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Did 'precautionary' 1080 baiting have a realistic potential to eradicate Red Fox (*Vulpes vulpes*) in Tasmania without *in situ* monitoring data?

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Summary Anecdotal reports in 2001 suggested that the European Red Fox (*Vulpes vulpes*) had been deliberately released in Tasmania and thereafter an eradication programme using buried fluoroacetic acid (1080) baits was believed to be a necessary precautionary action until mid-2013. Prerequisites for the successful eradication of foxes relate to the scale of the undertaking and the ability to collect *in situ* data such as the distribution and abundance of the target population and measures of the efficacy of the control technique. Previously, 1080 baiting has demonstrated only limited potential as a fox eradication technique on islands when used on a scale between 685 and 2141 times smaller than Tasmania. In the absence of empirical monitoring data confirming the distribution or abundance of extant foxes, buried baiting was targeted to specific landscapes believed to be preferred by foxes. No empirical data was collected concerning the *in situ* effectiveness of baiting in Tasmania, yet an *a priori* assumption of lethal efficacy was extrapolated from four heterogeneous mainland studies to suggest that foxes would have only a 0.23 probability of surviving each bait treatment. We show that these studies were unrepresentative of Tasmanian baiting methods used and influenced by imprecise fox population surveys and misreported data. Overall, in the absence of key population monitoring and efficacy data, the 'precautionary' baiting strategy adopted did not have a realistic potential to eradicate fox incursions in Tasmania, nor is it an appropriate risk management strategy for other large offshore Australian islands. Contingency plans to counter fox incursions on offshore islands must address the currently inadequate technical capacity to reliably detect and monitor low-density fox populations, which is an essential component of successful fox eradication.

Key words: *1080 baiting, eradication, Red Fox, Tasmania, Vulpes vulpes*.

Introduction

In 2001, it was reported that up to 19 European Red Fox individuals (*Vulpes vulpes*) had been translocated from mainland Australia and intentionally released in the island state of Tasmania (area = 68 500 km^2; Dennis 2002; Saunders *et al.* 2006; Sarre *et al.* 2007). Although this claim was later revealed to be entirely anecdotal, it was supported by a range of opportunistically acquired physical evidence collected in the same year (Marks *et al.* 2014b). By mid-2012, 61 predator scats (Marks *et al.* 2014a), later revised to 56 (Sarre *et al.* 2012), were determined to be positive for fox mitochondrial DNA (mtDNA) and included in a model to suggest a widespread fox population and 19 865 km^2 of potential fox habitat in Tasmania (Sarre *et al.* 2012). However, inadquate mtDNA assay design potentially resulting in mixed species templates (Gonçalves *et al.* 2014), anomalies in the distribution of molecular data indicative of Type I error and a failure to validate the model (Marks *et al.* 2014a), together with poor evidentiary quality (Marks *et al.* 2014b), suggested that the presence and proposed distribution of an extant fox population was equivocal.

The *precautionary principle* (Applegate 2000) outlines the justification to use *anticipatory* measures to mitigate a potential environmental threat during a period of scientific uncertainty (Ward & Dubos 1972; Anon 1992) to counter threats such as possible biodiversity loss (McNeely 2001; Ramsay *et al.* 2010). Importantly, precautionary measures (Anon 1992) must be plausible and effective in managing a potential threat (COMEST 2005). Support for the effectiveness of buried 1080 baiting as a viable eradication technique was based upon another model proposed by Parkes and Anderson (2009, 2011). This strategy aimed to progressively treat between one-third to a half of the island (≈22 833 km^2) believed to be suited to fox colonisation (Saunders *et al.* 2006; Parkes & Anderson 2009; Kitchell *et al.* 2013), and ideally the entire island (Parkes & Anderson 2009), with buried 1080 baits. A critical assumption in this model was that each fox would have only a 0.23 probability of surviving each baiting treatment (Parkes & Anderson 2009, 2011) based on baiting efficacy assess-

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ments reviewed by Saunders and McLeod (2007).

The Tasmanian Fox Eradication Program (FEP) has significant implications for risk management of actual or speculative fox incursions on other Australian island reserves that are currently free of foxes (Anon 2002). We briefly review three key prerequisites commonly associated with the feasibility of successful eradication and contrast them with the baiting strategy proposed by Parkes and Anderson (2009). We sought to determine whether the baiting strategy used in Tasmania until 2013 had a realistic potential to eradicate foxes if any were present and if it was an approach that should be adopted to counter confirmed or speculative fox incursions in Tasmania or other Australian offshore islands.

Feasibility of Eradication is Dependent Upon Scale

Techniques used for fox control such as buried 1080 baiting on the Australian mainland (Saunders *et al.* 1995; Saunders & McLeod 2007) have been applied to the suppression of fox abundance and justified whether they result in a positive cost-benefit by reducing the impact of foxes, rather than resulting in eradication (Braysher 1993). Accordingly, baiting with 1080 is commonly used to augment the recovery of threatened or endangered species on the mainland Australia (Priddel & Wheeler 1997; Glen *et al.* 2007; Claridge *et al.* 2010; Kinnear *et al.* 2010) and has produced some positive ecological benefits (Dexter & Murray 2009; Claridge *et al.* 2010). When used on Phillip Island, Victoria (0.15% of the Tasmanian landmass), buried baiting the island four times a year for 9 years produced a significant suppression of the fox population, but has yet to cause declared eradication (R. Kirkwood, D.R. Sutherland, S. Murphy and P. Dann, unpublished data). In contrast, foxes have been eradicated from small islands up to 32 km^2 in Western Australia (0.047% of the Tasmanian landmass), using the aerial dissemination of fresh meat baits containing 1080, despite some islands requiring recurrent baiting to counter later recolonisation from mainland fox populations (Burbidge & Morris 2002). Fox populations established after the release of selectively bred 'farmed' European Red Fox and Arctic Fox (*Alopex lagopus*) were also successfully eradicated from 39 islands in the Aleutians using a wide range of methods, with the largest being up to 1.3% of the Tasmanian landmass (Ebbert & Byrd 2002). In contrast, Parkes and Anderson's (2009) proposal to attempt eradication of a putative fox population from the entire Tasmanian island area, is an undertaking on a scale 685 and 2141 times larger than attempted or achieved previously for offshore islands in Australia.

The longer the time period that has elapsed since the incursion of an invasive species until its detection, the larger the area of landmass can be assumed to have been colonised before eradication attempts begin (Hulme 2006). Therefore, time since the incursion of an invasive species is generally associated with the cost and practicality of eradication overall (Hobbs & Humphries 1995) that declines as the species progressively colonises all suitable habitats and becomes established (Fig. 1). For established species in particular, island area is highly correlated with the cost and feasibility of invasive species eradication (Cromarty *et al.* 2002; Clout & Russell 2006; Martins *et al.* 2006), making it essential to appreciate the limitations of scale on the likelihood and practicability of achieving eradication.

The criteria necessary to eradicate invasive species include: the need to ensure immigration of survivors from outside the immediate control area is prevented; that all reproductively active animals are put at risk; and that the pest can be detected even at very low densities to ensure measurement of progress and adaptation of strategies towards eradication (Bomford & O'Brien 1995a,b). Each criterion becomes progressively harder to ensure as time elapses from the incursion and the scale of the eradication attempt increases. Scaling up the resources and effort proportional to a smaller and successful eradication programme will not necessarily ensure that sufficient resources are allocated or used efficiently to produce eradication. Importantly, the relationship between the density of the target animal and required resources and effort needed to achieve eradication is nonlinear (Bomford & O'Brien 1995a,b). For example, elimination of the last 1–10% of a pest population may require

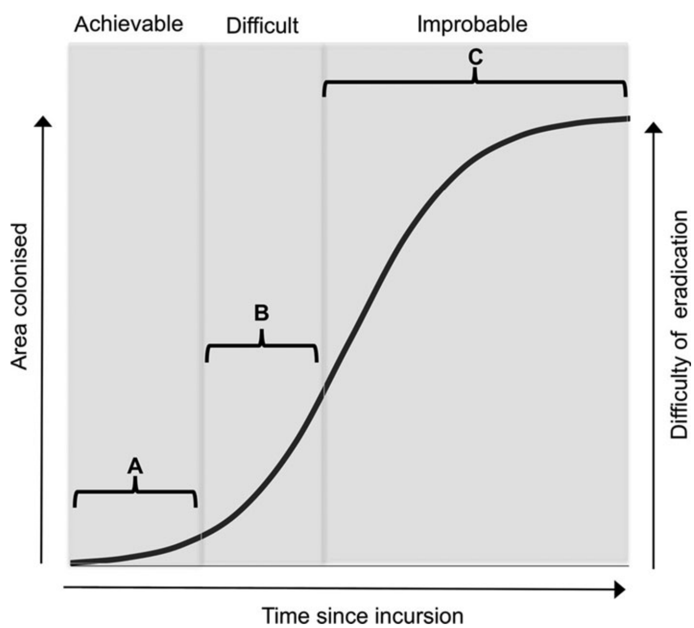

Figure 1. Relationship between elapsed time since the incursion of an invasive species, the area colonised, and relative difficulty associated with eradication. The first detection of the incursion and commencement of management action corresponds with eradication being (A) achievable, (B) difficult and requiring substantial resources or (C) improbable given the widespread distribution of the pest (C) (modified from Hobbs & Humphries 1995).

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more effort than that required to kill the first 90–99% of the population (Myers *et al.* 1998). Costs associated with feral Goat (*Capra hircus*) eradication were found to follow an exponential function (Fig. 2), where the resources required to kill the last survivor in a population within a discrete 100 km^2 area (0.15% of the Tasmanian landmass) were estimated to be >15 times greater than that required to initially reduce the population by 50% (Maas 1998). Given the exponentially increasing costs of lethal control required to obtain a 100% reduction in population even within a discrete area (Fig. 2) together with the potential for the logistic expansion of the area colonised by a pest if control is unsuccessful (Fig. 1), eradication is dependent on efficiently detecting and targeting the last survivors and ensuring that the effort required to achieve eradication is known.

Of 1129 attempts to eradicate plant and animal species worldwide, some 97% were attempted on islands and few successful examples exist for those approaching 1% (685 km^2) of the Tasmanian landmass (Genovesi 2011). In New Zealand, some 218 successful eradication efforts of 17 different mammalian species were reported for islands up to 131 km^2 in area (Clout & Russell 2006) that equate to a maximum of 0.19% of the Tasmanian landmass. Notably, the eradication of localised populations of the feral Coypus (*Myocastor coypus*) in the United Kingdom remains a rare example where an invasive species, even with a restricted area of occupancy, has been eradicated from within a much larger landmass (Gosling & Baker 1987; Baker 2006). However, this was achieved due to possibly 90% of the population declining due to cold weather and thereafter ensuring that critical population-monitoring data and a control technique of known efficacy were available to assist targeting survivors (Baker 2006).

Empirical Population and Efficacy Data are Essential for Eradication Success

Without an ability to survey changes in the fox population in response to control on a large scale, matching the resources and effort needed to achieve eradication cannot be determined. Population monitoring must have sufficient precision to detect dynamic changes in the abundance and distribution of a pest so that control efforts can be adapted and targeted until eradication is achieved (Baker 2006). Problematically, the detection of the last survivors at low density is technically difficult to achieve even on a small scale (Bomford & O'Brien 1995a,b) due to limitations in fox survey precision (Marks *et al.* 2009; Vine *et al.* 2009). For instance, the presence and distribution of a small population of <6 foxes on the Isle of Man (572 km^2: 0.8% of the Tasmanian landmass) were estimated to be detectable only with a 15–25% probability, and these surveys were unable to unequivocally determine whether foxes existed on the island (Reynolds & Short 2003). Consequently, attempting to target surviving foxes at low density over an increasing scale suggests that survey error will become a proportionally greater problem in determining where survivors should be targeted and the quantification of resources and effort required to bring about eradication. This is a key reason why eradication is far more likely to be successful if incursions are quickly detected in discrete areas prior to a population establishing and becoming widely distributed (Bogich *et al.* 2008; Fig. 1). Eradication in Tasmania was originally believed to be time bound and dependent upon demonstrating the effectiveness of the control method upon the fox population (Kinnear 2003). Instead, Parkes and Anderson (2009) proposed that in the absence of timely population data, buried 1080 baiting should be undertaken in landscapes that foxes were assumed to colonise preferentially and ideally the entire island (Parkes & Anderson 2009). This departs from the accepted need for population monitoring to actively target survivors and to determine whether all individuals are equally susceptible to baiting and when eradication has been achieved (Bomford & O'Brien 1995a,b). In two mainland trials, 27% and 8% of a fox population did not consume fox baits when provided in the field at an unprecedented rate of 8 baits/ha (800 baits/km^2 as opposed to the target of 10 baits/km^2 in Tasmania) in an experiment designed to test whether *ad libitum* bait availability could overcome poor bait uptake

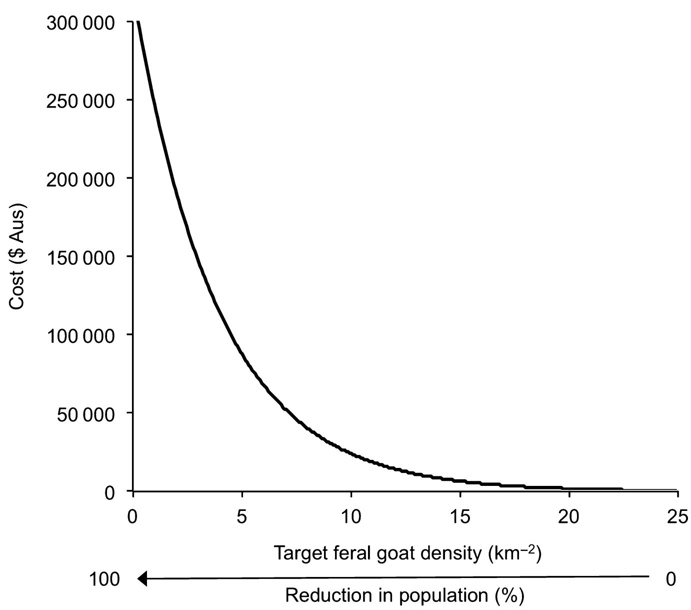

Figure 2. Modelled cost of reducing a feral Goat population within a 100 km^2 area using aerial shooting from an original density of 25 goats/km^2 to eradication (100% population reduction), where the predicted cost of removing the last goat was approximately A$300 000 (adapted from Maas 1998).

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previously reported in other trials (Marks & Bloomfield 1999a). This implies that additional control techniques may be required to target individuals within the population that appear refractory to baiting (Marks *et al.* 2009). However, without monitoring data of sufficient precision, it is impossible to determine whether all foxes within the population are susceptible to 1080 baiting (Marks *et al.* 2009) to make eradication a possible outcome (Bomford & O'Brien 1995a,b) and to determine whether other techniques may be required to remove those foxes that do not respond to the baiting methods used.

Biological invasions have been successfully modelled by understanding the prior ecological niche dimensions of a species (Peterson 2003). However, broad landscape and environmental classifications (e.g. agricultural or urban), or correlation with widespread plant communities and geomorphology believed to be associated with fox populations (Sarre *et al.* 2012), do not describe a useful fine scale of actual 'habitat' (Hall *et al.* 1997) that defines where foxes can be targeted, nor does it replace population data accounting for dynamic trends in the distribution and abundance of foxes. The model used to correlate environments believed to be associated with a putative fox populations in Tasmania (Sarre *et al.* 2012) used equivocal data and was not validated with independent empirical data of extant foxes (Marks *et al.* 2014a,b). Overall, the concept of 'core habitat' associated with a putative fox population in Tasmania was recognised as an untested hypothesis (Parkes & Anderson 2009) and one that may be at odds with the reported capacity of foxes to invade and colonise a much wider diversity of environments. For instance, foxes on mainland Australia presently inhabit landscapes such as urban (Marks & Bloomfield 1999b), semi-urban and riparian (White *et al.* 2006), alpine (Bubela *et al.* 1998), forest (Dexter & Murray 2009), arid (Read & Bowen 2001), semi-arid (Risbey *et al.* 2000) and coastal (Meek & Saunders 2000). Foxes continue to expand their range into urban habitats worldwide (Wandeler *et al.* 2003; Harris 2008) and have been shown to colonise new habitats in California in the last 100 years (Lewis *et al.* 1999). It appears that the presence of important dietary species may be a far stronger predictors of fox distribution (Catling & Burt 1995). In mainland Australia, the distribution of the European Rabbit (*Oryctolagus cuniculus*) in most subtropical terrestrial habitats (Williams *et al.* 1995) is closely associated with the distribution of the fox (Saunders *et al.* 1995). This suggests that the greater abundance of medium-sized mammals in Tasmania relative to the mainland, as well as greater availability of road-killed wildlife (Hobday & Minstrell 2008), may influence the pattern of fox establishment (Abbott 2011), and this will be difficult to predict without *in situ* empirical survey data.

Determining the 'Efficacy' of 1080 Baiting of Foxes in Tasmania

Foxes were believed to be widespread in urban environments in Tasmania (Saunders *et al.* 2006; Parkes & Anderson 2011; Sarre *et al.* 2012). Significantly, while the majority of the mtDNA fox assigned scats came from urban and peri-urban environments (Marks *et al.* 2014a), no baiting had been attempted in urban environments by 2009 and neither was direct empirical evidence of any successful lethal control reported (Parkes & Anderson 2009, 2011). However, for eradication to be feasible, a viable means of measuring control efficacy is required (Baker 2006) that ensures foxes in all environments are put at risk and killed at a rate exceeding their rate of increase at all densities (Cromarty *et al.* 2002). Further, because the efficacy of poison baiting may vary widely given environmental, population and operational constraints (Saunders *et al.* 1995), the *post hoc* measurement of *in situ* control efficacy in different habitats and over time is essential to refine predictions and determine the potential for eradication success. The Australian Pesticides and Veterinary Medicines Authority holds no data pertaining to the lethal efficacy of baiting on foxes that can be assumed for Tasmanian habitats (Alan Norden, APVMA, pers. comm.). A key justification for the Tasmanian baiting strategy (Parkes & Anderson 2009, 2011) was that only 23% of foxes would survive each baiting episode based upon data in four mainland studies compiled by Saunders and McLeod (2007). This assumption was affected by at least three broad methodological problems:

Heterogeneity of studies

Key differences between the four mainland studies and the Tasmanian fox baiting strategy included: the habitat in which the study was undertaken; whether or not free-feeding was used to promote bait uptake; bait type, poison and poison concentration; capacity to confirm bait take by foxes; and the ability to estimate both the presence and population density of foxes. In all four published trials, free-feeding with unpoisoned baits was used for between 10 and 16 days to achieve higher bait uptake, yet no period of free-feeding was used in the Tasmanian baiting programme. Baiting density in the cited mainland trials ranged from 1.2 to 12.3 baits/km^2 with corresponding fox density estimated between 0.05 and 7.16 foxes/km^2 in contrast to a progressive lineal distribution of baits in Tasmania over a protracted period with an objective of achieving a baiting density of 10 baits/km^2. In 2013, it was revealed that the average baiting density achieved had been 6.2 baits/km^2 with a range of 1–6 baits/km^2 in the southern midlands (Kitchell *et al.* 2013). In contrast, baiting treatments used by the cited research studies were contemporaneous and largely homogeneously applied in 10–14 days while the FEP approach was asynchronous and applied over specific portions of the landmass considered to be 'core' fox habitat. The lack of fox density estimates has implication for the assessment of whether the scale and targeting of baiting in Tasmania over at least 30 000 km^2 (Kitchell *et al.* 2013) (which was 657 times greater than the largest of the mainland field trials cited and was conducted over a period at least 200 times longer in duration than any of the cited research trials) was matched to the scale of the problem and capable of targeting survivors. In two of the four mainland studies, synthetic fermented egg (SFE; Bullard *et al.* 1978; Bullard 1982) was used as a lure to enhance bait uptake, but was not consistently used by

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Table 1. Comparison of the Tasmanian (TAS) Fox Eradication Program (FEP) baiting methods with the four New South Wales (NSW) studies cited by Saunders and McLeod (2007) and used by Parkes and Anderson (2009, 2011) to predict (Study: 1 = Fleming 1996; 2 = Thompson & Fleming 1994; 3 = Fleming 1997; 4 = Dexter & Meek 1998; Habitat: B = bushland, F = forest, G = grassland, H = heath, P = pasture, S = scrub, S = swamp, U = urban, W = woodland; Bait type: F = Foxoff, K = kangaroo baits, M = meat baits, P = Probait)

Study	Location	Habitat	Area (km^2)	Baiting duration (days)	Free-feeding (days)	Bait	Lure	Poison	Bait depth (cm)	Bait density ($/km^2$)	Foxes (n)	Estimated fox density ($foxes/km^2$)	Bait take confirmed?	Population reduction by buried baiting (%)	
														Original study	Reported data*
FEP	TAS	G, P, U, W	≈30 000 km^2†	>3000	None	F, P	None	3 mg 1080	5-10	1–10†	–	–	N	na	na
1	NSW	F	24	10-14	9-14	K	–	5 mg 1080	1-5	1.7–3.1	–	0.05–0.2	Y	90.8	91
2	NSW	P, S, W	20.3	10	10	K, M	SFE‡	6 mg 1080	1-3	12.3	101§	4.55–7.16	Y	69.5	70
3	NSW	P, S, W	45.7	14	16	K*, F†	SFE‡	None	1-5	4.4	19	0.86–1.95	Y	0	50
4	NSW	B, F, H, S, W	42	10	13	F	–	2-3 mg 1080	10	7.1§	6	–	Y	66¶	97

*Saunders and McLeod (2007). †Kitchell *et al.* (2013). ‡Synthetic Fermented Egg, §Estimated, ¶Based upon early responders. Note that given a sample size of $n = 6$ the 95% confidence limit is between 0.27 and 0.94.

the FEP in Tasmania. Overall, the heterogeneous methods used in each study are not readily comparable to those adopted in Tasmania (Table 1).

Misreported efficacy data

Only one of the mainland studies (Dexter & Meek 1998) directly measured the lethal impact of Foxoff baits containing 1080 upon radio-collared foxes, yet in the Saunders and McLeod (2007) review, it was misreported that this trial achieved a 97% reduction of foxes, yet this referred only to the percentage of bait uptake. Correctly, the estimate of efficacy may have been calculated from the proportion (0.66) of radio-collared foxes that died initially after baiting, the nature of the mortality associated with foxes that died later in the trial not convincingly linked to 1080 toxicosis. If higher efficacy is suggested, as the sample of collared foxes was small ($n = 6$), the confidence limits on this estimate are broad (95% CI 0.27–0.94) suggesting that the potential for this assessment to inaccurately represent the actual population response of foxes to baiting is high. Saunders and McLeod (2007) also misreport that Fleming (1997) achieved a 50% reduction of a fox population through lethal baiting, yet this study used spotlight shooting to sample the population as the sole lethal control technique. The authors reported the uptake of baits containing a nonlethal marker chemical used in place of a poison that were ingested by a mean of 58.3% of foxes subsequent to sampling by spotlight shooting. However, because an age bias in the sampling of subadult and yearlings foxes has been reported to result from the use of spotlight shooting (Coman 1988) and that yearling foxes were shown to consume larger quantities of Foxoff baits relative to older age groups (Marks & Bloomfield 1999a), Fleming's (1997) data cannot be used to directly extrapolate the lethal efficacy of baiting for all age structures in a fox population.

Influence of imprecise fox population estimates in past studies

The precision of fox population estimates used in the four studies before and after

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1080 baiting will influence the robustness of baiting efficacy estimates extrapolated by Parkes and Anderson (2009). Past estimates of 1080 baiting efficacy based on activity indices recorded at bait stations placed on roads (Thompson & Fleming 1994; Fleming 1996, 1997) were highly dependent upon assumptions made concerning the relationship between bait uptake and fox population abundance that were not later supported by assessments that used molecular survey (scat DNA) techniques (Marks *et al.* 2009). New knowledge about the response of fox populations to baiting invalidates some of the original assumptions made in three of four of the studies (Thompson & Fleming 1994; Fleming 1996, 1997) reviewed by Saunders and McLeod (2007) that assume: (i) foxes seldom cache baits; (ii) one bait removed from a bait station will result in the death of a single fox; (iii) all foxes in the population are equally susceptible to baiting; and (iv) all foxes visit bait stations at the same frequency (Thompson & Fleming 1994; Fleming 1997). Using such assumptions, a high level of baiting efficacy (91% reduction in the fox population) was nonetheless attributed to Fleming (1996) [as a 'personal communication'] (Saunders & McLeod 2007). However, later studies showed that foxes routinely cache baits (such as Foxoff) and the observation of bait uptake alone is not an accurate indicator of bait consumption, bait palatability or lethal efficacy (van Polanen Petel *et al.* 2001). In contrast, molecular surveys on mainland Australia revealed different levels of bait uptake by individual foxes, including a proportion of the population that were not attracted to bait stations, in contrast to other foxes that removed multiple baits in one evening by sequentially visiting bait stations (Marks *et al.* 2003, 2009). Some foxes will remain undetected if visits to bait stations are used as the sole index of baiting efficacy (Marks *et al.* 2009), and these data may promote a false indication of baiting effectiveness. Moreover, although Fleming (1996) extrapolated change in fox abundance within the entire field site area, this study monitored bait stations only on roads separated by 250 m in a lineal distribution. This is unlikely to yield a valid assessment of overall population changes given that a measurements of baiting efficacy that uses bait station indices cannot detect the activity of foxes that do not visit bait stations (Marks *et al.* 2009). Overall, it is unlikely that prior population assessments that used these indices produced reliable data concerning the response of the entire fox population to the baiting methods used.

Conclusions

The feasibility of fox eradication is highly correlated with the scale of the undertaking and whether the distribution and abundance of a population can be measured. The efficacy of the control methods must also be determined to ensure that the population is targeted with adequate resources to remove the last survivors. Buried 1080 baiting appears to have no evidentiary support as a means of eradicating established fox populations on a scale approaching 1% of the Tasmanian landmass area. Without accurate and timely *in situ* monitoring data, the response and susceptibility of the putative Tasmanian fox population to baiting will remain unknown along with the effort required to eradicate the last survivors. Because fox distribution and abundance is dynamic, ongoing refinement of an eradication programme must be driven by timely empirical survey data that permits control to be targeted and adapted rather than relying upon static, untested and equivocal assumptions concerning fox distribution and control efficacy. Baiting efficacy estimates used in Tasmania were extrapolated from mainland studies that have little relevance to Tasmanian baiting practices, and consequently, there was inadequate justification for the *a priori* assumption of baiting efficacy used in the model of eradication proposed by Parkes and Anderson (2009). Therefore, the baiting strategy appears to be unrealistic as an anticipatory measure to prevent fox establishment in Tasmania or other large offshore islands. Strategies to counter fox incursions on offshore islands must address the currently inadequate technical capacity to reliably detect and monitor foxes enabling the *in situ* measurements of eradication success to be based upon appropriate empirical data.

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