What is required to eradicate red foxes (*Vulpes vulpes*) from Tasmania?

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Abstract The red fox is a major threat to middle-sized native vertebrates in Australia, many of which still thrive on the island state of Tasmania. Increasing evidence of the arrival of foxes in Tasmania since 1998 led the government to begin a campaign to intercept the invasion. An eradication programme began in earnest in 2002 but has not yet achieved its goal. The work of the Fox Eradication Program (FEP), as it was designated in 2006, was reviewed in 2009 and we summarise the main achievements and problems identified in that review. The feasibility of eradication was always uncertain because the island is large (6.3 million ha), foxes are cryptic and at very low densities, finding them is difficult, control methods are few (1080 poison baiting), and the methods do not provide direct evidence of success with a dead fox in hand.. Planning and practice had to be adaptive as the techniques for monitoring and control developed. The FEP has developed detection methods with estimated detection probabilities and now needs to integrate these systems with the deployment of the control to put all foxes at risk. Killing foxes that may survive baiting, and those potentially living in urban areas (where poisoning is difficult) or remote forest (which is assumed not to harbour foxes) remain as issues to be resolved.

Keywords: Detection, search, surveillance, validating eradication

INTRODUCTION

The red fox (*Vulpes vulpes*) was introduced into Australia in the 1860s and has spread over the mainland apart from the tropical north (Saunders *et al.* 1995). Foxes have caused extinctions of native animals between 35 g and 5500 g, and are the primary agent of decline for at least 77 vertebrate species listed as threatened on the mainland (DEWHA 2008). Neither dingoes (*Canis familiaris*) nor foxes reached the island state of Tasmania (Fig. 1), where there are still surviving suites of native species lost from the mainland. However, in 1998 several people saw a fox leaving a container ship at Birnie in the northwest of Tasmania, and in 1999 there were reports that foxes had been deliberately released in Tasmania (Saunders *et al.* 2006). These reports were followed by public sightings of foxes, which raised the possibility of their detrimental effects on 78 species of native Tasmanian vertebrates, including 12 already listed as threatened. In response, the Tasmanian Government formed a task force to attempt to eradicate the foxes. Their work began in 2002, was reviewed in 2003 (Kinnear 2003), in 2006 (Saunders *et al.* 2006), and again in 2009 (Parkes and Anderson 2009). This eradication is not a simple task. Despite a significant allocation of resources from State and Federal governments, evidence of foxes in Tasmania was continuing to appear in late 2009. In this paper we review why the task is difficult, and analyse with the advantage of hindsight what needs to be done to either improve the chances of successful eradication or, should that the task not be feasible, to set some change or stop rules.

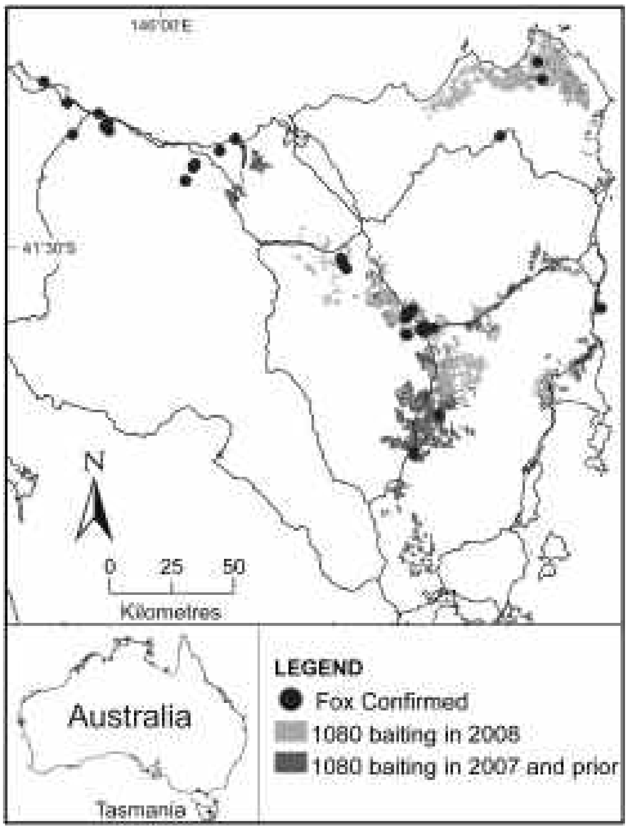

Fig. 1 Location map of Tasmania and location of fox scats in areas never baited with 1080 baits and therefore potentially never at risk as of late 2009. We assume a scat more than 1 km from a baited site meant that fox was not at risk, but without information on fox home range sizes in Tasmania this may be a pessimistic assumption.

RESULTS

The general problem

The Fox Eradication Program (FEP) faces daunting problems that means early assessments of the feasibility of eradication inevitably left large unresolved residual uncertainties and risks of failure:

Tasmania is large at 6.3 million ha. Half of the island is rugged, forested and remote, and the other half is rural and urban with a human population of 0.5 million.

Foxes are rare, cryptic, and hard to find. Some reports of foxes are unreliable (the public can mistake other animals for a fox, especially when glimpsed at night). Other detection methods are not instantaneous with lags between the certain presence of a fox and instigation of control at that site.

The behaviour and ecology of foxes in such colonising populations are unknown. Home range, dispersal, rates of increase, and potential Allee effects (the fragility of very low density populations due to chance events) that might lead to extinction of the population are all unknown and mostly unknowable for foxes in Tasmania.

Some Tasmanians doubted that foxes were present, despite the evidence from three foxes killed on the road and a fourth one that was shot. It was not until the development of faecal DNA tests in 2003 (Berry *et al.* 2007) that any rational doubt was allayed. Nevertheless, the dilemma of 'absence of proof versus proof of absence' argument

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remains a valid problem for the need to delimit the range of foxes and to validate the efficacy of any control. This issue typifies the end of all eradication operations (Ramsey *et al.* 2009, 2011).

Tasmanian managers of the FEP have relied largely on expertise and tactics available from mainland Australian states, where circumstances are quite different. On the mainland there are many foxes and fewer native prey, which makes extrapolation to a situation with few foxes and abundant prey a risky one. Although foxes are widely controlled in mainland Australia, the mind-set and practices of managers attempting sustained control may not always be appropriate for eradication. For example, the target for sustained control is to reduce the impact of the pest to some tolerable level, whereas the target for the eradication is to get the last one. In addition, there are few relevant precedents of fox eradication that could guide the Tasmanians. While Parkes and Anderson (2009) list 50 successful attempts, most do not resemble the Tasmanian problem.

At present, Tasmanian managers have only one effective control tool: baiting with compound 1080 (sodium monofluoroacetate). Elsewhere, trapping was also effective for the eradication of red and Arctic foxes (*Alopex lagopus*) in the Aleutians (Ebbert and Byrd 2002). Poisoning is not socially popular in Tasmania (Coleman *et al.* 2006), partly because it is perceived to place native non-target animals at risk. At a practical level, poisoning does not provide direct evidence of success if animals do not die on the spot. Baiting cannot usually be used immediately after a fox is reported because landowners have to be notified through a formal process and agree to allow the application of baits. In addition, 1080 baiting cannot be applied in urban or peri-urban areas.

All these uncertainties require managers to adapt their plans as they go along, which is not always simple when priorities change quickly but management structures are more difficult to modify in response. Uncertainty also creates unease among those funding the programme especially if success is not quickly achieved.

Locating foxes and delimiting their range

There have been more than 2000 public reports of foxes in Tasmania since 2002 (Fearn 2009, unpubl. FEP report; Parkes and Anderson 2009). An unknown proportion of these are in error as the public also reports seeing extinct thylacines (*Thylacinus cynocephalus*) and many reports of foxes (such as carcasses on roads) turned out to be other species when checked. The FEP grades the credibility of reports and checks those that are most credible or are from places of interest. For example, of the 32 public reports received in May 2009, only four were ranked as "excellent" by the FEP investigators.

In 2008, the FEP also deployed three dogs trained to find fox faecal scats, and tested the ability of these dogs and of people alone at finding scats (Parkes and Anderson 2009; D. Ramsey, unpubl. data). The dogs had between 10 – 40% chance of finding a fox scat known by the experimenter to be present somewhere in the 100-ha search areas and within a 30 minute search time. Teams of people searching for 300 minutes found a scat between 30 – 60% of the time. For a comparative search effort of 30 minutes, people found a scat less than 10% of the time. Operationally, such searches are made in response to a reliable public report, or as more planned surveys of areas of interest ('hot spots'). Faecal scats also give false positives as the scats of other predators such as cats (*Felis catus*), dogs, and Tasmanian devils (*Sarcophilus harrisii*) can be visually mistaken for those of foxes. The dogs' reactions do give some indication of reliability, but all scats are also tested for the presence of fox DNA. This test can identify individual foxes if the scat is fresh enough (Berry *et al*. 2007).

A stratified survey for fox scats began in 2008 to cover the half of Tasmania thought to provide the most suitable habitat for foxes during their establishment and colonisation. In all, 900 cells each 3 × 3 km were to be searched by people (without dogs) over three years (FEP, unpubl. data). In 2007/08, of more than 3000 scats found, seven (at four sites) contained fox DNA (Parkes and Anderson 2009).

As of January 2010, of 45 scats confirmed to contain fox DNA only 15 have been attributed to individual foxes (FEP, unpubl. data). No fox has been detected more than once from its scat. Assuming no error in the DNA testing, this finding creates some major uncertainties in the control campaign. First, the detection abilities of the dogs and people may be much lower than revealed in the trials. Second, the half-life of scats in the environment may be very short in Tasmania. Some scats may have been eaten by Tasmanian devils or buried by ants or dung beetles. Third, colonising foxes may be nomadic or have unusually large home ranges resulting in very low scat densities. If so, present searches are conducted at the wrong scale. All these issues are testable and the answers would inform managers on the optimal scales of both monitoring and control.

The current detection system has developed from mixed motives: to delimit the range of foxes or to locate individuals in order to deploy control and to prove foxes are present in the State to counter sceptics. The FEP's efforts have sometimes been diverted away from the biologically essential delimitation and reactive control motives towards the politically necessary 'proof of presence' questions.

Deploying control

Foxes in Australia are usually controlled with dried meat or manufactured meat-based baits containing 1080. In Western Australia, these are aerially-sown because native animals in this State are not susceptible to 1080 (Twigg and King 1991). In the rest of Australia native animals are susceptible to 1080 so baits are buried to limit non-target risks (Saunders *et al.* 1996). In Tasmania, two main types of bait have been used: dried kangaroo meat baits and Foxoff baits. Both are buried to a depth of C. 10 cm and laid C. 200 m apart. Baits are flagged, logged by GPS and uneaten baits removed after 14 days to limit any risks to native animals and domestic dogs. Trials to estimate non-target risks showed this method to be acceptable because even if all baits eaten were taken by non-target native species and these animals died, the annual kill of about one death per 120 ha would not have any population effect.

In July 2002, a reactive strategy was implemented, which involved baiting all areas three or four times within a year after foxes were reliably reported. It is unknown how effective single or multiple applications of toxic baits are against foxes in Tasmania. However, on the mainland, about 10 days pre-feeding with non-toxic baits followed by toxic buried baits for about the same time can kill between 70% and 97% of foxes (Saunders and McLeod 2007). We assumed that the efficacy of the baiting on Tasmania would be less than on the mainland, given the abundance of natural food and the lack of pre-feeding with non-toxic baits.

Since 2006/07, about 1.2 million hectares have been baited with nearly 78,000 baits (Table 1). The decline in

Table 1 Baiting with buried 1080 baits for foxes in Tasmania since 2007.

Year ending April	No. baits buried	Mean % baits taken	Area baited (ha)
2007	10,953	NA	118,676
2008	40,156	18.2 ± 7.3	448,110
2009	26,724	10.9 ± 2.4	616,973

bait-take was significant but interpretation as evidence of fewer foxes (or fewer non-target animals) is confounded by changes in bait type.

The original reactive baiting strategy was only partially followed as areas were baited between once and seven times over several years. The reactive strategy as originally conceived had some problems. First, there were lags of up to 603 days between the reliable report of a fox or a scat and the application of bait (Table 2). This lag was caused by the time required to obtain landowner compliance and access to the area, and (for the scats) time required in the laboratory to validate the presence of fox DNA. Such lags were sufficient for foxes to move far away from the targeted baiting area. Second, there was a planning disconnection between the monitoring and control parts of the FEP. This may explain part of the above lag, but there were also 25 of positive locations of a fox where there was no reaction with control (Table 2).

The data also show that 61% of scats that were found lacked any control response (Fig. 1), partly because many of the scats were in the urban and peri-urban areas in the northwest of the island where baiting was not possible. It also revealed a planning issue to be resolved. If the FEP is to follow a reactive strategy, they need to react in space (bait where foxes are located) and in time to increase the chance that the fox is still present. An alternative approach to the reactive strategy and its attendant lags is to deploy baits under a precautionary strategy. The current baiting regime can cover up to 10% of the island in a year (Table 1) so it would be possible to deploy baits on rolling front(s) in some rational way (based on prior data on the presence of foxes or habitat risk analysis) across the island. However, this still leaves the problem of how to detect and deal with potential survivors of the initial baiting – and that is where a detection and reaction model can assist in planning a response and in setting success and stop rules.

Detection model for fox eradication

Like many eradication programmes, the FEP is data-rich but analysis-poor. The review proposed that the FEP use the data to inform management decisions on where to search for foxes (usually scats) and when to stop and declare success at a regional or island scale. These surveillance and stop rules can be done by quantifying the probabilities of a sequence of events that must occur to confirm the presence of a fox. First, a fox must in fact be present, it must defecate in the search area, the scat must survive, the scat must then be found, and its identity as a fox scat must be confirmed ideally via the presence of DNA. Bayesian analyses can be used to quantify these probabilities and used to inform the search efforts to achieve desired levels of certainty that no foxes found equals eradication and thus stopping rules for managers and funders.

The success of eradication can then be assessed in a small grid, at local scales, in areas where 1080 has been deployed, or over the whole island to give a probability that at least one fox persists given none are detected. Of course, to be 100% sure that no foxes are present one would have to look everywhere in Tasmania with a perfect detection system. However, as with all eradications, this is not possible. So managers have to set a probability at which they are comfortable – and that requires some analysis of the costs (in money, political embarrassment, damage to biodiversity) of falsely declaring success and stopping the programme too early. However, an additional advantage is that it does allow for risk analysis leading to some rational end point of the programme, which is something funders like; they rightly get nervous about open-ended campaigns that purport to be eradication.

Using existing estimates of scat-detection probabilities we can make some preliminary (and probably optimistic) predictions on the search effort necessary to achieve an acceptably low probability of fox persistence (i.e. successful eradication) if no fox scats are detected. For example, FEP managers could have a probability-of-persistence goal of ≤ 0.05, as was set in the Santa Cruz pig eradication (Ramsey *et al.* 2009), set some scenarios about the search effort based on fox habitat quality in each search cell (of say 1 km^2), and use the probability data currently available. A search of 20% of the cells in the highest risk areas without finding a scat would then meet the desired stop rule. We stress this prediction is based on a sensitivity analysis used by Parkes and Anderson (2009) to compare the relative probabilities of not finding a fox given one was actually present under different search scenarios. Obtaining a 'real' prediction would require better data on the parameter estimates in the model.

DISCUSSION

The FEP developed its strategies based on the best knowledge available from mainland fox ecology and control but was still faced with daunting uncertainties. To their credit, FEP managers have attempted to resolve these issues through a learn-by-doing approach and research focussed on: 1) improving safety to non-target animals, 2) the use of detector dogs and people, and 3) DNA analyses to validate fox presence. Learn-by-doing is more risky than formal adaptive management (Parkes *et al.* 2006)

Table 2 Baiting histories at sites where 41 fox scats have been located as an indication of whether the foxes are potential survivors of baiting, were potentially killed, or were never at risk.

Risk category	Number of scats	Time between baiting and scat location		Time between scat located and next baiting	
		Range (days)	Mean (days)	Range (days)	Mean (days)
Scat found in area previously baited (since 2006), i.e. a potential survivor	8	161–350	210 ± 52		
Scat found in an area subsequently baited, i.e., potentially at risk.	15 (includes 7 of the above)			0 – 603	142 ± 94
Scat found in area never baited since 2006, i.e., never at risk	25				

as the knowledge it provides can be unreliable. These characteristics may put the whole eradication campaign at risk if it takes too long and if the funders become nervous about the probability of success or find higher priority areas in which to invest. Aware of these risks, the FEP managers commissioned the 2009 review to describe what had been achieved, what had not been done and what must be done. The review noted the substantial amount of spatially-explicit data on fox locations and where control had been deployed. This meant that the use of Bayesian techniques could be used in this, and other similar projects, where zero pests is achieved by successive culls, to inform the uncertainty around when to stop.

The 2009 review showed how the monitoring component of the programme had drifted apart from the control component of the programme, as a consequence of following a reactive approach but with lags in the reaction time. If these time lags between detection and response cannot be resolved, moving to a precautionary baiting strategy, at least for the initial response, would allow the two components to be re-integrated.

However, under either the reactive or precautionary strategy, a major need for the programme is to develop a reliable alternative method to kill foxes that: a) may survive baiting for whatever reason and b) live in urban or peri-urban areas. Trapping, spotlight shooting, snaring and hunting have been tried without any success. The review suggested using trained predator detector dogs – not those trained to sniff out scats – to locate foxes in their daytime lairs so that they can then be killed by other means. So far as we know detector dogs have not been used to detect foxes but they are regularly used in eradication campaigns against other predators such as feral cats in Mexico (e.g., Wood *et al.* 2002), and stoats (*Mustela erminea*) in New Zealand (Theobald and Coad 2002).

A second residual uncertainty is that about half of Tasmania is dense temperate rainforest. On mainland Australia, such areas are not the usual habitat of foxes. However, these areas have no human population to report foxes and have not been surveyed in the scat detection systems. The probability that no foxes found equals successful eradication is thus lowered if there are gaps in the surveillance – by how much depends on the likelihood that the assumption is not true.

The review showed some areas where the FEP has made progress but also identified clear problems that have to be resolved. Funding agencies will take on risky projects as long as potential benefits are identified and the risks are clear. It is the lack of transparency that scares decision-makers when all can see that the task is difficult. A Parliamentary committee of the Tasmanian Government has just reviewed the FEP (Anon 2009) and despite the ongoing difficulties has accepted that the costs of failure are too high and has recommended that the programme should continue.

There is an additional lesson from this example. Planning paradigms for eradications that require successive actions or culls to reach zero numbers are intrinsically different from those such as aerial baiting for rodent eradication where there is a single intense period of activity. In the latter, the need is for meticulous plans that focus on getting everything right on the day (Cromarty *et al*. 2002). In the former, flexibility and change are required as events unfold and the best laid plans go astray (Parkes *et al.* 2010). Here probabilistic models are useful as part of managing these uncertainties and risks.

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