CHAPTER 8

GENERAL DISCUSSION

In the preceding chapters several important factors likely to affect the efficiency of fox baiting practices have been examined: the longevity of poison bait in the environment, bait palatability and caching behaviour, the spatial coverage of current baiting practices, and the relative cost-effectiveness of different strategies. In this chapter I first outline the key findings of this study, compare these with previous research, and then discuss the implications of these results for improving the efficiency of fox management. Finally, recommendations for fox management and future research are presented.

8.1 Key findings

In this thesis, I have used a combination of ecological and modelling approaches to assess factors affecting the efficiency of fox baiting practices on the central tablelands of New South Wales. The following conclusions have emerged:

I. The influence of climate and rainfall on degradation of 1080 in bait is not consistent for different bait types. The loss of 1080 from wingettes was independent of the tested rainfall and climate conditions, with wingettes remaining lethal to foxes for, on average, 1.1 weeks. Foxoff® baits remain lethal for longer than wingettes under all tested conditions although their degradation generally increased with increasing rainfall. Bait degradation rates did not change significantly between the central tablelands and western slopes of New South Wales.

II. There may be significant problems with the assay for determining 1080 concentration in fresh meat baits. Despite using a relatively accurate method of injecting 1080 solution into baits (graduated 1 ml syringes), assay results showed significant variation of 1080 concentration for freshly prepared bait. Commercially prepared Foxoff® baits do not suffer from this problem, partly due to the consistency of the substrate between individual baits. Inability to determine 1080 concentration accurately may result in safety, efficiency and effectiveness concerns.

III. Defluorinating micro-organisms are present in soils on the central tablelands and western slopes of New South Wales. A total of thirty-one species of defluorinating micro-organisms was isolated from soil samples. The defluorinating ability of four bacteria, two fungi and two actinomycete species had not previously been recorded. The variety of micro-organisms isolated proves the existence of defluorinators in eastern Australia, supporting arguments that 1080 will not persist in the Australian environment.

IV. Caching intensity is largely dependent on the palatability of the bait presented, reflecting the bait type and the presence of 1080. In the non-toxic trials Foxoff® baits were cached the most (66.9%) compared to wingettes (5.7%) and day-old chicks (4.5%). Higher rates of caching were recorded in the toxic trials, with 74.3% of Foxoff® baits compared to 43.1% of wingettes and 26.2% of day-old chicks being cached. Worryingly, 1080 baits were cached more often and caches are less likely to be retrieved compared to non-toxic baits, suggesting multiple bait uptake by foxes and reduced palatability of 1080 bait. Seasonal differences in caching intensity were inconsistent across sites, but some seasonal peaks occurred within sites, and were possibly related to variations in food availability.

V. The incorporation of an illness-inducing chemical (levamisole) into highly palatable bait can reduce multiple bait consumption by wild foxes. The mechanism driving the reduced consumption appears to be a learned avoidance of levamisole rather than development of a true conditioned aversion to bait. Use of levamisole to reduce multiple bait uptake by individuals may increase the efficiency and cost-effectiveness of baiting operations.

VI. Strategies for the use of conditioned taste aversion in the field (including reducing multiple bait uptake) must consider the dietary diversity of the target animal. Laboratory trials showed that freshly-weaned rats raised on a single food had a stronger and more persistent aversion than those raised on a variety of foods. This indicates the need for caution in extrapolating results from laboratory trials to field situations, particularly for animals with diverse feeding habits such as the fox.

VII. When temporal coordination between landholders and the likely impact on re-colonisation by foxes are taken into account current baiting practices in the Molong Rural Lands Protection Board appear to be largely ineffective at achieving desired objectives. The strategy of encouraging cooperative baiting campaigns to reduce the impact of immigration may be difficult and impractical in production environments where property sizes are small.

VIII. The central tablelands region provides highly suitable fox habitat and supports high density fox populations. In conjunction with published information on group structure, counts of natal dens produces population density estimates comparable with previous studies using different techniques.

IX. The cost-efficiency of baiting practices is dependent upon the length of the baiting campaign and replacement regime in addition to bait palatability, longevity and purchase cost. When measured on a cost per bait consumed basis, the fresh bait types (wingettes and day-old chicks) were more cost-effective for campaigns up to 4 weeks duration. However, it is recognised that other considerations, such as handling time, may be equally or more important in deciding the most appropriate strategy to use.

8.2 Discussion of key findings

The rate of caching in the present study was considerably greater than that reported previously (Saunders *et al.* 1999; Van Polanen Petel *et al.* 2001; Thomson and Kok 2002). Saunders *et al.* (1999) found that 38% of non-toxic and 32% of toxic Foxoff® baits taken by foxes were cached, while Van Polanen Petel *et al.* (2001) found that 41% of non-toxic Foxoff® baits were cached compared to only 12% of deep-fried beef liver baits. Thomson and Kok (2002) trialled non-toxic dried kangaroo meat baits and found that 25% of baits removed by foxes were cached. Given that the largest difference in caching intensity in the current study was a result of the bait type, the differences between the reported caching rates may be due to differences in palatability of the presented baits (Van Polanen Petel *et al.* 2001). However, comparisons may be confounded due to differences in free-feeding techniques, including free-feeding with replacement (Saunders *et al.* 1999; this study), free-feeding without replacement (Van Polanen Petel *et al.* 2001) and no free-feeding (Thomson and Kok 2002). Results from the current study suggest free-feeding can increase caching.

The majority of non-toxic caches appear to be retrieved within a short period. This is supported by the findings of other studies: Thomson and Kok (2002) found that 59% were retrieved and consumed within 10 days, most of these within 3 days; Saunders *et al.* (1999) found that 80% of non-toxic bait caches were retrieved within 10 days. This concurs with the hypothesis that most caches should be retrieved as a means of securing food for later consumption. However, fewer toxic baits were retrieved following caching, probably as a result of the death of the responsible animal (Saunders *et al.* 1999). Scatter hoarders, such as foxes, can recover caches through a variety of mechanisms (see Vander Wall 1982, 1990), most likely through remembering the precise location of cache sites using visual cues. This hypothesis is supported by empirical data (see Macdonald 1976), suggesting that caches are usually retrieved only by the individual responsible for making them. Additionally, foxes usually directly approach the cache site and, if a previously made cache has been moved a short distance, foxes are less likely to retrieve it (Macdonald 1976). This suggests that caches are unlikely to be found and raided by foxes other than the individual responsible for making the cache. This is important for baiting campaigns given that these caches may remain in the environment until consumed or degraded.

The caching of 1080 bait has been recorded in only one other study (Saunders *et al.* 1999). The greater rate of caching of toxic bait compared to non-toxic in the current study is in contrast to Saunders *et al.* (1999), who found that fewer toxic Foxoff® baits were cached compared with non-toxic baits (32% vs. 38%) (current study Foxoff® 74.3% vs. 66.9%). One possible explanation is that Saunders *et al.* (1999) presented only one bait type (Foxoff®) whereas the current study presented three bait types, albeit at different bait stations. Foxoff®

is less palatable than the other bait types, and foxes would have had greater access to bait stations since they were spaced at shorter intervals (minimum of 200 m) than Saunders *et al.* (1999) (400-500 m). It has been noted that food discovered is usually eaten until an animal is satiated, after which it is cached. It may be possible that foxes may have preferred to consume the more palatable, alternative bait types before removing and caching Foxoff®. This suggests that the relationship between food palatability and caching can be confounded by the availability of the food, and may be responsible for the differences between studies. Therefore, the availability of bait, together with presentation of bait of varying palatability, may interact to affect caching intensity.

Previous studies have suggested that caches may not be detrimental to baiting campaigns if they are consumed by immigrating foxes (e.g. Twigg 2001). However, the ability of cached baits to act as a temporal buffer may be limited since it is unlikely that immigrants locate many baits. Additionally, since less than half (43%) of toxic caches are removed before ten days (Saunders *et al.* 1999), they may degrade to sub-lethal levels before being consumed. Consumption of caches may, therefore, have a detrimental effect on baiting campaigns since it may result in consumption of sub-lethal doses of 1080, leading to re-population with bait averse foxes.

Ideally, baiting should be undertaken during periods that increase the probability of foxes consuming bait. Bait uptake and consumption will be affected by relationships between fox density, food abundance, individual nutritional status and energy demands, and seasonal differences in food preference (Saunders and McLeod *in press*). The effectiveness of baiting operations may be improved by undertaking campaigns during periods of peak food demands. Winstanley *et al.* (1999) assessed body fat in different seasons and found that foxes have greater levels of body fat in autumn than spring (especially November), when the predicted high daily food consumption suggests a high daily expenditure of energy in foraging activities. Specific periods of greater foraging activities include August to October for males (reduced feeding during mating and supplying females with food) and September to October for females (increased nutritional demand of lactation). The period August to November, coinciding with the peak whelping and cub-raising period (McIlroy *et al.* 2001) may thus be optimal for baiting since it suggests increased foraging to support lactation and provision of cubs. Considering all factors, November may be the optimal month for baiting since it reflects the period between maximal energy depletion and gain (Winstanley *et al.* 1999; Saunders and McLeod *in press*).

Surprisingly, in view of this, the results from the caching trials indicate no seasonal difference in caching rates between autumn, winter and spring. It is possible that any short-term changes may have been disguised by the testing regime, which, by necessity, was undertaken within the same season rather than the same month. The lack of consistent seasonal variation in caching found in this study supports Thomson and Kok (2002), who also found no difference in caching between winter and spring. The lack of consistent seasonal differences in caching intensity across sites suggests that targeting foxes during any seasonal period may not offer advantages for reducing caching. However, there are likely to be interactions between the availability of food (i.e. bait) and caching behaviour (Vander Wall 1990), suggesting that site-specific peaks in food availability may be more responsible for variation in the intensity of caching than actual seasonal influences.

It is important to recognise that the timing of any campaign may be restricted by its goals and the ability to satisfy these goals. In agricultural enterprises, baiting programs may need to be undertaken only when prey are susceptible, for example prior to and during lambing periods (Balogh *et al.* 2001). Campaigns for nature conservation, though, may require constant management effort for reducing predation pressure on prey. These goals may be equally or more important in deciding appropriate temporal baiting strategies than the biology of the fox.

From the above it could be concluded that the largest variation in caching behaviour identified thus far is due to the type of bait presented. Given that caching is a major determinant of the cost-effectiveness of using a particular bait type, choosing highly palatable bait should assist in improving the cost-effectiveness of control operations and reducing caching-associated problems.

There have been concerns about the effects of 1080 poisoning campaigns on non-target animals, both native and introduced. Apart from the potential to result in non-target deaths, such uptake may reduce the cost-effectiveness of delivering bait to foxes (Twigg 2001). Many studies have reported the removal of bait by non-target species including birds, native rodents, reptiles, cats, dogs, quolls and other marsupial mammals (e.g. McIlroy *et al.* 1986; Allen *et al.* 1989; Calver *et al.* 1989; Fleming 1996; Belcher 1998; Dexter and Meek 1998; Twigg *et al.* 2001; Glen and Dickman 2003; Kortner *et al.* 2003). Many of these studies have used non-toxic bait as a proxy for toxic bait, which may be misleading given that the palatability of 1080 bait may be reduced relative to non-toxic bait (Sinclair and Bird 1984). Additionally, most have assumed non-target susceptibility from baiting campaigns through measuring bait uptake, rather than bait consumption. The variation in the fate of bait once removed from a station in this study confirms the importance of assessing bait consumption rather than just uptake in assessing the impact of baiting. This finding supports Kortner *et al.* (2003), who found that quolls removed many baits but actually consumed very few.

The results of the caching chapter deal with baits removed by foxes only; those removed by other animals or disturbed by weather or stock were excluded from analyses. Over the course of the study, dogs, birds (probably corvids) and unidentified species removed and consumed several baits, both toxic and non-toxic. None were consumed by domestic stock, despite bait stations and baits being frequently disturbed, particularly by cattle. Overall, the level of non-target bait take was very low (<4% of baits presented), and was probably indicative of the lack of non-target species in the study area capable of removing and consuming bait. This is not surprising given that the central tablelands region is a highly modified landscape that has been significantly impacted by agriculture (see Chapter 1). Low levels of non-target impact should assist viability of the buried bait technique on agricultural lands, supporting the continued use of the technique for fox control.

Species of fungi, actinomycetes and bacteria capable of defluorination were isolated from soils on the central tablelands and western slopes (see Chapter 2). This is the first confirmation of their presence in soils from eastern Australia; previous studies have shown that such organisms are present in the soils of central (Twigg and Socha 2001) and Western Australia (Wong *et al.* 1991; King *et al.* 1994). In central Australia (Finke Gorge), soil samples contained a total of 24 species of micro-organisms capable of defluorinating 1080

(Twigg and Socha 2001), while in Western Australia, a total of 20 defluorinating species have been isolated (Wong *et al.* 1991). Since the relative abundance and activity of micro-organisms, and hence probability of isolation, may vary with soil conditions, including moisture and organic matter (Clark 1967), it is likely that the number of species isolated will vary according to seasonal conditions (see Twigg and Socha 2001) in addition to region. This variation in the number of species isolated between these studies is therefore likely to represent the soil conditions at the time of collection in addition to the number of species actually present in each area.

It is not surprising that fluoroacetate-degrading microbes are present in eastern Australian soils. Fluoroacetate-bearing plants are part of the Australian flora (Twigg and King 1991) and it would be expected that micro-organisms capable of detoxifying fluoroacetate would be present in Australian soils. Such organisms also occur on other continents where fluoroacetate-bearing plants may or may not be present (Twigg *et al.* 1996; Cremasco 2002), including New Zealand (Bong *et al.* 1979; Parfitt *et al.* 1994; Walker 1994), South Africa (Meyer 1994), Britain (Kelly 1965) and Japan (Kawasaki *et al.* 1983), supporting the suggestion that the ability to metabolise fluoroacetate may be common amongst many soil micro-organisms (Walker 1994). This would suggest that 1080 will not persist generally in soils. Additionally, a combination of micro-organism activity, uptake from aquatic plants and physical breakdown from ultra-violet radiation and heat will also degrade fluoroacetate, indicating that prolonged persistence in natural waterways should not occur (Parfitt *et al.* 1994). Nevertheless, confirmation of the presence of defluorinators in the soils of eastern Australia provides further evidence to indicate that 1080 will not persist in the environment, one important consideration in support of the continued use of 1080 for pest animal control.

The 1080 content of freshly prepared bait is highly variable. With some baits measured at almost twice the nominal concentration, it is almost inconceivable that all of this variation is due to injection error, given the accuracy of the injected dose and the concentration of the stock solution (Chapter 2). Other studies (published and unpublished data) have also reported, or presented, data showing high variability in 1080 concentration in fresh meat bait (e.g. Korn and Livanos 1986; Kramer and Merrell 1987; McIlroy and Gifford 1988; Fleming and Parker

1991; A. Claridge, Department of Environment and Conservation, unpublished data) despite using a variety of bait substrates, solution concentrations and volumes, and application techniques. The ability of 1080 to bind to meat, amplified by the time lag between injection and analysis means that the percentage recovery of 1080 (relative to the injected dose) is low (Frost *et al.* 1989; Fleming and Parker 1991). Given that 1080 recovery within substrates varies according to the substrate type (Frost *et al.* 1989) and composition (R. Parker, Department of Natural Resources and Mines, pers. comm. 2003), it appears that variation in tissue composition between individual baits may result in variations in the measured concentration. The calculated variation may then be compounded through correcting the (low) measured recovery rate.

The 1080 content of baits prepared experimentally, where great care and attention is undertaken, should be more consistent than that for non-commercial bait prepared for normal usage. An example of this is the accuracy of the insulin syringe technique (this study) compared with the use of a vaccinator gun (Fleming and Parker 1991) more typically used by practitioners to impregnate baits. Given the variability encountered in this study, this is a concern and suggests that the variation in 1080 content of fresh baits used in everyday campaigns is likely to be greater. Furthermore, variation in the physical state of meat baits would be expected due to differences in the preparation techniques and state of the bait when presented in the field. Bait is prepared whilst fresh but, depending on the period and the storage medium (i.e. refrigerated or not) between preparation and presentation, bait may be laid in a condition ranging from fresh to spoiled. This inconsistency is a concern given that safe, effective and efficient strategies for use rely on presenting bait with a known, accurate dosage of 1080 – all determined from freshly prepared bait. These preparation and spoilage issues do not affect Foxoff®; its shelf-stability ensures that the contained dose is consistent, and the bait substrate at presentation is consistent. In fact, Foxoff® baits have the most consistent dose of all fox baits tested to date (R. Parker, Department of Natural Resources and Mines, pers. comm. 2003). Therefore, the superior quality control and shelf stability of Foxoff® provides an important criterion for favouring its use over freshly prepared bait types. It is important to recognise consistency of dose, as it will directly affect issues such as cost and degradation and, in turn, usage strategies (Chapter 7).

The ability to induce a learned aversion to bait may be beneficial to baiting campaigns, particularly those that present non-toxic bait. Each bait used in a poisoning operation contains sufficient poison to kill a fox (McIlroy and King 1990). Following consumption of a single bait, foxes would have only limited opportunity to consume additional baits before succumbing to the effects of the toxin. Therefore, inducing an aversion to bait, may only be of benefit to campaigns that rely on non-toxic bait. Oral vaccination programs, where bait is used as a delivery mechanism for vaccines, should only require consumption of a single bait to provoke an immune response (Linhart *et al.* 1997), although consumption of multiple baits may sometimes be necessary (Artois *et al.* 1993). Recent developments toward an anti-fertility vaccine by the Pest Animal Control CRC (now Australasian Invasive Animal CRC) have shown that consumption of a single non-toxic bait coated with wild-type canine herpesvirus (CHV) results in an immune response in all foxes consuming the bait (Pest Animal Control CRC 2004). In circumstances such as this, where consumption of only one bait is required, incorporation of an aversion-inducing agent such as levamisole would be advantageous. However, where it is necessary for foxes to consume multiple baits, the application of CTA or learned repellency to bait would reduce the probability of this occurring. Additionally, where individuals need to be re-treated over time (e.g. rabies vaccination programs, fertility control agents such as cabergoline or an immunocontraceptive), an aversion may hamper the ability to re-dose the animal. In these circumstances, the persistence of the aversion must be considered relative to the interval required for the re-dosing to be effective.

Perhaps the most important finding of this study is with respect to the perceived effectiveness of current baiting techniques. Commonly used indicators of success in baiting campaigns, such as the number of baits distributed, number of landholders involved and area of land covered may not be necessarily correlated with the actual success of baiting campaigns. The assessment of the spatial coverage of baiting in the Molong Rural Lands Protection Board area suggests that the effectiveness of current baiting operations in eastern Australia is compromised by the ability of foxes to re-colonise baited areas. This is supported by the empirical findings of Greentree *et al.* (2000) and Molsher (1999). Greentree *et al.* (2000)

found that undertaking best practice fox baiting once and three times per year had no significant effect on fox abundance on sheep farms, despite baiting additional buffer zones up to 3 km wide surrounding each site. Immigration was cited as the likely cause of no effect. The immigration problem was confirmed by Molsher (1999) who found that fox abundance did not decline even when baiting was carried out monthly. These studies confirm the findings of the present study, which suggest that immigration into baited areas would be rapid unless they were protected by buffers greater than 9.5 km wide (as estimated from mean recovery distances and home range sizes (Trewhella *et al.* 1988; Saunders *et al.* 2002a- see Chapter 5).

These results suggest that there may be a need to extend baiting practices to cover larger areas. The ease with which bait can be distributed over large areas may make aerial baiting more attractive and potentially more cost-effective than ground-based baiting. Aerial baiting for foxes is undertaken over large tracts of land in Western Australia (Armstrong 1997) and is suggested as an alternative technique to ground baiting in New South Wales. Aerial baiting may be highly effective, with kill rates of up to >95% (Thomson *et al.* 2000) and offers the advantages of uniform bait coverage over all areas, particularly those that are difficult to commute to on the ground. However, there are several differences between conditions in eastern and western Australia that may affect the application of the technique, and would require refinement if aerial baiting were to be considered for eastern Australia.

Thomson *et al.* (2000) reported that although the majority of monitored foxes (~75%) were killed during the first 14 days of a baiting campaign, the remainder perished between 4 and 6 weeks following bait presentation. This is slower than that occurring in ground baiting campaigns; a slower rate of bait uptake in aerial campaigns is probably a function of bait placement and subsequent location by foxes. This slower rate of uptake suggests that bait in an aerial campaign may have to remain lethal for longer to allow all foxes sufficient time to consume bait. Given that bait in higher rainfall agricultural areas will, generally, degrade within 2 weeks (Chapter 2), the success of aerial baiting in these areas is likely to be reduced. To counter this it may be necessary to present bait with greater longevity, continue regular re-baiting to ensure that bait still remains lethal, or increase the bait density to promote faster rates of uptake. Using bait with a greater lethal longevity may be advantageous for targeting foxes (e.g. Twigg 2001) but may be detrimental for non-target safety reasons (see Chapter 2). Similarly, increasing the bait density relative to ground baiting may have non-target implications, since individuals will have increased access to multiple baits (Glen and Dickman 2003). Aerial strategies may thus be detrimental to safety and cost-efficiency in comparison to ground baiting.

In addition to immigration, fox populations may respond through compensatory processes. Foxes are resilient to increases in mortality; populations exposed to control may compensate through increased reproduction or increases in litter size or juvenile survival (Marlow *et al.* submitted). Even without compensatory mechanisms, an estimated population reduction of >65% is required to stop maximum population growth (Hone 1999), a level probably achieved in most 1080 control operations (see Hone 1999) despite occasional lower reductions (50% - Fleming 1997). Such estimates suggest that, without sustained reductions of fox density, fox populations would soon return to pre-control levels regardless of immigration.

It is important to assess the effect of management strategies on the predator, but ultimately the effect on prey needs to be considered to determine the effect of management. Even if current management programs are effective at reducing fox density on a temporary basis, immigration may nullify efforts in the longer term. Regardless, we must assess whether current baiting strategies are effective in terms of the prey response. A major, replicated experiment was undertaken on the southern central tablelands of New South Wales to estimate the benefits associated from undertaking best practice fox baiting operations (Saunders *et al.* 1997a; Greentree 2000; Greentree *et al.* 2000). Fox abundance, lamb production and lamb predation were monitored on two replicate sites at three levels of fox control (once per year, three times per year and no control) over two years. Fox control had no significant effect upon lamb production, most probably due to the inability to significantly reduce fox abundance. Immigration was touted as the most likely cause (Greentree *et al.* 2000).

Similar issues relevant to immigration have occurred in international studies of predation. Conner *et al.* (1998) found that the removal of coyotes was not correlated with sheep losses. Control efforts did not have a lasting effect on coyote density; immigration, reduced mortality of young and compensatory reproduction were likely causes. Reynolds *et al.* (1993) assessed the impact of fox culling on two fox populations in southern England. Study sites consisted of core areas where foxes were deliberately, intensively controlled with 'surround' buffer areas where control efforts were sporadic. Both core and surround areas were recolonised each year due to immigration, although immigration was probably at lower levels in the breeding season compared to the peak dispersal period. However, despite immigration, hen partridges increased in the core area, suggesting the control technique was beneficial for game conservation (Reynolds *et al.* 1993).

The above examples demonstrate the importance of assessing management strategies in terms of the prey response. However, it is important also to consider the benefits of undertaking control in terms of the costs associated with generating the prey response. The cost-effectiveness analyses undertaken in this study (Chapter 7) indicate the cost of undertaking baiting campaigns, including the cost per bait consumed. Measures such as these are useful for comparing alternative control techniques, but alone are not a true measure of cost-effectiveness, or the economic benefit derived from undertaking control. A more appropriate measure of performance may be to determine whether there is a net benefit to agricultural protection or wildlife conservation programs (Twigg 2001). Therefore, the cost of undertaking control should, ideally, be compared to the benefits from undertaking control to assess whether the control is economically worthwhile, or cost-effective.

There have been few assessments of the cost-effectiveness of management strategies for preventing livestock predation, although such an approach has been recently undertaken for foxes (Moberly *et al.* 2004). Moberly *et al.* (2004) completed an economic analysis of fox predation on lambs in Britain through comparing the cost of preventative measures including shed lambing and fox control with predation losses. Their results suggested that the majority of farms would not benefit economically from undertaking additional fox control, and that reducing fox density had only a small effect on expected lamb losses; additional control only influenced the probability of predation occurring.

8.3 Other factors that may affect the efficiency of baiting

Although this study investigated several important factors affecting fox baiting, many other aspects are likely to influence the effectiveness of baiting practices, associated costs of control, and hence, efficiency. In this section these are briefly summarised with examples from previous studies.

Bait density, or the number of baits laid per unit area, will affect the efficiency of the baiting program. The appropriate bait density to effectively target foxes is likely to vary with fox density, home range size and habitat use, and the method of bait presentation (Saunders and McLeod *in press*). Obviously, bait density must exceed fox density to ensure that sufficient baits are presented for each animal. However, laying excessive bait may result in an excessive number of baits being available to each individual, wasting bait, and perhaps encouraging problems such as caching and increased non-target uptake (Thomson and Algar 2000).

A variety of baiting densities has been used in Australia, but comparisons between studies are difficult due to differences in underlying fox density. Thompson and Fleming (1994) suggested that comparisons between baiting rates should be made on the number of baits available per fox rather than the absolute bait density. For example, aerial baiting in Western Australia was successful (>95% kill) using a bait density of between 5-6 baits/km^2 at an estimated fox density of 0.5-1 foxes/km^2 (Thomson *et al.* 2000). This equates to between 5 and 12 baits available per fox. At a similar fox density, aerial baiting at 5 baits/km^2 (5-10 baits per fox) was found to be just as effective as at 10 baits/km^2 (10-20 baits per fox), resulting in a potential population reduction of 79% (range = 63-88%) (Thomson and Algar 2000). Considering these studies, it would be expected that the bait density should be greater in the more productive lands in eastern Australia where fox densities are generally higher. Thompson and Fleming (1994) reported that ground baiting of agricultural lands in New South Wales at a density of 12 baits/km^2 and fox density ranging between 4.6 - 7.2 foxes/km^2, resulted in a 70% reduction of fox numbers. Similarly, a 50% reduction was recorded on farmland at a bait density of 4.4 baits/km^2 for a given fox density of 1.3-1.9 foxes/km^2 (Fleming 1997).

In addition to the number of baits laid in an area, consideration must be given to how baits are distributed within the area, i.e. the bait placement. Ideally bait should be distributed in consideration of fox distribution, including territorial boundaries, to ensure that all foxes within the population will have physical access to bait (Saunders 1992). Increasing bait density without considering the distribution may simply increase the bait availability within fox groups rather than to a greater proportion of fox groups (Thulke *et al.* 2004). For example, uniform distribution of baits is likely to give more individuals access to bait than if they are clustered due to the fact that foxes mainly live in family territories (Hässig 1984 in Linhart *et al.* 1997). However, uniform bait placement is usually achieved only through aerial baiting; ground bait placement may be restricted by such factors as topography and vegetative cover to areas able to be traversed by vehicle. As a result, ground-placed baits are usually laid along roads, fencelines or other features likely to be conducive to fox activity. Such placement would be likely to encourage uptake by foxes (Korn and Lugton 1990) whereas uniform bait placement, as would occur from aerial operations, would probably increase the amount of time before discovery by foxes (Thomson and Algar 2000; Thomson *et al.* 2000). Placement of bait has been shown to affect bait uptake in urban areas (Trewhella *et al.* 1991), suggesting that knowledge of where to lay baits would increase the probability of successful removal by foxes (Saunders *et al.* 1997b). With these factors in consideration, it appears that, despite considerable differences between studies, a lower bait density may be required for ground baiting in comparison to aerial baiting to achieve a similar result due to differences in bait placement (Saunders and McLeod *in press*).

The density, distribution and placement of bait will affect the number and availability of baits to each fox, but how bait is presented may also affect the ability of foxes to locate the bait and additionally, the fate of the bait following discovery. Baits may be either buried or laid on the surface. Conventional baiting programs in eastern Australia bury bait as a means to reduce non-target uptake; in New South Wales baits must be either buried under the surface of the ground, or within mounds of sand (known as mound baiting). Some studies have noted that burying bait appears to decrease the rate of take in comparison to some surface laid bait (Allen *et al.* 1989). A decline in the rate of take by target species from buried bait is generally well regarded. However, in addition to affecting bait uptake, there is evidence that bait presentation may also affect the intensity of caching. Increased caching of buried baits (35.3%) compared to surface-laid baits (21.6%) was reported by Thomson and Kok (2002). There is no obvious reason for the increased caching of buried bait other than it may mimic a cache; since caching is inversely related to food palatability (Van Polanen Petel *et al.* 2001), buried bait may be recognised as less palatable by a raiding fox, and thus more likely to be cached.

The frequency of baiting campaigns is also likely to have an effect on the efficiency of baiting operations. Baiting on agricultural lands is usually undertaken to protect domestic stock, although the importance of fox control for nature conservation appears to be increasingly recognised (Oliver and Walton 2004). Assessment of baiting practices in the Molong RLPB area indicates that most landholders who undertake baiting (>80%) do so only once per year (see Chapter 5). Given that baiting undertaken at this frequency will be rendered ineffective due to fox immigration, which may be almost instantaneous, it is commonly recommended to undertake baiting more regularly to target re-invading foxes. However, baiting more regularly, including three times per year (Greentree *et al.* 2000) and even every month (Molsher 1999) cannot be guaranteed to reduce fox abundance, indicating susceptibility to re-invasion. This suggests that simply applying current strategies more frequently and over a bigger area may not solve the immigration problem.

Behavioural changes, as related to the fox reproductive cycle may also affect our ability to target foxes. In addition to changes in nutritional status that are likely to affect foraging behaviour (Saunders and McLeod *in press*), changes in ranging behaviour may affect the ability of foxes to locate baits. For example, den sites are the focal point of activity during the whelping and cub-raising period. Juveniles may not be targeted by baiting campaigns during this time if these areas are not targeted (Robertson *et al.* 2000).

The timing of the baiting campaign can also influence the uptake of poison baits by non-target species. Soderquist and Serena (1993) suggested that western quolls (*Dasyurus geoffroii*) are more likely to take baits during winter since prey is relatively scarce then. They predicted that January to March was the period that held the least danger to quolls. The large proportion of egg baits (up to 61%), removed by goannas (*Varanus rosenbergi*) during the warmer months (Twigg *et al.* 2001) may be reduced by timing campaigns during periods of reptile inactivity (i.e. cooler months). Goannas are probably not considered at risk due to their high tolerance to 1080, but removal of 60% of baits would reduce the cost-effectiveness of operations (Twigg 2001).

8.4 Management and research implications

Baiting, as part of any fox management program, is a complex issue affected by a plethora of factors that influence whether foxes will locate and consume baits. The costs associated with undertaking baiting will be affected by the methods chosen and used. There are many factors pertinent to these considerations that are affected by current management practices and require further investigation. In the following section I will comment on the applicability of the present study to other areas/situations, and the most appropriate directions for future research on fox baiting that have been highlighted during the course of this study.

The study area around Molong on the central tablelands of New South Wales is broadly representative of highly modified landscapes associated with grazing and mixed farming. Although these represent typical landscapes and enterprises likely to undertake fox baiting, differences between the agricultural lands of the central tablelands and other areas within New South Wales, or indeed Australia, mean that some of my results may not be immediately applicable to other areas (e.g. specific bait degradation rates). Differences in the climate, landuse (e.g. agricultural vs. conservation), amount of natural vegetation retained, presence and diversity of native species and other species capable of consuming bait must be considered before directly applying my results across a variety of habitats. However, baiting practices, as detailed in this study, are undertaken across New South Wales and, indeed, are very similar to those undertaken throughout most of eastern Australia. Therefore, regardless of regional variations in conditions, many implications of the results of this study may be generalised beyond the immediate central tablelands area.

The inability to accurately measure 1080 concentration has serious implications for the use of 1080 baits in the field. Bait must be prepared to contain the approximate dose to be sufficiently toxic to the target species, but not to constitute a non-target threat (McIlroy and King 1990). Quality control is an important means to ensure that prepared baits contain the appropriate amount, and random checks of operators are undertaken currently under the conditions of registration (S. Balogh, NSW Department of Primary Industries, pers. comm. 2003). The inability to accurately measure 1080 concentration and separate operator from measurement error may impede our ability to undertake such assessments and monitor the safety of 1080 programs. Additionally, it is important that bait is presented with a consistent, accurate dose since strategies for field use are formulated with respect to bait longevity.

The difference in palatability between 1080-laced bait and non-toxic bait warrants further investigation. The ability of native species to detect 1080 content has been previously confirmed (Sinclair and Bird 1984), and the reduced palatability recorded in my caching trials suggests the same may be occurring with foxes. This could be further explored by comparing the consumption of toxic and non-toxic bait at each of a number of sites to counter any possible site/regional differences in palatability. Procedural controls (e.g. Coleman and Connell 2001) should also be established for freshly prepared bait types to ensure that it is indeed the presence of 1080 rather than preparation techniques that reduce bait palatability.

Similarly, the potential for reducing multiple bait uptake through inducing conditioned taste aversion appears to be hampered by the detectability of levamisole. It is important for the further development of this technique to determine whether this is due to cues associated with the chemical or the injection process. An experiment could be undertaken using similar methodology to the 1080 trials as mentioned above, making sure to include procedural controls.

Further development of the CTA method may provide a means of testing whether baits are monopolised by individual foxes, and evaluating the extent of the monopolisation. The use of an aversion technique may assist in improving the effectiveness of all baiting operations through allowing additional foxes access to bait (see Chapter 4). This may be evaluated by incorporating a biomarker in bait on sites where CTA has been induced compared to a normal baiting campaign. Sampling for the presence of the biomarker in an unbiased sample of foxes obtained by shooting, trapping and cyanide baiting would then quantify the proportion of foxes consuming bait. Any differences in the proportion of foxes consuming bait between the sites would indicate whether monopolisation by individuals is occurring, and the extent that the monopolisation reduces the population level of bait consumption. This will assist in determining whether monopolisation is significantly deleterious to the cost-effectiveness of baiting campaigns.

The relationship between bait presentation and caching behaviour also warrants further investigation. The widespread practice of burying bait may be detrimental to the efficiency of baiting programs if it increases caching, although this has been observed only for dried meat bait (Thomson and Kok 2002). This may provide further indications of the potential differences between aerial and ground-based baiting campaigns. Such an assessment should also extend to mound baiting, given its increasing use and the considerable differences between it and conventional ground baiting practices. An appropriate testing regime should present bait types of differing palatability either on the ground (surface), under the ground (buried) or in the ground (mound). The fate of these baits should then be monitored through incorporating transmitters in these baits to determine any differences in caching behaviour.

The most important factor influencing caching behaviour that has been identified to date is the palatability of the bait type. Given that palatability was an important determinant of the cost per bait consumed, and hence cost-effectiveness, it may be beneficial to assess the efficiency of baiting programs using different bait types. Pen trials may be useful to rank between bait types but ultimately field-testing should be undertaken to ascertain caching rates under different field conditions.

Since it is likely that caching is a response to the overabundance of food, knowing the relationship between food abundance and caching behaviour may assist in predicting the required baiting intensity (i.e. bait density, spacing and placement) for given fox densities. Additionally, the density, spatial placement and spacing of baits are important determinants of the ability of foxes to locate baits. An experiment to evaluate the food abundance-caching relationship could be undertaken through monitoring bait uptake and caching behaviour at different levels of bait abundance per fox, as determined by the spacing between baits and overall bait density with regard to fox density. Alternatively, supplementary food could be provided to foxes while undertaking baiting to determine the effect of total food availability on caching behaviour. Consideration must be given to the abundance of other food resources, but given that baits are unlikely to be less preferred than naturally occurring prey items, this may not be as important as bait abundance.

Additional trials should be undertaken to assess the degradation of commonly used bait types, particularly fresh meat. Ideally, these trials should be undertaken in a range of environments, especially more arid environments where degradation is likely to be slower. Given the obvious logistical constraints of investigating all likely environmental conditions, it may be more efficient to quantify and model the processes driving degradation. Improved understanding of the effect of and interaction between intrinsic (e.g. bait type, 1080 dosage) and environmental variables (e.g. rainfall, temperature, soil type and decomposer activity) on the rate of 1080 degradation would assist in developing suitable degradation models. This would be an efficient approach since general relationships may then be applied to untested situations.

Perhaps most importantly, the process of undertaking the cost-effectiveness studies has highlighted the importance of incorporating economic analyses in evaluating management strategies. Determining the most cost-effective strategy for reducing fox abundance is useful for cost minimisation, but, ultimately, cost-effectiveness should be measured in the terms of the response of the prey population. The cost-effectiveness of fox management, regardless of the chosen technique, must be evaluated in terms of the response of the prey rather than that of the predator. This has proven difficult, especially in agriculture where impacts of predation can be variable.

Current levels of baiting coordination, and therefore coverage, appear insufficient to have any long-term impact upon fox populations due to the ability of the fox to re-colonise areas following removal. There may be a need to encourage greater coordination of baiting programs among landholders to reduce the potential for re-immigration into baited areas. The basic strategy of undertaking short-term control has been shown to be relatively ineffective at reducing fox predation, and simply applying this technique across the landscape will not result in any dramatic improvements. Fox populations are resilient to control, with some evidence of compensatory processes resulting from reducing fox density.

In the absence of empirical data, it is often assumed that the relationship between pest density and damage is linear. Therefore, much effort is undertaken to improve control techniques to ensure the maximum reduction in pest density. Perhaps greater recognition should be given to reducing pest density to levels of acceptable damage (Hone 1994). This would require the relationship between fox density and fox-associated damage to be refined in regard to the prey species to be protected, especially as different levels of predation upon each prey species will have different effects.

8.5 Specific recommendations for current baiting practices

Changes are required to current best-practice techniques (Saunders *et al.* 1995) to incorporate deficiencies found during this study. Specific recommendations for the management of foxes on agricultural lands with poison baits include the following:

I. Free-feeding should be discouraged unless the presence of susceptible non-target species such as the spotted-tailed quoll, is suspected. Free-feeding has been shown to increase the potential for caching; the resultant additional cost of bait procurement, bait checking and replacement would substantially increase the costs associated with this strategy. Where quolls are suspected, free-feeding in conjunction with track plots is recommended to determine if quolls are present and visiting bait stations (NSW National Parks and Wildlife Service 2001).

II. If replacement baiting is undertaken, the minimum interval between bait uptake and replacement should be 3-4 days. Given that continual replacement of free-feed bait increases the potential for caching, the continual replacement of toxic bait may also encourage caching by increasing the availability of bait to individual foxes. In the current study, removed baits were replaced daily; this may have resulted in learning by resident foxes. The majority of toxic caches that were consumed were retrieved within 4 days of their initial removal from the bait station; this retrieval is likely to be by the fox responsible for making the cache. Therefore, changing the currently recommended replacement interval of 3-4 days to the minimum interval may reduce the potential of individual foxes to access multiple baits. This may assist in reducing the number of baits cached, improving the safety and cost-efficiency of baiting campaigns.

III. Bait stations should be spaced at greater intervals than the minimum 100 m specified (Environment Protection Authority 2002). Distances between stations in this study were 200 m but this still appears insufficient to reduce multiple bait uptake. Distances of 400-500 m may reduce this occurring, but proposing this as the minimum distance may be restrictive for smaller properties, or for areas where prey are clumped (e.g. lambing paddocks). Increasing the minimum distance to 200 m but recommending a 400-500 m interval would be a suitable compromise.

IV. Where possible, the most palatable bait should be presented to reduce the potential for caching and hence, caching-associated problems. Using palatable bait has also been shown to increase the cost-effectiveness of baiting campaigns. However, the most appropriate bait type for baiting campaigns will depend on the campaign duration, replacement strategy, and approach to caching.

8.6 Specific recommendations for future research

1. Several aspects of baiting should be investigated as a priority. These are specifically:
   a. The difference between caching of toxic bait relative to non-toxic bait to determine if it is due to reduced palatability or death of the individual responsible for making the cache. Comparisons between toxic bait and non-toxic bait need to be continued to ensure that addition of 1080 is not reducing palatability.
   b. The influence of presentation method on caching behaviour, specifically testing buried bait (conventional and mound) and surface laid bait.
   c. The influence of resource availability, as determined by bait density, bait placement and bait spacing, and the effect upon caching behaviour.

2. The use of CTA to reduce multiple bait uptake requires refinement to improve its practical application. The most important issue to resolve is the detectability of the conditioning agent. Given that poisoning is likely to continue as an important technique in the management of exotic species, further development of CTA could potentially improve the efficiency and cost-effectiveness of poisoning practices for a range of exotic species. This potential range of applications, and the encouraging trial results to date strongly indicate that research into improving our understanding and practical application of the technique should continue.

3. Aerial baiting should be considered in eastern Australia to improve our ability to cover large areas rapidly. However, a thorough assessment of all the costs and benefits of such a technique, including non-target issues, would be required, given that the rate of bait uptake by foxes is likely to be lower, and bait density would have to be increased relative to ground-baiting.

4. Decision tree modelling should be further developed to encompass a variety of likely scenarios and factors in exotic species management to assist practitioners in choosing between alternative strategies. Given the increasingly pecuniary nature of exotic

species management, such modelling should incorporate economic analyses of management practices.

5. Further investigation and/or consideration of the impact of management strategies on the prey population, in addition to the impact upon the exotic species, is needed to assist in formulating more appropriate exotic species management strategies. This would help to ensure that valuable resources for exotic species management are allocated strategically, where they are needed most. Such an approach is imperative where only limited resources can be allocated to managing the ever-increasing issues associated with exotic species.