Review of the Program to Eradicate Foxes (*Vulpes vulpes*) from Tasmania

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Introduction

The Tasmanian Government has been managing a program to eradicate red foxes (*Vulpes vulpes*) from Tasmania since 2002 in response to growing evidence of the presence of a small population. The funding partners in the program have been the Australian Government (curently through the Caring for Country initiative), the Tasmanian Government and the Invasive Animals Cooperative Research Centre. In April 2009, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) commissioned Landcare Research New Zealand Ltd to review the program to assess whether eradication was still a feasible goal and to identify changes that might be required.

Terms of Reference

- Evaluate progress towards the program's goals and objectives, including use of cost–benefit analysis and appropriate assessment tools to determine whether the current program design and expenditure profile are the most cost effective for achieving eradication.
- Review current investment and effort in detection/monitoring, research/analysis and reporting/communication activities, consider other approaches and techniques and recommend changes and improvements required to cost-effectively achieve the program objective of eradication.
- Input into the development of an exit strategy – identifying possible decision points for deciding whether eradication has been achieved or that eradication is not possible.
- Identify risks with the eradication strategy and exit strategy.

Current Management

The current program team consists of nearly 60 staff divided into four work streams with an annual budget of $5.6 million in 2008/09 reducing to $4.1 million in 2009/10. The main 'delivery' streams consist of (a) three regional operational teams responsible for killing foxes and (b) an investigation and monitoring team with four units responsible for investigating public reports of foxes, general monitoring for foxes, searching for fox scats with dogs, and using people for a general survey for fox scats. These teams are supported by (c) a research team and (d) a community engagement team.

The team has made considerable progress over recent years. Some key successes include the technical ability to detect foxes with increasing certainty using scat searches and DNA tests, improvements in the interpretation of public reports of foxes, more certainty about the extent of non-target risks from the 1080 baiting, and in the collection of operational data. The analyses in this review would not have been possible without such progress.

Feasibility of Eradication

Foxes have been eradicated from other islands, but all were at least an order of magnitude smaller than Tasmania. Analysis of the rules that must be met (all animals at risk, killed quickly, no immigration) to achieve eradication and the particular constraints pertaining to Tasmania suggests eradication is possible under a modified program. The unresolved constraints we identify means there will always be a high level of uncertainty in the program

and therefore a residual risk of failure to eradicate. However, the benefits of success are considerable and worth a continued effort despite this uncertainty.

Conceptual and Quantitative Models

We describe a conceptual and quantitative model that incorporates expert opinion and field data to inform high priority areas for surveillance, quantifying probability of local extirpation following control, and a broad-scale probability of eradication for Tasmania. The model is conceptual because it identifies key relationships and uncertainties in the eradication program. It is quantitative because it decomposes the larger model into components that are linked probabilistically and informed by data. Once evidence of fox presence is no longer being found, the model will provide the quantitative basis for 'stopping rules'.

Main Conclusions

Program strategies

There are two strategies that might be employed to underpin the attempted eradication of foxes in Tasmania. (1) Precautionary strategy: Initial control might be deployed across all areas predicted or likely to have foxes based on habitat suitability or on past evidence of the presence of foxes. (2) Recative strategy: Initial control might be deployed only at sites where foxes are reported with some confidence or located by pro-active monitoring such as scat searches. Monitoring to detect survivors of this initial control (on average some are certain to survive) and the subsequent response to such detection are of course common to both strategies and represent residual uncertainties and timeframes for the program but may be resolved by applying the model suggested in this review.

The advantages of the first strategy are that (a) all foxes potentially present, detected or not, will be put at risk, (b) the baiting might be deployed in some planned way to reduce risks of foxes immigrating into the baited areas, (c) it is simple to set a milestone and timeframe for the initial control and (c) the formal monitoring effort now spent searching for foxes before initial control is deployed could be reallocated to extra control effort or more post-control monitoring. The disadvantages are that more 1080 baiting is likely to be used, reponses to the informal monitoring from public sightings may be delayed, and some baiting would be used in areas that might have no foxes. Given the uncertainties around detecting foxes, this represents a precautionary strategy for the initial response phase of the eradication.

The advantage of the second strategy is that 1080 baiting is more focussed and only deployed around areas where foxes are reported or detected, thus saving money and reducing potential adverse non-target impacts of the baiting. The disadvantages are that foxes may exist but remain undetected in areas searched and some areas of potential fox habitat may never be searched. If no control is deployed in such areas any foxes actually present are not at risk. This represents a reactive strategy and does not lend itself to setting simple milestones and timetables.

The current program has evolved to be a mix of the two strategies. The management structure and process lacks the necessary seamless integration between the monitoring and reporting to locate foxes and the initial control response, 1080 baiting, to be the optimal reactive strategy. The current post-control monitoring is inadequate. The response to either detection of survivors or a low probability of fox persistence despite none being located (see the model) requires further development both in its planning and application.

A risk comes from the lag between reporting a fox, validation of its presence, reaction with initial control, monitoring to assess the efficacy of this control and subsequent secondary control if required. Reducing these lags is possible to some extent but the costs (wasted reaction when say the scat proved DNA-negative) need to be balanced against the benefits (the control was implemented in time to put the putative fox at risk). Generally, in eradication programs the balance should favour the latter type of decision. There are management issues with respect to the risk to dogs when they are used after 1080 baiting. We think these risks (and the lag) can be removed by muzzling the dogs as is routine elsewhere in the world.

If the program changes to the precautionary planning option a larger change in program structures will be required. Much of the current surveillance and monitoring becomes redundant and the resources should be redirected to 1080 baiting to be deployed across all risk areas (defined by habitat suitability). This may be funded within current budgets by reallocating some of the monitoring budgets (most of the 'scat survey' budget and most of the 'investigation' budget) and perhaps some of the research budget to the operational baiting budget. We note that at current baiting rates of about 600 000 ha per year all of Tasmania could be covered in 10 years or the current 'risk' areas in 5 years. If program resources are maintained at 2008/09 levels but reallocated the current 'risk' areas could be covered in 3 or 4 years.

Both strategies require substantial effort to detect and kill survivors (if any) in areas already baited. The scat dog team needs to be integrated with this post-control measure of efficacy, and perhaps increased if the workload demands more effort.

The problem of killing urban foxes is slightly different because, although detecting them is similar in principle to that for rural foxes, the control response is different. The inability to use 1080 baits means the response to urban foxes is akin to the problem of dealing with potential survivors of baiting in rural areas where those survivors are not susceptible to further baiting.

The remaining research budget should focus on developing the model to enable interpretation of search results, and on the development of secondary control methods, other than baiting, to deal with survivors that avoid 1080 baits and urban foxes. We suggest a new dog team be developed to locate surviving foxes (not scats). The locator dogs do not necessarily kill the fox – it has to be dispatched by some other appropriate means.

Main constraints

The issue of access to all lands irrespective of tenure must be resolved. Apart from the urban fox issue, there are some landowners who refuse access to the fox control team. If the areas are large (in relation to potential fox home ranges) and in likely fox habitat, this represents a huge risk to the eradication attempt. In any event the access issue should be resolved now and not at the end of the campaign.

The problem of detecting and killing urban and peri-urban foxes requires both social (a task for the community engagement team) and technical (we suggest trained fox-detector dogs might provide this) solutions.

Information and Management Needs

Detection and field life of fox scats

The ability to reliably detect foxes or their sign with known levels of certainty is a key need under both management strategies. Under the reactive strategy it is required both prior to control to direct control, and after control to locate survivors and focus the ‘mop-up’ control. It is required only after control under the precautionary strategy, again to locate survivors and focus ‘mop-up’ control. Scats can now be identified, in many cases, as belonging to an individual fox thereby enabling more detailed interpretation of post-control foxes as survivors or immigrants.

Scat-detection abilities of dogs and people were measured in an earlier trial. However, the trial needs to be repeated under more usual Tasmanian conditions to improve the estimates of detection probabilities for individual dogs and individual searcher effects.

Knowledge on scat detection probabilities also enables managers to interpret ‘zeros’. If one looks and finds no scats, what is the chance that no foxes are present? This is a critical element in the development of ‘stopping rules’ and an exit strategy to declare success.

The field life of scats is unknown yet such information is required to plan and interpret the post-control detection and search results, and to inform secondary control needs. Fox scats are very rare in the landscape, even in areas where DNA-confirmed scats have been located. Understanding the field life of scats will clarify whether this rarity is due to high scat disappearance rates or to highly mobile foxes – the answer having important management implications.

Use of data

The program has databases on potential and known fox locations, increasing amounts of data on individual fox locations, areas searched for sign, and areas controlled with 1080. While all the critical data elements are being collected, it appears as if they are not organised such that key information can be quickly extracted. These data need to be analysed and integrated at an operational level to drive key management decisions particularly on where and when to apply control under the reactionary strategy, where and when to look for surviving foxes under both strategies, and where and when to try to locate and kill these foxes.

Killing survivors of 1080 baiting and urban foxes

Some foxes are likely to survive 1080 baiting and may survive repeated baitings. This method cannot be used in urban areas. Use of an alternative toxin, such as PAPP, may (or may not since it remains to be tested) target foxes that survive 1080 baiting. It also has an antidote so might be of use in urban or peri-urban areas where domestic pets are present. Thus, there is a need to develop control tools that can be used for such foxes and in such places. We suspect the best might be dogs trained to find foxes at their daytime locations or dens, with the foxes being dispatched by other means. Such dogs are regularly used for similar purposes in other predator control and eradication operations.

Main Recommendations on the Terms of Reference

Progress towards goals

- Eradication is of course an absolute goal – any survivors capable of breeding represent failure. Thus, the project has not yet succeeded.
- On the positive side, the program has developed some of the tools (e.g. scat detection, scat dogs), infrastructures (e.g. trained staff), and knowledge (e.g. non-target mitigation) required to realistically make the attempt.

Program structure

- We recommend changing toward the precautionary strategy with consequent reallocation of resources within the program. This is mainly because there are such large uncertainties, irresolvable in the urgent time frame required to achieve success, in managers' abilities to delimit fox range in Tasmania, and to locate individual foxes within that range. The reactive approach to initial control does not allow for easy risk management, target time frames, or thus exit strategies.
- Refocusing efforts away from pre-control monitoring towards control and post-control monitoring allows time frames to be set for the initial control actions, although the uncertainties around locating and dealing with survivors remain as in the reactive approach. These latter decsions would be informed if the model suggested is applied.

Cost minimisation

- The appropriate economic analysis for eradication when the benefits of success accrue to non-market values from zero pests is cost-minimisation – rather than cost-benefit or benefit-maximisation approaches. That is, what is the cheapest way to achieve eradication – within a set time frame to limit risks of funder fatigue or being beaten by fox biology?
- This is simplest to analyse under the precautionary approach. At 2008/09 annual budgets with some reallocation of resources between functions, we think the initial control in all rural areas of likely fox habitat could be achieved within 4 years or within 8 years if the foxes prove to be present over the whole of Tasmania. The major uncertainties on this time frame and cost are the costs to deal with survivors of a single baiting and the ability and costs to deal with urban foxes. We cannot estimate these costs with current information (but see the points below).

Exit strategy

- The positive exit strategy is to set a level of confidence that the eventual absence of definite fox sign means foxes have been eradicated from Tasmania, and utilise the model suggested in this review to determine whether the monitoring (with no evidence of foxes) achieves this level, or whether more monitoring (with no evidence of foxes) is required to achieve the set level.
- The program should be terminated if access to high-risk areas is not enforceable, or if the tools to kill foxes that survive 1080 baiting or live in urban areas cannot be deployed.
- The program would need to be reassessed if reliable evidence of foxes is found outside the current habitat-based risk areas.
- Otherwise, we think a rearrangement of the program towards the precautionary approach and would allow realistic milestones for the initial baiting to be set.
- Development of the model suggested in this review would then allow decision-makers to analyse the risks of being wrong as the number of fox reports declined (there may always be false reports) and when fox scats cease to be found in management zones and across the whole of Tasmania.

1. Introduction

The Tasmanian Government has been managing a program to eradicate red foxes (*Vulpes vulpes*) from Tasmania since 2002 in response to growing evidence of the presence of a small population. Since 2007 this has been conducted under the Fox Eradication Program (FEP). The funding partners in the program have been the Australian Government (curently through the Caring for Country initiative), the Tasmanian Government and the Invasive Animals Cooperative Research Centre. In April 2009, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) commissioned Landcare Research to review the program up to the end of the first phase to assess whether eradication was still a feasible goal and to identify changes that might be required under the next phase of the program.

2. Background

The introduced the red fox has been implicated in the extinction of many native animals on the mainland of Australia (Saunders et al. 1995) and is currently listed as a key threat for a large number of extant native species (DEWHA 2008). The fox is also a predator of lambs on the mainland of Australia (Saunders et al. 1995). Tasmania retains many of the native species, generally those in a critical weight range of between 35 and 5500 grams, which have suffered from predation on the mainland partly because of the presence of foxes. It has been estimated that 78 native Tasmanian vertebrate species, including 12 already listed as threatened under Commonwealth or State legislation, would be at risk if the fox established in Tasmania.

Although foxes have occasionally been released or arrived accidentally in Tasmania since the late 19th century they did not establish (Saunders et al. 2006). However, a more deliberate attempt to establish a population was apparently made in late 1999 with an alleged introduction of 11 foxes from two litters released at three places in Tasmania (Nature Conservation Branch 2001; Saunders et al. 2006).

Irrespective of how foxes arived in Tasmania, subsequent evidence from road-kills and widely distrubuted DNA-positive faecal scats (summarised in Fearn 2009) has shown that a population has persisted. The evidence led the government of Tasmania to instigate some initial surveillance, followed by the formation of a Fox Free Taskforce in early 2002 and a program of 1080 baiting that began in late 2002. This stage of the program was reviewed in 2003 (Kinnear 2003). Following a report by Saunders et al. (2006) this taskforce evolved into the current Fox Eradication Program (FEP). The aim of the program is to eradicate foxes from Tasmania, an aim also given very high priority by the Australian Government (DEWHA 2008).

3. Terms of Reference for the Review

The terms of reference for this review are to:

- Evaluate progress towards the program's goals and objectives, including use of cost–benefit analysis and appropriate assessment tools to determine whether the current program design and expenditure profile is the most cost effective approach to eradication.
- Review current investment and effort in detection/monitoring, research/analysis and reporting/communication activities, consider other approaches and techniques, and recommend changes and improvements required to cost-effectively achieve the program objective of eradication.
- Input into development of an exit strategy – identifying possible decision points for deciding whether eradication has been achieved or that eradication is not possible.
- Identify risks with the eradication strategy and exit strategy.

In doing these, we interviewed program staff in late April 2009 and accessed program reports to:

- Review operational procedures, budget allocations, and current program activities.
- Assess the advice already given to the program on methods to delimit, detect and destroy foxes in Tasmania.
- Review whether this advice (assuming it is correct and adequate) is being used appropriately to achieve the project goals, or if not why not.
- Work with relevant specialists within Landcare Research and elsewhere, including the Applied Environmental Decision Analysis Hub of the University of Queensland, to access additional analytical support and professional input into the review and its findings. Make recommendations on the projects' adequacy to achieve its goal.

The logic we have used in the review is first to give a bioeconomic overview (to set the scene for answering the cost–benefit and risk-analysis tasks from the terms of reference) of the management strategies potentially available to eradicate foxes. We then provide a summary of the program's management and activities, noting key issues that we think will need to be addressed if the program is to succeed. Next we provide an analysis of the intrinsic feasibility that foxes can be eradicated from Tasmania by considering (a) precedents from elsewhere, (b) an analysis of the ability of the current or modified program to meet the obligate rules (Parkes 1990) for successful eradication and overcome key constraints and risks (Bomford & O'Brien 1995) noted in DPIW (2009), and (c) capture these points in a preliminary model to assess the probability that foxes have been eradicated as the program proceeds. Finally we reiterate in the conclusions and recommendations the sort of information and actions that will be required to give acceptable levels of certainty to decision-makers that eradication can be achieved within a set time. Caveats on this are that not all such key information is currently available and, of course, if eradication is judged not to be intrinsically feasible and unlikely to be so irrespective of new information and changes in management. In the latter eventuality an immediate stop rule for eradication could be imposed with a major change in strategy to one of sustained control, or of alternative means of protecting Tasmanian native wildlife such as relocation of at-risk species to island sanctuaries.

The FEP Management Group commented on a draft of the review. Input from the FEP Technical Advisory Group and the interested university groups was not possible before the reporting deadline but will proceed as appropriate after the review has been released.

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4. Bioeconomic Strategies

Assuming eradication is intrinsically feasible and the budgets and/or time frames for success are adequate there are two possible discrete strategies to attempt eradication. In essence a program could deploy initial control (1080 baiting is the method of choice) over all areas assumed or known to harbour foxes, or it could deploy the initial control only at areas where foxes were detected. In either case some foxes are likely to survive the intial control so some form of follow-up monitoring and response would be required.

- Precautionary strategy (Fig. 1): the control could be deployed on some rational basis (we discuss the rules for such a rationale in saection 7.4) that would eventually cover all areas that might be predicted to have foxes based on habitat suitability or past knowledge of where they have been found. This would be a partly precautionary strategy as a completely precautionary approach would do this over all Tasmania.

  The costs to do this within a set time frame could be easily estimated, or the time frame to do it could be set by the annual budgets available. Under this strategy no costs would be allocated towards pro-active searching for foxes prior to the initial control; the bulk of the costs being deployed towards control. However, assessing the efficacy of this control would require post-control monitoring and further action if foxes had survived or if the subsequent searches had low probabilities of detection (see below).

- Reactive strategy (Fig. 2): the initial control would be deployed only where foxes are reported or known to be present.

  The costs to this would include a substantial budget for the monitoring to locate foxes, but with lower costs and non-target or social consequences than the first strategy for the initial control as it would be more targeted and presumably cover smaller areas. Again, the control efficacy would need to be assessed and secondary control applied where required. Costs to do this within a set time frame could not be predicted a priori – although the component to fund the detection of foxes could be predicted. Similarly the time frame to achieve this strategy under variable annual budgets would depend on results, and an adaptive budgeting process would need to be developed.

- Mixed strategy: of course a mix of these two strategies is possible and even desirable. For example, monitoring for scats to direct initial control could be halted and the resources moved to bolster control or post-control monitoring for survivors. However, the initial control plan might still need to react to higly plausible reports from the public and so modify the roll out of the precautionary baiting (see section 7.4).

The control techniques available are common to both strategies. The problem is that the primary control method (1080 baiting) is unlikely to kill 100% of the foxes at a single application, and it does not provide direct evidence of success via a carcass. To solve the first problem there are again two options. Either the control can be repeated (using either the same or a different technique) as a precaution, or the site can be monitored for survivors whose detection indicates the need for a repeat control event of some sort. The problem of what to do if a baited area is searched and no foxes are detected – declare success or repeat the monitoring or control – will be solved by the resolution of the model suggested in this review.

Clearly these bioeconomic options lead to different management requirements, particularly on the timing and purpose of scat monitoring.

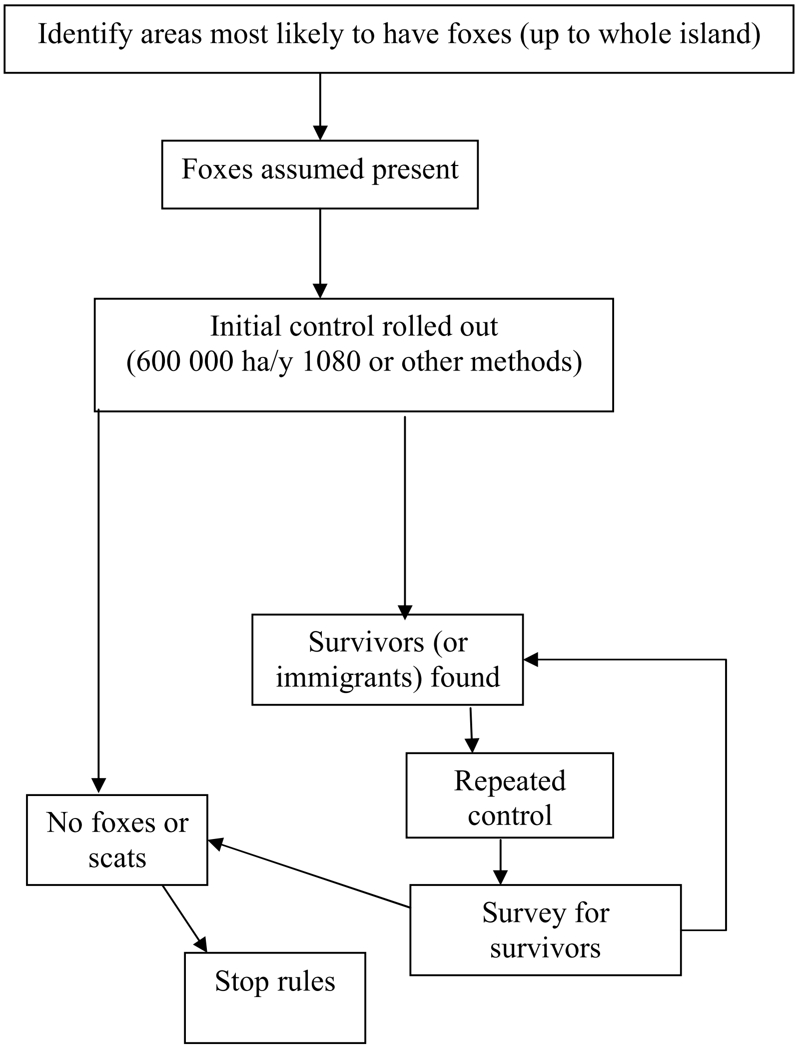


Fig. 1 Management process for precautionary strategy.

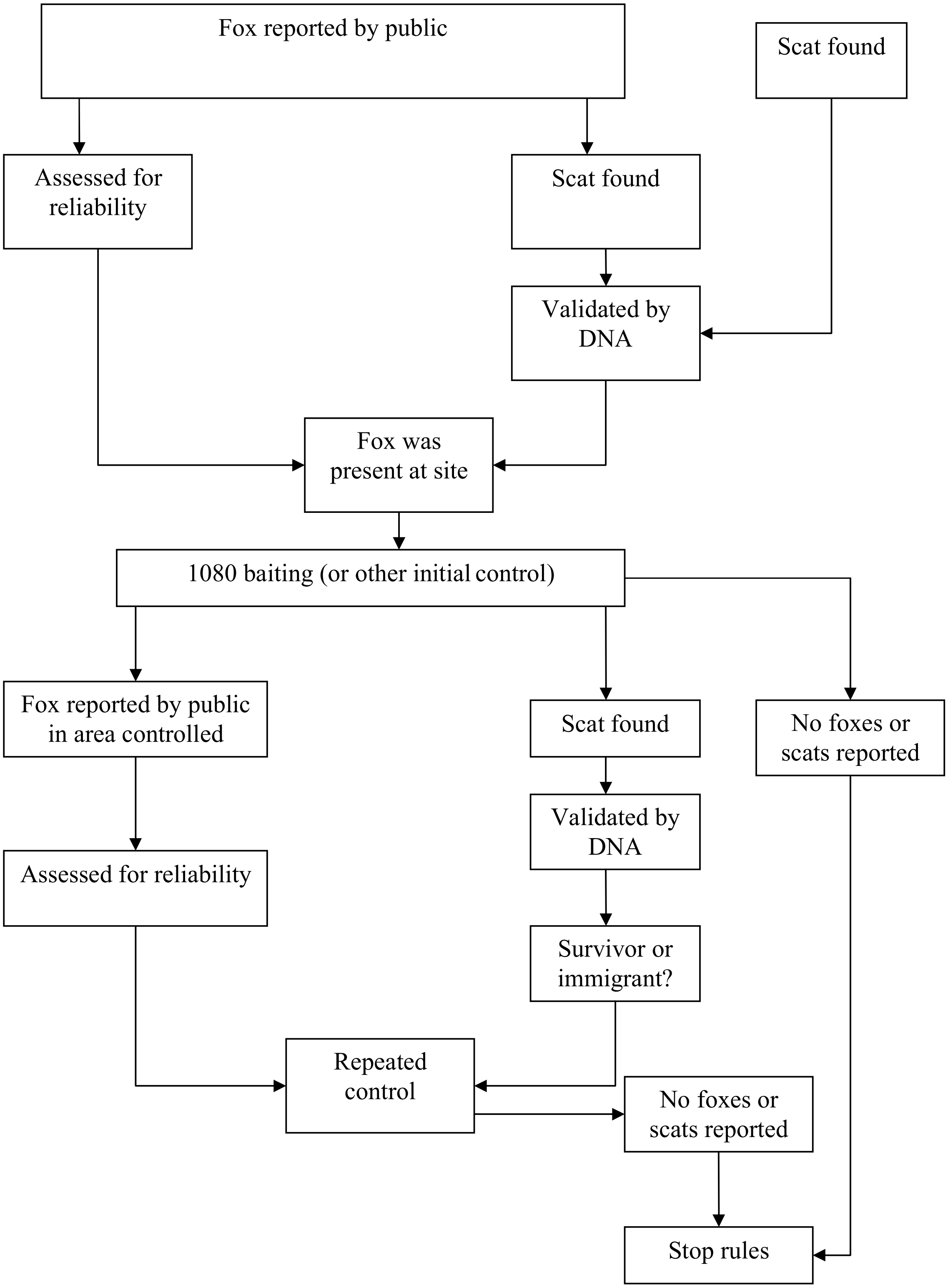


Fig. 2 Management process for reactive strategy.

5. Current Management

In this section we summarise the current management being undertaken within the program. The purpose is not to provide a complete history of the program but rather to highlight key issues that may affect the feasibility that foxes can be eradicated. We return in detail later in the review to each of the key points where we think changes in management are required.

5.1 Program structure and budget

The project is now organised as a separate branch of the DPIPWE with four units reporting to a Branch Manager (Fig. 3). Staffing levels have increased from around 10–15 FTEs between 2002 and 2006, to 40 FTEs in 2007/08 and current totals of nearly 60 FTEs. We note reports that this structure may alter in 2009/10 as a result of a planned reorganisation of government departments and that the Australian Government contribution to the budget for 2009/10 has been reduced by $1.5 million.

The sharp end of the program is the unit responsible for killing foxes. It is divided into three regional operational groups each with a coordinator reporting to an operational manager and with a total of 22 field staff. These are supported by a monitoring group with 16 staff reporting to a coordinator and are responsible for ‘finding foxes’ by investigating reports of foxes and validating these reports, often using the dog teams or more rarely by using the monitoring field officers to search for sign of foxes.

The monitoring field officers primarily attempt to find foxes using a structured and repeatable process. They search for fox footprints or scats at likely sites such as ‘edges’, riparian areas or waterholes and deploy sand pads, cameras or spotlight searches along these transects.

Most of the post-1080-baiting monitoring done by the field monitoring staff uses the above methods, rather than dog teams apparently because the dog handlers fear their dogs would be at risk from 1080 poisoning. It is not clear which baited sites get what post-control monitoring.

Sitting outside these ‘action clusters’ the scat collection project is responsible for the wider survey of the State for the presence of foxes, although of course any fox scats they find are also used to direct fox control decisions. The community engagement and research and development teams essentially service the monitoring and operations managers.

The 2008/09 budget was $5.6 million (Table 1) with contributions from the Tasmanian Government ($3.1 million), the Australian Government ($2.5 million), for the core functions, and from the Invasive Animals Cooperative Research Centre for the scat survey ($75 000).

Table 1 Annual budget for 2008/09 year broken down by function

Function	Annual budget	% of total
Project management	$627,000	11.2
Community engagement	$396,000	7.1
Research	$462,000	8.2
Monitoring: investigations	$438,000	7.8
Monitoring: dog teams	$336,000	6.0
Monitoring: scat survey	$442,000	7.9
Monitoring: monitoring team	$605,000	10.8
Operations	$2,296,000	41.0
TOTAL	$5, 602,000	

5.2 Current management process

The current management process is a mix of the reactive strategy and the precautionary strategy. The reactive management process begins when a fox is reported, usually by the public via a 24-hour hotline or when a fox scat is found by the survey team or the monitoring field officers. The credibility of the public reports is evaluated by one of four 'investigators' and may be followed by an attempt to validate the report by attempting to find firm evidence of a fox. To date the main way the presence of foxes has been validated has been by finding fox faecal scats. This is done by deploying a scat detection dog or the 'monitoring field officers' to search for scats in the area where a fox has been reported. Confirmation of some scats as fox scats is made by testing for the presence of fox DNA, at the University of Canberra. Alternative means of validating the presence of a fox (cameras, search for footprints, spotlight searches) have been tried without success (cf. Vine et al. 2009).

At some point in this chain of events a tactical or hotspot control operation using 1080 baiting may be mounted by the operations unit. The way this response is determined is unclear.

The precautionary management process is partially undertaken by the more widespread baiting that has been going on since 2002 (see 5.4.1).

There does not appear to be any consistent or formal audit of the efficacy of this control by targeted post-control searches for scats or other sign, although this is apparently done in some places. Efficacy becomes apparent as further public reports followed by scat detections are revealed at baited sites over time.

> **Key point on current management process:**
> **The current line management structures for the operations team and the monitoring coordination component of the Investigation and Monitoring section do not best reflect the actual management process (report of a fox – investigation – validation – reaction with control – audit of the control).**

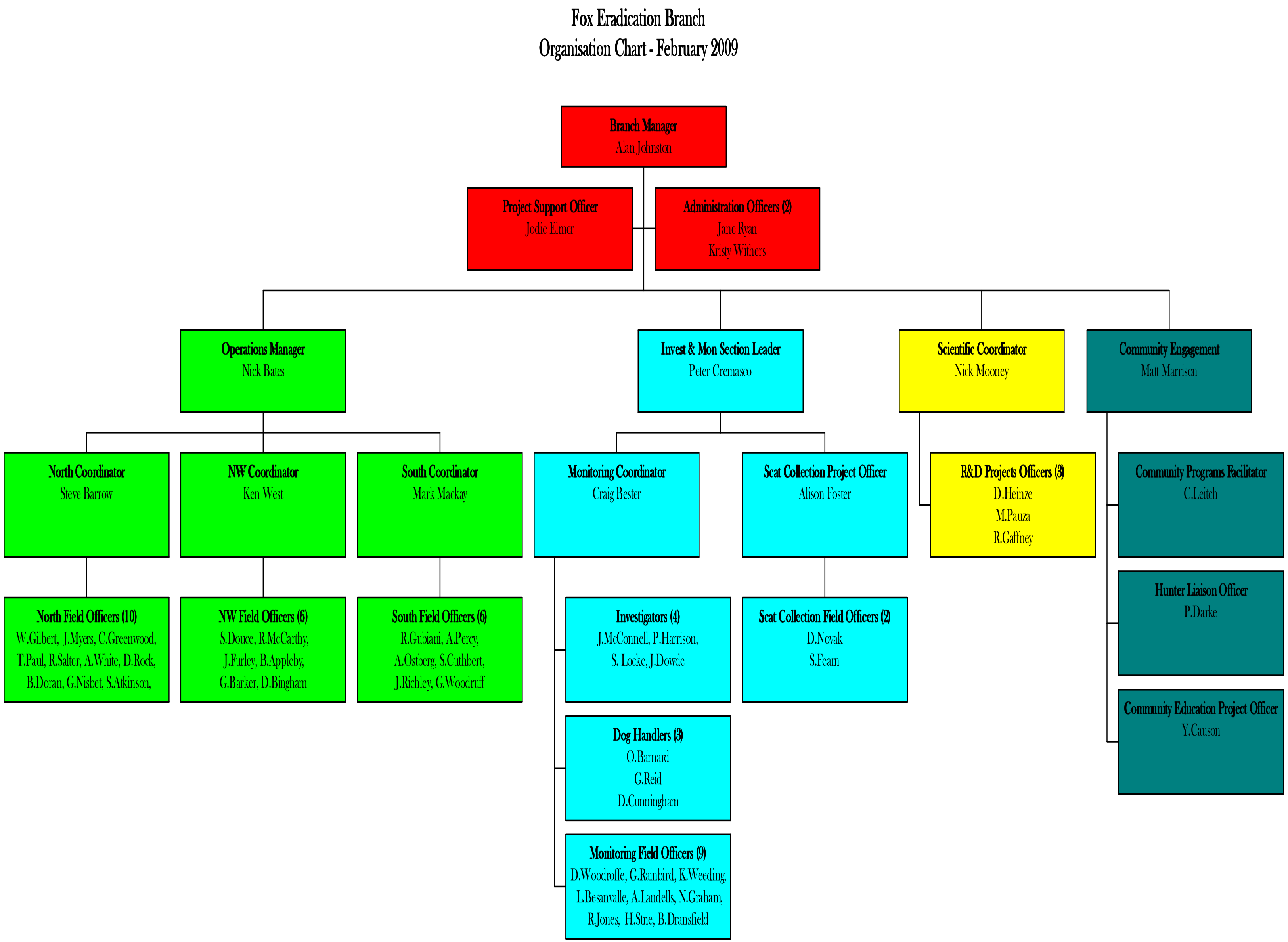


Fig. 3 Staff and line management accountabilities in the Fox Eradication Branch.

5.3 Detecting foxes outside the scat survey process

There are two key parameters in any surveillance system:

- The detection probability (= the probability that the detection system finds a fox given a fox is present).
- The search area.

The FEP has three main methods that have detected foxes: public reports, finding scats using dogs, and scat surveys without the use of dogs. Other ways to detect a fox have included road kills ($n = 4$), footprints ($n = 2$) and the presence of fox blood on prey ($n = 1$), all too few to act as a reliable general detection method. All methods will have detection probabilities less than 1, and all will include false positives (public reports having the highest level of false positives). Other methods trialled have failed to detect foxes (cameras, spotlight searches) or only done so rarely (footprints). Further development of these monitoring tools may be justified under the reactive strategy but given their lack of success to date they would be even less likely to find survivors of 1080 baiting.

Vine et al. (2009) noted the relative success of several detection systems at finding foxes at bait stations or lured sites. They reported that cameras found more foxes than people found scats at the stations. But of course this ignores or confounds the spatial scale of the search area and of the question of whether there is a fox in the area. A bait station may lure a fox, but the same fox is represented over the landscape by many scats. They also noted that spotlight counts detected foxes more often across the landscape than people detected scats at a bait station, but again the comparison is confounded by the different scales of the search.

5.3.1 Public reports of foxes

Since 2002, there have been 1949 reports of foxes made to the project hotline. These include reported sightings (generally around 60% of the total) and a variety of other types of reports on potential fox presence. These reports are ranked by an investigator as ‘excellent’ or ‘possible’ and a response is made depending on the quality of the report. In May 2009, 32 reports were received, of which only four were ranked as excellent.

These reports provide the majority (although least reliable) of the information on the presence of foxes. The problem with relying on this method is that the search area is biased towards areas frequented by people, the detection probability is unknown (what is the probability that a report will be filed given a fox is present?), and of course an unknown proportion of reports are false (e.g. the person mistook another animal for a fox). Trends in public reports might be expected to be related to actual fox densities, although again there are probably biases in reporting caused by social facilitation – publicised reports of foxes or publicity and action from the FEP lead to a cluster of further reports. For example, the trend in public reports (Table 2) shows no downward trend since 2006 as might be expected if reported sightings were an index of fox abundance and if the control was reducing the population.

Table 2 Number of sighting of foxes reported each month, 2006–2009 (data from DPIW 2009)

Year	Foxes reported per month
2006	21.8
2007	20.8
2008	24.5
2009	27.0

Key points on the response to fox reports:
It is unclear to us what response is triggered by each report of a fox. The options are to:

- **Further investigate the report by instigating a search for scats followed by control action (usually 1080 baiting) if a positive scat is found. Note, a positive scat might be claimed based only on the behaviour of the dogs, or it might require validation via the DNA tests carried out in the laboratory with the consequent lag in response, particularly if the scat was found by people rather than dogs.**
- **Proceed straight to a control response – presumably if the report is judged as 'excellent'.**

In any event the lags between report – validation – control actions – certifying success are a critical consideration in efficacy of the eradication under the reactive strategy and under the response to survivors in both strategies.

5.3.2 Detecting scats using dogs

The FEP has three Labrador dogs, each with a single handler, trained to find fox scats. Since 2008, detector dogs have provided the bulk of fox-positive scat records (20 out of 27 scats up to February 2009). Each dog team (dog + handler) searches a target area of 100 ha at least twice for a total of 40 minutes, and for target areas with lots of potential edges and other fox-preferred habitats they may search more. Each dog is expected to do between two and four target areas per day. Thus an effective working day for a dog team is between 2 and 3.5 hours depending on the task.

The detection probability of the dogs has been partially tested (D. Ramsey unpubl. data). The probability that a dog finds a scat when the scat is present at one search event depends very much on the time the dog spends searching (Fig. 4). In the trial conducted in Tasmania, the dogs would only search for about 30 minutes, perhaps because the temperatures were high at around 40°C. The dogs had similar detection abilities but these varied between sites from nearly 0.4 and the worst only about 0.1 when the search time was short (Fig. 4a). Ramsey has extrapolated these detection curves to match the time spent by human searches and predicts dogs would do much better if they searched longer without losing efficiency (Fig. 4b).

Scats appear to be uncommon as there are no obvious clusters (see Figs 7–9) and no individual fox has been identified more than once from DNA in scats, i.e. when a fox is clearly present in an area (e.g. a scat is found), why are many more scats not discovered in the vicinity? Foxes produce about 8–9 scats per day (Sadlier et al. 2004; Webbon et al. 2004) so we may speculate that the dearth of detected scats may be due to:

- A short field life for scats, meaning that few scats are present within a fox's home range. This is unknown for Tasmanian conditions, but fresh fox scats in Namadgi National Park (ACT) lasted for at least 30 days in spring, summer and winter (Banks 1997).
- Low probability of detection. If we extrapolate from the Ramsey trial, a dog searching a 100-ha area for 40 minutes has at best only about a 40% chance of finding a scat given a scat is present.
- A large area over which a fox ranges, combined with very low fox densities, leads to very low scat densities in the areas searched. Abundant food is available to foxes

in Tasmania, which suggests small home ranges would be the rule, but low densities might lead to large forays in search of mates.

- Some combination of the above.

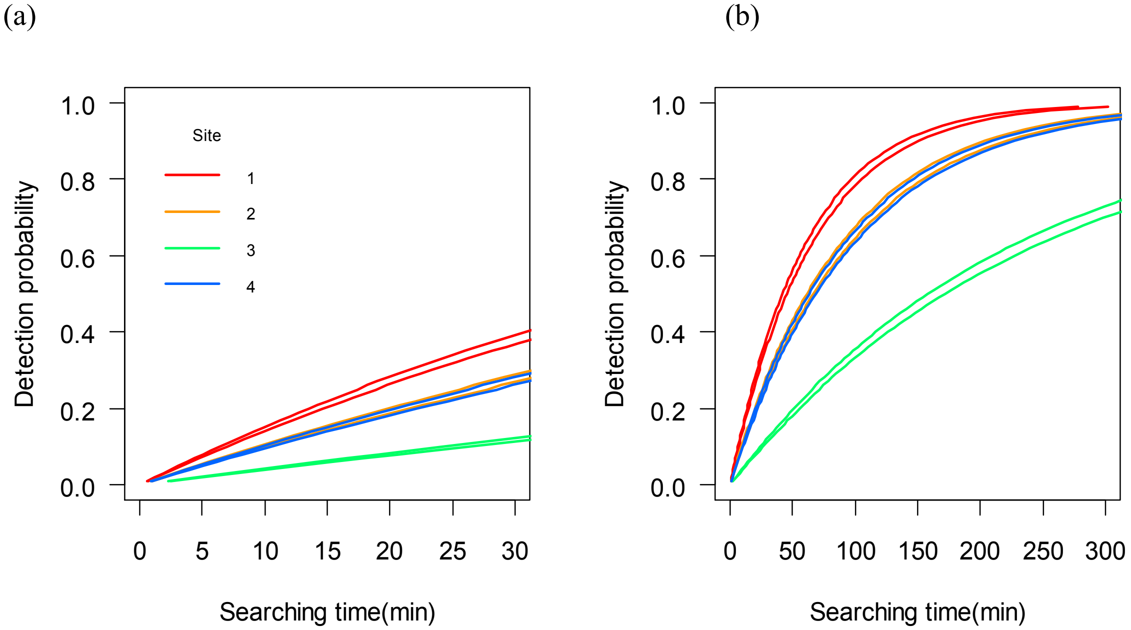


Fig. 4 (a) Probability that a dog (*n* = 2) would detect a fox scat at four study sites in Tasmania, (b) extrapolated to 300 minutes to compare with searches by people.

Key point on fox scats:
Scat detection is a critical tool in the FEP. It provides the only successful absolute method of validating the presence (or more properly the past presence of a fox) in an area. If the DNA is typed to an individual, scats may also provide added information on the efficacy of control. Thus, understanding the 'behaviour' of scats is a key information need to inform reaction time and to assess the efficacy of control.

We note the concern of the dog handlers about the risk to their dogs in areas recently baited with 1080. We expect post-control monitoring will be a key requirement in future strategies so this risk will have to be negated. We suggest that muzzling the dogs would overcome this risk without adversely affecting their detection abilities – as is the norm when Labradors and other breeds are used to detect rare flightless birds and predators such as stoats and cats in New Zealand (J. Cheyne, Department of Conservation, NZ, pers. comm.).

5.3.3 Detecting scats and sign, using people

Fox scats are also reported by members of the monitoring team, usually when investigating public reports of foxes, and during the scat survey (section 5.7).

The detection ability of people was tested in the same trial as that for dogs (D. Ramsey unpubl. data). In this case people could search for much longer than dogs (up to 300 minutes in this trial). The best team of people had a detection probability of about 0.6, twice that of the other three teams (Fig. 5).

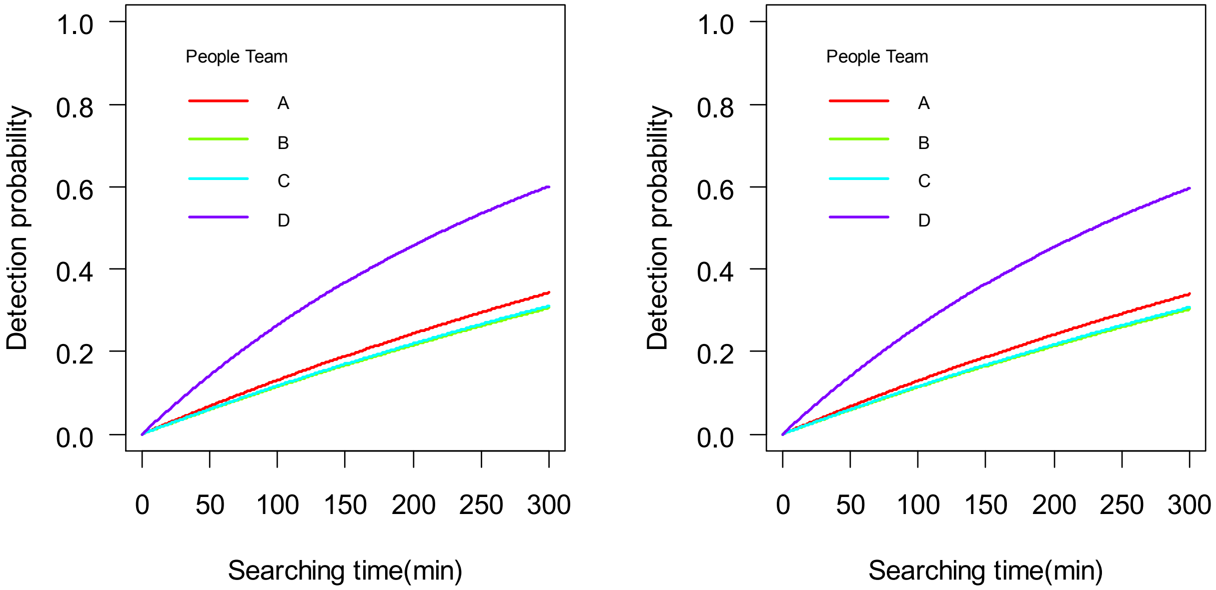


Fig. 5 Probability that a team of people (A – D) would detect a fox scat as their searching time increased at two study sites. Note the consistency between the sites.

If we account for search effort, dogs are clearly better than people at finding scats (Fig. 6).

The attempts by the field monitoring team to find foxes using sand pads, cameras, or spotlighting in their 'structured and repeatable' surveys have proved unsuccessful. A decision needs to be made whether to persist with these efforts or redirect the surveillance to scat surveys, particularly post-control.

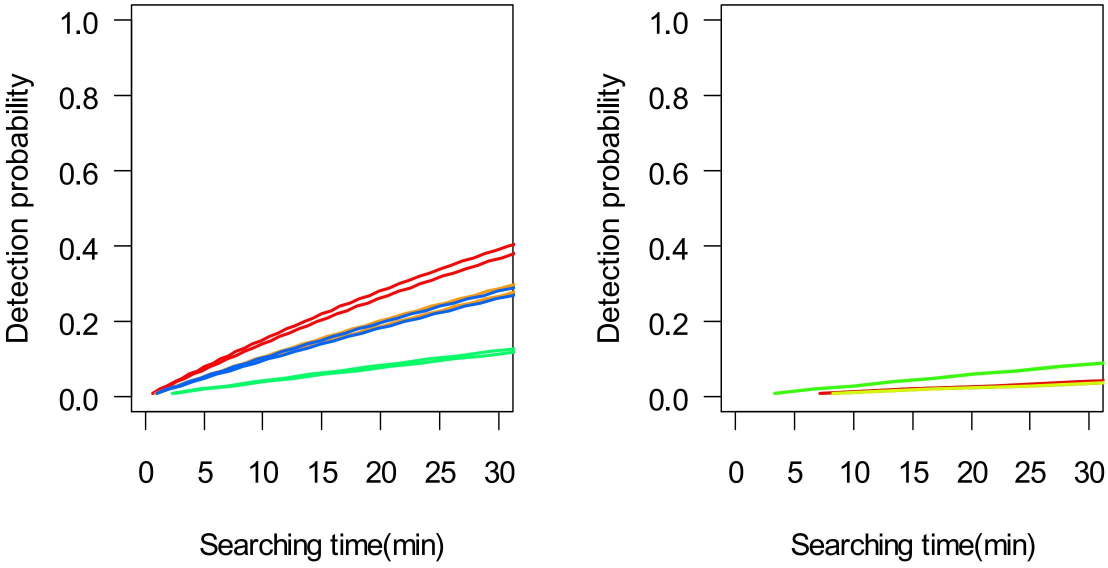

(a) (b)

Fig. 6 Comparison of detection ability of (a) dogs and (b) people for the same search effort.

5.3.4 Identifying individual foxes

It is now possible to use the DNA in scats to identify it as coming from a fox (Berry et al. 2007) and to identify individuals from at least some (about 22%) of the scats. By early April, eight scats had been of sufficient quality to allow the DNA to be identified at individual level. These were all different animals – five males, two females and one of unknown gender (O. Berry, unpubl. data). Seven of these animals were located along the northern coast from Devonport to Wynyard, conceivably indicating an established fox population.

Clearly the ability to identify and sex individual foxes is important if the same fox can be identified before and after control is attempted, and even more importantly if control methods that provide a corpse are used.

The quality of scats appears to be important in identifying individuals from their DNA, so again some understanding of scat field life may inform or improve this ability.

5.4 Fox control

5.4.1 1080 baiting

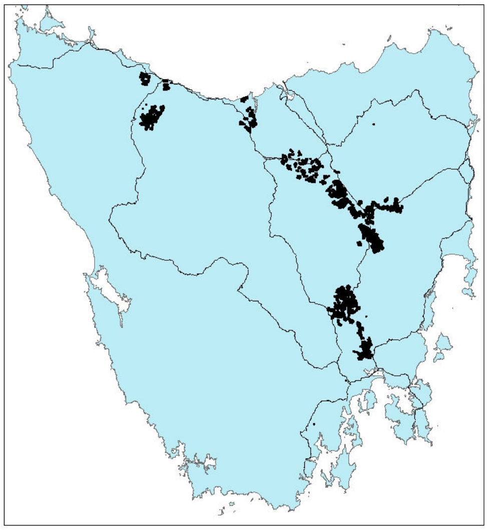
Trials on different bait types and presentation were conducted in the early 2000s (Mooney 2004). Dried kangaroo meat baits (40 g containing 3 mg of 1080) were used as the primary fox control tool largely because fewer were taken by non-target animals when presented as buried baits than other bait types and methods of presentation. However, problems with supply of these baits have meant Foxoff® baits (35 g containing 3 mg of 1080) are now the primary control tool for broadscale baiting. Small quantities of fresh liver baits are used for small-scale, targeted control. Baits are buried to a depth of c. 10 cm and placed about 200 m apart at sites that can be re-located (flagged and GPS located) as all baits not eaten are retrieved after 14 days as a precaution to limit non-target impacts.

Baiting began in July 2002/03 with the aim of baiting all areas three to four times within a year after foxes were reliably reported (i.e. the reactive strategy). Saunders et al. (2006) noted that this aim was not generally achieved although each target area was baited between one and six times between 2002 and 2005 (Fig. 7).

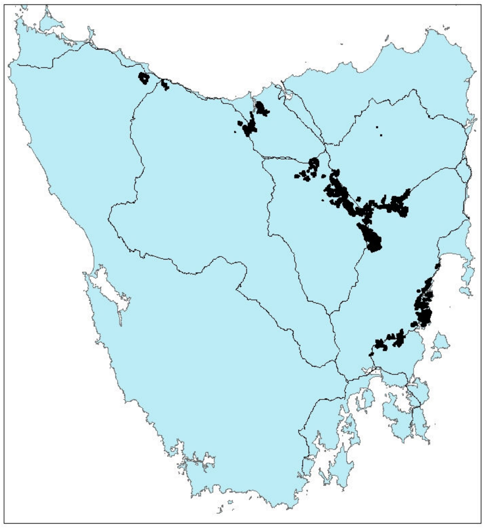
Since 2006/07, about 1.2 million hectares has been baited with nearly 78 000 baits (Table 3). Interestingly, there was a significant decline in the percentage of baits taken between the 2008 and 2009 years ($t = 2.16$, $P = 0.02$), although whether this is due to the change of bait material, or to a change in animal numbers taking the baits in different areas is not clear.

Table 3 Baits laid each year since 2007

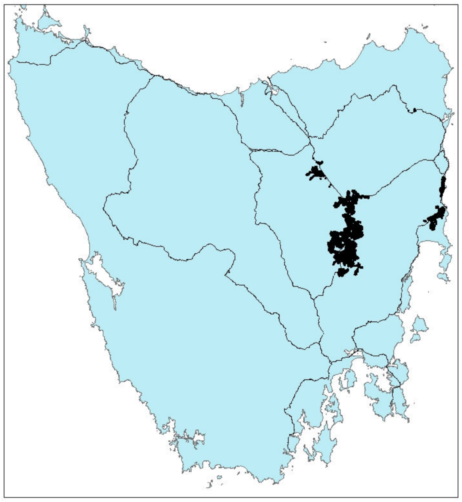
Year ending April	Baits laid	Mean % baits taken	Area baited (ha)
2007	10 953		118 676
2008	40 156	18.2 ± 7.3	448 110
2009	26 724	10.9 ± 2.4	616 973



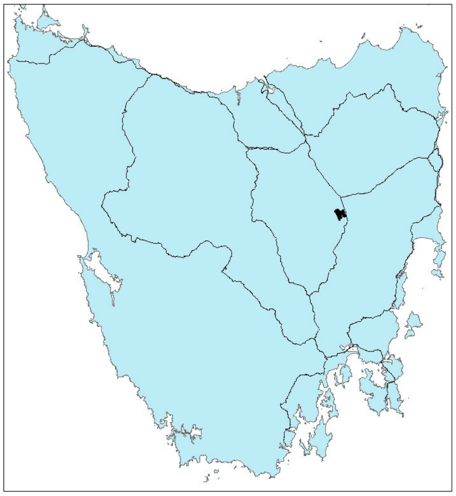
Baiting 2003



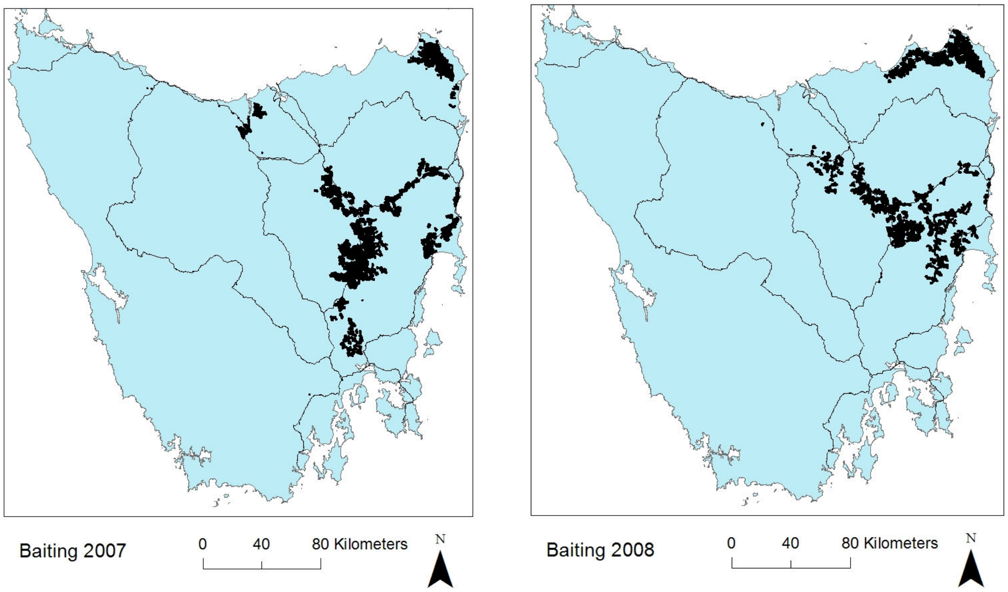
Baiting 2004



Baiting 2005

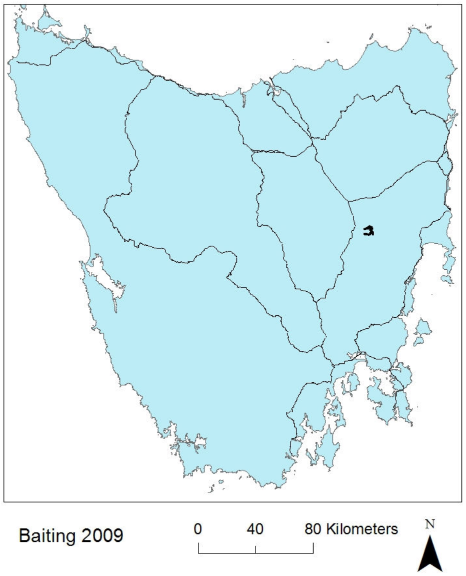


Baiting 2006



Baiting 2007

Baiting 2008



Baiting 2009

Fig. 7 Extent of annual 1080 baiting, 2003 to part of 2009.

Some foxes appear to survive all control using either buried or aerially sown 1080 baits at mainland sites. Saunders et al. (2006) list kills of between 50% and 97% (mean = 77%) for four operations using buried baits in New South Wales. So, a priori, we might expect a single fox in a baited area in Tasmania to have perhaps a 0.23 chance of surviving a single baiting event assuming such colonising foxes behave in the same way as foxes in established mainland populations. Put another way, if there were *n* foxes in the baited area there would be 0.77^n chances that all would be killed in a single baiting, i.e. 59% chance if only two foxes were present, but only 20% chance if there were say six foxes present. It is unclear whether a surviving fox would be at risk of a second baiting, or whether it would always survive baiting because of some behavioural trait. If survivors avoided baits by sheer chance (i.e. that individual was not averse to baits), then a second baiting would reduce its chance of survival to 5% and a third to 1%.

Saunders et al. (2006) showed that the number of foxes reported by the public from places within 5 km of a baited area declined over the period 2001–2005, and concluded that repeated baiting over a year should kill all resident foxes and most foxes that immigrate into the area during the baiting period – assuming all foxes eat baits.

The Tasmanian program now has new data that will allow more certain conclusions about the efficacy of baiting (and multiple baiting), namely, the location and date on which scats are found in relation to baiting events, and the ability to identify individual foxes from the DNA in the scats, will allow managers to judge whether foxes have survived 1080 baiting or are more likely to be immigrants into the baited area.

In Table 4, we categorise all fox scats found since March 2005 by their relation to past and subsequent baiting events.

Table 4 Baiting histories at sites where 41 fox scats have been found, as an indication of whether the foxes depositing the scats are potential survivors of the baiting, have been at risk from the baiting, or were never at risk at the site

Scat category	No. scats	Time between baiting and scat		Time between scat and next baiting	
		Range (days)	Mean (days)	Range (days)	Mean (days)
Scat found in area previously baited (since 2006), i.e. potential survivors of baiting	8	161–350	210 ± 52		
Scat found in area subsequently baited, i.e. potentially at risk (includes 7 of the above 8)	15			0–603	142 ± 94
Scat found in area never baited since 2006	25				

The sample sizes are obviously small but we have used the results to illustrate some key points that might be improved as more scats are located, or if, say, the best quality public reports are included in the analyses. Note: we have arbitrarily used a distance of 1000 m from the scat to the nearest bait as a cut-off for determining whether a fox was exposed to baiting or not. Clearly, this distance might be altered if information on fox movements was available.

First, 61% of scats found led to no control reaction (Fig. 8). Most are clustered in the north-west and presumably represent scats found in urban and peri-urban areas where 1080 baiting is not possible and where spotlight shooting and trapping have proved ineffective. The few in rural areas appear to represent scats found more than 1000 m from the nearest bait – and so we assume under our arbitrary rule that the fox was not atrisk. Note: the location south of Hobart represents two scats found in August 2009 well outside previous known range and for which a response had not occurred at the time of writing.

Second, the time between finding scats and the time of previous baiting (at least since 2006) (Fig. 9) averaged 210 days. Thus to assume these eight foxes were survivors of that baiting is risky – it is possible but not certain.

Third, the average time between the location of a scat and any subsequent baiting (the last column in Table 5) was 142 days (Fig. 10). This indicates that the reactive strategy is sluggish, and if one is sceptical about the above argument about survivors versus immigrants, one would be equally sceptical that this delay in reaction was targeting the fox that left the scat.

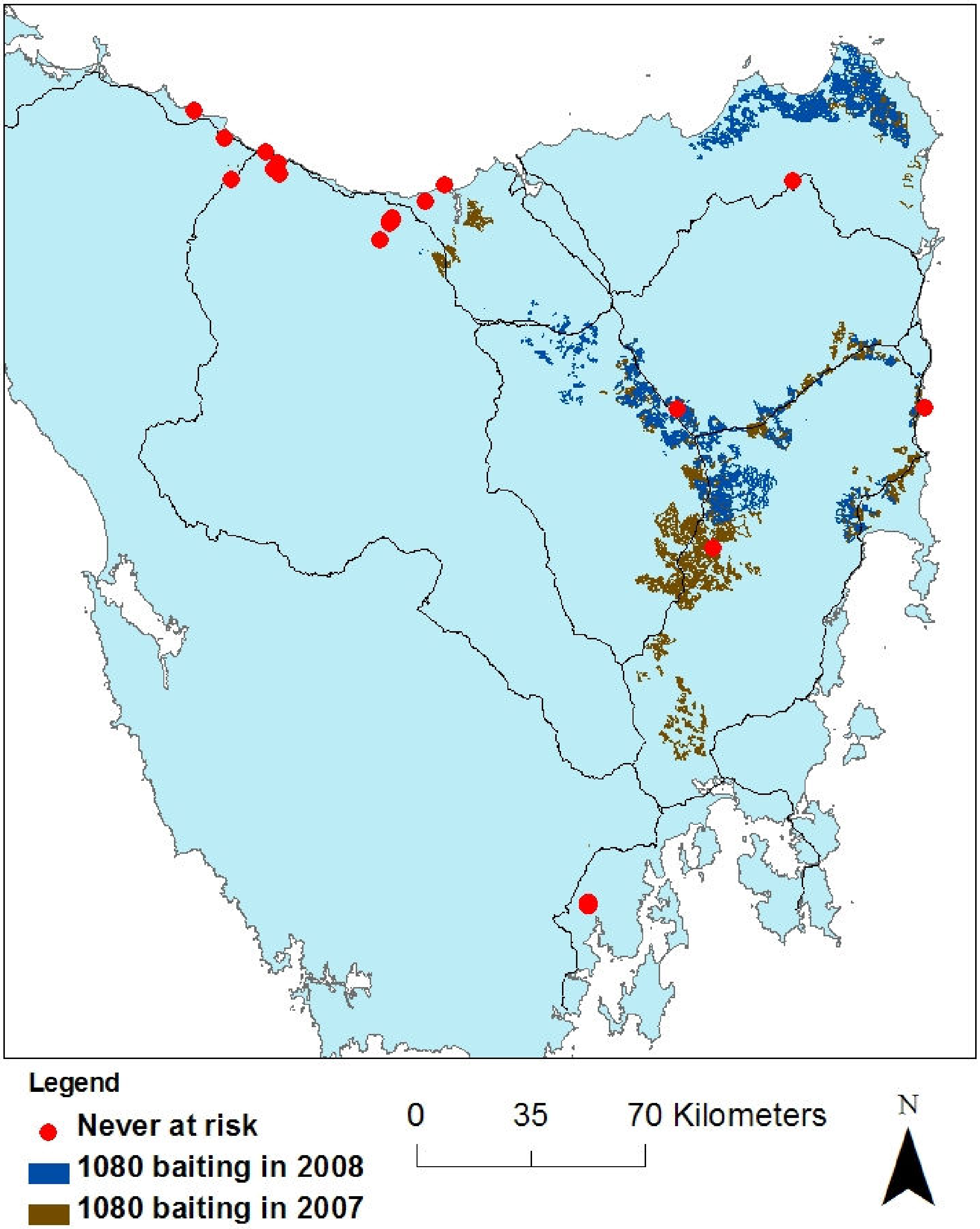


Fig. 8 Location of fox scats in areas never baited (since 2006) with 1080 baits before the scat was found.

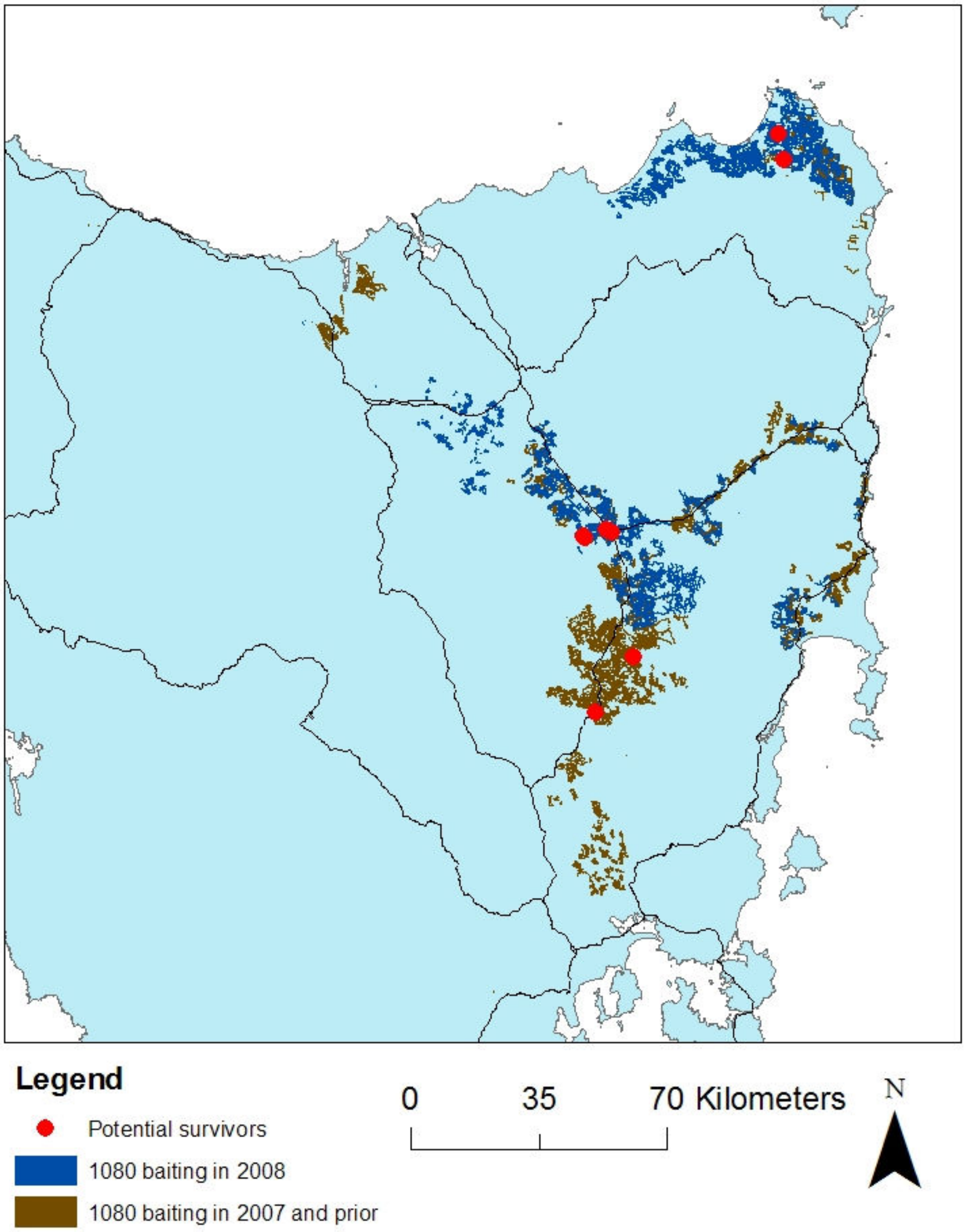


Fig. 9 Location of fox scats found after previous 1080 baiting, and thus potentially representing survivors.

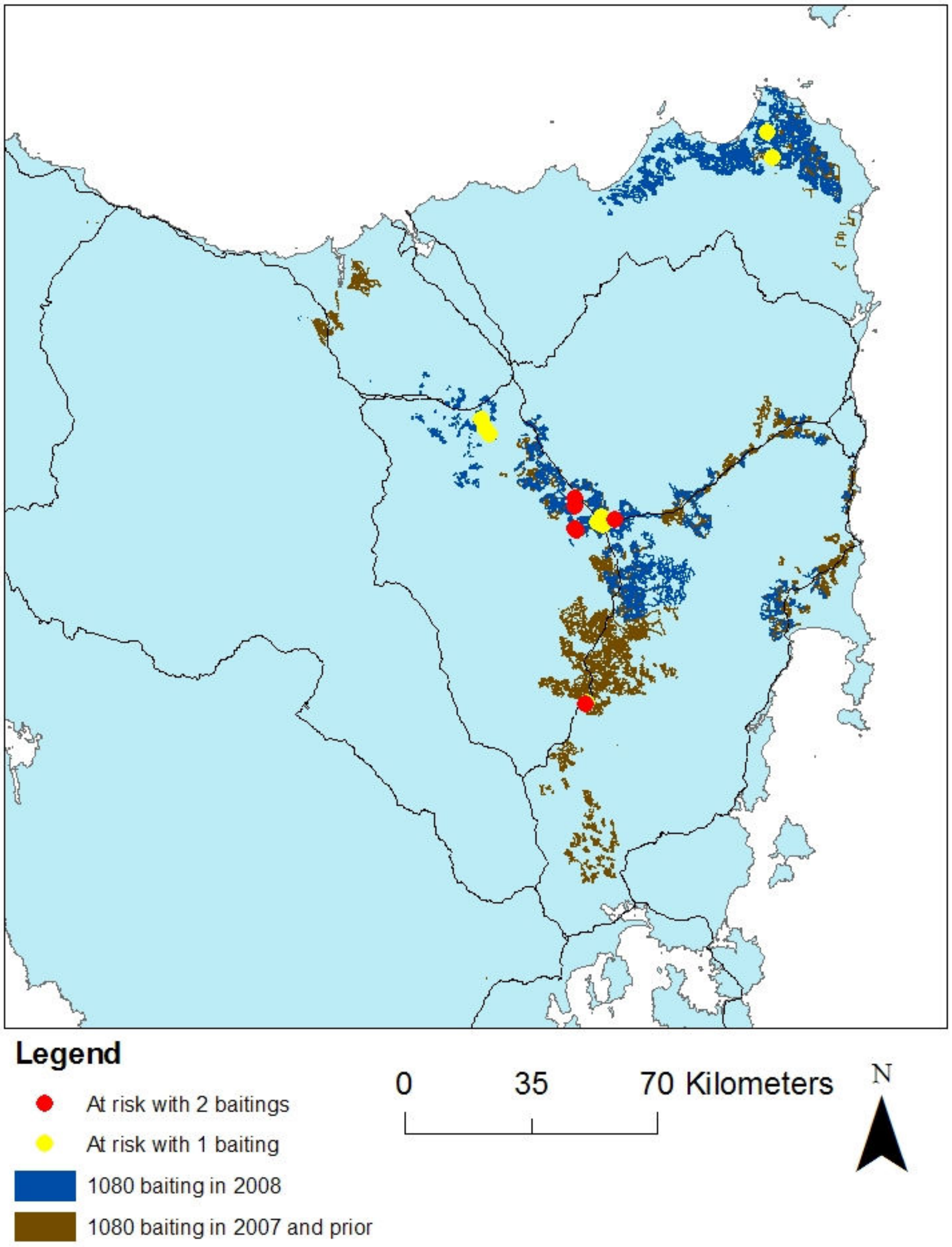


Fig. 10 Location of fox scats in areas subsequently baited, i.e. foxes potentially at risk.

5.4.2 Other control methods

There are of course many other ways of killing foxes (Saunders et al. 1995). Trapping and spotlight shooting have been tried in Tasmania without success – no foxes have been caught, detected or killed by these or any other method.

> **Key issue around other control methods:**
> **A very great risk in the program is the lack of knowledge about the efficacy of 1080 baiting, especially in low fox density–high natural food cases such as Tasmania. The current inability to guarantee survivors (if any) are killed by repeated 1080 baiting or by other methods if necessary is also a risk.**
>
> **We suspect the only method that might fulfil this need, and perhaps to deal with urban foxes, is via the use of trained dogs to locate surviving foxes (e.g. to their daytime locations or dens) that can then be killed by direct methods such as shooting. The use of baits with different toxins, such as PAPP, is under development.**

5.4.3 Measuring control efficacy

It is unclear how formal post-control monitoring is conducted. Given that 1080 baiting is unlikely to kill all foxes, it is critical for eradication that survivors are located and killed.

The ideal process after each 1080 baiting event under both the reactive or precautionary strategy would be to search for fox sign (presumably scats since they are the only method that works) or encourage public reporting (but noting this may increase false positives) as soon after the 1080 baits are removed as is practical. The timing, extent and intensity of this monitoring should to be informed by the suggested model (see section 7).

We note the need to understand scat field life to avoid confusing pre-1080 scats with those of survivors, and the need for better measures of detection probabilities of scats so that the absence of scats can be interpreted. We also note the concern of the dog handlers about the risks to their dogs when operating in areas where 1080 has been laid, but see section 5.3.2.

5.5 Community engagement

The community engagement team and communications strategy aim to ensure the Tasmanian public are ‘intolerant of foxes in Tasmania’ and will therefore support the program to eradicate them (DPIW 2007). This is not an easy task given foxes are not obvious to the community and have no obvious impacts at their current densities.

We suspect a fair part of the effort of the team has gone into the debate with sceptics who doubt the existence of foxes in Tasmania – now surely resolved by the ongoing DNA evidence for all but the most ardent conspiracy theorists. This effort is understandable but is a diversion from the main social issues that we suggest are now largely on how to gain peoples’ support to find and kill foxes in urban and peri-urban areas. Rational scepticism about whether foxes have been eradicated once scats are no longer found will be informed by the Probabilities suggested in the detection model.

5.6 Quarantine and border control

The department has prepared a risk analysis of potential pathways for new foxes to arrive in Tasmania (Phillips 2008). To date, the actions to manage foxes at the most likely source population (the Port of Melbourne) appear the most effective remedy. Given the infrequency of actual accidental incursions, surveillance and reaction at Tasmanian entry points is probably best done as part of general biosecurity procedures.

Deliberate introductions cannot be precluded, but hopefully the general fuss and expense of the current program, and its eventual success, will discourage those who may consider new liberations.

5.7 Scat survey

Foxes are rare in Tasmania, perhaps absent from large parts of the island, and the main initial evidence of their presence and location came from reported sightings from the public – as well as four carcasses of foxes (1 shot and 3 killed on roads) reported since 2001. These are of course biased against areas people do not frequent and suffer from an unknown but certain level of false reports. The program sought more objective ways to determine the distribution of foxes and since mid-2008 has been surveying the island for fox (and other predator) faecal scats (Fox Eradication Branch 2007). Some scats can be categorically identified as fox scats because they contain fox DNA (see 5.3.4).

The stated objective of this survey was to determine the distribution of foxes as a guide to control activities. A secondary objective was to survey the distribution of feral cats, wild dogs, Tasmanian devils, eastern quolls and spotted-tailed quolls to provide baseline data on these species; either to assess the consequences if fox eradication failed and foxes became widely established and abundant in Tasmania, or to assess any adverse effects of 1080 baiting – as it turns out apparently not a serious issue (see section 6.3.3).

5.7.1 Delimiting the distribution of foxes in Tasmania

The scat survey began in autumn 2008 and is intended to end in early 2011. It has been organised in three phases (Fig. 11) beginning in the north-east – which has been completed, then the central and southern part of the island, and ending in the north-west. The actual areas to be surveyed were selected on a rules-based system with only fox-preferred areas to be sampled (Fig. 11). Candidate cells (each 3 × 3 km) for survey had to have at least 6% 'open' habitat so that forested areas (and urban habitats) were excluded. Three hundred cells were selected systematically for each phase, and each cell searched by two or four people for 10 person-hours along GPSed routes focusing on likely fox habitats (edges, riparian areas). The survey has been assisted by volunteer labour. All scats found are being tested at the University of Canberra for the presence of fox DNA.

Of the 3000 predator scats found in Phase I of the survey in 2008, seven (found at four sites so possibly only representing four foxes) were positively identified as foxes because they contained fox DNA (Figs 8–10).

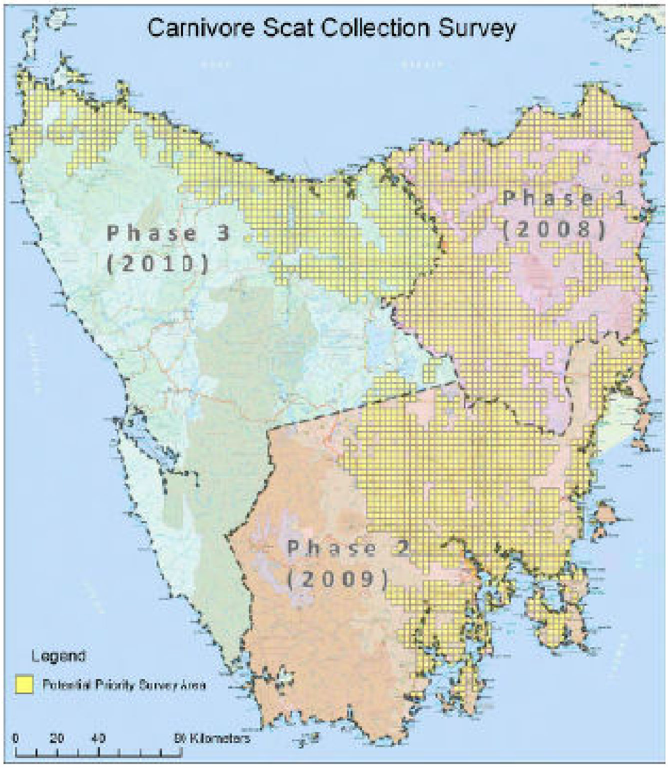


Fig. 11 Areas of Tasmania to be surveyed for fox scats in the three phases of the scat collection survey process. The cells are the predicted fox-preferred habitats and about 33% are to be surveyed.

We pose two questions:

- What is the risk that excluded habitats in fact harbour foxes? Clearly urban areas do have foxes judging by public sightings and validated fox scats found by the dog teams, and foxes do live in forested areas in mainland Australia.
- The survey has searched areas that would not have been searched under the operational monitoring process. However, if delimitation is the primary purpose of the survey, should more emphasis be placed on suspected distributional boundaries rather than core areas based on sighting evidence?

5.7.2 Providing physical evidence of foxes in Tasmania

The fox DNA in scats found in Tasmania is proof that foxes have been or are present in the State. We ignore the contrary view of the few people who believe it is all a conspiracy as no evidence, however forensically linked, will convince them.

5.7.3 Locating foxes for subsequent control

The scat survey has found 18% of all fox scats located. A total of 32 additional fox-DNA-positive scats have been recorded from other monitoring (incidental searches, dog searches, etc.) between May 1998 and February 2009 (Fearn 2009) (Figs 7–9).

5.8 Research

Current and proposed research to support the program has been catalogued in a draft research plan (Mooney et al. undated) which along with previous work covers much of the applied needs of the program (Table 5).

We consider the highest priority needs among the research proposed are to determine detection probabilities for fox scats under Tasmanian conditions and to measure scat field life. Scats appear the only reliable way of detecting foxes, so a decision has to be made whether to persist with research on cameras or the lured Judas fox idea (neither seem promising in our opinion but the latter will be discussed in a separate report on the potential uses of telemetered foxes).

Table 5 Previous, current and proposed FEP research projects to support fox eradication in Tasmania

Research need	Projects	Status	Our priority
Consequences of foxes/no foxes	Baseline monitoring of native species likely to decline if foxes establish or benefit if foxes are eradicated	Trial phase and plan in 2009 (Pauza 2009)	High but ongoing funding should be outside the fox program
Non-target risks of fox baiting	(a) From1080 in kangaroo baits	(a) Completed	(a) NA
	(b) From 1080 in Foxoff baits	(b) Proposed	(b) Medium given (a)
	(c) From PAPP		(c) Medium given (a)
Detecting foxes or sign	(a) Scat detection probabilities	(a) Trial completed (Ramsey unpubl. data). Repeat recommended	(a) Repeated trial very high
	(b) Scat field life	(b) Trial required	(b) Very high
	(c) DNA life in scats	(c) Trial proposed	(c) Very high
	(d) Camera detection probabilities	(d) Trial proposed	(d) Low given data to date (low p expected)
	(e) Judas and lured fox	(e) Review proposed	(d) Done in this report
Delimiting fox range in Tasmania	Part of purpose of the CRC scat survey	Ongoing, but partial	Depends on management paradigm. Low if precautionary approach taken
New control tools	(a) M44 bait devices	(a) Trials on mainland	(a) Low for use in urban or low density fox situations.
	(b) Review of bait types for standard use	(b) Proposed	(b) Medium unless mainland data suggest one will get 100% of foxes

We do not think development of the new control tools proposed (M44 and different baits or toxins) will solve the key constraint – the inability to kill 100% of foxes in the control area or to kill survivors with certainty – so rank these projects more lowly.

A new control tool suitable for both urban and mop-up control needs to be developed urgently. We think that dogs trained to find foxes (rather than scats) that can then be killed (e.g. shot) are likely to be the best tool. A decision to use this technique is required now given the lead time to obtain, train and deploy such dogs and the urgent need to deal with urban foxes and those that may survive baiting.

6. Assessing the Feasibility of Fox Eradication

Feasibility that a pest may be eradicated can be judged (a priori) in two ways, by looking at precedence and by analysis of the ability of managers to meet certain obligate conditions and overcome constraints for the case in point.

The chances of success for some types of eradications – e.g. eradication of rodents from islands using aerial baiting – rely on meticulous planning and precise delivery. This is because you only get one shot at it, a single control event, which succeeds or fails. However, eradications that rely on a complex process of detection, usually several control events informed by monitoring, that targets individual animals require more flexible planning to respond to the outcomes during the process, but also a mindset among the managers to be flexible and get each animal (Parkes 2006). The general rule for the latter type of eradication is to apply first the method that will kill most foxes but teach the survivors least about avoiding control.

6.1 Precedents for fox eradication

Foxes have been eradicated from about 50 islands worldwide, including seven small islands from Australia.

Both red foxes and Arctic foxes (*Alopex lagopus*) have been eradicated from eight large islands in the Aleutians, Alaska, with the largest being Attu at 93 000 ha (Ebbert 2000). One or other species have also been eradicated from a further 31 islands in the Aleutians (Ebbert & Byrd 2002). Trapping alone was successful on the largest islands while the use of trapping and toxic baiting was used on others. On one island (22 000-ha Seguam Island), the foxes were trapped and poisoned using cyanide in M44 ejectors. On 28 200-ha Kiska Island the arctic foxes were eradicated using a single aerial baiting using 1080 baits.

In Australia, foxes have been extirpated from four islands and some peninsulas – that is, all foxes have been removed, but, as the islands are usually connected to the mainland by causeways or at low tide, reinvasion is likely (Table 6).

However, no successful eradication has been at the scale of Tasmania, or even the part of Tasmania presumed to have foxes, so the issue of scale does preclude judging feasibility on the grounds of precedence alone.

Table 6 Australian islands from which foxes have been removed (extirpated or eradicated)

Island (State)	Area (ha)	Joined to mainland?	Method	Reference
Dolphin (WA)	3281	Almost	1080 in dried meat baits	Burbidge & Morris (2002)
Legendre (WA)	1286	No	1080 in dried meat baits	Burbidge & Morris (2002)
Angel (WA)	927	No	1080 in dried meat baits	Burbidge & Morris (2002)
Gidley (WA)	798	Almost	1080 in dried meat baits	Burbidge & Morris (2002)
Churchill (Vic)	57	Yes	?	Johnson (2008)
Benison (Vic)	8	Yes	?	Johnson (2008)
Muttonbird (NSW)	8	Yes	?	O'Neill (2006)

6.2 Analysis of the obligate rules for fox eradication in Tasmania

There are three obligate rules that must all be met before eradication is feasible (Parkes 1990). These are:

- All the target individuals must be placed at risk
- The animals must be killed at rates faster than they can replace their losses
- The risk of immigration must be zero or at least manageable.

6.2.1 Can all foxes in Tasmania be put at risk?

There are four issues in the current program that cause us to doubt that this rule can be met.

(a) It is currently assumed that foxes are not present in the suboptimal habitats that are neither surveyed nor poisoned (see section 7.4).
(b) It appears that access is restricted on some land within the presumed priority habitat areas for either survey or 1080 baiting.
(c) The apparent presence of foxes within urban and peri-urban habitats where the use of 1080 baiting is prohibited means other, as yet untested, control methods must be deployed.
(d) The possibility that a few foxes will survive at least a single 1080 baiting and perhaps multiple baitings, and the lack of any effective way to detect such survivors and kill them.

It is possible that Allee affects will make such isolated individuals irrelevant, but this assumption is risky.

6.2.2 Can the foxes be killed at rates faster than they can breed?

The annual intrinsic rate of increase of foxes is 0.84 (Pech et al. 1997). If we assume that each baiting kills 77% of the foxes present, then at the very low numbers likely to be present, one to three baitings should be sufficient to achieve functional extinction, assuming no immigration from outside the baited area.

6.2.3 Can new immigration be stopped or managed?

Immigration of foxes into Tasmania is always possible but the current crisis has led to attempts to limit the risk at the likely source, the Port of Melbourne (Phillips 2008). The risk of further illegal introductions is unknown but probably very low.

6.3 Analysis of constraints on fox eradication in Tasmania

Apart from the obligate rules there are many constraints that, unless managed, may at worst make eradication impossible or at best more costly than needed.

6.3.1 Legal constraints

There are several legal, regulatory or policy constraints on fox control in Tasmania. In brief these and the main consequences are:

- Landowners must be notified and agree to the use of 1080 baits on their land, and neighbours must be notified if any baits are to be laid within 500 m of their boundary. This adds to the delays in the desired rapid action following validated reports of fox presence, and at worst may exclude baiting from some areas.
- Baiting is prohibited in some areas, notably within 200 m of any house without the occupant's written permission or 500 m of certain defined recreational sites. This causes significant problems in urban and peri-urban areas where gaining approval from all occupants is unlikely.
- It is policy that all baits that remain uneaten must be recovered after 14 days. This nearly doubles the cost of baiting.

6.3.2 Social constraints

Controlling pests always has significant social consequences. For foxes in Tasmania these human constraints include scepticism that foxes exist at all in the state, objections to killing animals at all, objections to the use of 1080, and concerns about non-target impacts of the control.

The need to convince sceptics that foxes do exist in Tasmania has distorted the allocation of resources. We understand the political necessity for this but it has diverted energy and funds from higher-priority areas of the program. The DNA evidence is unequivocal so residual scepticism that foxes are currently present is not rational, although residual uncertainty about the presence or absence of foxes after control is rational.

Those who object to killing animals or to the use of 1080 must be reconciled to not having their way if the eradication is to proceed. Those who worry about non-target impacts of the baiting should be mollified by the data collected under the program (Mooney 2004), and by the potential costs of not eradicating foxes.

A symptom of social constraints is the refusal by a few landowners to allow access to their land. This may be a critical issue and at worst will require imposition by the State of its public good rights of access.

6.3.3 Non-target constraints

Many Tasmanians are concerned about the use of 1080, partly as a result of past use of the toxin to control overabundant native herbivores (Coleman et al. 2006). However, eradicating foxes was only a realistic goal if 1080 baiting was used. Therefore, the program has attempted to assess the risk to non-target animals and to mitigate these risks so far as possible.

A series of trials on bait uptake by foxes and non-target animals (Mooney 2004) and monitoring both baseline abundance of non-target species (Pauza 2009) and the fate of buried baits in the field (Mooney 2004), and the practice of burying and then recovering uneaten baits have been used to allay these fears. Put crudely, even if all the baits taken led to a non-target death, the annual 'kill' (1909 baits taken over 228 871 ha between December 2008 and April 2009 for example) would equate to about one non-target death per 120 ha.

While unfortunate, this mortality rate would not be significant for most of the at-risk species. Non-target native species observed to eat baits in the field are brushtail possums (*Trichosurus vulpecula*), eastern quoll (*Dasyurus viverrinus*), long-nosed potoroo (*Potorous tridactylus*), spotted-tailed quoll (*Dasyurus maculatus*), Tasmanian bettong (*Bettongia gaimardi*), and Tasmanian devil (*Sarcophilus harrisii*) (DPIW 2009).

6.3.4 Technical constraints

We identify two related technical constraints. First, 1080 baiting is the only control tool that is (presumably) effective against Tasmanian foxes. It does not provide direct evidence of success as foxes do not die where they eat baits and it is unlikely to kill 100% of the foxes exposed at a single baiting event.

Second, the rarity of foxes, especially after 1080 baiting, makes finding them difficult and so makes interpreting the lack of evidence as success very difficult. Detecting foxes before the control is imposed is hard enough, so assuming 1080 baiting kills 70–80% of them, detecting survivors will be even more difficult. Nevertheless, it is a desirable condition for efficient eradication (Bomford & O'Brien 1995) and ideally should be done before survivors can breed and replace the population's losses.

Killing these survivors and those foxes living in areas where 1080 baiting is not possible requires different methods. The failure to date of traditional methods, such as spotlight shooting or trapping, in Tasmania suggest novel methods may need to be developed and deployed as soon as possible.

6.3.5 Logistical constraints

The current budget may be sufficient over the next few years (see section 8.4) to remove all foxes from the primary habitat over about 50% of the state, but should foxes be found elsewhere, an increased budget would be required to remove them within the same time frame. Lengthening the program time frame increases the risk of failure due to either funder-fatigue or fox breeding ecology.

6.4 Is eradication intrinsically feasible?

Saunders et al. (2006) thought eradication was feasible given the resources were available. We think the resources have been adequate, but would add the caveat that eradication is unlikely unless the resources are reorganised and refocused. The decrease in budget does not fundamentally change this conclusion although clearly the attempt will take longer with added risk of failure from that delay.

The key questions are to know, with measured certainty, whether there are foxes left in an area after baiting, however that is deployed, and how to deal with any found. There are technical solutions to the first question and potentail control solutions to dealing with survivors and urban foxes. If these are resolved, we agree with Saunders et al's conclusion.

7. Development of a Model to Inform an Exit Strategy

Management decisions on where to search and when to stop searching should be based on quantitative and objective measures. We propose a conceptual and quantitative model that incorporates expert opinion and field data to inform high priority areas for surveillance, quantifying probability of local extirpation following control, and a broadscale probability of eradication for Tasmania (Fig. 12). It is conceptual because it identifies key relationships and uncertainties in the eradication program. It is quantitative because it decomposes the larger model into components that are linked probabilistically and informed by data. Consequently, it has the potential to provide objective guidance on where to prioritise search and control efforts, and to provide probabilities of control success.

7.1 Conceptual model of fox eradication (no equations)

The probability of finding confirmed evidence of foxes (usually scats containing fox DNA) will vary across the landscape, which will depend on a sequence of events (Fig. 11). First, a fox must be present, the fox must defecate, the scat must survive, we must find the scat, and obtain a positive result from a genetic laboratory test. All of these dependencies add uncertainty to our ability to confirm fox presence. While the focus of this model is on the detection of fox DNA in scats as this is the primary means of confirming fox presence, the model can be adapted to include multiple forms of hard evidence of fox presence.

The probability that a fox is present ($P(PRES_{fox})$) in a particular location can be informed by biological and human-related factors. Biological factors may include landscape structure (forest edges, agriculture, distance to purported introduction, proximity to other confirmed fox locations, and others). Human-related factors that inform $P(PRES_{fox})$ are, among others, public sightings, Fox Eradication Program (FEP) investigator rating, scat-tracking dogs sitting at a scat, and previous application of 1080. The probability of scat presence given a fox is present ($P(PRES_{scat} \mid PRES_{fox})$) is not certain and depends on movement and defecation rates of foxes. Despite the high reported rates of defecation (Webbon et al. 2004), it is conceivable that a fox could move through a particular area without leaving any scat.

The probability of scat survival given that fox and scat are present ($P(SURV_{scat} \mid PRES_{scat}, PRES_{fox})$) is included in the model because understanding the dynamics of scat survival will have a big impact on the timeliness of management decisions. While decomposition and scat predation rates have been reported to be slow on mainland Australia (Banks 1997), conditions may be very different in Tasmania. We must investigate the perplexing finding that fox scats are extremely rare on the landscape, even in areas where DNA-confirmed scats have been located. Indeed, only one scat has been found per individual fox that has been confirmed with DNA testing. This suggests that either the disappearance rate (mortality) of scats is very high due to decomposition and/or coprophagy, or the foxes are moving over large areas resulting in a very low scat density. If it turns out that foxes are moving more than expected from data reported from elsewhere, and are not exhibiting normal home-range behaviour, then it is clear that searching for scats is a waste of valuable resources and that nearly all efforts should go into a ‘rolling-front’ control approach (the precautionary approach). If scats are disappearing quickly due to decomposition and predation, then it is clear that the FEP must have a very quick reaction time when presented with evidence of fox presence. In this case, delayed reactions to field signs would be a clear waste of resources.

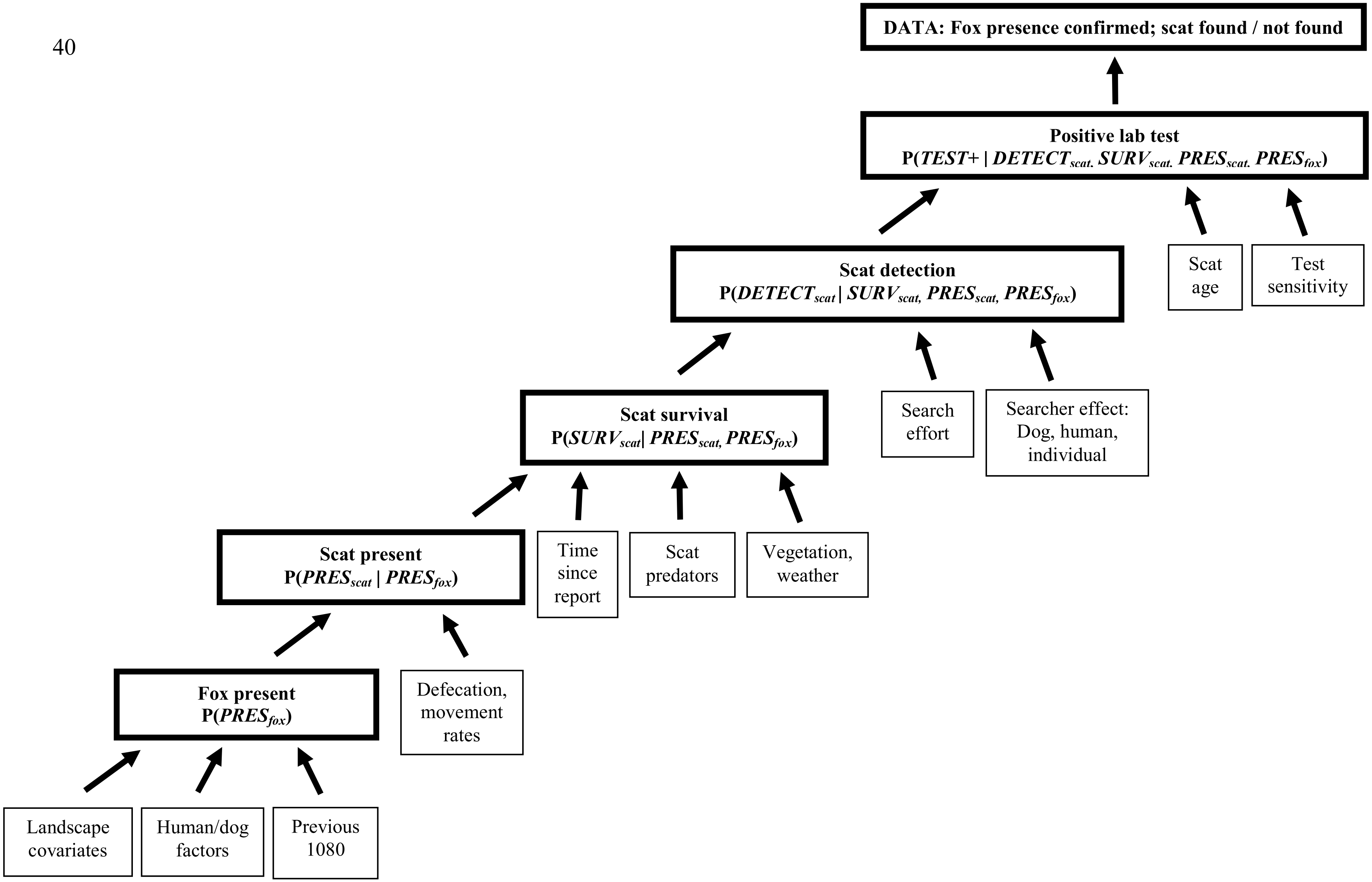


Fig. 12 Directed graph of events and probabilistic relationships. Light boxes are factors that influence the marginal probabilities of events (bold boxes).

A second critical application of understanding the dynamics of scat survival is in the post-1080-application surveillance for survivors. As mentioned previously, it is critical to know if the control method has killed all the animals in an area. Understanding the scat survival dynamics would inform the FEP on the time that must elapse for all scat to disappear, and consequently the minimum time between the application of 1080 and the beginning of the follow-up survey. If the survey is conducted too soon, scats from animals killed by 1080 might be found and assumed to be from survivors. This would result in a potentially unnecessary second control effort (using 1080 or another control tool). Quantifying the probability of scat survival will necessitate a controlled field experiment, which is discussed below (section 7.2.3).

The probability of finding a scat given a fox and scat are present and the scat has survived ($P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox})$) represents an important uncertainty in the FEP. Field trials demonstrate that the probability of finding a scat depends on the amount of search effort and searcher ability.

The last event is obtaining a positive laboratory test for fox DNA in scat (Fig. 12). The probability of obtaining a positive test given the necessary preceding events ($P(TEST+ \mid DETECT_{scat}, SURV_{scat}, PRES_{scat}, PRES_{fox})$) is strongly dependent on the test sensitivity, which is defined as the probability of obtaining a positive result given that fox DNA was present. Obtaining a positive test result should also be influenced by the age of the scat as DNA will degrade with time.

Quantifying the probabilistic relationships described in the conceptual model allows us to objectively prioritise management decisions and assess the probability of success of local extirpation and regional eradication. Knowing the $P(PRES_{fox})$ across the landscape at any given time based on biological and human-related factors will provide the means to objectively prioritise surveillance and/or control operations. Further, focusing search effort in high risk areas will improve our confidence that eradication has been successful once no fox evidence is found. This modelling will provide us with a quantified probability of fox persistence given that we are no longer finding fox evidence, which will give us the much desired basis for ‘stopping rules’. Once the local or region-wide probability of fox persistence goes below the management-defined level for success, operations can shift from control to monitoring and success can be ‘provisionally’ (risk will always remain) claimed (see section 7.3 for methods).

7.2 Probabilistic modelling (suggested model forms included)

Effective probabilistic modelling will depend on the explicit identification of the spatial scale used to link field surveillance and control to the probabilistic relationships. Spatial scale is composed of extent and grain. Extent refers to the total area over which the analysis is conducted, and the grain is the finest or smallest unit of area over which measurements are taken. Consequently, the model can be applied at a local extent or at a broad regional extent. For example, extent could be restricted to an area in which there had been a couple of potential fox sightings. This area would be defined by management to be a conservative estimate of the area (erring on the large size) in which a fox may be ranging (10 km^2 for example). Searching, control, and follow-up surveillance would all occur within this extent. The model would inform us on where to begin our search in this area, where to prioritise control application, and following post-control surveillance the model would give us an estimated probability of success given no further fox signs. We can also apply the probabilistic modelling to the extent of the entire island, or the 'reasonable risk' areas, which excludes the central tier and the western part of the island. Below (section 7.3) we discuss in more detail the implications for quantifying and declaring eradication success over varying extents, from local to broad-scale regional extents.

The logic behind explicitly identifying the grain size is that all of the appropriate probabilities ($DETECT_{scat}$, $SURV_{scat}$, $PRES_{scat}$, $PRES_{fox}$) need to be quantified within grid cells of this size. A grain size of 1 km^2 is presently used in the adaptive-search responses to DNA-positive scats and, in the absence of information on fox home range sizes in Tasmania, is an appropriate size for the modelling.

Before describing the details of quantifying the probabilistic relationships it should be noted that the proposed model represents a starting place for modelling to guide eradication efforts and to assess success. It will likely need modification as new ideas come to light or the feasibility of certain elements proves to be too low. As will be discussed below, certain data elements of the model are being collected as routine procedures of the FEP, while other areas of uncertainty (parameter estimates) will necessitate separate controlled experiments. The primary data that are available on the presence or absence of foxes across Tasmania are scats that have been confirmed to contain fox DNA (top model element in Fig. 12). Although hard evidence could also include a carcass or a highly probable visual sighting, the model is described in terms of fox-DNA detection because DNA-positive scat is the principal means of confirming fox presence. The model can be easily adjusted to include other forms of hard evidence. As more data are collected, model parameters can be updated and the predictive strength will be enhanced.

Confirming fox presence with DNA-positive scat is the result of a sequence of events: a fox moving through an area, defecating, the scat not disappearing, searchers finding the scat and obtaining a positive laboratory test. The probability of occurrence of all of these events is the following joint probability, which can be factored into marginal probabilities of the individual events:

$$\begin{aligned}
&\mathrm{P}(TEST+, DETECT_{scat}, SURV_{scat}, PRES_{scat}, PRES_{fox}) \quad = && (1)\\
&\mathrm{P}(TEST+ \mid DETECT_{scat}, SURV_{scat}, PRES_{scat}, PRES_{fox}) \quad \times\\
&\mathrm{P}(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox}) \quad \times\\
&\mathrm{P}(SURV_{scat} \mid PRES_{scat}, PRES_{fox}) \quad \times\\
&\mathrm{P}(PRES_{scat} \mid PRES_{fox}) \quad \times\\
&\mathrm{P}(PRES_{fox})
\end{aligned}$$

7.2.1 Probability of fox presence (P($PRES_{fox}$))

A fox presence sets off a series of events that lead to the confirmation of fox evidence. The probability that a fox is present in a particular location is at the base of the model (*PRESfox*; Fig. 11). As described above, the P($PRES_{fox}$) in a particular location can be informed by biological or human-related factors. P($PRES_{fox}$) could be modelled in the following way:

$$Logit(P(PRES_{fox})) = X\beta + \varepsilon \qquad (2)$$

$$\varepsilon \sim MVN(0,V) \qquad (3)$$

$$V = \sigma^2 e^{-\rho d} \qquad (4)$$

Where β represents the coefficients for the biological and human-related covariates (X). The model error (ε) incorporates spatial dependence and is distributed as a multivariate normal with mean zero and covariance V, which is determined by the variance (σ^2), a distance-correlation parameter (ρ), and distances among locations (d). The spatial covariance structure will quantify the residual error in P($PRES_{fox}$) not accounted for by the covariates and may be related to social aggregation of foxes. For example, the probability of finding foxes should be higher in close proximity to where other foxes have been confirmed than in areas far from previously located foxes. The added complexity of the spatial covariance structure may not be necessary, in which case the estimated errors (ε) can be assumed to be independently and identically distributed.

7.2.2 Probability of scat presence (P($PRES_{scat}$ | $PRES_{fox}$))

Once a fox has moved through an area, the probability that it will defecate will be a function of time in the area, movement speed and defecation rate.

7.2.3 Probability of scat survival (P($SURV_{scat}$ | $PRES_{scat}$, $PRES_{fox}$))

A critical influential factor in the probability of scat survival (P($SURV_{scat}$ | $PRES_{scat,}$ $PRES_{fox}$)) is time since deposition, and under most circumstances it will be impossible for FEP staff to put a reasonable estimate on the time/date of deposition in a particular area. The one exception would be following a public sighting. In this case, the date of deposition could be assumed to be the date of observation and a specific model could be generated to prioritise where to focus search efforts or 1080 applications. In all other cases, it will be difficult to estimate a date of deposition and use P($SURV_{scat}$ | $PRES_{scat,}$ $PRES_{fox}$) in the calculation of the full joint probability.

We propose that an experiment be conducted by the FEP to assess scat survivorship under a variety of conditions. Fresh fox scats should be obtained from the mainland and placed in carefully selected locations in Tasmania. Factors to consider are vegetation cover, vertebrate predator density (perhaps peri-urban area vs rural area), weather and season. Scat survival should subsequently be monitored at regular intervals. The P($SURV_{scat}$ | $PRES_{scat,}$ $PRES_{fox}$) should be modelled using a continuous parametric survivorship analysis with an exponential or Weibull survivorship function (McCallum 2000; Crawley 2002):

Exponential: $P(SURV_{scat} \mid PRES_{scat,} PRES_{fox}) = e^{-\rho t}$ (5)

Weibull: $P(SURV_{scat} \mid PRES_{scat,} PRES_{fox}) = \exp(-(\rho t)^{k})$ (6)

where ρ is a rate parameter and κ is a dimensionless parameter that determines whether survival rate varies with time. The effect of the explanatory variables (vegetation, season, weather, etc.) on ρ can be explored by the following linear equation:

$$Ln(\rho) = X\beta + e \qquad (7)$$

7.2.4 Probability of scat detection P($DETECT_{scat}$ | $SURV_{scat}$, $PRES_{scat}$, $PRES_{fox}$)

Incorporating the uncertainty involved with the probability of scat detection (P($DETECT_{scat}$ | $SURV_{scat,}$ $PRES_{scat,}$ $PRES_{fox}$)) is critical for obtaining accurate parameters for the overall model, including those influencing P($PRES_{fox}$). Given that fox scats persist in a particular search area, our ability to detect a scat will be influenced by search effort and searcher effectiveness. Detection probability will increase with increasing search effort. Dogs are more effective than people, and some individuals and teams will be better at detecting scats than others.

An experimental study to quantify the probability of scat detection given scat survival was conducted by the FEP, data were subsequently analysed by Dave Ramsey, and some preliminary results are presented in this report (sections 5.3.2 and 5.3.3). While these results are very informative and can contribute to the modelling effort, we suggest additional scat-detection experiments be conducted using the same general approach. Due to excessive high temperatures during the trials, detection probabilities by dogs as a function of effort were not adequately quantified. Given the high importance of scat-tracking dogs in the success of the FEP, it is essential that accurate detection probabilities are estimated for dogs and individual teams.

Additional scat-detection experiments should be conducted where the probability of scat detection within a 1-km^2 grid cell is quantified as a function of search effort and searcher effect. Again, note the use of the grain size here as we will eventually want to assign probabilities of scat detection ($P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox})$) within this spatial unit, which will lead to stopping rules. We propose the general approach previously conducted in which people place a known number of scats within a 1-km^2 grid cell. Searchers, having no knowledge of the location of the scats then seek the scats beginning at random locations. The time to locate each scat in a given trial will be treated as the failure time (death) in a survival analysis. Distance travelled by search team could also be used as a measure of effort. The $P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox})$ should be modelled using a continuous parametric survivorship analysis with an exponential or Weibull survivorship function (McCallum 2000; Crawley 2002) where scats not found are right-censored with time equal to the maximum search time in that trial:

Exponential: $P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox}) = 1 - e^{-\rho t}$ (8)

Weibull: $P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox}) = 1 - \exp(-(\rho t)^{k})$ (9)

where ρ is a rate parameter and κ is a dimensionless parameter that determines whether the scat detection rate (death rate) increases, stays the same or decreases with time. The analyses by Dave Ramsey show that detection rates do not vary with time, therefore, the exponential model is likely to be the most appropriate. The effect of the team or searcher on ρ can be explored by the following linear equation:

$$Ln(\rho) = X\beta + e. \tag{10}$$

While it is unclear how the distribution and abundance of scats in this experiment compare with environments with real foxes, we feel that with all constraints considered, this is the best approach to quantifying $P(DETECT_{scat} \mid SURV_{scat}, PRES_{scat}, PRES_{fox})$. The logical alternative to this approach would be to collar a live fox on Tasmania with GPS technology and conduct the experiment in the fox's home range. While the placement of scats would be realistic, we would never know the density of scats in the experimental grid cells, and this would create enormous uncertainty in our estimates of detection probabilities. To obtain reasonable estimates of detection probabilities we would have to have many replicates, which is certainly not feasible in Tasmania or on the mainland. In the experiment where people place scats in the environment, density is controlled because we are modelling the detection of every scat. The downside is that we are assuming that the placement of scats is realistic, and that the movement of people and scats during the placement doesn't influence the tracking of dogs and people.

7.2.5 Probability of obtaining a DNA-positive test (P($TEST+ \mid DETECT_{scat}, SURV_{scat}, PRES_{scat}, PRES_{fox}$))

The last marginal probability to quantify is the probability of obtaining a DNA-positive test given that a fox was present and defecated, the scat persisted and we found it (P($TEST+ \mid DETECT_{scat}, SURV_{scat}, PRES_{scat}, PRES_{fox}$)). The laboratory test sensitivity will decrease with increasing age of scat. The parameters associated with test sensitivity and scat condition will have to be developed in collaboration with the scientists conducting the genetic analyses.

7.3 Probability of eradication success

Assessing eradication success can be assessed using the proposed modelling framework in three different scenarios: (1) in localised areas with or without confirmed signs of foxes; (2) in localised areas previously controlled with 1080; and (3) across the at-risk portion of Tasmania. For convenience, we use the probability of fox persistence (π) in reference to extirpation/eradication success, which is really the probability of eradication failure (i.e. if the probability of fox persistence is high then we have failed).

It is imperative to set a threshold probability of persistence to determine stopping rules, and this threshold must be agreed to in advance by those taking the risk (managers, politicians and scientists). A threshold of 0.05 was used as a benchmark for eradication of pigs from Santa Cruz Island, California (Ramsey et al. 2009), and there the risk of falsely declaring success was a combination of financial (the costs to redeploy the contractor) and political (the eradication was socially contentious and legally contended through the US courts). In the case of foxes in Tasmania both these factors might be included, as well as the biodiversity and economic costs of foxes – the point being that the acceptable risk is not simply the market cost of being wrong but has to include political and social judgements.

We use the model and parameters to calculate a posterior probability of persistence given no detection of foxes ($\pi|D^-$), where D^- is 'no detection'. When this posterior drops below the defined goal threshold, eradication success can be claimed. To calculate the posterior, we need the estimates for all of the marginal probabilities for each grid cell i within the defined extent. We recognise that the risk of fox presence varies among cells and we account for this in our surveillance and in our calculations (Martin 2008). To do this we first calculate the relative risk for each cell (RR_i), which is specified relative to the lowest risk cell within the extent:

$$RR_i = \frac{P(PRES_{fox,i})}{\min(P(PRES_{fox}))}. \tag{11}$$

The RR_i are then modified to create an 'adjusted relative risk' ($ARISK_{fox,i}$) of fox presence in cell i:

$$ARISK_{fox,i} = \frac{RR_i}{\sum RR_i \cdot PROP_i} \tag{12}$$

where $PROP_i$ is the proportion of area of the extent that is covered by cell i (1/n), and the weighted average risk across cells is 1.

The marginal probabilities (abbreviated in equation below) are used to calculate the sensitivity for the extent, or the probability of confirming fox presence given a fox is present within the extent (*SeE*; equation 13).

$$SeE = 1 - \prod_{i=1}^{n} (1 - ARISK_{fox,i} \cdot P^* \cdot P(PRES_{scat,i}) \cdot P(SURV_{scat,i}) \cdot P(DETECT_{scat,i}) \cdot P(TEST +_i))$$

The calculation of the *SeE* is based on the assumption that foxes are present within the extent. The probability of detecting a fox in this area depends on a minimum expected prevalence, or 'design prevalence' (P*; Martin 2008). Because the unit for quantifying the marginal probabilities described above is the 1-km^2 grid cell, the P* must be stated in terms of proportion of cells in the extent that have a fox. The value of the P^* should be set by a committee of managers and scientists. For example, if we were looking for a single fox in a 400-km^2 area (400 cells) we might expect to find evidence in four of those cells, given a home-range size of 4 km^2. A reasonable starting value for P^* would therefore be 0.01. The P* is not related to actual prevalence as it becomes relevant only when no foxes are being detected. In practical terms, the level of P* determines the amount of surveillance necessary to achieve the eradication goal. As the level of P* decreases, the amount of surveillance must increase.

Recognising that that 1 − *SeE* is the probability of not detecting a fox given fox presence (D^- $|\pi$), we can use Bayes' theorem to estimate the posterior distribution of $\pi|D^-$ within the extent of interest:

$$\pi \mid D^- = \frac{(1 - SeE) * \pi}{(1 - SeE) * \pi + (1 - \pi)} \tag{14}$$

Equation 14 gives the posterior probability of fox presence in the extent. Alternatively, one could consider the complement, the probability of eradication (at the design prevalence):

$$\pi^- \mid D^- = 1 - \frac{(1 - SeE) * \pi}{(1 - SeE) * \pi + (1 - \pi)} = \frac{1 - \pi}{1 - SeE * \pi} \tag{15}$$

Of course these calculations are relevant only following a search of the area of interest with no scats or foxes detected. The prior probability of fox persistence (π) can be obtained by querying managers and scientists in a manner outlined by Ramsey et al. (2009). One can see from this series of equations that as surveillance effort increases, the *SeE* increases and the posterior $\pi|D^-$ will decrease. However, as the extent of search and analysis increases, it will become increasingly difficult to search a high proportion of the cells and obtain a favourable posterior $\pi|D^-$ (i.e. high confidence of eradication success). This problem may be attenuated to some degree by focusing search efforts in high-risk cells. Recall that the modelling approach gives disproportionate weighting to high-risk areas in the calculation of the *SeE* if these areas are searched more than low-risk areas (Martin 2008).

We conducted a quick sensitivity analysis to demonstrate how the posterior $\pi|D^-$ responds to: (1) varying proportion of extent searched; and (2) varying the search effort within a cell in response to relative risk of fox presence. To do this we randomly allocated each cell a fox-risk level between 0.05 and 1. To mimic a 'focused' search effort, the probability of detecting a fox (within-cell search effort) was the fox-risk level squared. To mimic a 'fixed' search effort the probability of detection was set at the mean fox-risk level. The prior (π) was fixed at 0.15 and we calculated the posterior $\pi|D^-$ with a design prevalence (P^*) of 0.01 when 50, 25, 20, and 5% of cells were searched. Results demonstrate the importance of searching a high proportion of cells, and focusing effort in high-risk cells (Table 7). If we arbitrarily decide that we would be satisfied with a probability of fox persistence ≤ 0.05 (equivalent to the value set for pigs on Santa Cruz Island; Ramsey et al. 2009), then we would have to search 20% of the extent with a focused search or up to 50% of the extent with fixed search effort in searched cells.

Table 7 Results of a sensitivity analysis of the posterior $\pi|D^-$ in response to varying the proportion of extent searched and focused search effort within cells according to fox-risk level

Proportion of area searched	$\pi|D^-$ focussed effort	$\pi|D^-$ fixed effort
0.50	0.01	0.03
0.25	0.04	0.07
0.20	0.05	0.08
0.05	0.12	0.13

The results of this analysis represent 'relative' posterior $\pi|D^-$ to illustrate the effect of varying search strategies. They are not real values as we do not yet know the marginal probabilities necessary for making accurate predictions. The quantification of the relative risks of fox presence depends on parameter estimates, and this illustrates the immediate need for model development, efficient data management, and rigorous data collection on detection probabilities and field surveys.

7.4 Decision rules for deploying precautionary 1080 baiting

In this section we raise the issues that might be used to determine where to deploy initial 1080 baiting under a more precautionary strategy. We avoid the term 'roll-out' to describe this as a sensible deployment may move out from several centres determined by pragmatic assessments of risk. Note: Saunders et al. (2006) developed some arguments, with bold extrapolations from limited mainland data on fox dispersal, for determining the trade-offs between the scale of baiting with the frequency of baiting required to place all foxes (residents and immigrants) at risk. Here we concentrate on the scale and location of baiting rather than its frequency – the latter is probably best determined by the results of post-control monitoring.

First we note the factors that might influence where to bait for foxes, and consider the relative importance of each so that they might be applied in order to reach a decision that maximises the ability to put all foxes at risk but minimises the costs of applying control at places where, in retrospect, it was not needed.

(a) Suitable fox habitat
Saunders et al. (2006) mapped six vegetation types across Tasmania and judged their

suitability as fox habitat. Agricultural land with fragmented forest was rated as ‘very high’, dry eucalpt forest as ‘high’, wet eucalypt as ‘low’ and the other three (high altitude areas, sedgelands and rainforest all as ‘very low’ (Fig. 13). These vegetation types were also the basis for allocating effort in the scat survey (see section 5.7 and Fig. 11). In the absence of any data on fox distribution the whole island would have to be baited to be 100% sure that all potential foxes were at risk. At 600 000 ha baited per year this would take 10 years and would require aerial baiting in inaccessible areas.

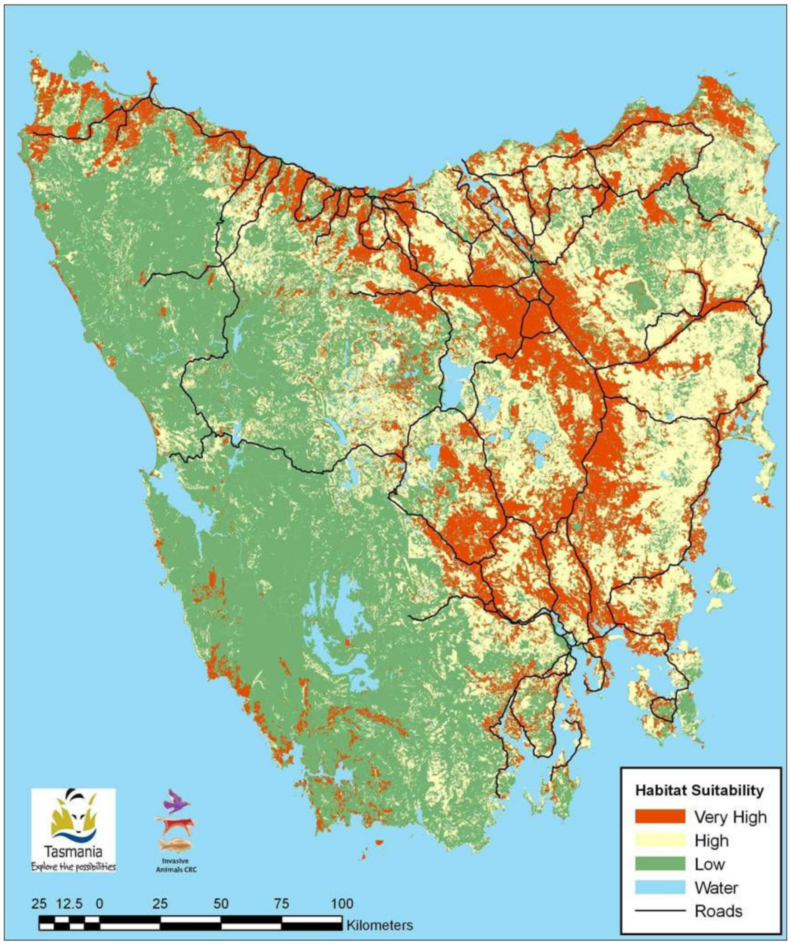


Fig. 13 Habitat suitability of different broad vegetation and land-use types in Tasmania.

(b) Past baiting

Figure 14 shows where all previous baiting has been caried out in Tasmania since 2002/03. Clearly, the baiting has covered much (but not all) of the highly suitable fox habitat in agricultural landscapes, but little of habitats ranked as high sutability and none in the least suitable habitats. We suspect that some ‘highly suitable’ habitat might be difficult to bait using the buried bait method. Some focussed scat surveys in such areas would inform the FEP of the risk of excluding these areas from baiting.

Given the evidence that some foxes either survive baiting or immigrate back into baited areas (e.g. as suggested by Fig. 9), it would be best to consider only recent baiting (perhaps since 2008) and plan future deployment around that.

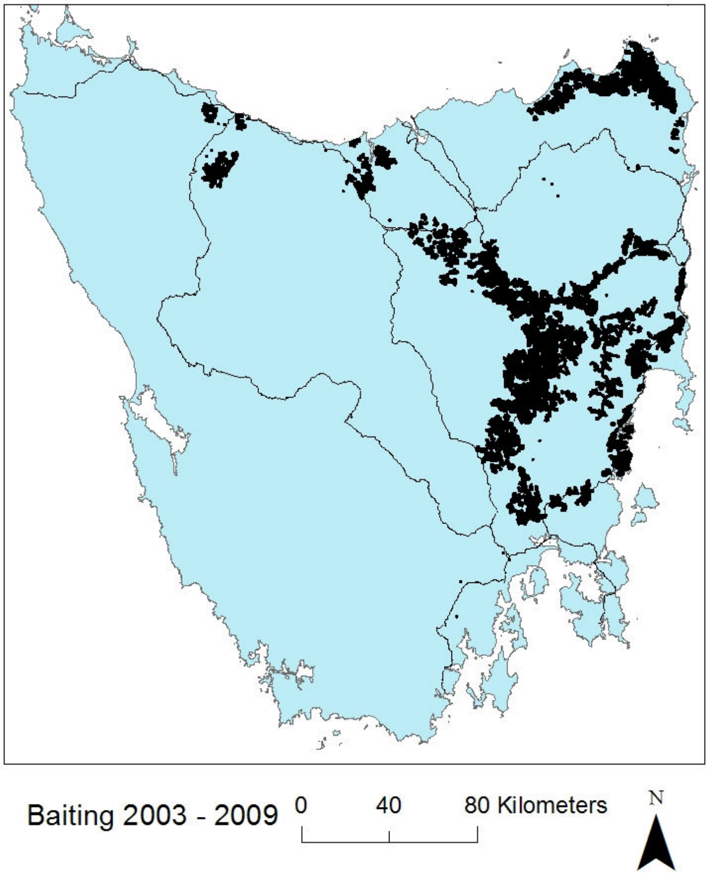


Fig. 14 All areas baited since 2002/03

(c) Information on fox locations

Of course even under a completely precautionary strategy there will still be information from public reports or the final phases of the scat survey that indicate the presence of a fox. Managers might consider some pragmatic rules to decide how to react to such quality information. For example, if the fox was adjacent to a previously baited area, the next baiting might cover that location rather than another adjacent block. However, what to do if the fox is off the planned deployment?

In the past the FEP has used small scale, ‘hot-spot’ baiting to react to such events, and we suggest this might continue. The proviso being that the baiting is applied promptly after the fox or scat is reported so that there is a good chance the fox is still present and at risk.

(d) Areas searched without foxes being detected

Whether areas (either post-initial control or as new areas) that have been searched for scats but none found should be re-baited or baited should depend on the probability that this ‘none found’ equals ‘none there’. This can be assessed from the model.

8. Conclusions

8.1 Program strategy

There are two bioeconomic options that might be employed to underpin the attempted eradication of foxes in Tasmania. (1) A precautionary approach, where initial control is deployed across all areas predicted/likely to have foxes (about 50% of Tasmania). Monitoring under this approach would be largely restricted to measurement of control efficacy to direct management of survivors. (2) A reactive approach where initial control is targeted to sites where foxes are reported or located by proactive monitoring, and again with post-control monitoring to detect and focus control to deal with any survivors. The current management is a suboptimal mix of the two strategies.

If the program continues with the reactive planning option it will need to explicitly link the actions to locate foxes or their sign to the subsequent deployment of 1080 baiting. This has implications for how the project team should be structured and managed – largely the surveillance work to direct control should be managed as an integrated part of the control response so that detection or suspicion of a fox presence should lead to prompt deployment of 1080 baiting.

If the program changes entirely to the precautionary planning option, a larger change in program structure will be required. Much of the current surveillance and monitoring becomes redundant and the resources should be redirected to 1080 baiting to be deployed across all risk areas. This may be funded within current budgets by reallocating some of the monitoring budgets (most of the ‘scat survey’ budget and most of the ‘investigation’ budget) and perhaps some of the research budget to the operational baiting budget. We note that at current baiting rates of about 600 000 ha per year all of Tasmania could be covered in 10 years, or the current ‘risk’ areas in 5 years or about 3 or 4 years if resources are reallocated. We note that one advantage of the precautionary strategy (if applied as a rolling front of baiting) over reaction to foxes (applied as hot-spot baiting) is that the risk of post-control immigration from unbaited areas should be lowered.

Both strategies require additional effort to detect and kill survivors in areas already baited. The remaining research budget should focus on developing secondary control methods other than baiting to deal with survivors that avoid 1080 baits, and to developing the system to interpret searches that find no scats. The scat dog team needs to be integrated with this ‘mop-up’ control, and perhaps increased if the workload demands more effort. We suggest a new dog team be developed to locate surviving foxes (not scats) as a secondary control tool.

A risk in the reactive strategy (both in the initial deployment of control and in response to detection of survivors of baiting) comes from the lag between reporting a fox, validation of its presence, reaction with control, and monitoring to assess the efficacy of this control. This risk is also present in the precautionary strategy if there are delays between the deployment of primary control and assessment of its efficacy. There are management issues with respect to the risk to dogs when they are used after 1080 baiting. We think these risks can be mitigated by muzzling the dogs.

8.2 Unresolved problems

We identify four main constraints that increase the risk of failure:

- The assumption that foxes only occur in the habitats they are likely to prefer (about half of the island) is untested.
- Access to land of all tenures, particularly to deploy 1080 baits under both management strategies, is not guaranteed.
- The problem of detecting and killing any foxes that survive 1080 baiting requires both redirection and focus of the monitoring effort and possibly new ways to kill such survivors if they will not take 1080 baits.
- Locating and killing foxes in urban and peri-urban areas also requires redirection of the community liaison effort and development of new ways to kill such foxes.

8.3 Information needs

Scat detection

The ability to reliably detect foxes or their sign with known levels of certainty is a key need under both management paradigms. It is required both prior to control to direct that control and after the control to locate survivors and focus the ‘mop-up’ control under the reactive paradigm. It is required only after control under the precautionary paradigm again to locate survivors and focus ‘mop-up’ control. Scats can now be identified, in many cases, as belonging to an individual fox so enabling more detailed interpretation of post-control foxes as survivors or immigrants.

Scat-detection characteristics of dogs and people were measured in an earlier trial. However, the trial needs to be repeated under Tasmanian conditions to improve the estimates of detection probabilities for individual dogs and individual searcher effects.

Knowledge on scat detection probabilities also enables managers to interpret ‘zeros’. If one looks and finds no scats, what is the chance that no foxes are present (see section 7)?

The field life of scats is unknown but the information is required to plan and interpret the post-control detection and search results, and to inform secondary control needs.

Databases

The program has good databases on potential and known fox locations, increasing data on individual fox locations, and good databases on 1080 control. These data need to be analysed and integrated at an operational level to drive key management decisions particularly on where and when to apply control, where and when to look for surviving foxes, and where and when to try to locate and kill these foxes.

8.4 Cost minimisation, risks, time frames and exit rules

The terms of reference asked us to assess whether a cost–benefit analysis would help to improve the program. A formal cost–benefit analysis is impossible since the benefits are largely non-market values (biodiversity) that cannot be accrued in the same currency as the program operational costs. The appropriate economic analyses in these cases are either a benefit-maximisation approach to identify the control strategy that gives the best result for a fixed budget, or a cost-minimisation approach to identify the cheapest way to achieve a set goal (Parkes et al. 2006). Clearly, for eradication the cost-minimisation approach is best given the goal (no foxes) is set. The only other variable of interest is time – how quickly can this be achieved?

Here we step into risk analysis. The longer eradication takes, the higher the risk of failure because of funder-fatigue or because the foxes simply outpace the control effort. However, the shorter the time frame, the higher the annual costs are to be effective.

This leads us to our options to organise the project – the consequences of either the reactionary or precautionary approaches.

If 600 000 ha of rural habitat is baited each year, the entire 'risk' area of about three million hectares could be baited once over 5 years. However, we guess that over one million hectares has been baited within the last few years, so a time frame to bait all 'risk' areas once is 3.3 years. We can reduce this time frame further by reallocating resources under the precautionary approach, or double it if the whole of Tasmania proves to have foxes.

The large uncertainties, for which we lack information to resolve, include the costs and time to deal with survivors of this primary control and the costs and time frame to deal with urban foxes.

The positive exit strategy is to set a level of confidence that the eventual absence of definite fox sign means foxes have been eradicated from all or the high-risk half of Tasmania, and utilise the model suggested in this review (section 7) to determine whether the monitoring (with no evidence of foxes) achieves this level, or whether more monitoring (with no evidence of foxes) is required to achieve the set level. This approach is simplest under the precautionary strategy as a time frame to deploy the primary control can be set (we suggest less than 5 years). Dealing with any survivors of this primary control remains an area of uncertainty without more data on their detection probabilities, and possibly on the availability of different control techniques.

On the negative side, the program should be terminated if access to high-risk areas is not enforceable, or if the tools to kill foxes that survive 1080 baiting or live in urban areas cannot be deployed.

The program would need to be reassessed if reliable evidence of foxes is found outside the current habitat-based risk areas.

9. Main Recommendations

- The key need is to be able to interpret the result ‘no fox scats found’ in places where a search has occurred, and to assess the risk that no foxes are present in places where no one has looked.
- We recommend changing to the precautionary strategy with consequent reallocation of resources within the program. This is largely because there are such large uncertainties, irresolvable in the urgent time frame required to achieve success, in managers’ abilities to delimit fox range in Tasmania, and to locate individual foxes within that range.
- Refocusing efforts away from pre-control monitoring towards control and post-control monitoring allows time frames to be set for the main initial control actions, although the uncertainties around locating and dealing with survivors remain.
- We recommend that the efforts of the monitoring team and the dog team be focused on this post-control work to detect survivors. We are not convinced that the monitoring team or the dogs are being utilised optimally under the current strategy.
- Dealing with any survivors is not simple and we are not confident that merely repeating 1080 baiting will kill these animals. We recommend investing research funding (initially) and then operational funding to develop dog teams that can find foxes in their daytime locations or dens so that immediate follow-up lethal action can be taken.
- Dealing with urban foxes is a critical weakness in the current program. We recommend that finding control tools that will work in urban and peri-urban areas is urgent, and that most of the community engagement budget be allocated to supporting this issue.

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