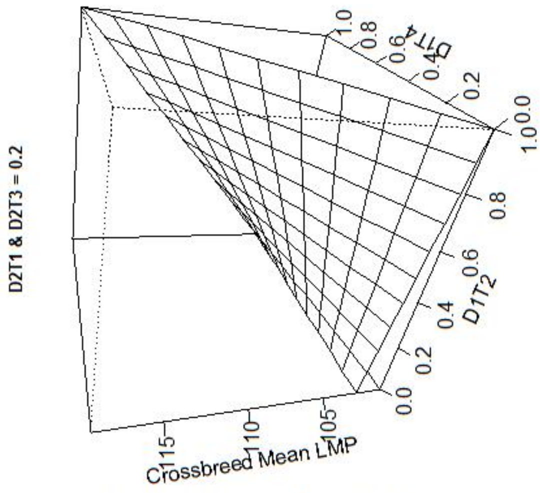
Table B4.3: The results from the Analysis of Variance analysis for the expanded model including covariate interactions with themselves and other fixed effects (as described in the above text).

Source	*NumDF*	*DenDF*	*P-value*
mu	1		
Breed	1	784.3	<0.001
D1T2	1		
D1T4	1		
D2T1	1		
D2T3	1		
D1T2.D2T1	1	1516.5	0.004
D1T2.D1T4	1	1281.2	<0.001
D2T1.D2T3	1	1234.1	0.005

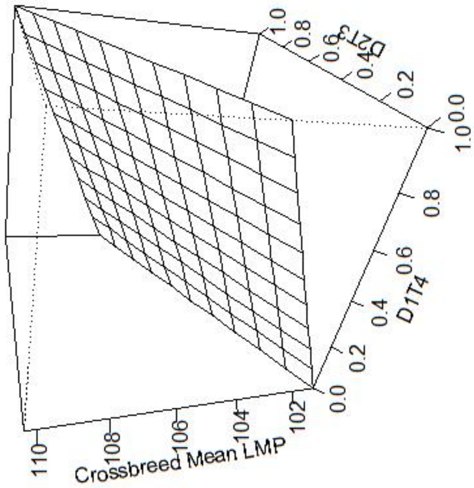
Figures B4.6a-h plot the predicted mean lamb marking percentages (LMP) for crossbred lambs versus each possible pair of the four covariates D1T2, D1T4, D2T1 and D2T3 when the remaining two covariates are set at 0.2. The corresponding plots



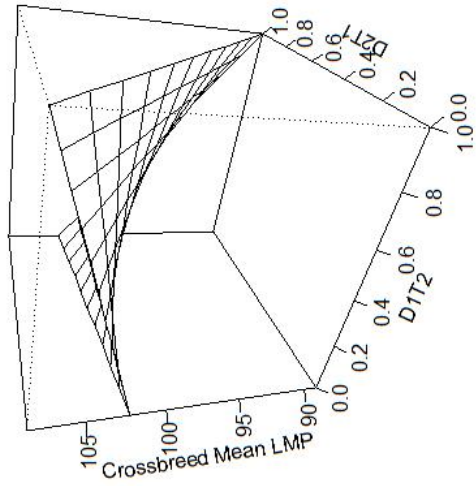
a) D1T4 vs D2T1, D1T2 & D2T3 = 0.2



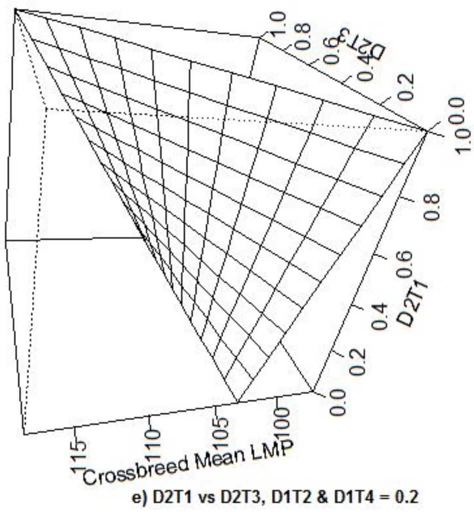
b) D1T2 vs D1T4, D2T1 & D2T3 = 0.2



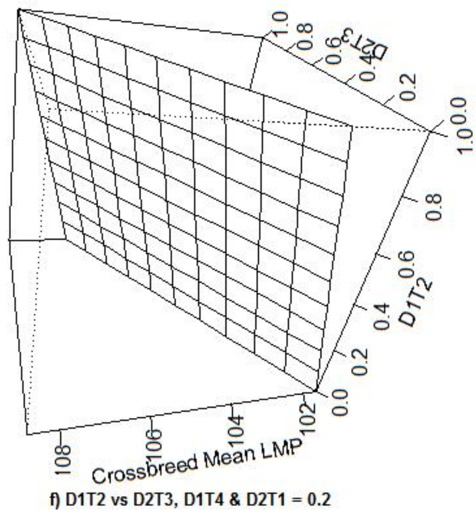
c) D1T4 vs D2T3, D1T2 & D2T1 = 0.2



d) D1T2 vs D2T1, D1T4 & D2T3 = 0.2



e) D2T1 vs D2T3, D1T2 & D1T4 = 0.2



f) D1T2 vs D2T3, D1T4 & D2T1 = 0.2

Figures B4.6a-f: The predicted mean lamb marking percentages (LMP) for crossbred lambs versus each possible pair of the four covariates D1T2, D1T4, D2T1 and D2T3 when the remaining two covariates are set at 0.2.

For merinos were similar but with different units on the LMP axis (the LMP values for merinos were 24.0% uniformly lower). Figure B4.6b shows the significant increase in LMP when a property baits twice a year, approximately six months apart. In all three figures that include the variable D2T3 (Figure B4.6c,e and f), LMPs significantly increase as the number of neighbours participating in baiting at that time increases. Figures B4.6a and d show a decline in LMP if a property baits a year or three to six months prior to lambing and the number of neighbours baiting closer to this lambing time increases.

To assist with identifying significance of differences with changing values of the covariates D1T2, D1T4, D2T1 and D2T3 the values of predicted mean lambing percentages (Pred.Val) and their associated standard errors for the extreme values of the four covariates are tabulated in Table B4.4. The predicted LMPs with no fox control (i.e.D1T2, D1T4, D2T1 and D2T3 are all 0) are 102% for crossbreds and 78% for Merinos.

Table B4.4: Predicted mean lambing percentages (Pred.Val) and their associated standard errors (Std.Err) for the extreme values of the four covariates D1T2, D1T4, D2T1 and D2T3. Also given is an LSD ranking wherein any two predicted means with a letter in common in the LSD.Rank column are not significantly different at the 0.05 level.

D1T2	D1T4	D2T1	D2T3	Crossbred Pred.Val (Std.Err)	Merino Pred.Val (Std.Err)	LSD.Rank
1	0	1	0	81.17 (6.79)	57.19 (6.70)	a
1	1	1	0	99.21 (7.38)	75.23 (7.33)	b
0	0	1	0	99.75 (2.59)	75.77 (2.28)	b
0	1	1	0	100.06 (3.02)	76.08 (2.74)	b
0	0	0	0	102.01 (1.75)	78.04 (1.25)	b
0	1	0	0	102.32 (2.24)	78.35 (1.85)	b
1	0	1	1	102.56 (8.43)	78.58 (8.43)	b e
0	0	0	1	103.25 (3.40)	79.27 (3.25)	bc
0	1	0	1	103.56 (3.73)	79.58 (3.58)	bc
1	0	0	0	104.47 (2.73)	80.49 (2.39)	bc
1	0	0	1	105.70 (4.03)	81.72 (3.88)	bc
1	1	1	1	120.60 (8.76)	96.62 (8.70)	cd
0	0	1	1	121.14 (5.95)	97.16 (5.80)	d
0	1	1	1	121.45 (6.13)	97.48 (5.97)	d
1	1	0	0	122.51 (4.97)	98.53 (4.83)	de
1	1	0	1	123.74 (5.90)	99.76 (5.83)	de

The results from Table B4.4 show that the worst possible outcome in LMP occurs when a property baits three to six months prior to lambing, all the immediate neighbours bait within three months of the lambing and no other baiting in the immediate vicinity is conducted during the twelve months prior to lambing. All outcomes involving the neighbouring properties baiting six to nine months prior to lambing lead to a higher LMP than with no baiting. When this baiting is combined with either; a second baiting on the neighbouring property near the time of lambing; or with two baitings on the lambing property itself (approximately six months apart), the increases in LMP become significant.

Table B4.5 gives the corresponding increase in gross margins for the significant predicted increase in LMPs from Table B4.4, using data calculated by NSW Department of Primary Industries (DPI). Because only LMPs were collected it was assumed that the weaning percentage (WP) was three percent lower than the LMP (NSW DPI 2007a, b).

Table B4.5: Increases in gross margins (GM) per dry sheep equivalents (DSE) and per ewe associated with corresponding increases in lamb marking percentages (LMP) and weaning percentages (WP).

Breed	LMP	WP	GM/DSE[2]	GM/ewe
Crossbred[1]	102	99	$22.31	$58.00
	120	117	$27.58	$71.71
	123	120	$28.46	$74.00
Merino[1]	78	75	$22.80	$54.72
	96	93	$27.60	$66.24
	99	96	$28.28	$67.87

[1]DSE ratings: crossbred ewe - 2.6 DSE/ewe and merino ewe - 2.4 DSE/ewe.
[2]Sources NSW DPI (2007a and b), average crossbred lamb price $86.05 per head and merino lamb price $64.50 per head.

These results in table B4.5 show that for a crossbred ewe enterprise (joined to terminal rams) an increase in LMP from 102% (no fox control) to 123% (two baiting programs and one neighbour baiting program) returns an increase in gross margin of $16.00 per ewe. The cost of two baiting programs on the average 2000 hectare property would be $795.82 ($397.91 x 2) (see section 3.2.5). In the study area such a property would run approximately 1000 crossbred ewes along with other stock. Therefore for an outlay of $800 the producer could obtain a gross margin of $16,000.

4.5 Fox Population Monitoring

Table B4.6 illustrates the frequency of spotlighting and numbers of foxes seen in the baited (transect 1) and non-baited transect (transect 2) areas. Only two counts were completed for transect 2 in early July because of access concerns. Between the August counts in 2004 and the late February counts in 2005, one of the landholders situated along transect 2 laid 1080 fox baits. Only two counts were completed along this transect. This projects involvement in the monitoring program was discontinued after this time. Each night of spotlight counting involved two people working for four hours (one hour per transect and two hrs travelling time to, from and between sites), with nearly 200 kilometres covered per night. The cost for performing these counts compared to the data that was being collected was considered disproportional and thus the decision made to cease the project's involvement.

For transect 1 the average number of foxes seen per night was about one, while for transect 2, the average was roughly six. The figures indicate a consistent higher number of foxes spotted along the non-baited transect compared to the baited one for the nine nights of spotlighting. There was no difference in fox numbers after baiting had occurred along the baited transect in 2004.

Table B4.6: Spotlight results from Goonoo area, in Dubbo RLPB

	Number of foxes counted	
Time of Count	Transect 1 (baited)	Transect 2 (non-baited)
Prior to baiting program - July 2004	0	6
	2	7
	0	-
After baiting program – August 2004	1	7
	0	3
	1	5
Prior to baiting program – February 2005	1	-
	1	5*
	1	6*

* 1080 fox baits had been laid in the area prior to this count

5. DISCUSSION

5.1 Questionnaires and Response Rates

Even though postal questionnaires are a cost effective method of collecting information from a large number of participants, they are susceptible to low response rates and sampling bias (White et al. 2005), which is clearly illustrated with the lamb production questionnaire. Only 13.6% of questionnaires were returned in the initial survey in 2004, with only 20% of lamb producers responding. In the following year only 39% of questionnaires were returned despite the targeting of producers who had expressed an interest in participating and the offer of an incentive for completing and returning the questionnaire. A number of landholders indicated on their returned questionnaires that, due to the continuing drought, they had decided to reduce the number of ewes lambing, or had not joined at all. It is likely that the worsening dry conditions, and the presence of plague locusts in the study area played a part in the low response rate of this questionnaire, as producers had other priorities and concerns.

The poor response to the initial 2004 questionnaire may have been influenced by the dual nature of the questionnaire; collection of lamb production data as well as fox management perceptions. The responses to the 2004 questionnaire were heavily biased towards landholders who had an interest in lamb production and fox control issues, and who were active fox baiters. Landholders who were neither lamb producers and/ or actively control foxes may have been put off or had no interest in returning the questionnaire. This bias towards lamb producers who were active fox baiters resulted in small sample sizes for some of the covariates used in the bait strategy analysis (e.g. landholders who supplied lamb production figures but did not bait, but had neighbours who did bait). Because of the bias in respondents, their responses to the questions on fox control methods and perceptions of fox management programs could not be viewed as being representative of the rural community in general.

5.2 Effectiveness of 'Outfox the Fox'

The 'Outfox the Fox' baiting program has been effective in promoting landholders participation in group baiting and conducting these group baitings twice a year (although not necessarily were individual landholders consistently baiting twice a year). Participation of landholders in group baiting showed a significant overall increase from the commencement of the 'Outfox the Fox' baiting program in September 1999. However after the initial success of the program in 1999/2000 there was a lull in participation across all Boards until 2004, when interest was once again sparked, and participation increased.

This wane in participation during 2000 to 2003 corresponded with a reduction in the high profile media promotion of the program. After initial promotion of the 'Outfox the Fox' baiting program by NSW DPI in 1999 and 2000, the participating Boards were encouraged to run and promote the program themselves. In 2004, the program's main instigator at NSW DPI, Suzy Balogh, brought together interested parties to discuss ways of better promoting and encouraging landholder participation, as well as ensuring NSW DPI's continued support by means of timely media releases. The improved promotion and ownership of the 'Outfox the Fox' baiting program by the Boards are major factors for the increased participation rates from 2004 onwards.

Another major factor in the gradual acceptance of the 'Outfox the Fox' baiting program was its flexibility. The program allowed each Board to retain their own management practices (e.g. personnel structure and deployment, bait costing and availability), as well as take into account the different sheep husbandry practices in each area, with minimal impact on its objectives. For example the baiting program was initially conducted both in March/April and August/September, however the latter time proved unpopular with many landholders and was moved one month forward in some areas to correspond with lambing periods, and thus increasing participation.

Despite the increased participation of individual landholders in group baiting efforts, there was no trend in the total number of landholders involved in baiting at any one time over the experimental period. Although some landholders consistently baited every year, many did not (evident in figures B4.3a-d which mapped the baited properties from year to year). Both the presence of locusts and the ongoing drought conditions did not significantly affect the number of landholders choosing to bait, however in three of the four boards, drought did significantly impact on the number of landholders baiting within a group.

5.3 Baiting Strategy

The results of this analysis support the objectives of current fox management programs such as 'Outfox the Fox' to increase group baiting participation and to bait twice a year. It was not only the fox control efforts that were conducted on an individual property that impacted on it's lambing percentages, but just as important were the fox control efforts of the neighbouring properties (within a 2.5 km radius). This impact could be both positive and negative, depending on the timing of the control efforts. These results support the study of Linton (2002), which was the first Australian study to investigate the benefits of fox control at a regional level. Linton's study found lamb producers who did not bait but were surrounded by neighbours who did bait also shared in the benefits of improved lamb marking percentages and thus hypothesised that fox control was having an effect at a scale larger than a property.

The results reported in this study provide evidence for the spatial buffer zone concept that has become increasingly incorporated in fox control programs. Such programs advocate group participation so that fox control can extend over a wider area with more chance of long-term respite from damage (Saunders et al. 1995). This study showed that as the proportion of the near neighbours who baited increased (buffer zone area increased), so did the benefit to lamb production in most cases. Maximum benefit would be attained when all the neighbouring properties were involved in the group program, however those on the fringe of the group would also benefit to some degree.

Thomson et al. (2000) recommended that, for a buffer zone to be effective, fox densities in the buffer should be kept as low as possible to maintain an effective ‘dispersal sink’, particularly during the dispersal phase of foxes. In this study area the majority of baiting occurred in autumn and late winter coinciding with the main dispersal period for foxes (autumn), and with the lead up to breeding (late winter). Baiting at these two times is thought to deliver maximum impact on the local fox populations (Saunders and McLeod 2007). This was supported by the results with strategies that involved baiting twice a year, approximately six months apart significantly enhancing lamb production.

Current popular fox management strategies have landholders baiting just prior to their lambing, and a common reason given for not participating in group baiting programs is the timing of the group does not fit in with the individuals lambing time. These results show that when the baiting is conducted twice a year, it need not be timed directly prior to the property’s own lambing (but up to three months prior) allowing more flexibility to bait with surrounding neighbours to achieve maximum benefits.

These results suggest for maximum effectiveness of a fox control program there should be a movement away from current reactionary short-term fox management practices of baiting small areas just prior to lambing to a more consistent, larger scale group effort which would give long term as well as short term benefits. This long term strategy has been successfully employed in conservation areas to provide protection to endangered wildlife (see examples in Saunders and McLeod 2007), and would also be able to provide similar benefits to the agricultural sector. Individuals could still do some form of control such as shooting, or maintaining some bait stations, around their own lambing time if they felt it was necessary but their main emphasis should be on participation in the group control programs.

As lamb turnoff rate (number of lambs surviving until weaning) is the major profit driver for lambing enterprises (Fogarty et al. 2006), the effectiveness of a fox control program can be measured by the total number of lambs weaned. Using the results from this study we were able to model the outcome of different baiting strategies. The strategy with the largest increase in lamb weaning was two baiting programs six months apart along with at least one neighbour baiting program preferable six to nine months before lambing. Following this strategy, a producer with a typical crossbred ewe enterprise (joined to terminal rams) could return a gross margin of $16.00 per ewe, for the outlay of the two baiting programs and some neighbourly cooperation.

Therefore on an average 2000 hectare property running 1000 ewes a producer could obtain a gross margin of $16,000 for outlay of $800 along with a small cost of time associated with participating with a group program.

5.4 Fox Population Monitoring

The fox population monitoring carried out was indicative of the method used by many programs when trying to access trends in the fox population. The number of foxes counted was low at both sites, and even though there was a difference in fox numbers between sites, there was no significant change in the fox abundance at either site after intervention (fox baiting). Therefore you would have to conclude that the fox population at each site was not effected by the intervention (fox baiting).

Even though spotlight counts are commonly used to monitor trends in fox populations, the reliability of this method is questionable. The reasons this method is chosen is that it is relatively quick and simple, large distances or areas can be sampled, and many different habitat types can be covered. Unfortunately the counts are prone to high variability, due to sightability, fox behaviour and activity (e.g. Ables 1969, Stahl 1990, Weber et al. 1991, Mahon et al. 1998, Molsher 1999, Field et al. 2005), and are not recommended for comparisons over seasons or censuses of short-term trends (Stahl and Migot 1990), such as in this project.

The reliability of spotlighting can be improved by repeated counts, longer transects, and standardising when and under what prevailing conditions the technique is used (Wilson and Delahay 2001). Spotlight counts also tend to use formed roads and tracks for vehicular access. In some studies it may be necessary to ensure that transects incorporate all habitats in proportion to their availability across a study site. Most studies assume three consecutive counts will be enough without understanding that the standard error (measure of the accuracy of the mean) of these counts needs to be within 10% of the mean over these counts otherwise more counts are required. Field et al. (2005) suggest that, because of the low detectability of foxes, at least five (and as many as nine) repeat visits might be required.

5.5 Summary

The ‘Take Home Message’ for producers from these results are:

- Fox baiting on neighbouring properties has a significant impact on a property’s lamb production. Generally as the proportion of neighbours who bait in a group increases, so does lamb survival on the individual property.
- Baiting twice a year, approximately six months apart (to impact on fox breeding and dispersal), by either a property and/or its near neighbours also significantly enhances that property’s lamb production.
- It is more beneficial for a property to time its baiting with a group of near neighbours up to a few months prior to lambing than baiting alone just before lambing.
- Group baiting programs such as ‘Out-fox the Fox’ increase the number of landholders baiting with a group and can increase landholder involvement outside of their lambing period.
- Continual and effective promotion of group programs is required to maintain the landholder support required to be successful.

PART C: IMPROVING THE EFFECTIVENESS OF 1080 IN FOX CONTROL

1. INTRODUCTION

Currently in Australia, 1080 remains the most appropriate toxicant for the lethal baiting of foxes. Canids are among the most sensitive species to this toxin and although resistance to 1080 has been reported in some mammalian species, the chance of it developing in canids is considered very small (Twigg et al. 2002). Of more concern is the development of bait aversion which occurs when a sub-lethal dose of toxin is consumed, making the animal ill (Gustavson 1977). When the animal recovers, the association between the bait and the illness is remembered, and the source is avoided in future foraging events. The potential exists for foxes to consume sub-lethal doses of 1080 because of the combined consequences of bait caching and the decay of 1080.

The substance 1080 is known to be environmentally safe as it breaks down relatively quickly, and is neither mobile nor persistent in the soil. The decline of 1080 in fox baits occurs as a consequence of seepage of 1080 solution, defluorination by microorganisms, decomposition by invertebrates, and leaching by rainfall (Korn and Livanos 1986, Kramer et al. 1987, McIlroy et al. 1988, Fleming and Parker 1991, Wong et al. 1991, Staples and McPhee 1995). Thus rainfall, soil moisture and temperature play an important role in the longevity of 1080 in baits, both directly as well as indirectly by affecting the activity levels of microorganisms and invertebrates. Bait type is also an important factor, with 1080 persisting longer in baits that offer some protection from water infiltration and microbe activity, such as the ‘crust’ on dried-meat baits, the shell of egg baits, and (to a lesser extent) the skin on chicken wingettes (McIlroy et al. 1988, Fleming and Parker 1991, Saunders et al. 2000, Twigg et al. 2000, Twigg et al. 2001, Gentle 2007, Mooney et al. 2005).

This decline of 1080 concentration in fox baits with time is an advantage in terms of non-target risk, however there is a potential for the consumption of sub-lethal doses, which could allow bait aversion to develop in the target animals (Gustavson 1977, Saunders et al. 1999). Although this potential has been mooted, it has never been investigated under Australian conditions. This study uses simulation modelling to evaluate the likely outcomes from the combined effects of bait degradation and bait caching on the development of bait averse foxes, and the impact this will have on current fox baiting strategies.

1.1 Bait Degradation

The degradation of 1080 in fox baits has been investigated by several authors under varying conditions, and using different bait substrates. Saunders et al. (2000) investigated 1080 degradation in buried Foxoff® baits in central NSW. Baits were exposed to five different treatments: shelf storage (controls), prevailing weather, no rainfall, average weekly rainfall and twice average weekly rainfall. The concentration of 1080 in baits from the ‘no rainfall’ treatment was highly variable with some baits still remaining lethal to foxes after eleven weeks. Modelling of the 1080 decay rates in baits suggested that, under mean rainfall conditions for central NSW, sub-lethal doses of 1080 for foxes would be present after 2.8 weeks.

Gentle (2007) also studied the persistence of 1080 in buried Foxoff® baits, as well as in buried chicken wingettes, under two different climatic and three rainfall regimes. He found that the rate of 1080 degradation did not change significantly between the two climatic sites (Central Tablelands and the warmer Western Slopes of NSW), but Foxoff® remained lethal for longer than the wingettes under all conditions. The Foxoff® baits remained lethal to a five kilogram fox for an average of 2.1 weeks, and some baits remained lethal for up to five weeks. On average, wingettes remained lethal for 1.1 weeks, the longest lasting two weeks. Under no-rain treatment, the degradation of the Foxoff® baits was highly variable, a similar finding to that of Saunders et al. (2000).

Dried meat baits produced similar findings to the Foxoff® bait. In a trial in Tasmania Mooney et al. (2005) reported that after two weeks more than 80% of buried dried kangaroo meat baits did not have enough 1080 to kill an average-sized fox. Kirkpatrick (1999) found in temperate areas, with moderate rainfall, buried dried meat baits became non-lethal to foxes after as little as one week. Unburied baits could potentially remain lethal for up to one or two months, depending on rainfall. In arid parts of Australia, in the absence of rainfall, unburied dried-meat baits remained lethal for at least eight months (Twigg et al. 2000).

An implication of these studies, and lending support to the practice of picking up baits that have not been taken (where it is practicable), is the potential for consumption of sub-lethal doses of 1080, which could allow bait aversion to develop (Saunders et al. 1999). This could occur after three weeks (or possibly even quicker in higher rainfall areas) if resident foxes do not immediately locate baits or when baits are found by foxes re-invading the area after the death of the resident fox.

1.2 Bait Caching

The caching of food by foxes is an important adaptive strategy as it allows a means of securing surplus food from the attention of competitors, in anticipation of lean periods, the birth of young or to train offspring (Macdonald 1977, 1987, Macdonald et al. 1994). Foxes are known as scatter rather than central-place hoarders (Kruuk 1964) and depend on olfactory and visual cues to locate their caches (Tinbergen 1972, Henry 1977, Macdonald 1977). They tend to bury their caches about ten centimetres below the surface, a compromise between being able to locate it later but having it hidden sufficiently to protect it from other scavenging animals (Henry 1977). Burying baits in shallow depressions, as is the recommended procedure in most States, is considered to mimic caching behaviour in foxes.

Studies into the caching behaviour in foxes have found that individuals tend to retrieve the majority of their caches within a relatively short period, particularly when preferred prey is cached (Scott 1943, Macdonald 1976, Henry 1977, Macdonald et al. 1994, Saunders et al. 1999, van Polanen Petel 2001, Thomson and Kok 2002, Gentle 2005). However, in some cases, caches may not be revisited for a number of months (Kruuk 1964, Tinbergen 1972, Frank 1979), particularly when toxic baits are employed (Saunders et al. 1999, Gentle 2005). There is evidence of foxes raiding other foxes' caches if they locate them (Macdonald 1976, Henry 1977).

Caching of baits by foxes is thought to have important implications for fox-baiting programs (Saunders et al. 1999, van Polanen Petel 2001). Fewer baits may be available in a control program if a small number of foxes monopolise the supply, and potential risks exist for non-target species and the development of bait aversion in foxes if the 1080 in cached baits degrades over time (Saunders et al. 1999).

2. OBJECTIVES

- Develop a model of fox poisoning that incorporates the known effects of bait degradation and bait caching on bait uptake
- Using this model evaluate the likely outcomes from the combined effects of bait degradation and bait caching on current baiting programs.

3. METHODS

3.1 Model Development

A model was developed following the compartmental model of feral pig poisoning described by Hone (1992). This type of model is based on dividing the population into compartments, with differential equations describing the rates of change of individuals between these compartments. Figure C3.1 illustrates a flow diagram of the developed model. When poisoned bait is offered, susceptible animals can be poisoned at a per capita rate *β*, and after a latent period (1/*σ*), during which poison signs are not apparent, they show signs of poisoning. Animals showing signs can die at a per capita rate *α*, or recover at a per capita rate *υ*, and again become susceptible. Because of the small timeframe over which the model was run (3 months), natural birth and death rates were considered unimportant so were not included in the model. The amount of poison in the environment is increased by additions (A), and decreases because of intake by foxes and by loss due to degradation. The bait passes through two stages during degradation, from a sub-lethal stage (at a per capita rate *μ*) to a non-lethal stage (at a per capita rate *τ*).

The change in the number of individuals in the fox population can be described by a series of differential equations:

$$\frac{dy_1}{dt} = -\lambda_L y_1 x_1 - \lambda_{SL} y_1 x_2 - \nu$$

$$\frac{dy_2}{st} = \lambda_L y_1 x_1 - \sigma y_2$$

$$\frac{dy_3}{dt} = \sigma y_2 - (\alpha + \nu) y_3$$

$$\frac{dy_4}{dt} = \lambda_{SL} y_1 x_2$$

where y_1 is the density of susceptible foxes, y_2 is the density of latent foxes, y_3 is the density of poisoned foxes, and y_4 is the density of averse foxes. The parameter λ_L is the per capita rate at which new poisoned foxes are "created" (and it is analogous to the force of infection in epidemiological models), λ_{SL} is the per capita rate at which new averse foxes are created, σ is the rate which latent foxes (those that have consumed a bait but are yet to show signs of poisoning) move to the poisoned state, α is the death rate due to poisoning, and v is the rate at which poisoned foxes recover (and for this example v = 0, i.e. no foxes that eat a lethal bait recover).

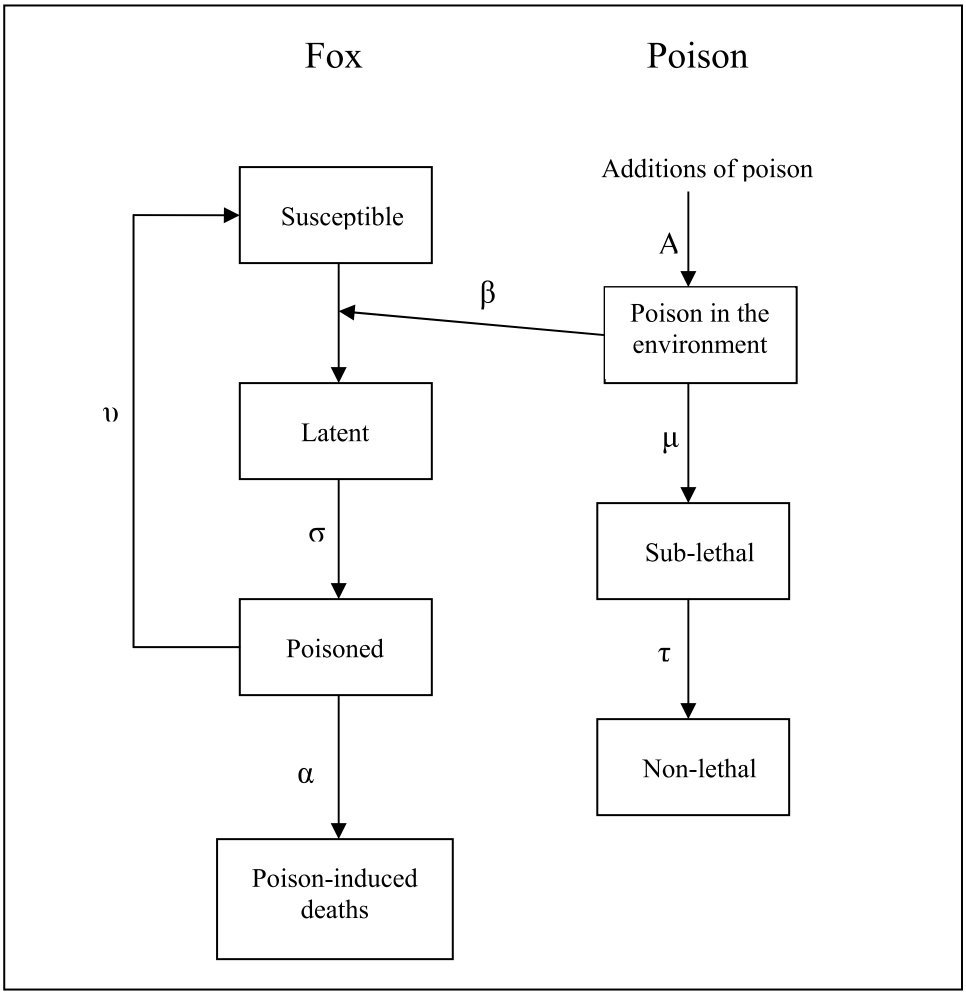


Figure C3.1: Flowchart of the compartmental model of a fox population subject to poisoning with 1080 bait. See text for explanation.

In the above diagram (Figure C3.1) susceptible animals are described as being poisoned at a per capita rate β. This rate of poisoning is dependent on the:

- rate of bait consumption
- probability that the consumed bait is lethal
- probability that consumption of a lethal bait results in mortality

The rate of consumption of baits by individual foxes can be affected by many factors including bait factors (such as bait type, palatability and density), population, seasonal and environmental factors as well as behavioural factors (Saunders and McLeod 2007). For this study, bait consumption was modelled as a Type II functional response to bait density. The most common type of functional response is the Type II functional response, where the rate of bait consumption by a consumer rises as bait density increases, but eventually levels off so the rate of consumption remains constant regardless of the density. Holling's disk equation (Holling 1959) was used to model the relationship between the number of baits eaten during a period of time and the bait density, and is described by the equation:

$$N_a = \frac{a' T N}{1 + a' T_h N}$$

Where Na is the number of baits attacked, $a^{\prime}$ is the attack rate (searching efficiency), N is bait density, T is total search time available, and T_h is the handling time (the time spent locating, pursuing and consuming each bait plus preparing to search for next item).

The probability that the consumed bait is lethal can be described by the equations:

$$\frac{dx_1}{dt} = -(\lambda_L y_1 + \mu) x_1$$

$$\frac{dx_2}{dt} = \mu x_1 - (\lambda_{SL} y_1 + \tau) x_2$$

where x_1 and x_2 are the densities of poison bait and sub-lethal bait, respectively. Parameter μ is the rate at which poisoned bait becomes sub-lethal and τ is the rate at which sub-lethal bait becomes non-lethal.

For the purposes of this study it is assumed that all individuals that consume a lethal bait die (i.e. the probability that consumption of a lethal bait results in mortality is one).

3.2 Model outcomes

The model simulated baiting with Foxoff® in both dry (no rainfall) and wet (average rainfall) conditions, and chicken wingettes. Both bait types were simulated with daily bait replacement and no bait replacement. Table C3.1 lists the values for the parameters and variables used. Rates for the degradation of Foxoff® baits were obtained from Saunders et al. (2000). The rate for 1080 degradation in chicken wingettes was sourced from Gentle (2007), who found no difference between dry and wet conditions. Sharp and Saunders (2005) state the latent period for foxes to 1080 poisoning as approximately four hours, with death usually occurring within two hours. The density of foxes in agricultural land in eastern Australia is on average around five foxes per square kilometre (Saunders and McLeod 2007). All foxes were initially assumed to be susceptible. A baiting density of ten baits per square kilometre is typical of most baiting programs in eastern Australia (Saunders and McLeod 2007). The searching efficiency for both bait types was assumed to be the same.

Table C3.1: Parameters and variables used in the model in both dry (no rainfall) and wet (average rainfall) conditions.

Parameter	Description	Value
σ	rate from latent to poisoned (per day)	5.99[1]
α	poison bait induced death rate (per day)	12.5[1]
υ	recovery rate after eating poison bait	0.000001
Foxoff®		
dry - μ	rate baits move from lethal to sub-lethal under dry conditions	0.0119[2]
wet - μ	rate baits move from lethal to sub-lethal under wet conditions	0.0549[2]
dry - τ	rate baits move from sub-lethal to non-lethal under dry conditions	0.0058[2]
wet - τ	rate baits move from sub-lethal to non-lethal under wet conditions	0.0260[2]
Wingettes		
μ	rate baits move from lethal to sub-lethal	0.1250[3]
τ	rate baits move from sub-lethal to non-lethal	0.0714[3]
Variables		
y_1	density of susceptible foxes (foxes/km^2)	5
y_2	density of latent foxes (foxes/km^2)	0
y_3	density of poisoned foxes (foxes/km^2)	0
y_4	density of averse foxes (foxes/km^2)	0
N	density of baits (baits/km^2)	10
a^i	attack rate (searching efficiency)	0.0005
T	total search time available	6
T_h	handling time	3

Source: [1] Sharp and Saunders 2005, [2] Saunders et al. 2000, [3] Gentle 2007

4. RESULTS

The model was first simulated using Foxoff® baits in both dry (no rainfall) and wet (average rainfall) conditions, with and without bait replacement. Results are graphed comparing the density of lethal and sub-lethal baits in the environment over time (up to 60 days after baits first laid) (see Figure C4.1), and the density of susceptible and averse foxes over the same time frame (Figure C4.2).

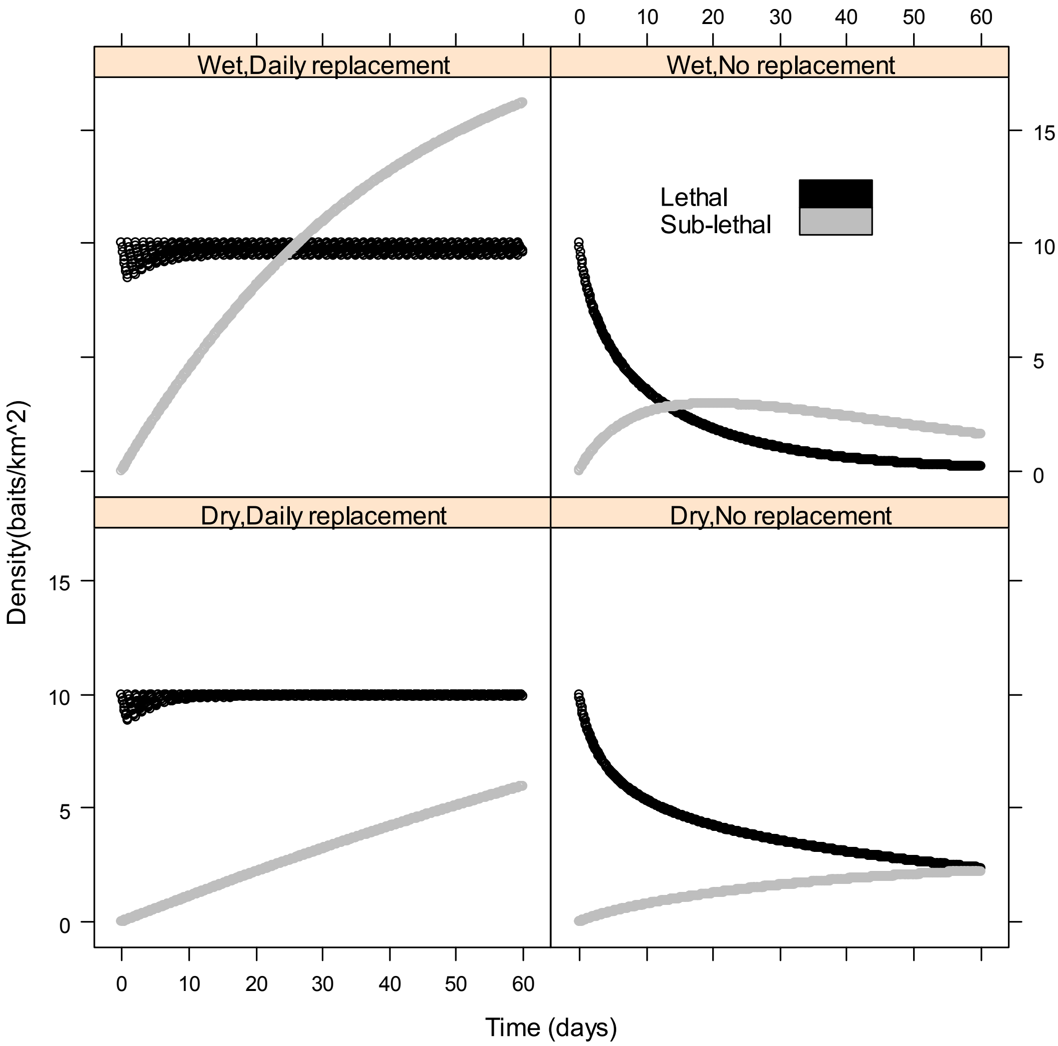


Figure C4.1: Density of lethal and sub-lethal Foxoff® baits in both dry (no rainfall) and wet (average rainfall) conditions, with and without daily bait replacement over time.

As expected, the creation of sub-lethal baits was much slower under the dry conditions than the wet conditions. The number of sub-lethal baits in the environment increased dramatically with daily replacement of taken baits, especially under wet conditions. Despite this dramatic increase in sub-lethal baits under the wet conditions, the development of averse foxes remained lower than that for the no replacement treatment as it took longer for the susceptible foxes to decline, giving them more chance of consuming a sub-lethal bait and becoming averse to the poison.

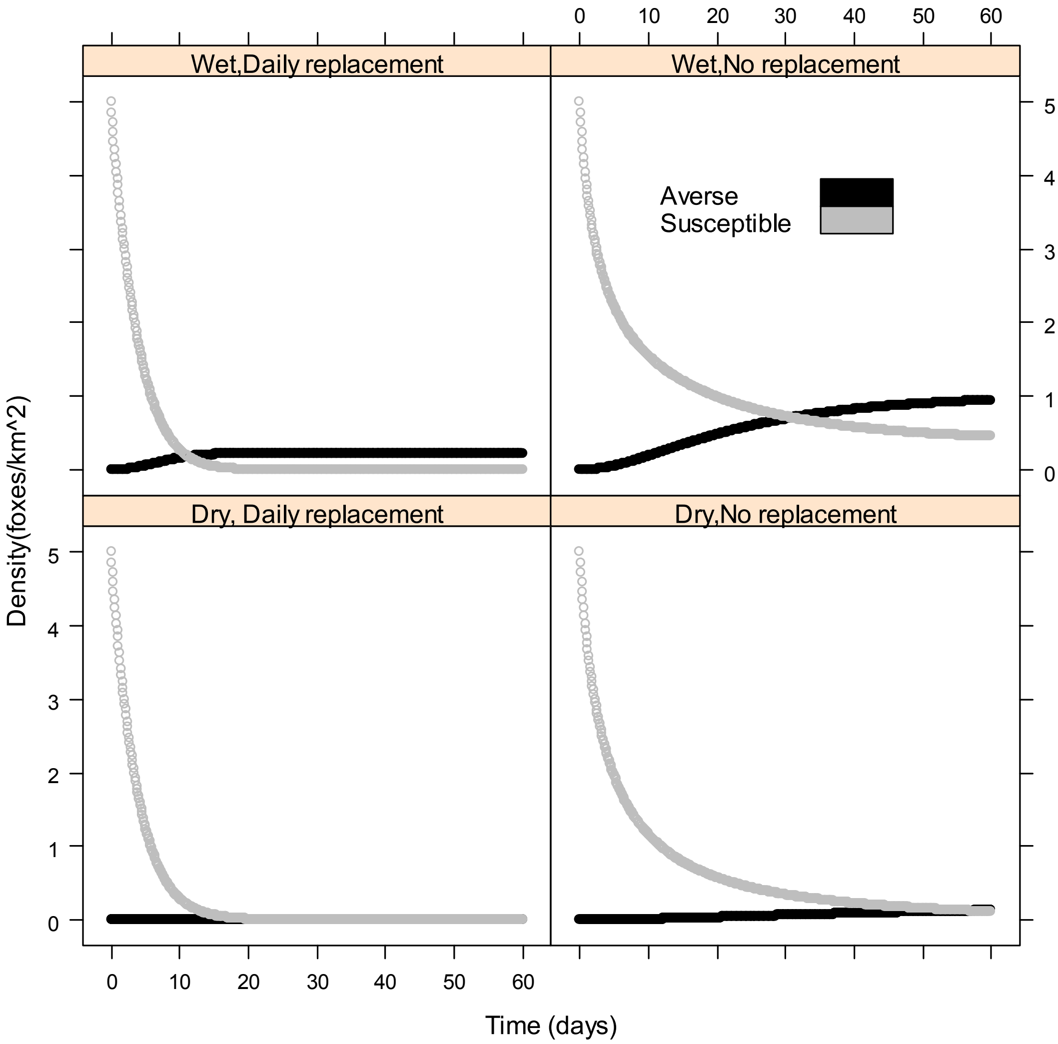


Figure C4.2: Density of susceptible and averse foxes after using Foxoff® baits in both dry (no rainfall) and wet (average rainfall) conditions, with and without daily bait replacement.

As a comparison the model was then simulated using chicken wingettes, with and without bait replacement. Gentle (2007) found no significant difference in the 1080 degradation rate within this bait type between dry and wet conditions, so only the average rate over both these conditions was tested. Results are presented, again comparing the density of susceptible and averse foxes over time and the density of lethal and sub-lethal baits in the environment over the same time frame (Figure C4.3). The time for these baits to pass from lethal to sub-lethal and then sub-lethal to non-lethal was faster than that for Foxoff® underwet conditions, so the development of averse foxes was not as great under the tested baiting scenario. As for Foxoff® baits, daily replacement of taken baits increased the number of sub-lethal baits present in the environment over time.

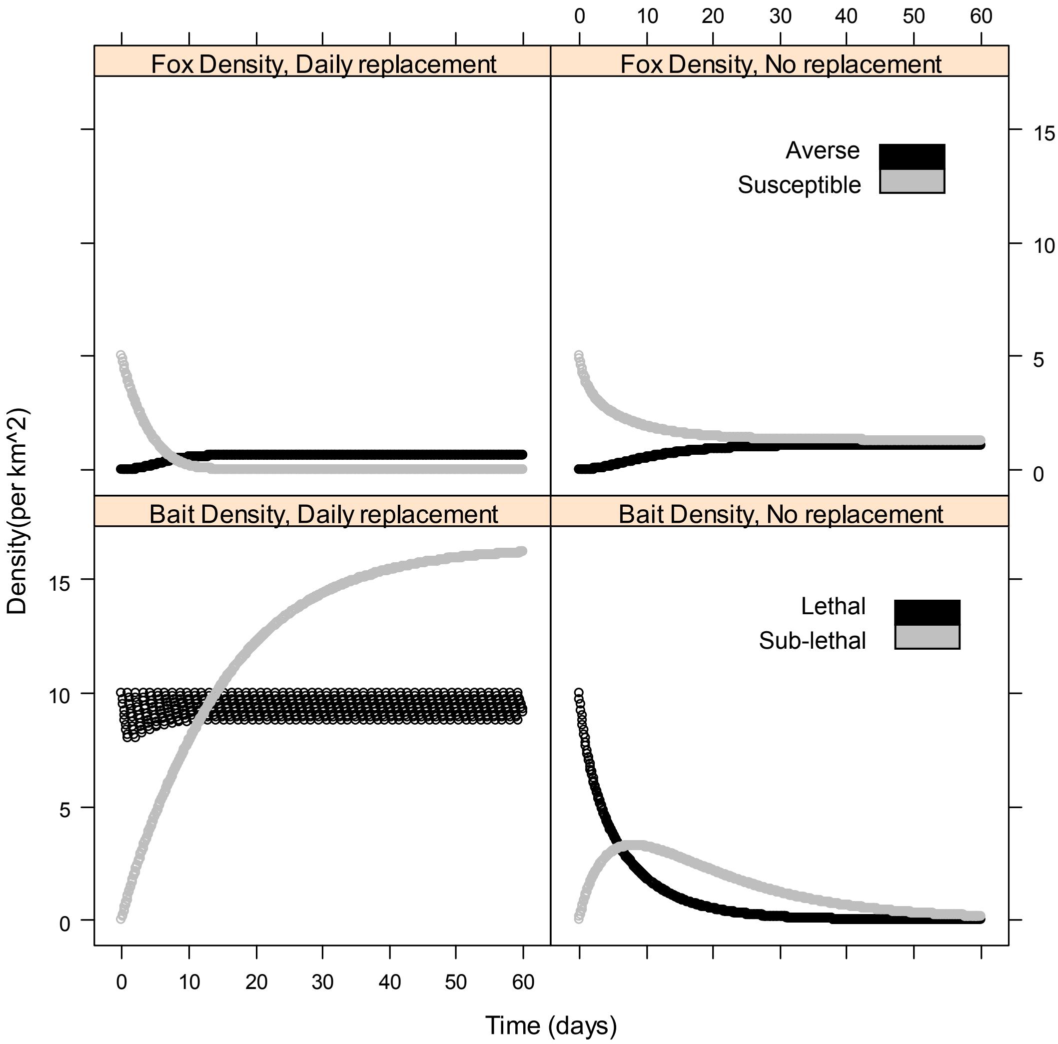


Figure C4.3: Density of lethal and sub-lethal wingette baits, and density of susceptible and adverse foxes, with and without daily bait replacement.

5. DISCUSSION

Continual efforts are needed to improve the application of 1080 and to promote its advantages to ensure its longer-term registration and acceptance by the community at large. This desktop study developed a model to investigate the effect of bait degradation on the presence of sub-lethal baits and development of averse foxes during a fox baiting program. Results show baits do change from lethal to sub-lethal during the course of a baiting program, and averse foxes can develop as a result. It is the intensity at which this occurs that can seriously affect the outcomes of a 1080 baiting campaign.

Best practice baiting procedures promote the checking and replacement of taken baits during a baiting campaign (Saunders and McLeod 2007). The scenarios modelled here represent the two extremes of this procedure - daily replacement and no replacement. The results show that continuous daily replacement dramatically increased the likelihood of sub-lethal baits in the environment, however because of the relative quick decline in the fox population (around 10 days), this had less of an impact on the development of averse foxes than the no replacement strategy, which took nearly twice as long to knock down the initial population of susceptible foxes. Continuous bait replacement over a 60 day period is a scenario that is unlikely to occur in normal baiting programs, but these results show the importance of replacement of baits in the early stage of the baiting program. Once the fox population has declined sufficiently (bait take declines) this replacement should cease, as baits will have a low probability of being taken by foxes, and the increase in sub-lethal baits, and risks to non-target species therefore becomes greater.

Both bait types tested: Foxoff® and wingettes, showed similar responses, however because of the faster breakdown of 1080 in wingettes, the time frame of the development of sub-lethal then non-lethal baits was quicker than for Foxoff®. Because of this the wingettes would need to be initially replaced more often than the manufactured Foxoff®. However as the wingettes degrade at a quicker rate, sub-lethal baits of this type should not remain in the environment as long as the Foxoff® baits under most conditions.

Although landholders in NSW are legally required to collect and dispose of all untaken baits at the completion of a baiting campaign (Environment Protection Authority 2002), many do not comply. These results highlight the need for compliance with this regulation as the longer the baits are left in the environment, the higher probability they will contain sub-lethal doses, and the more likely bait aversion will develop in the remaining foxes. Non compliance would also lead to increase risks to non-target species.

The presence of moist conditions increased the degradation rate of the baits, resulting in sub-lethal baits appearing at a faster rate than when conditions were dry. With the exception of extreme drought conditions, baits that are buried in the soil will come into contact with enough moisture to initiate the breakdown (Saunders et. al 2000), so in most cases landholders should be mindful of the enhanced bait degradation and follow correct handling procedures. In such cases where baits are placed within some type of container away from direct contact with soil (e.g. Figure C5.1), they would be expected to degrade slower than those placed in direct contact with the soil so again landholders would need to take into account the slower degradation rate, and adjust their procedures accordingly.

Figure C5.1: Example of mound baiting used on agricultural lands in northern NSW. The bait is placed in an open ended container within a raised mound of dirt. The open end is then concealed behind a tussock of grass.

Initially it was planned to add the effect of bait caching to this model, however although there have been studies on the caching behaviour of foxes, there was a lack of data on the probability of foxes (and non-targets) finding and consuming baits that have been cached by other foxes. There is no doubt that caching would lead to an increase in the number sub-lethal baits present in the environment, however how this impacts on the development of averse foxes is less clear. If the probability of a fox (or non-target species) finding another fox's cache is low, the risks posed by these sub-lethal doses to foxes (and non-targets) may be correspondingly low. However as the probability of increases, especially with particular bait types, the risks would also increase. There is a need for more studies on this aspect of caching before the full impact of caching on the development of averse foxes can be determined.

PART D: SHOOTING AS A MANAGEMENT TOOL

1. INTRODUCTION

Up until the 1990's the shooting of foxes was the most popular control technique used by the agricultural community in Australia (Saunders et al. 1995). With the reduction in the fox fur trade in the early nineties, and the increasing popularity of 1080 baiting, the prevalence of professionals diminished, leaving landholders and enthusiastic amateurs to do the bulk of the shooting (Saunders et al. 1995). At present the use of 1080 baits is the most common control action used against foxes (77% of all control actions in NSW during 2004 – West and Saunders, unpublished data), however shooting plays an important role (13% of control actions), particularly in areas where baiting is restricted or not a preferred option.

The popularity of shooting as a control strategy for foxes is reported to be on the increase. There is little or no documentation of how this shooting is being conducted (professional, land owners or recreational shooters), or of the impact and resultant changes in production values. Since most of the scientific evaluations on fox control impact and efficacy on agricultural lands are based on trials focussed on lethal 1080 baiting, the effectiveness of this control technique needs to be further evaluated in line with other methods of control.

Shooting is a very selective method of control (Beasom 1974), however past Australian studies have described it as an ineffective method in significantly reducing fox population numbers, particularly over the long term (Coman 1988, Newsome et al. 1989, Fleming 1997). Reasons for this ineffectiveness include the biasing towards younger, less wary individuals (Coman 1988) which, although altering the age structure of the population, is thought not to necessarily lead to a decline in the population or to the impacts these foxes cause. The compensatory effects of the culled population may also allow the remaining animals' survival and breeding to be enhanced, immigration rates to increase, and dispersal rates to decrease (Caughley 1977). Newsome et al. (1989) report that the replacement rate of foxes was very high after an intensive shooting campaign conducted in western NSW.

These past studies have investigated shooting in isolated, one-off programs. Since the mid 1990's large coordinated group fox management programs have become popular in both agricultural and conservation areas. These large-scale programs give more chance of long-term respite from predation damage mainly by slowing down the immigration rates of foxes into the culled area (Saunders et al. 1995). Studies have been conducted investigating the effectiveness of large-scale fox management programs that primarily use 1080 baiting as the control method (e.g. Linton 2002, see section B of this report). No studies have investigated the effectiveness of such large-scale group programs that use shooting as the main method of control. This section reports on the effectiveness of two such programs conducted on the south coast of NSW.

2. OBJECTIVES

The aim of this study is to monitor the effectiveness of fox shooting as a means of reducing the agricultural impacts of foxes. The specific objectives of the study are to:

- Assess the trend of fox shooting across agricultural lands in NSW
- Benchmark current fox shooting practices for future reference
- Measure the impact of fox shooting on fox abundance and agricultural production
- Evaluate the cost-effectiveness of shooting with respect to agricultural production.

The data for the first two objectives was collected from fox shooters within NSW using a voluntary questionnaire. Objective 3 was measured using two case studies on the south coast of NSW. Data for Objective 4 was collected from both the survey and case studies.

3. FOX SHOOTER QUESTIONNAIRE

3.1 Methods

3.1.1 Questionnaire Design and Sampling

Procedure for the fox shooter questionnaire is set out below (following the recommendations for best practice in questionnaire-based studies by White et al. (2005). See also the section 2.3.1 in Part A for further discussion of the design and use of questionnaires in this project.

The target population for this particular questionnaire was fox shooters, both recreational and professional, throughout NSW. A comprehensive questionnaire of this population was impossible, not only because it is so large, but because a complete list of all fox shooters is not available. However, due to Australia's strict gun and hunting laws, most shooters are members of at least one of the many shooting and gun clubs, associations and organisations that are available or are listed with government and agricultural agencies, and other known sources who undertake regular fox control programs.

Volunteer sampling in questionnaires have many inherent problems, the main one being that you have no way of knowing how representative the respondents are of the larger population (List 2002). There are several methods to check or reduce this uncertainty including random questionnaires or ensuring the response rate is high from all sections of the target population. Volunteer sampling through publicity from organisations such as the Game Council and the Sporting Shooters Association Australia (SSAA) and the associated clubs and organisations, as well as approaching shooters involved in the agricultural sector, government agencies and other sources who undertake fox control programs reached a large proportion of the fox shooting community. Stressing the importance of the study, making the shooters feel their contribution was valued and gaining the trust of the participants are all important to ensure a high response rate.

A postal questionnaire was the survey method chosen because it is a cost effective way of reaching a large number of participants across a large geographical area (White et al. 2005). The questionnaire was carefully designed to eliminate measurement and non-response errors (Appendix IV). As most of the information required was of a factual nature, the questionnaire contained mainly closed-format questions to eliminate uncertainty. To further improve the design of the questionnaire it was piloted on a subsample of shooters to gauge their responses, and correct any questions that were ambiguous or open to misinterpretations.

A follow-up postal questionnaire of non-respondents to quantify non-response bias was not feasible. Instead, the degree to which the respondents were representative was assessed by comparison of relevant characteristics (ie the category of shooter - recreational, primary production and professional vertebrate pest operators) with those of the target population. This was supplemented with the results from a small number of face-to-face interviews with local non-respondents.

3.1.2 Statistical Analysis

The chi squared test for homogeneity (Pearson's Chi-squared test) was used to test if the respondents of the fox shooting questionnaire were representative of NSW shooters with respect to licence category (ie recreational, primary production/rural occupation or professional vertebrate pest controllers).

For comparisons between day and night shooting forays, data was first checked for normality and difference in variances. A one-way Anova was used to compare time spent, distance travelled, number of people involved, foxes spotted and success of shooting. A Fisher's test was used to compare vehicle use between day and night as well as a comparison of the number of juveniles and adults shot.

3.2 Results

Information was received from 40 fox shooters (3 farmer / rural occupiers, 36 recreational and 4 professionals), documenting 169 separate forays from the period of March to August 2006. This was an extremely poor response considering the number of fox shooters in NSW is estimated to be in the thousands. The proportion of respondents in each category (ie recreational hunters, primary production and professional vertebrate pest operators) differed significantly from the shooting community as a whole ($X^2 = 46.82$, df = 2, $p < 0.001$), as gauged by the number of gun licenses issued in the licence categories A and B (containing rifles and shotguns that are not self loading) in 2006 by NSW Police (Table D3.1), with primary producers and rural occupiers being considerably under represented.

Table D3.1: Firearm licence holders as at December 2006 for NSW (supplied by the NSW Police Firearms Registry).

Licence Category	Total Category Issued	No. Licence holders with Genuine Reason		
		Rec. Hunting/Vermin control	Primary Production/ Rural Occupation[1]	Vertebrate Pest (professional)
A	163 639	121 964	44 715	1 219
B	139 688	106 327	37 761	1 222

[1] Primary production and rural occupation are separate categories for licence reasons but are combined as the participants of the survey in these two groups could not be separated.

Because of the poor response, a short face to face interview was conducted with ten fox shooters from the Orange area who did not respond to fox questionnaire. The main reasons given for non-response were lack of interest, they didn't know about the questionnaire, and wariness of providing information to a government department, either personal (this was also evident in some of the anonymous responses received) or location (“I’m not telling you where I shoot my foxes because you’ll go and poison them all” – fox shooter interviewed when selling fox skins).

With the exception of the one battue reported which had 21 people involved, both the average and median number of people involved in each foray was two (range 1 to 5). The participating shooters visited nearly 100 different locations across the state; shooting was the sole form of control at over half of these locations. Three quarters of the shooters travelled less than 100km from their home base, but some travelled over 300km. The three shooters categorised under primary production / rural occupier all shoot at their home location (property), with two shooting at other locations as well. Over half of the shooters had favoured locations that they revisited at least every three months.

Fox shooting was conducted both during the day and at night (59 day, 104 night, 6 day and night). There was a significant difference between the number of people involved (day shoots averaging 1.5 people and night forays averaging 2.2 people: $F=21.34$, $df=1$, $p<0.001$). There was a significant difference in the use of vehicles (53% of day and 94% of night forays used vehicles: $p<<0.001$, Fisher’s Test), a significant difference with the distance covered (day shoots averaging 5km, and night forays averaging 48km: $F=52.65$, $df=1$, $p<0.001$), and the average time spent shooting during these times (3.2 hours for the day, 3.9 hours at night: $F=9.26$, $df=1$, $p<0.001$).

There was a significant difference in the number of foxes spotted per hour during these two periods (0.89 per hour during the day compared to 1.88 per hour at night: $F=21.87$, $df=1$, $p<0.001$) and the number of foxes shot per hour (0.54 per hour during the day compared to 0.96 per hour at night: $F=11.69$, $df=1$, $p<0.001$), however there was no difference in the success between day and night (the proportion of foxes shot to those seen per hour was 63% during day and 60% at night: $F=0.22$, $df=1$, $p=0.64$). Only 33 forays provided information on the age of the foxes shot. There was no difference between the ratio of adults and juveniles (<1year old) shot at night compared to the day ($p=0.27$, Fisher’s Test). Table D3.2 gives the details for all these analyses.

Table D3.2: Comparisons of day and night fox shooting forays

	Day		Night		Inadequate data (n)	P value
	n	mean	n	mean		
Time spent	58	3.2 hrs	95	3.9 hrs	16	p<0.001*
Distance travelled	54	5.2 km	92	47.8 km	23	p<0.001*
Foxes spotted	58	0.89 / hour	68	1.88 / hour	43	p<0.001*
Foxes shot	58	0.54 / hour	96	0.96 / hour	15	p<0.001*
Success - foxes shot/spotted	52	63%	67	60%	50	p=0.64
	n	vehicle/walk	n	vehicle/walk		
Vehicle Use	58	31/27	103	97/9	8	p<0.001*
	n	Adult/juvenile	n	Adult/juvenile		
Adult/juveniles	16	32/13	17	67/16	136	p=0.27

* significant difference at 0.05 level

All but one shooter used a spotlight for night time shooting. This exception used a night scope. One shooter also used infrared spotting equipment. Seven shooters used red filters on their spotlights. Whistles and predator calls were used in 110 of the 169 reported forays. They were more common in the day (85%) than at night (54%). One shooter reported using a hide for both day and night forays.

3.3 Discussion

Postal questionnaires, despite being a cost effective method of collecting information from a large number of participants, are susceptible to low response rates and sampling bias (White et al. 2005). This was shown to be the case with the lamb production questionnaire in the previous section, and again is illustrated with this fox shooters questionnaire. The poor response to the questionnaire and bias towards recreational hunters highlights short-comings in the promotion of the questionnaire and the awareness and education of its purpose. The promotion of the questionnaire through the Game Council and the SSAA missed many primary producers and rural occupiers, who are not active members of these groups, and thus would need to have been targeted in some other fashion.

Because of the low number of responses, particularly from the primary producers themselves, the data collected from the survey can not be used to assess any trends in fox shooting across agricultural lands in NSW. The majority of recreational hunters who replied, especially those with rural postcodes, tended to shoot locally and many have favoured locations that they revisited several times in the season. Recreational shooters based in the larger metropolitan areas tended to travel further to reach their shooting locations.

Even though the small number of respondents can not be claimed to be representative of fox shooters in NSW, an indication can still be gained of current fox shooting practices from the data collected. These current practices do not seem to have changed much to those reported by Saunders et al. (1995). About two thirds of fox shooting takes place at night, with the aid of a spotlight and vehicle. The remaining third of fox shoots are conducted during the daylight hours, with approximately half of these using a vehicle, and the other half carried out on foot. One battue (or fox drive) was reported, indicating they are still used in some communities.

The use of whistles and predator calls to lure foxes within range was more popular during the day than at night, although at least half of night shooters indicated they used them. Despite more foxes being spotted at night, the success (i.e. the number of foxes shot to those spotted) is similar for both night and day forays. There was no difference found in the ratio of adults and juveniles shot at night compared to the daytime, however there was not enough information to comment on the age bias of this method as reported by Coman (1988).

4. CASE STUDY – MILTON FOX CONTROL PROGRAM

4.1 Background

This program was initiated in September 2004 when various stakeholders in the Milton/Ulladulla region of NSW raised concerns about the number of foxes. Unable to run a coordinated group baiting program because of the small nature of many holdings and the proximity of dwellings, the alternative method of shooting and trapping was trialled. A management committee was formed with members from the South Coast Rural Lands Protection Board (RLPB), Shoalhaven Council, the RSPCA, Department of Environment and Conservation, Southern Region Catchment Management Authority, local Landcare groups as well as community members. Overall coordination of the program was conducted by the RLPB.

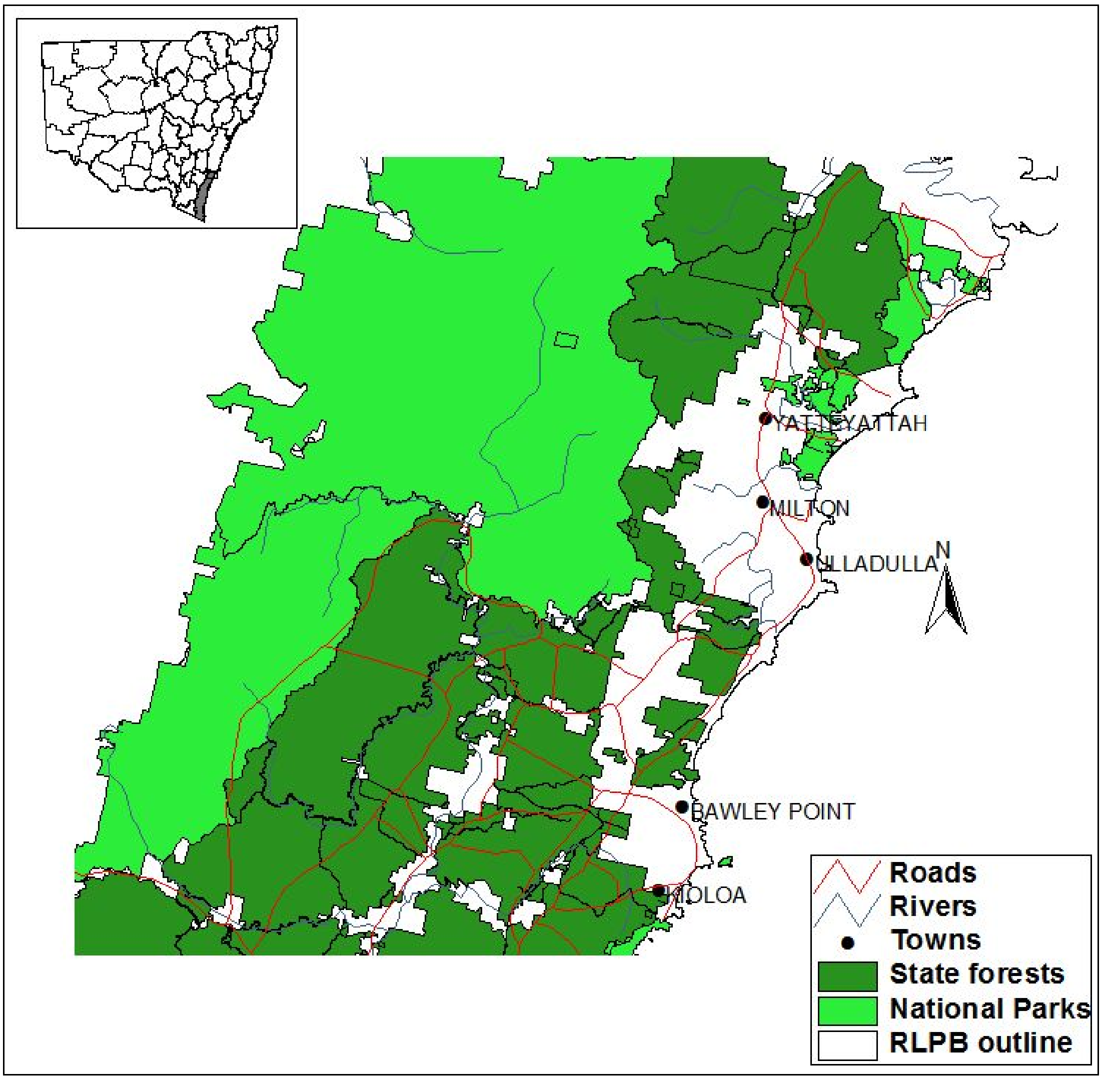


Figure D4.1: Milton Fox Control study site.

The program was divided in two areas, with the first area operating in the spring and covering approximately 2500 ha around Lake Conjola / Croogyar Creek, north of Milton. The program in the second area was conducted during autumn, and covered approximately 6000 ha in a region south of area one down to Burrill Lake (just south of Ulladulla). In the second year of operation an area of approximately 1000 ha around Bawley Point was added to the program conducted in spring (see Figure D4.1).

In addition to organising the professional shooter/trapper, training programs in the use of leg-hold traps were offered to interested landholders. Trapping kits were made available so that trained landholders could incorporate this method in their own control programs at any time.

Other agencies such as State Forests and National Parks also conducted their fox controls in surrounding areas to coincide with this fox control program. These agencies used a combination of 1080 baiting, shooting and trapping.

4.2 Objective

The objective of the group program was to reduce the number of foxes over the largest possible area (and thus reduce the predatory impact on native birds, wildlife, and domestic animals, slow down the rate of immigration and reduce the threat of parasite and disease transmission).

4.3 Participation

The RLPB ranger believed the key to success of the program was good communication. Initial contact with a letter to landholders detailing what the program was about, also included the consent form and self-addressed envelope so landholders could easily express their consent and become involved. An induction day was held prior to each program so landholders could meet the people involved in the program and discuss any queries or concerns. Letters were also sent to small landholders who were unable to participate because of the size of their holdings, explaining the program. The results of the program were also reported back to the participating landholders.

Initially all landholders within the area were approached, however in the following years this was limited to landholders who had previously expressed an interest to participate, or were new to the area. Landholders expressed their desire to participate by returning the appropriate documents to the Board office. The number of landholders participating in each of the programs is given Table D4.1. Because of the great range in sizes of properties owned by the landholders, even though less participated in Stage 3 than Stage 1, the control area remained similar.

Table D4.1: Landholder participation rates in the fox control program.

	Area (ha)[1]	Landholders Approached	Participating Landholders
Stage 1- September 2004	2500	85	48
Stage 2 – March 2005	6000	62	45
Stage 3 – September 2005	2500	45	23
Stage 3 (Bawley Pt) – Sep 2005	1000	14	12
Stage 4 – March 2006	6000	60	49

[1] control area rounded to nearest 100ha

4.4 Fox Control Methods

Foxes were either shot or trapped. The same professional shooter/trapper was hired for the entire program. He notified the landholders and their neighbours when he was working on or near their properties and conducted all of the trapping and shooting operations. Night shooting was the main method used, done with the aid of night vision equipment. Traps were laid for evasive foxes and in areas where shooting was inappropriate.

4.5 Monitoring

4.5.1 Fox Population Counts

Spotlight counts were conducted before and after the program to monitor fox abundance. The spotlight counts were conducted over three consecutive nights by the RLPB ranger using a white spotlight and 4WD vehicle. He used the same route for each night's count.

4.5.2 Landholder Questionnaire

As part of the monitoring of the program, a questionnaire was sent to all landholders in the region of the baiting program (see Appendix V). This questionnaire was designed to assist in monitoring the effectiveness of programs and record changes in fox impact that may have occurred.

4.6 Results

4.6.1 Trapping and Shooting

The programs ran for an average length of six weeks, however shooting was not conducted every night over this time. The number of nights that shooting occurred and the number of foxes shot and trapped for each of the programs is given in Table D4.2. The shooter spent an average of eight hours each night shooting and laying traps. Data, such as sex, weight and size measurements, was collected for each of the culled animals (not given here), as well as a GPS reading of their location. An example of this location data is mapped in Figure D4.2.

Table D4.2: The results from the each of the fox control programs.

	No. of Nights*	Foxes shot/trapped	Foxes/night
Stage 1 – North Milton	20	62	3.1
Stage 2 – South Milton	30	132	4.4
Stage 3 – North Milton	20	34	1.7
Stage 3- Bawley Point	10	11	1.1
Stage 4 – South Milton	27	128	4.7

* at an average of 8 hours a night

The timing of the programs north of Milton (spring) coincided with the breeding season, when most of the vixens either just giving birth, or heavily pregnant. The timing of the program to the south of Milton (autumn) coincided with the peak in dispersal activity as well as the start of the breeding season. The shooter noted that foxes were particularly active with many foxes pairing up, making them easier to locate. Over 80% of the foxes culled in Stage 2 were males, with the largest fox weighing 8 kg and measured a total of 75cm (tip of nose to tip of tail).

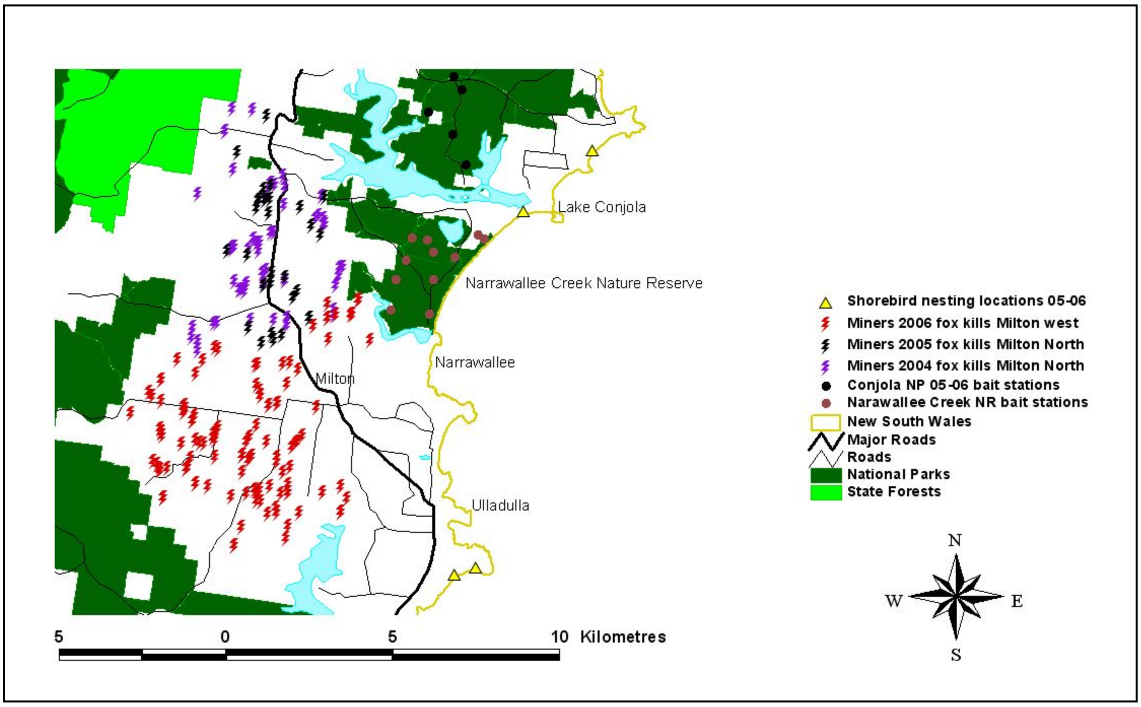


Figure D4.2: Map of Milton area indicating the position of each fox culled in the programs conducted from 2004 to 2006 (map courtesy of South Coast RLPB).

4.6.2 Fox Population Counts

Because the night shooting was conducted using night vision gear other than the normal white spotlight, it was considered acceptable to use a white spotlight to conduct fox population counts pre and post the control program. The same observer was used for all of the counts. The counts were conducted over three nights (except for the post counts for Stage 1 where wet weather limited access to only two nights) and are given in Table D4.3. The distance of each transect was not provided however the same route was driven for each Stage's count.

Table D4.3: Results from the fox population counts conducted before and after each of the fox control programs in the Milton area.

	Pre-program	Post-program
Stage 1 – North Milton	10,8,12	8,7
Stage 2 – South Milton	5,12,12	3,8,3
Stage 3 – North Milton	4,5,4	6,3,0
Stage 3- Bawley Point	4,4,2	0,0,1
Stage 4 – South Milton	8,8,10	0,3,4

A linear mixed-effects model looking at the effect of the fox control pre and post-program and year was fitted using REML:
Model1 <- lme(count~control + Year + control:Year, data = spotlight, random = ~1|Site)
The results from the ANOVAR analysis (Table D4.4) shows that there was a significant effect of the control program between pre and post counts and a significant effect of year but no year/control interaction. Interaction plots for this data are given in Figures D4.3 and D4.4.

Table D4.4: Summary of analysis of variance test on spotlight count results.

	DF	Sum Sq	F value	P value
Control	1	110.95	17.26	0.0003 ***
Year	1	118.13	18.37	0.0002 ***
Control:Year	1	0.388	0.06	0.8080

*** significant 0.001 level

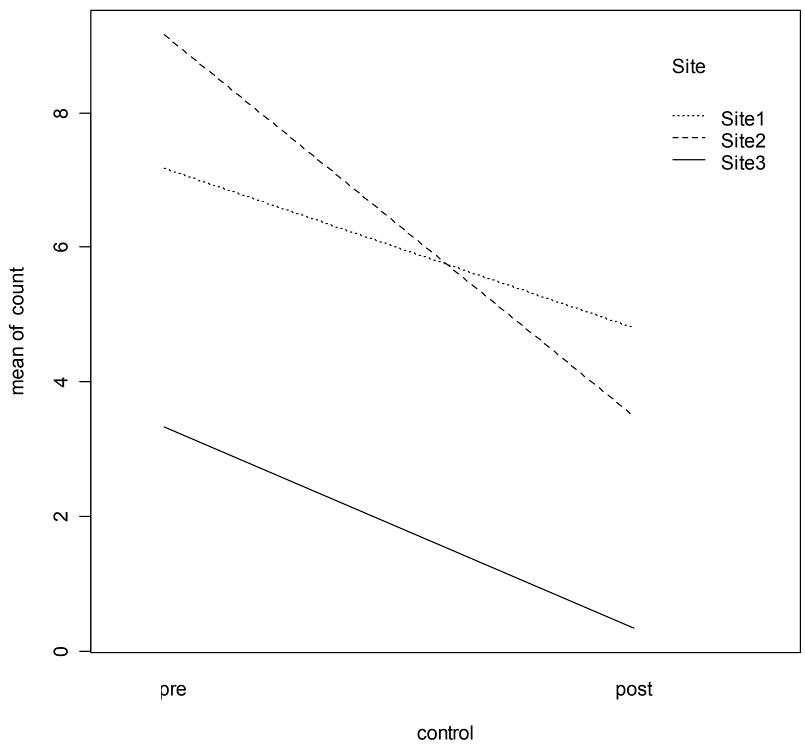


Figure D4.3: Interaction plot of spotlight counts of pre and post fox control at each of the sites (Site 1= North Milton, Site 2 = South Milton, Site 3 = Bawley Point).

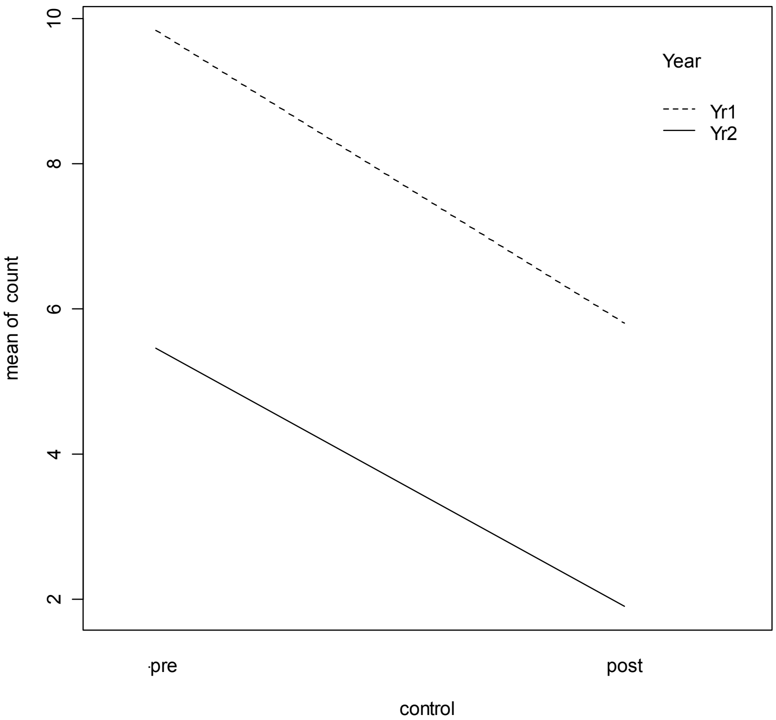


Figure D4.4: Interaction plot of spotlight counts of pre and post fox control over years (Yr1 = first year of control, Yr2 = second year of control).

4.6.3 Landholder Questionnaire

Questionnaires were sent out only in Stages 3 (North Milton and Bawley Point), Stage 4 (South Milton) and then again in September 2006 (North Milton again). Of the 59 landholders approached in stage 3, only 31 were posted questionnaires. Four were not posted questionnaires as they either lived out of the area or were deceased estates. The remaining 24 people had their consent forms hand delivered by either the ranger or contractor, and were not given a copy of the questionnaire. Stage 4's 150 questionnaires were posted to all 60 landholders who were approached as well all landholders who were notified about the program, but not necessarily in the program area, or had holdings too small to participate directly. Because of the mix-up in the distribution of questionnaires in Stage 3, a further 35 questionnaires were sent out in September 2006 to landholders who had participated previous years (see Table D4.5).

Table D4.5 Summary of distribution of questionnaires and the return rates.

	Questionnaires posted	No. returned	Return Rate
Stage 3 (Sep 05)	31	18	58%
Stage 4 (Mar 06)	150	67	45%
September 06	35	20	57%
Total		105	

The return rate for the survey was good (Table D4.5). The lower return rate for stage 4 was probably due to the distribution to the higher proportion of landholders who were not approached to participate in the program as can be seen in the higher proportion of non-participants who replied (Figure D4.5). There were eight responses from the September 2006 questionnaire who had already replied in 2005. One respondent from September 2006 had not actually participated in the 2005 program but was intending to participate in the upcoming program in 2006 (not covered by this report).

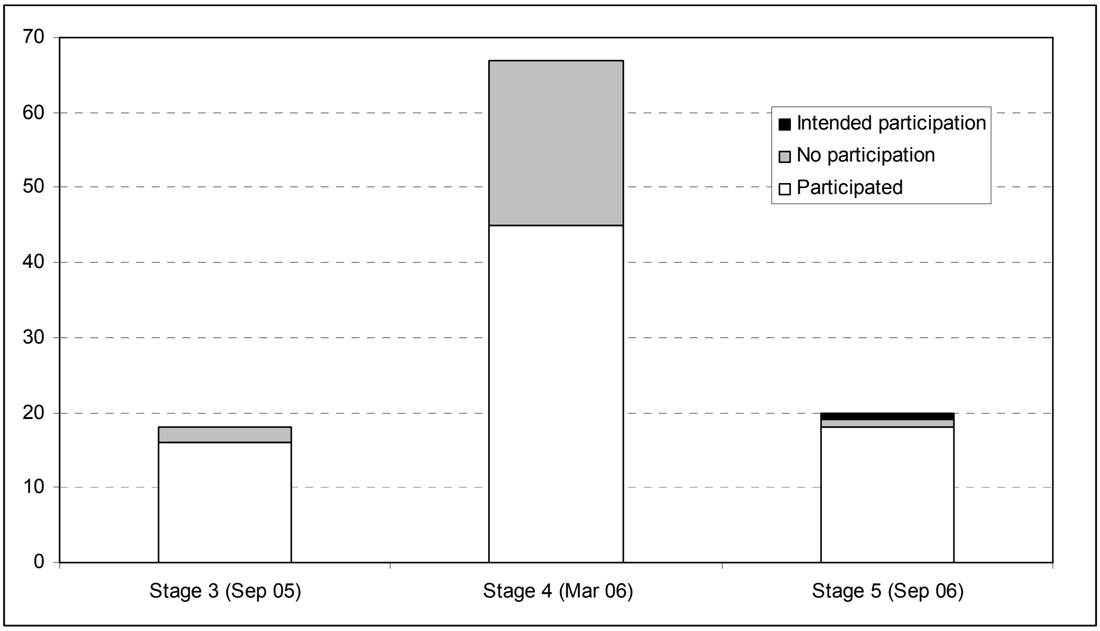


Figure D4.5: Participation in the group fox control program by respondents of the questionnaire.

All respondents from the North Milton area (Sep 05 and 06) classified themselves as rural landholders. Seventeen of the respondents from the Stage 4 classified themselves as residential with the rest being rural. The main enterprise of half of the respondents was cattle production or dairy (53 of total 105). Nearly a quarter (25) listed hobby farm as their main enterprise (assortment of cows, horses, sheep, goats, alpacas and chickens kept). Other enterprises included horse studs (4), and horticulture/plantation (3). Two respondents ran commercial enterprises such as bed and breakfast's and one was a university field station. Fifteen had no enterprise or did not specify.

Respondents were asked their opinion on a range of questions about foxes and their control methods. There were highly significant differences (using Fisher's Test) between the responses of landholders who participated in the program compared to those that did not for the three questions that rated the importance of foxes as a pest, fox control on their own land and group fox control programs (see Table D4.6 for results, and Figure D4.6). All landholders who participated in the program (and gave an opinion) thought that group control programs were important, with 89% rating them as very important. This was despite the fact that a small number did not think fox control on their own land was as important, or the fox was a pest in their area.

The opinions of non-participants in the group program were fairly evenly spread between the categories. Reasons for not participating in the group program despite rating the fox highly as a pest, or fox control as important included “prefer to do own shooting” and “rely on neighbours and government to do control”. One landholder wanted more information on the impacts of fox culling before agreeing to participate.

Table D4.6: Results from Fisher’s Test of responses from all questions which asked the landholder’s opinion on a range of questions about foxes and their control (participants / non participants).

Importance of:	Very	Moderately	Slightly	Not	Blank	p-value
a) fox as a pest	73/10	17/4	2/3	2/4	2/4	<0.001***
b) your fox control	76/9	16/4	0/3	3/5	1/4	<0.001***
c) group programs	80/3	9/3	1/3	0/2	6/4	<0.001***
Rate methods:	Excellent	Good	Fair	Poor	Blank	p-value
a) shooting	68/11	16/8	8/1	2/2	2/3	0.014*
b) 1080 baiting	41/6	26/8	15/2	7/4	7/5	0.100
c) trapping	25/3	21/4	15/2	24/10	11/6	0.174

* significant at 0.05 level, *** significant at 0.001 level

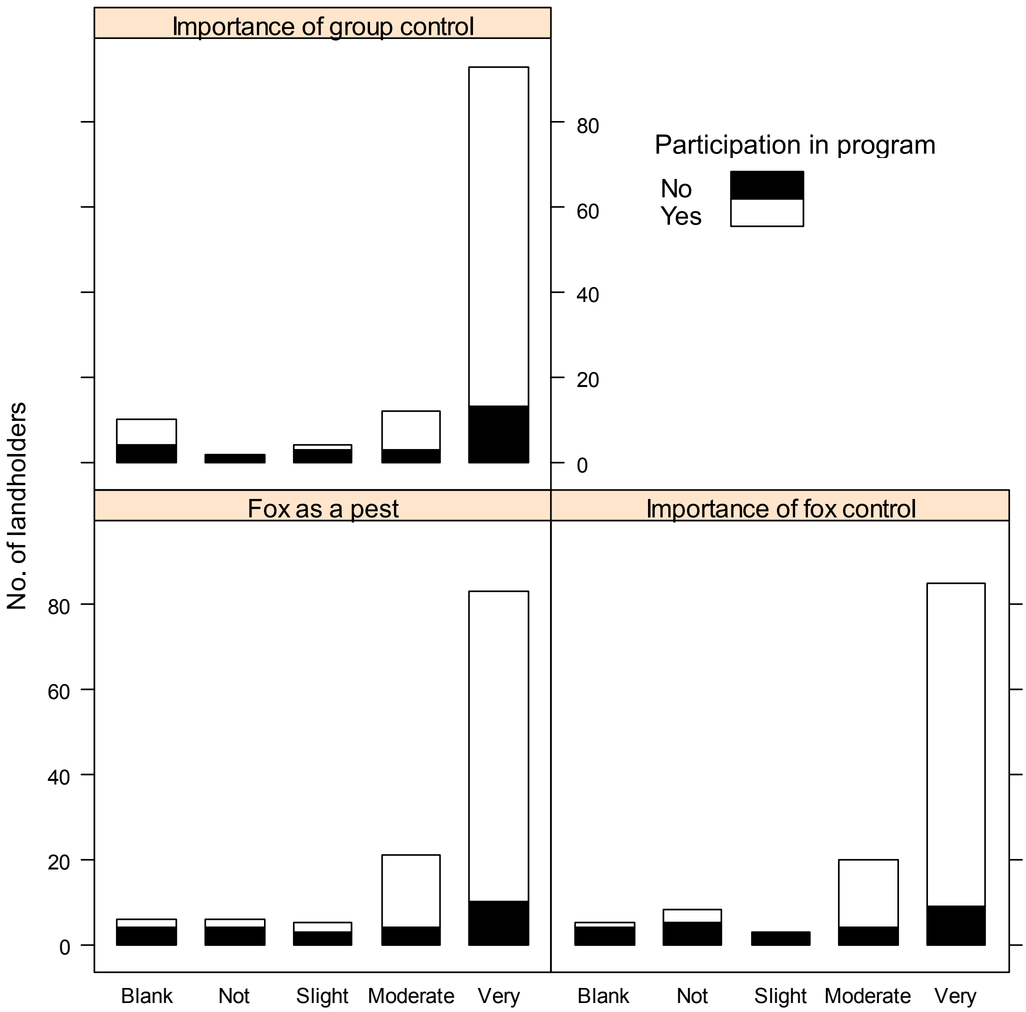


Figure D4.6: Response to the questions on rating the fox as a pest, the importance of fox control and group fox control programs.

There was a small significant difference between the opinions of the participating and non-participating landholders on rating the effectiveness of shooting as a control method for foxes (see Table D4.5 for results, and Figure D4.7), with 89% of participants rating it highly (Good to Excellent) compared to 86% of non-participants. There was no difference between these two groups' ratings of baiting and trapping.

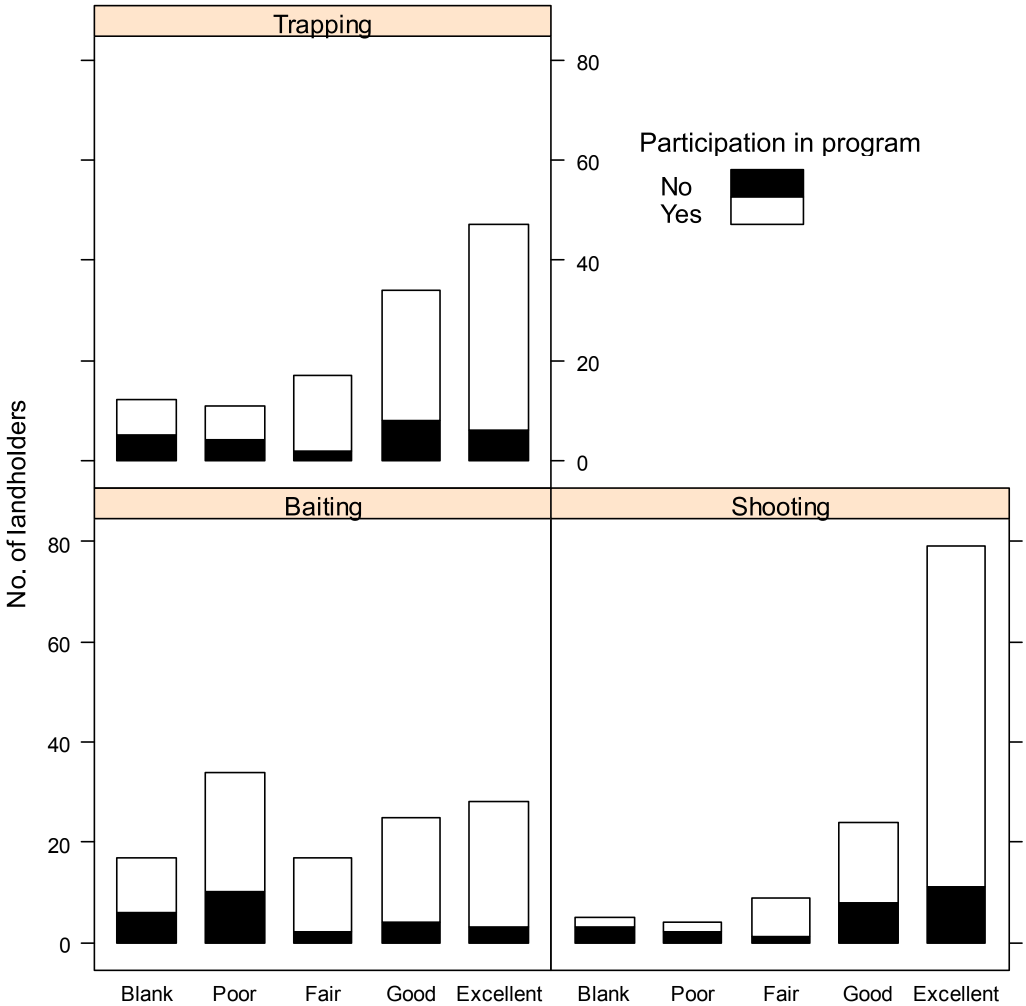


Figure D4.7: Response to the question on rating the fox control methods shooting, trapping and baiting.

Landholders indicated they used a range of methods to control foxes aside from the group program. Eighteen of the participants in the program used shooting at other times, compared to only one non-participant. Only four respondents indicated they used 1080 baiting (all participants in the group program), while four participants and one non-participant used trapping. Exclusion fencing was used by seven non-participants and three participants, and guard animals by five non-participants and six participants. Thirty four landholders who had participated (43% of total participating respondents) did no other fox control outside of the program, whilst twenty seven of the non-participants practiced no fox control on their land.

Sixty seven landholders responded that they observed a reduction in the occurrence of foxes (sightings and sign). Some commented that it only lasted up to six months after the program. Thirty five landholders observed no change and three observed an increase in fox presence (Table D4.7). There was a significant difference in these observations between participating and non-participating landholders (i.e. reduced fox occurrence, no observed occurrence and increased occurrence: p value = 0.011 - Fishers Test). Twenty six landholders reported a beneficial reduction in predation after the program (mainly a reduction in poultry predation), three reported increased rabbit numbers from a reduction of fox predation, and 76 landholders observed no change in fox damage after the program (Table D4.8). There was no difference in these reports between participating and non-participating landholders (i.e. beneficial reduction in predation (livestock, natives), detrimental reduction in predation (rabbits), no observed change: p value = 0.682 - Fishers Test).

Table D4.7: Landholders' observations in change of occurrence in foxes after the group program (divided into those that participated and those that did not).

Observed change in fox occurrence	Comment	Participants	Non - participants	Total responses
Reduction	Reduced sightings	33	12	45
Reduction	Reduced sightings but increased after approx. 6 months	6	1	7
Reduction	Reduced signs	2	1	3
Reduction	Reduced sightings and sign	4	0	4
Reduction	No comments	5	3	8
None	Same no. of sightings	10	1	11
None	No comments	7	17	24
Increase	Increased sightings	1	2	3

Table D4.8: Landholders' observations in change in fox damage after the group program (divided into those that participated and those that did not).

Change in fox damage	Comment	Participants	Non - participants	Total responses
Yes	Reduced poultry predation	5	6	11
Yes	Reduced stock predation	4	0	4
Yes	Increase in native water fowls	1	0	1
Yes	Increase in rabbits	2	0	2
Yes	No comments	6	4	10
No	Predation levels the same	18	1	19
No	No comments	31	26	57

All comments about the fox control program received were positive (e.g. "keep up the good work", "pleased with current efforts", "excellent program"). One respondent perceived foxes as an important control tool for rabbits, so therefore would not participate in the program. Other reasons given for non-participation in the program included a preference to shoot on their own property, no poultry or livestock present, no fox sightings on their land for ten years, and reliance on neighbours or government to conduct the control programs. Blackberry control and burial of dead livestock were suggested as better forms of management. One respondent felt that dog safety was an issue when the trapping/shooting program was being conducted. One non-participator suggested that foxes should be tolerated.

4.7 Discussion

Respondents of the questionnaire highlighted the concern in the area about the number of foxes and their perceived impact as a pest. The program's initial objective of reducing fox abundance in the area appears to have been achieved, at least over the short term. This result is supported by both the monitoring techniques of spotlight counts and landholders' observations. Unfortunately this objective is flawed as the objective of fox control programs should be to reduce the impacts of fox predation, not just to reduce fox populations *per se*. The effectiveness of fox control programs should be measured in terms of the response of the threatened population or in the increased agricultural production, not just by the change in fox abundance. Unfortunately the collection of such information to monitor the effectiveness with respect to the change in the impact of foxes is challenging as quantifying such impacts (e.g. increase in production (especially in non-sheep producing areas), response of the prey species,) is usually difficult and costly. Thus programs (including this one) rely on the measurement of fox abundance as an alternative, despite the fact that there has been no predictable relationship found between abundance and damage (Saunders and McLeod 2007).

To address this shortfall in monitoring of impacts a questionnaire was distributed so that the landholders could provide information on the changes of impacts from an agricultural perspective (response of native wildlife, although a very important issue, is outside the focus of this study). The advantages of this method were that it was relative cheap and non labour intensive, however much of the data supplied was of qualitative rather than quantitative nature, and the reliability and accuracy can not be tested. The main enterprise within the area is cattle (beef and dairy), an industry which does not directly suffer greatly from fox predation (although the transmission of parasites and disease is of some concern – Saunders and McLeod 2007), and hence there were no significant reports of changes in impacts on agricultural production. There were, however, many reports of changes in impacts on domestic livestock, particularly chickens, and a small number of reports on rabbits (an agricultural pest). Fox impacts on native species, particularly shore-birds, is a major community concern in this area, but as already stated is outside the focus of this study.

Even though many of respondents had not observed a direct change in fox impact, they perceived an importance of fox control on their land and of group/community fox control programs. Landholders' perceptions play an important role in participation and, hence, effectiveness of control programs. In a study in rural England, Macdonald et al. (2000) concluded that the perceived pest status of foxes affected a farmer's tendency to control foxes, independently of the reported damage, a claim which is supported by this study. Education and awareness programs can be important tools in influencing these perceptions and should be part of any group control program. Group ‘pressure’ also plays a large role in influencing individual’s perceptions and, hence their participation in a group program.

The perception of the importance of group/community fox control programs in this area is also shown in the community support for the establishment of the Pest Animal Advisory Committee, and the cross-agency coordination. This program demonstrates the importance of collaborative fox control programs and the community ownership of the fox damage issue. As an alternative fox control program for small holdings along the coast, the organisers, as well as most of the participants believe this type of group program is very effective. Many more landholders are able to participate in this type of program than one based on 1080 baiting, so a larger, more continuous area can be covered. Also, as most of the landholders in this area prefer this control method over baiting, participation rates are higher than would they would be for a baiting program.

The effectiveness of group baiting programs has been shown to increase when control is applied twice a year, approximately six months apart (see Section B of this report). This causes maximum disruption to both the breeding and migration stages of the fox’s life cycle, something that once yearly control can not achieve. This program seemed to suffer from same problem as those group baiting that only occur once a year, as some respondents reported the reduced sightings and impacts only lasted for three to six months, after which time the fox population returned to pre-control levels. Because of funding and labour limitations, and the reliance on one outstanding contractor it was not possible for the organisers of this program to run simultaneously in both areas, twice a year, however such a move should be considered to improve the programs effectiveness further.

5. CASE STUDY – LANDCARE ILLAWARRA FOX CONTROL PROGRAM

5.1 Background

The Illawarra area is sandwiched between the coastline and steep forested lands of the Illawarra escarpment. Pest animal problems that have been identified in the region include erosion caused by the activity of feral goats and deer in the escarpment areas, and reduced sightings of native animals thought to be due to fox and cat predation. Agricultural activity is limited mainly to dairy and cattle production, however there are many small holdings and hobby farms which report trouble from fox predation on chickens and pets. The area, like the Milton / Ulladulla area, is unable to run an effective coordinated group baiting programs because of the small nature of many holdings and the proximity of the urban areas. Many community members are also opposed to baiting (Barbara Mathie, Foxground Landcare, pers.comm 2007).

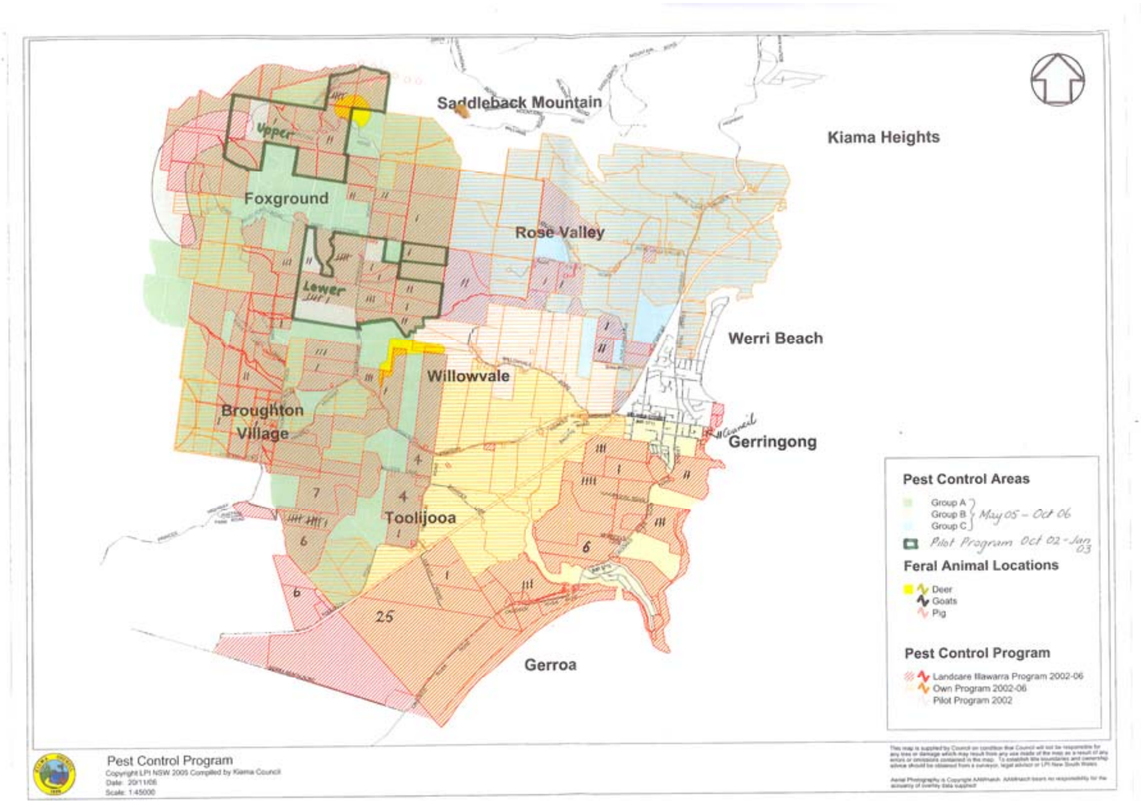


Figure D5.1: Map of the Illawarra Landcare area showing areas involved in pest animal control program (map courtesy of Landcare Illawarra).

A pilot pest animal culling program was organised and run by Foxground Landcare Group from October 2002 until January 2003 (see figure D5.1). This program involved hiring a contract shooter and concentrated on foxes and goats in the area around Foxground. In 2005 Landcare Illawarra, in conjunction with Kiama Municipal Council, NSW National Parks and the Southern Rivers Catchment Management Authority, extended the pest control area to incorporate more of the surrounding areas from the escarpment to the coastline (a total area of 6867 ha within the Rose Valley, Foxground, Broughton Village, Gerringong, Gerroa, Toolijooa and Willowvale areas). The program ran from the 24th May 2005 to the end of October 2006. A range of pest animals were targeted including foxes, goats, feral cats, pigs and deer. Landholders who did not wish to participate in the group program were still encouraged to conduct or continue there own pest control programs.

5.2 Participation

A total of 136 landholders, covering 3126 ha, took part in the group program, with another 45 landholders, covering 2894 ha conducting their own programs. This resulted in 87.6% of the targeted area to be included in the program, leaving 12.4% (37 landholders over 848 ha) not participating.

5.3 Fox Control Methods

Culling was by shooting and trapping only. Landcare Illawarra hired a contractor shooter for the group's program. Landholders who carried out their own programs used recreational hunters.

5.4 Monitoring

No formal monitoring of the program was conducted. Landcare Illawarra collected details of most pest animals culled in the program from the contract shooter (e.g. sex, age and habitat in which they were shot). Only numbers of fox culled were collected from landholders who had conducted their own programs. Participants were encouraged to report sightings of native animals in their area.

5.5 Results

5.5.1 Trapping and shooting

The pilot study ran between October 2002 and January 2003. Shooting was conducted over 16 nights (average 8 hours per night), and a total of 56 foxes were killed. Details are available for 29 of these - 21 adult and 8 sub-adult.

The main control program was commenced in late May 2005. There were four main control periods, winter 2005 (late May to August), spring 2005 (October to November), summer 2005/06 (January to February 2006) and winter 2006 (July to early September). A total of 171 foxes were culled over this time (1 fox / 18 ha), with data from 141 collected. This data from each of these culls is given in Table D5.1. The shooter averaged eight hours per night, however information on the area covered each night was not collected. In addition landholders that conducted their own programs reported culling a further 148 foxes over this time (1 fox / 19.5 ha). There was no further data collected from this group.

5.5.2 Native animal population

After the program there were many reports of increased sightings of native species in the area, including Red-necked wallabies and spotted quolls. Bandicoots (no species details) were sighted for the first time in many years (Landcare Illawarra 2006).

Table D5.1: Age of foxes culled over the four main control periods in Illawarra Landcare program.

	No. of nights*	Sub-Adults	Adult	**Total**	Foxes/night
Winter 2005	15	14	28	**42**	2.8

Spring 2005	4	2	26	**28**	7.0
Summer 2005/06	5	4	19	**23**	4.6
Winter 2006	10	8	40	**48**	4.0
				141	

* at an average of 8 hours a night

5.6 Discussion

This program demonstrates the importance of collaborative fox control programs and the community ownership of the fox damage issue. Community involvement in the management of the problem, with collaboration from government agencies and private landholders, is a pre-requisite to achieving lasting gains in a cost-effective and measurable manner (Saunders et al 1995, section B of this report). Advantages of this collaborative effort have been the generation of funding opportunities, cross-tenure (private and public) implementation of control activities, cost-efficient use of labour and equipment and public education and extension. Hopeful this collaborative effort, with its high participation will limit re-invasion rates and ultimately, lead to improved outcomes for everyone.

Monitoring and evaluation are important parts of any management plan to determine whether the objectives are achieved or if not, whether changes are needed in the management strategy, or even if the initial problem and objectives should be reassessed (Braysher 1993, Walker 1998). It is also important for reporting and extension, as well as future planning. There are two types of monitoring: operational monitoring (what was done where, and at what cost?) and performance monitoring (did the control meet the objectives?).

Operational monitoring is the easiest type of monitoring to perform, and is the most commonly conducted, as typified by this program. Managers need to know what control methods were used, how often and their cost as part of the financial management of the program. Participation rates, and area covered are also relatively easy to collect and can be used in monitoring the effectiveness the objectives such as improving group involvement and awareness.

Collection of information to monitor the effectiveness with respect to the change in the impact of foxes is more challenging. Quantifying such impacts (e.g. response of the prey species, increase in agricultural production) is usually difficult and costly. This program, like so many (e.g. Saunders and McLeod 2007), did not conduct any formal monitoring of impacts and relied on testimonial accounts from participants to indicate its success.

Because of the problems involved with monitoring fox impacts, fox abundance is often used as an approximate indicator, despite the fact that there has been no relationship found between abundance and damage (Saunders and McLeod 2007). But even the collection of abundance information is problematic and costly because of the secretive and elusive nature of the animal. Most management programs, again exemplified by this project, just opt for collecting the data such as the number of foxes removed. This type of data is useful in determining the success of the method used (in this case shooting – see the next section for a detailed description of shooting effectiveness), but does not allow for any measure of the effectiveness of the program as a whole. Little can be said about the trends in foxes number culled over such a short time without any knowledge of the abundance of foxes prior to the management program.

6. COST EFFECTIVENESS OF SHOOTING

6.1 Introduction

Owing to the difficult nature of quantifying the benefits of fox control, cost effectiveness analysis has been used as a measure of efficiency of fox control (e.g. Hone 2004, McLeod et al. 2004, Moberly et al. 2004, Gentle 2005). Cost effectiveness analysis is used to find the least expensive way to achieve a pre-determined threshold (Bicknell 1993). This type of analysis can be used to compare methods and strategies when a pest population needs to be held under a threshold, however in the case of the fox, the relationship between density and damage is poorly defined, so defining a meaningful threshold is difficult.

An alternative is to compare the cost effectiveness of a different range of strategies, so management decisions may be made on the basis of whether a particular strategy, or combination, would satisfy the management objective. In Australia, such cost effectiveness analyses has been conducted on baiting operations. McLeod et al. (2004) examined the cost effectiveness of different combinations of sterilisation and lethal baiting campaigns. Gentle (2005) used cost effectiveness analysis to compare different 1080 baiting strategies on the basis of longevity, palatability, and the handling/ replacement costs associated with three different bait types. Both these studies compared the effectiveness of a range of bait delivery decisions (such as when to bait, bait type, frequency and density of distribution).

No comparisons of cost effectiveness have been attempted to compare different lethal methods of control (i.e. shooting and baiting), mainly due to the difficulty in defining a measurable outcome that can be compared. One possible measure of effectiveness would be to assess the cost per fox killed by each of the methods. Unfortunately, although this is easily ascertained for shooting as the number of foxes killed is a known quantity, carcasses are difficult to detect after 1080 poisoning due to the time delay between consumption and death, so exact numbers of deaths are difficult to ascertain and must be estimated. By using information available in the literature on baiting efficiency this section attempts to compare the cost effectiveness of shooting with 1080 ground baiting.

A second measure of effectiveness would be to assess the catch per unit effort (CPUE), or in this case foxes killed per hour. This measure would be inappropriate for measuring the outcome of 1080 baiting, however may be useful when comparing different forms of shooting. Using both measures of cost per fox killed and CPUE, this section will also investigate the cost effectiveness of using recreational as opposed to professional shooters.

6.2 Methods

6.2.1 Data collection

Cost effectiveness data was collected from recreational shooters who participated in the survey described in section 3 as well as from the professional shooter from both the Milton program (section 4) and the Illawarra program (section 5). Information collected included the time spent shooting, the number of people involved, transport used, the number of kilometres travelled, and the number of foxes spotted and killed.

Data on the cost and efficiency of baiting programs was collected from the literature for comparison with the shooting data.

6.2.2 Statistical analysis

For comparisons of the CPUE between recreational and professional shooters forays, the data was first checked for normality and difference in variances before the use of a one-way Anovar.

6.3 Results

6.3.1 Cost calculations

The cost of shooting by recreational hunters was calculated by estimating labour, vehicle and equipment costs. The minimum labour wage paid during this time was $13.47 per hour (source from the Australian federal government fairpay website: http://www.fairpay.gov.au).

Vehicle operating costs were based on figures collected from the NRMA web site (NRMA 2007). They had calculated whole of life (WOL) operating costs for a range of vehicles, which included capital (including depreciation and interest), standing (registration and insurance), and running costs (fuel and maintenance). A typical 4WD vehicle as used by shooters ranged from $0.90 to $1.30 per kilometre (average $1.10). Recreational shooters were assumed to own their vehicles for private use other than shooting so it was decided not to include the capital costs for this study. Capital costs made up around 50% of the WOL cost, so if excluded, running and standing costs averaged $0.55 per kilometre.

The only equipment to be included is the cost of bullets. Capital cost of equipment such as a rifle, scope and spotlight were not considered. Most fox shooters use a .222 or .223 calibre bullet which cost on average $1.00 per bullet. From the success data collected from the shooter questionnaire it was calculated the just over half of the number of foxes spotted were shot. Fleming (1997) also reported a similar figure, although notes that not all foxes that are spotted are within range for shooting. Since distance of spotted foxes was not collected it is assumed that all spotted foxes reported in the questionnaire were within range. Therefore if it is assumed one bullet is fired at every fox spotted, two bullets are needed for every fox killed.

Table D6.1 tabulates the results from the cost calculations for the average day and night foray. The average cost per fox is calculated to be around $40.00 for both day and night forays. Despite night forays involving more people and longer distances, the total cost per fox is around the same amount as that for a day foray, owing to the more foxes shot during the night foray.

The cost of each of the group programs is given in Table D6.2. The professional shooter charged a flat rate per night of operation regardless of the number of animals destroyed. During the Milton / Ulladulla programs the average cost per fox was $77.00, in the Illawarra program the average was $72.00 per fox.

Table D6.1: Results collected from recreational shooters who responded to questionnaire (see Section 3) and calculated costs of their fox shooting.

Cost	Averages from questionnaire	Day Shoot	Night Shoot
Labour	No. people	1.5	2.2
	Time spent shooting (hours)	3.2	3.9
	Cost @$13.47 per hour	$64.66	$115.57
Vehicle	Distance travelled (km)	5.2	47.8
	Cost @ $0.55 per km	$2.86	$26.29
Equipment	No. foxes shot per hour	0.54	0.96
	Time spent shooting (hours)	3.2	3.9
	No. bullets used per hour	1.08	1.92
	Cost @ $1.00 per bullet	$3.46	$7.49
Total	Total cost per foray	$70.98 (1.7 foxes)	$149.35 (3.74 foxes)
	Total cost per fox	$41.75	$39.93

Table D6.2: The results from the each of the south coast fox control programs and associated costings.

	No. of Nights*	Cost/Night ($)	Total foxes shot	Foxes shot per hour	Cost/fox ($)
Milton / Ulladulla					
Stage 1 – North Milton	20	260	62	0.39	83.87
Stage 2 – South Milton	30	260	132	0.55	59.09
Stage 3 – North Milton	20	260	34	0.21	152.94
Stage 3- Bawley Point	10	260	11	0.14	236.36
Stage 4 – South Milton	27	280	128	0.59	59.06
Total	**107**	**1320**	**367**	**0.43**	**77.28**
Illawarra					
Winter 2005	15	300	42	0.35	107.14
Spring 2005	4	300	28	0.88	42.86
Summer 2005/06	5	300	23	0.58	65.22
Winter 2006	10	300	48	0.60	62.50
Total	**34**	**1200**	**141**	**0.52**	**72.34**

* at an average of 8 hours a night

6.3.2 Catch per unit effort

The catch per unit effort (CPUE), in this case foxes shot per hour, from each of the data sets is also included in Tables D6.1 and D6.2. These values averaged 0.54 for day forays and 0.96 for night forays from the recreational shooters, and ranged between 0.14 and 0.88 for the professional shooter. There was no differences of the CPUE between these two groups ($F=1.32$, $df=1$, $p=0.25$).

6.3.3 1080 Baiting Comparison

Using the cost structure published by Saunders and McLeod (2007), a 1080 ground baiting program (with baits checked and replaced twice) on a typical 2000 hectare property on the tablelands in NSW was costed at $19.90 per square kilometre (vehicle and labour costs increased to those used in section 6.3.1, i.e. $0.55 and $13.47 respectively). The average density of foxes in these areas averages five foxes per square kilometre (Saunders and McLeod 2007). The reduction of fox populations to typical ground baiting programs in NSW have been reported by four studies (Table D6.3), ranging from 50 to 97% with an average around 77%. The cost calculation using a range of efficiency values are given in Table D6.4. The cost per fox killed increases with a reduction in efficiency. Using the range of efficiencies reported in the literature, the cost per fox ranges between $4.10 and $7.96, well below the cost associated with shooting. The efficiency of a baiting program would have to drop to below 10% for the cost per fox to be equal to that calculated for recreational shooters.

Table D6.3: Effectiveness of fox baiting programs reported from NSW studies.

Bait density (per km^2)	Initial fox density (per km^2)	Population reduction (%)	Location	Reference
12	7.2	70	tablelands – farmland	Thompson and Fleming 1994
1.7 -3.1*	0.05–0.2*	91	tablelands – forest	Fleming 1996 * pers. comm.
4.4	1.3–1.9	50	tablelands – farmland	Fleming 1997
0.14	?	97	coastal area	Dexter and Meek 1998

Table D6.4: Cost calculations for fox baiting programs at different reduction efficiencies (Cost of laying baits is $19.90 per square kilometre, fox density set at five individuals per square kilometre).

Efficiency	Foxes killed/km^2	Cost per fox
97%	4.85	$4.10
77%	3.85	$5.17
50%	2.5	$7.96
10%	0.5	$39.80

6.4 Discussion

Drawing cost effectiveness comparisons between baiting and shooting is difficult. Not only is there a difficulty in defining a measurable outcome that can be compared, it is also difficult to measure the actual outcomes. This study attempted to compare the cost effectiveness of the two methods using the cost per fox killed as the measurable outcome. Unfortunately, although this is easily ascertained for shooting as the number of foxes killed is a known quantity, it is not quite so straight forward for baiting. Death from consuming a 1080 bait does not occur instantaneously, so carcasses can be difficult to detect as foxes have time to move to more secluded areas.
Directly determining the number of foxes killed (i.e. efficiency) of 1080 baiting programs was outside the scope of this study. General assumptions on the type of baiting program were made and the appropriate values used from relevant studies available in the literature. Another assumption that needed to be made was that the density of fox populations that were being controlled by either method was similar. Density estimates for fox populations in agricultural and rural areas in eastern NSW range between one to eight foxes per square kilometre (Saunders et al. 1995), with an average around five. The majority of the shooting data was collected from areas across NSW were this average would be an adequate assumption.

The cost of a typical 1080 baiting program was calculated to around $5.00 per fox. This contrasted with the cost of using recreational shooters of around $40.00 per fox. The low cost of the baiting was largely due to the assumed efficiency of the program. If the efficiency of baiting was reduced to below 10% (i.e. less than one fox in ten was killed), then the cost per fox of this method became comparable to that of shooting. Therefore, although 1080 baiting is more cost effective than recreational shooting in most cases, there would be some circumstances when shooting is the more cost effective method.

Some fox control programs opt for the hiring of professional shooters over the reliance of recreational shooters. These professional shooters tend to charge a flat rate per night of operation regardless of the number of animals destroyed. During the Milton / Ulladulla programs the average cost per fox was $77.00, in the Illawarra program the average was $72.00 per fox. This larger amount is to be expected as the professional shooter has to earn a living, so would factor in all the capital costs that were left out of the recreational shooters' costings (both vehicle and equipment), as well as other business expenses, insurance and probably a higher hourly wage than used in this study. The increase cost of the professional would also include factors such as reliability, availability and security, values that are difficult to include in a study such as this.

There was no difference found between the catch per unit effort (i.e. the number of foxes shot per hour) of recreational and professional shooters. The range of CPUE figures from this study were similar to other studies; Fleming (1997) reported pooled average CPUE's from three study sites in the northern NSW within a similar range (0.98, 0.44 and 2.0), and Coman (1992) reported a capture efficiency of 0.24 foxes per hour during a fox removal exercise in Victoria. There are many factors other than shooter experience and accuracy that would have large influences on this CPUE figure. Without attempting to correct for such variables as fox density, fox behaviour, terrain, vegetation cover, and weather conditions, it is impossible to make any comparisons using this method.

Although generally not as cost efficient as 1080 baiting in terms of the cost per fox killed, shooting by both recreational and professional shooters, is an important fox management tool. Each method has its weakness and strengths (see Table D6.5). No one fox control method is one hundred percent effective, so shooting provides a viable alternative in areas where foxes will not succumb to baiting. It can be a successful alternative in areas where 1080 baiting is not feasible, or where baiting may not be preferred option. The two cases studies described in this section offer evidence that group shooting programs can be just as successful as group baiting programs. The key to success involves incorporating as large an area as possible and conducting regular (twice a year) control programs to maximise the effectiveness.

Table D6.5: The advantages and disadvantages for the two fox control methods: 1080 baiting and shooting.

	1080 Baiting	Shooting
Advantages	Large areas covered quickly Relative inexpensive Not labour intensive	Target specific Humane Cover areas where baiting restricted
Disadvantages	Non target risk Humaneness Public perceptions Disruption to property management Need for notification Bait aversion / shyness Restricted use	Labour intensive Relatively costly Targets naïve animals Public perceptions Rogue shooters Damage to property Public liability / risk

PART E: ALTERNATE FOX MANAGEMENT STRATEGIES

1. INTRODUCTION

Currently in Australia the most popular fox management strategies use lethal techniques and this does not look set to change in the short term. Poison baiting, using 1080, is considered to be the most effective method of fox control and is the most widespread technique used. Shooting and other traditional hunting techniques, sometimes encouraged through the offer of bounties, have historically shown not to be as effective but are also common (Saunders and McLeod 2007).

Welfare, ethical and efficacy concerns about these lethal techniques, particularly the use of 1080, have been voiced in Australia and New Zealand. The continued use of the toxin 1080 cannot be guaranteed, with past experience suggesting that it could be banned with only short notice (Saunders and McLeod 2007), leaving no available alternatives in the short term, and little time to develop any suitable replacement.

A summary of alternative control techniques, both lethal and non-lethal, that have been proposed and trialled in Australia are reviewed below.

2. ALTERNATIVE TOXINS

Before any chemical could be registered for use against foxes, extensive evaluations of toxicity, efficacy, humaneness, non-target effects and bait delivery systems would be required. Although the expense of such evaluations is probably not commercially justified, the continuing uncertainty surrounding the use of 1080 supports the need for public funding of such work as a matter of priority. The feasibility of some alternate toxins and delivery systems are discussed below.

Potential alternative or additional poisons include anticoagulants such as brodifacoum, bromadiolone and warfarin (Saunders et al. 1995), although it is improbable (and undesirable) that these would ever be approved on welfare grounds.
Strychnine has been commonly used against foxes in the past, however this use is being phased out on welfare grounds. Cyanide is probably the most likely short-term adjunct to 1080 (although it would only be useful under restricted circumstances). The chemical, para-aminopropiophenone (PAPP), is being assessed in New Zealand and Australia as a longer-term alternative to 1080 for the control of foxes, cats and wild dogs.

2.1 Cyanide

Cyanide and cyanide compounds occur naturally in some plants and are synthesised from a wide range of industrial processes (Marks and Gigliotti 1996). Sodium, potassium and calcium cyanides have all been used for the control of vertebrate pests in different countries of the world. In North America, cyanide is currently used to control coyotes. Although cyanide is not a registered vertebrate pesticide in any Australian State, limited use permits may be obtained for research purposes.

Cyanide reacts with moisture in the animal's mouth to produce hydrocanic acid which causes asphyxiation by inhibition of respiratory enzymes and rendering tissues unable to absorb oxygen from the blood (Hone and Mulligan 1982). It is an extremely hazardous compound to use, and strict safety procedures must be followed (see Marks and Gigliotti 1996). Scientific appraisals from an animal welfare viewpoint show that cyanide is a preferred toxin (O'Connor et al. 2001), although this has not been tested at a policy level.

Recent developments involving encapsulation of cyanide for possum control in New Zealand (Feratox®) may prove extremely useful for fox control. This should be a subject of research in the immediate future. Although cyanide offers potential advantages for fox control, it must be recognized that it is a highly toxic substance to all species and will not offer many of the non-target safety mechanisms provided by 1080. The use of cyanide for fox control has some potential under strictly controlled situations, but is unlikely to be a suitable toxin for broad-scale use in Australia.

2.2 Para-aminopropiophenone (PAPP)

Since the 1940s, para-aminopropiophenone (PAPP) has been known as an effective treatment for cyanide intoxication because of its methaemoglobin-inducing actions (Vandenbelt et al. 1944). Methaemoglobin is a form of haemoglobin found in the red blood cells of mammals, but unlike normal haemoglobin it cannot bind oxygen. The toxic effects of PAPP are associated with the clinical condition methaemoglobinaemia, which arises from the excessive conversion of haemoglobin to methaemoglobin causing a lethal deficit of oxygen in cardiac muscles and the brain (Vandenbelt et al. 1944).

PAPP was investigated as a toxin for the control of coyotes in the United States in the 1980s (Savarie et al. 1983). Both the Canidae and Felidae families were found to be highly susceptible compared with rodents, mustelids and birds. Despite the very low LD_{50} in coyotes, Savarie et al. (1983) concluded that there was no practical value of PAPP as a selective toxin for coyotes, as theoretically a dose of 56 milligrams, required to kill 50% of (average 10 kilograms) coyotes would also kill the average-size cat, bobcat or kit fox. This study also reported that vomiting was a complicating factor in many of the animals when PAPP was delivered in a bait, as opposed to a stomach tube.

More recently, PAPP has been investigated in New Zealand as a toxin for stoats (Fisher et al. 2005), and future studies are proposed for ferrets, feral cats and wild dogs (Murphy et al. 2005). In Australia PAPP is currently under investigation for use against wild dogs, foxes and feral cats (Marks et al. 2004, Dall et al. 2005, Salleh 2005). In pen trials, Marks et al. (2004) used M-44 ejectors to deliver a standard dose of 226 milligrams PAPP in a formulation with dimethylsulfoxide and condensed milk. There was rapid onset of symptoms, with foxes becoming progressively lethargic until collapse after 14 to 25 minutes. Death was confirmed after a mean of 43 minutes, which is over seven times faster than that observed with 1080. The authors concluded that the PAPP formulation was fast acting and appeared to be a humane lethal agent, with victims showing few signs of activity or the convulsions, spasms and paddling commonly associated with 1080 poisoning. As yet no sensitivity assessments have been published for Australian marsupials. Recent developments suggest that this toxin could be a highly effective supplementary toxin for fox control although registration may still be some years away.

3. ALTERNATIVE DELIVERY OF TOXINS

3.1 M-44 ejectors

Bait delivery of toxicants is the principal technique used for fox control in Australia.
The only emerging alternative is the use of spring-loaded mechanical ejectors (known as M-44 ejectors), which are inserted partly into the ground. These are commonly used in the United States to deliver cyanide (Connolly 1988) and have been trialled in Australia using cyanide, 1080 and PAPP (Busana et al. 1998, Marks et al. 1999, Marks et al. 2003, Marks et al. 2004, Van Polanen Petel et al. 2004). Marks et al. (2002b) suggest that the M-44 may have a role close to urban areas where non-target risks posed by baits are high. Convincing the public that domestic dogs and children would be any less at risk to M-44s may be problematic. The Queensland Department of Natural Resources, Mines and Water (NRM&W) is currently preparing a registration application for the use of M-44 ejectors using cyanide as the toxin against foxes and wild dogs. The costs and benefits of using M-44 ejectors would need to be fully evaluated in both urban and rural landscapes.

4. ALTERNATE NON-LETHAL FOX CONTROL TECHNIQUES

The interest in non-lethal control techniques against predators has been increasing due to the ethically, welfare and efficacy concerns of the more traditional lethal methods (Treves and Karanth 2003). Most of this interest has been brought about through conservation issues arising from native predators overseas, however many similarities exist with exotic predators such as the fox in Australia. Non- lethal methods can prove more effective than lethal controls because the target animal is retained in its territory and social position thus any density-dependent responses in the population and immigration effects are avoided (Caughley and Sinclair 1994, Tuyttens and Macdonald 2000). Although this allows the individual animals to continue exerting whatever effect they have on other resources such as prey (which may not be beneficial in the case of fox predation on native animals), they maintain their territorial defence thus excluding conspecifics and other carnivores who may be limited by mesopredation (Baker and Macdonald 1999, Treves and Karanth 2003, see Saunders and McLeod 2007 for a discussion of mesopredation). The efficacy of non-lethal techniques may also be greater because the effect can last beyond the year of management (e.g. fertility control).

The issue of the overall benefits of lethal versus non-lethal techniques has never been investigated in Australia. Non-lethal techniques are not commonly used, and the common perception is that foxes are having a major impact by just existing in the Australian landscape (predation on native wildlife), so there would be no acceptable stable level at which the fox population could be sustained, even though in reality that is what is happening as foxes are so widespread now that eradication in not feasible (Saunders et al. 1995). Non-lethal techniques are seen as an adjunct to lethal techniques, generally requiring more time and resources and not suitable for broad-scale application.

4.1 Guard Animals

Guard dogs have been used to protect domestic stock from wild predators since ancient Roman times. Livestock producers in the United States began using guard dogs to protect sheep and goats from predators in the 1970s, and the extent of use has steadily grown, as well as research on their effectiveness (see Saunders and McLeod 2007 for a review). All studies reported similar findings that guard dogs, if they possessed the basic breed characteristics and were properly trained, were able to reduce predation. Although guard dogs are considered to be economical, their use is viewed as a complement to, rather than a substitute for, other control methods.

Although dogs are the main species used to guard livestock, other species such as cattle, donkeys, llamas and alpacas are also used to protect livestock from predation. The advantage of these types of animals over dogs is that, like sheep, they are herbivores, so they do not have to be fed separately, and they do not cross fence-lines and wander. There is a lack of scientific evaluation (particularly field studies) of the effectiveness of these alternative guard species (Saunders and McLeod 2007).

In Australia, three breeds of guard dog (Maremma, Anatolian Shepherd and Great Pyrenees), alpacas, llamas and donkeys are used to protect sheep and goats from fox predation. Evidence of their effectiveness consists mainly of testimonial accounts (Saunders et al. 1995, Jenkins 2003), with little empirical data to verify these claims. Only one Australian study that experimentally tested the value of alpacas in preventing lamb predation has been reported in the literature. Despite limitations with their experimental design, Mahoney and Charry (2004) concluded that the presence of alpacas resulted in a significant increase in lamb survival. Jenkins (2003) conducted a small phone survey of 85 producers in the ACT and Yass RLPB in NSW and found 8% in the ACT and 3% in the Yass RLPB already used livestock-guarding animals. There was a high level of interest, and about 50% of producers were willing to consider using guarding animals if they could be shown to be effective.

Overseas research suggests that guard animals may have potential in certain circumstances (e.g. raising of intensive livestock and stud animals), however many issues need to be resolved before the use of guard animals can be considered a viable technique that can be recommended to the agricultural community. These include evidence of efficacy under Australian conditions; availability of guard animals in Australia and costs of training; industry perceptions (and likely acceptance) of the technique as anything other than a novel measure of use in limited situations; security against theft; and the cost to the producer of using guard animals as opposed to the economic impact of predators.

4.2 Fertility Control

Fertility control has been advocated as a preferable form of pest animal management and considerable research effort has recently been dedicated to their development in Australia. It encompasses a whole suite of techniques aimed at reducing the birth rate by either preventing or interrupting pregnancy. Various recommendations have been made for the best use of fertility control.

These include: strategic timing of fertility control after population density has been first reduced by lethal control; targeting of bait-shy and genetically resistant animals that survive poisoning campaigns; and control in urban areas where conventional methods cannot be used for social, ethical or legislative reasons.

4.2.1 Immunocontraception

Immunocontraception is a technique whereby a vaccine is developed that immunises the target animal against one of it own reproductive hormones, gamete proteins or another protein essential to reproduction, thereby inducing sterility. The Cooperative Research Centre (CRC) for the Biological Control of Vertebrate Pest Populations, followed by the Pest Animal Control CRC, investigated possible immunocontraception techniques for the fox in Australia (see Saunders and McLeod 2007 for a full review). The most promising resulting vaccine was one containing ZP (zona pellucida) antigens. Recombinant canine herpesvirus was identified as a likely vector for delivering this oral vaccine antigen.

Proof of the concept of fox immunocontraception in the laboratory should not be seen as confirmation of efficacy in the field; there are many other issues surrounding the practicalities of implementation and the likely effects at a population level that need to be considered. Changes in the social behaviour of the fox, or excessive compensatory changes in other population parameters such as mortality, immigration and dispersal can have a major effect. Research results to date suggest that such social and compensatory responses are minimal, however results of population modelling show that fertility control in foxes has limited potential to lower population densities over the long term (McLeod et al. 2004). The proposed delivery system would need to be cost-effective and efficient. Another issue is the acceptance of immunocontraception (and its associated use of genetically modified organisms) by the public at large, as well as by national and international regulators.

4.2.2 Cabergoline

Cabergoline (CAB) is known to inhibit prolactin, a crucial luteotrophic hormone during pregnancy in some mammal species. It has been investigated as a potential fertility control agent for the red fox (Marks et al. 1996, Marks 2001, Marks et al. 2001, Marks et al. 2002a). The reported advantages of CAB are that it is simple to administer, has a high efficacy, a long duration of action, low toxicity, a wide margin of safety, and no severe side effects (Marks et al.1996, Tuyttens and Macdonald 1998). CAB is palatable to red foxes and can be included in oral baits (Marks et al. 1996).

Preliminary research on the use of cabergoline as a chemical fertility control agent is equivocal (Saunders and McLeod 2007). If proven, the technique may be appropriate where active dens can be targeted (e.g. in urban environments), but the suitability of cabergoline in rural settings remains to be seen. Any economic assessment would need to take into account the likely maximum effect of this chemical in the early stages of gestation and the spread of births that can occur in fox populations from early August to late September in south-eastern Australia. The technique also raises some ethical and animal welfare concerns.

4.2.3 Conclusion

Despite this intensive research to date no effective fertility control agents are currently available (or will be available in the foreseeable future) for broad-scale use against foxes.

4.3 Exclusion Fencing

Exclusion fencing is a non-lethal method commonly used to control canid predation on domestic livestock and threatened wildlife species. Well-designed and constructed fences provide a barrier to foxes but do not offer complete protection (Coman and McCutchan 1994). This type of fencing needs to be combined with a monitoring system and a management plan within the enclosure to rapidly detect and control breaches. One of the problems is the potential for surplus killing by foxes if the fence is breached, an event which would be catastrophic where endangered species are being protected from fox predation.

In Australia exclusion fencing for foxes is an important tool in the management and protection of threatened wildlife species and other valuable animals. The design of fox exclusion fences has generally been developed by trial and error in the field, and few have been rigorously tested using controlled experiments and research (Coman and McCutchan 1994, Saunders et al. 1995, Long and Robley 2004). One fence that has been experimentally tested is the Arid Recovery Project fence in South Australia, a fence designed for conservation purposes (Moseby and Read 2006).

Long and Robley (2004) comprehensively reviewed a range of exclusion fences that have been built in many different environments across Australia and provided recommendations for the minimum design specifications required for foxes. These recommendations were based on the measured effectiveness of those designs that have been tested, observational evidence from field personnel on fences in situ, and knowledge of relevant physical capabilities and behavioural responses of foxes. Features of the local environment such as topography, substrate, vegetation density, climatic conditions and geographical location were found to place constraints on the fence design, along with other considerations such as other species to be excluded, non-target animals present, as well as available funding and resources for ongoing monitoring and maintenance. They concluded that more research is required to fill the knowledge gaps to allow optimal, cost-effective fence designs to be determined.

Fence costs vary enormously, depending on the type and the ongoing maintenance program. Moseby and Read (2006) estimated the material cost of their fence design to range between $8,814 and $12,432 per kilometre. With such high costs, the design of exclusion fencing used for conservation purposes is non-profitable for private landholders over large areas in the agriculture sector, and is mainly restricted to small paddocks and poultry enclosures.

4.4 Food Manipulation

Manipulation of food supply to foxes has been suggested as a means of reducing fox impact. This includes the provision of diversionary sources of food at times of peak predation, as well as the removal of additional sources of food (e.g. rabbits and carrion) to reduce population capacity. These suggested practices remain untested and are most likely to be logistically impractical. Also exactly how food manipulation could be used to minimise fox predation remains unclear and also untested.

4.5 Taste and Food Aversion

Animals can be trained to avoid eating specific foods by being offered the food which has been treated with an undetectable illness-inducing chemical. The animal associates the taste of the food with the induced illness and subsequently avoids the taste of that food. CTA has used successfully to train livestock to avoid toxic plants (Ralphs 1992) and to treat various illnesses in humans (Bernstein 1999). Exploiting this CTA response is thought to provide a humane and effective means of controlling vertebrate pest problems.

There are many factors to be considered before CTA could become a useful tool for wildlife managers. Foremost is the discovery of an appropriate illness-inducing chemical which is undetectable and physically stable in the bait substrate, can induce a robust CTA after a single or small number of oral doses, but cause neither chronic illness or persistent detrimental effects in the target or any non-target species at risk of exposure (Reynolds 1999). The substance should also be safe to handle by humans and be environmentally safe as well.

Strict CTA could not be expected to protect untreated foods, as it is the taste of the food that needs to be experienced before aversion occurs and hence damage would still occur before the pest is averted (Cowan et al. 2000). This restricts CTA’s use to those foods which could be treated, for example crop and fruit damage and or live prey items such as eggs (e.g. Hoover and Conover 2000). To make aversion a more effective management tool the required protection should extend to untreated food, as it is not always practical or desirable to treat all food to be protected. Thus the development of a more general learned food aversion that would incorporate other mechanisms besides simple taste aversion, such as odour cues, would be more appropriate (e.g. Baker et al. 2007).

There were initial reports of success in some early CTA trials in the United States at deterring consumption and predation by captive large mammalian predators. Further investigations using primarily lithium chloride (LiCl) in baits, carcasses, livestock protection collars and on live sheep, has been the subject of much research and controversy due to poorly designed and executed experiments (see Saunders and McLeod 2007), and the focus on practical attempts to manage predation without having established the steps to creating CTA in these animals (Reynolds 1999). A further complication was differentiating between the motivations for killing live prey and consumption. Even though LiCl bait aversion could be conditioned, it failed to reduce coyote predation on live prey as the taste and odour cues on baits and carcasses had no influence during the killing process (Conover and Kessler 1994).

Gustavson et al. (1983) conducted experiments on captive dingoes to evaluate the effectiveness of an alternative aversion-producing agent, the anthelmintic thiabendazole. They reported that thiabendazole-treated meat produced a conditioned taste aversion in dingoes, but further field investigations were not conducted. Rathore (1984) evaluated LiCl taste aversion in penned domestic dogs as a preliminary step in evaluating taste aversion to reduce dingo predation, but he found that the induced aversion lasted less than 24 hours. Other chemicals used to induce taste aversion have been carbachol and oral oestrogen (Baker and Macdonald 1999).

Baker and Macdonald (1999) suggested that finding a safe, undetectable and sufficiently fast-acting emetic for foxes is likely to be a problem, and that a better goal may be to explore the use of a bitter taste in place of an emetic. Primary aversion to compounds that taste bitter is thought to result from natural selection for avoidance of toxic alkaloids and glycosides (Garcia and Hankins 1977). Macdonald and Baker (2004) conditioned captive foxes to avoid drinking milk containing Bitrex® (a bitter compound detectable only by taste). Similarly, Massei et al. (2003) found that levamisole hydrochloride (a broad-spectrum anthelmintic used in veterinary medicine) induced strong, long-lasting conditioned taste aversion in captive foxes. When Gentle et al. (2004) tested levamisole on free-ranging foxes they could not replicate this induction of CTA to meat baits; instead, they achieved a learned aversion to the levamisole hydrochloride itself. Baker et al. (2007) reported free-ranging foxes displayed an innate aversion to the substance ziram (in the form of AAProtect™, a bird and mammal repellent registered in the United Kingdom), developing into a learned aversion to untreated baits. This work needs further evaluation to determine whether aversions can be induced in free-living fox populations and to determine whether aversions can be transferred from dead to live prey.

Even though taste aversion might not prevent predation, it is still useful in situations where feeding is undesired. Cornell and Cornely (1979) reported on a trial using LiCl baits to discourage coyotes from feeding on handouts and rubbish at campsites in the United States. Ternent and Garshelis (1999) used thiabendazole to deter black bears from feeding on pre-packed food in a military camp. Similar methods are also suggested for discouraging dingoes from campsites on Fraser Island (Anon 1999), and could be useful in situations where fox scavenging around residential areas is undesirable.

The fact that research into taste aversion with the aim of reducing predatory impact has been done for nearly 30 years with still no universally accepted technique or chemical demonstrates that there is a considerable gap between theoretical and field application. Taste aversion is more likely to have application in changing behaviour towards baits, sources of food, and possibly the eggs of endangered bird and reptile species. These aspects warrant further investigation.

4.6 Habitat Manipulation

Caughley and Sinclair (1994) describe habitat manipulation as the most elegant of wildlife management techniques, because it does not work against the negative feedback loops, e.g. density-dependent responses to population reductions. Habitat manipulation can be divided into two different approaches; habitat manipulation to enhance the survival of prey species (threatened wildlife) or habitat modifications to reduce fox abundance by either direct impact or by diverting this pest away from the commodity being protected. Habitat modification can only work if the habitat resource has been identified as a limiting factor and it can be modified economically (van Vuren 1998).

Successful examples of manipulating habitats to reduce fox impact are rare. Den destruction, particularly around breeding, has been advocated as an alternative strategy to help manage fox populations in the rural areas, but is not supported by any empirical data in the literature. There is no evidence to support the fox population is limited by den sites, being known to use multiple den sites, with no preference for their location (Gentle 2005). On the other hand, urban foxes in the Melbourne area have show a consistent preference for diurnal shelters associated with exotic weed infestations such as blackberries and wandering tradescantia (Marks and Bloomfield 2006). The authors suggest that since these exotic weed infestations are an identifiable resource requirement for the foxes, its removal would assist in reducing urban fox abundance.

The effects of predation are thought to be counteracted by improving the survival of endangered prey through habitat manipulation (Sinclair et al. 1998). In Australia, there is growing evidence of how minor habitat modifications or fragmentation can increase the impact of fox predation. Habitat modification alters habitats to attract or repel certain wildlife species or to separate prey from predator (Bergman et al. 1998). Kinnear et al. (1988) concluded that fauna subject to fox predation can survive only at sites that act as refuges from predators. Removal of predators allows the prey to use less protected sites. The results from some areas involved in the Western Shield project in Western Australia support this conclusion (e.g. de Tores et al. 2004, Haywood et al. 2005), as does a study of brush-tail possums in south-eastern Australia woodlands (Pickett et al. 2005).

Disturbance to forests by logging and by clearing for agriculture has been found to influence fox movements within their range (Catling and Burt 1995). It has been suggested that foxes do not live entirely within closed canopy forests but can penetrate some distance into them in search of food through the use of roads and tracks (Jarman 1986, Mansergh and Marks 1993). Meek and Saunders (2000) found that foxes consistently use roads and tracks for access but also found foxes living within dense forest and heath. Although foxes may use roads to optimise their foraging efficiency (e.g. by scavenging on road kills), these authors questioned the conclusion that foxes will use forested habitats only if assisted by man-made roads and tracks.

Increasing the structural complexity of habitats that support predator-threatened fauna may not be the simple answer as although it provides protection for these species, it may also enhance the survival of other pest species (Pech and Arthur 2001). More case studies of effective habitat manipulations that enhance the survival of threatened species and of habitat modifications that have the opposite effect are needed before we should make dramatic changes to existing land management practices. Until then, the concentration on directly reducing the predatory effect of foxes, will remain the preferred option.

4.7 Alternative Farm Management Practices

Alternative farm management practices may reduce fox predation (Newsome 1987, Hulet 1989, Bergman et al. 1998, Connolly and Wagner 1998, Moberly et al. 2004), however little information is available about the associated benefits and costs. These practices include livestock management practices as well as farm hygiene practices (some of which have already been discussed in earlier sections). For example:

- modify the level of care or attention given to livestock (e.g. lambing in sheds or small enclosures near human habitation)
- improve maternal nutrition and select for more protective mothers
- change the timing or duration of the lambing period
- synchronise lambing
- select paddocks to maximise protection from predators
- use exclusion fencing
- reduce alternative foods (e.g. rabbits, carrion) to reduce long-term fox populations
- change habitats to deter foxes.

Modified farm management practices aimed at reducing fox impact generally require additional resources and effort and frequently only delay the onset of predation or have undesirable side effects. For example, changing the time of the year in which lambing takes place to coincide with low fox numbers may be unrealistic, given the absence of demonstrated improved profit levels. Further, if such a density/damage relationship existed, would it have a greater impact on livestock reproduction than other seasonal effects such as pasture, nutritional, market or climatic conditions?

Fox management is only part of the overall farm management and should be considered within this context. Verification of the costs and benefits of suggested changes to management practices would facilitate greater adoption of these approaches for reducing fox impact.

5. SUMMARY

Lethal techniques look set to retain their importance in fox management in Australia in the foreseeable future, especially for broadscale application. However due consideration needs to be given to welfare and ethical issues, with the need for a proactive strategy to educate the community at large as to the inherent advantages of these techniques, in particular the use of 1080 as the preferred lethal control agent for foxes. The necessary research and development required to register an additional toxin to 1080 for foxes are probably not commercially justified. Public funding will therefore be important if such alternatives are to be developed. The importance of non-lethal techniques will increase if the techniques can be improved and refined. Ongoing research is mandatory if these additional methods of fox control are to be adopted.

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APPENDICIES

Appendix I: **2004 Media Release and Lamb Production Questionnaire**

Appendix II: **2005 Lamb Production Questionnaire, Landholder Letters, Reminder and Media Release**

Appendix III: **2005 Lamb Production Questionnaire Prize Draw**

Appendix IV: **2006 Fox Shooter Questionnaire, Media Release and Media Articles**

Appendix V: **Milton / Ulladulla Fox Management Questionnaire**