**Effect of British hunting ban on fox numbers**

**Baker et al., 2002**

Pressure to ban the hunting of foxes with hounds in Britain has fueled debate about its contribution to the control of fox populations.

the ban had no measurable impact on fox numbers

The arguments are that the number of foxes killed by hunting is relatively small, and therefore that hunting has little influence in regulating population size3, and conversely that hunting is important for limiting fox numbers

The main fox-hunting season in Britain runs from November to March/April; cub hunting lasts from August to October, and ‘problem’ foxes are targeted after the main season.

Does culling reduce fox (Vulpes vulpes) density in commercial forests in Wales, UK?

Baker & Harris, 2006

The agency responsible for the management of forests in upland Wales, UK, has permitted the killing of foxes (Vulpes vulpes) on their land as a “good neighbour policy” with the aim of reducing fox numbers.

the use of dogs to drive foxes to a line of waiting shooters; a small number of foxes were also killed by shooting at night with a rifle.

Fox faecal density counts were conducted in commercial forests in Wales in autumn 2003 and spring 2004.

The over-winter change in faecal density was negatively related to the proportion of felled land and the proportion of land more than 400 m altitude, these associations probably reflecting reduced food availability.

Over-winter change was positively associated with culling pressure (i.e. more foxes were killed where more foxes were present, or vice versa), but this was not significant. The number of foxes killed was large relative to the estimated resident population, but losses appeared to be negated (most likely) by immigration.

there was no evidence to suggest that culling reduced fox numbers.

Faecal transect surveys (Baker et al. 2002; Webbon et al. 2004) were undertaken in 44 Forest Enterprise forests (Fig. 1) between 1 October–12 November 2003 (autumn) and 3 March–13 April 2004 (spring)

Faecal counts have been shown to be a reliable index of abundance in fox species in terms of comparisons between spatial locations (Cavallini 1994) and to reflect changes in fox numbers between seasons (Sharp et al. 2001). In addition, estimates of absolute abundance derived from faecal counts have been shown to correlate well with estimates derived from other methods in the UK (see Webbon et al. 2004).

Spring faecal density was positively related to the area of coniferous woodland aged 1–30 years,

This relationship is likely to be related to changes in stand structure affecting the increased availability of prey groups such as small rodents and rabbits

with known patterns of food availability. For example, recently cleared land is likely to hold lower densities of small mammals because of the lack of cover (Fernandez et al. 1994; Ecke et al. 2002), and rabbit and field vole (Microtus agrestis) abundance tend to decrease with increasing altitude (Adamczewska-Andrzejewska 1999; Trout et al. 2000).

The over-winter change in faecal density was not significantly associated with culling pressure. In fact, faecal density declined from autumn to spring (C-negative, SSPRING<SAUTUMN) at low levels of culling and increased (C-positive, SSPRING>SAUTUMN) with increased culling pressure.

more foxes were killed where more foxes were present or vice versa. Therefore, there is little evidence to suggest that culling in these forests exerted a significant negative effect on fox numbers.

The most likely explanation for this failure to reduce the size of the predator population is immigration from neighbouring areas.

These systems tend to be typified by two properties: (1) the number of animals culled on individual properties can dramatically exceed the carrying capacity for that property, and (2) even where large numbers are killed, this can still result in no or only a temporary reduction in fox numbers (e.g. Kinnear et al. 1998; Reynolds et al. 1993; Thomson et al. 2000; Burrows et al. 2003; Summers et al. 2004).

Over-winter culling of foxes is likely to be particularly ineffective, as this is coincident with the main period of dispersal, and dispersing foxes can move considerable distances (Trewhella et al. 1988), so recolonization is likely to be rapid and occur over a large spatial scale.

Habitat-related characteristics and not culling pressure were the best indicators of change in fox faecal density and spring faecal counts in the study forests. Those habitat characteristics associated with these variables were consistent with known patterns of food availability.

Further consideration should also be given to the possible effects of culling in exacerbating levels of damage. For example, the perturbation of populations and amplifying patterns of movement is known to exacerbate the transmission of diseases (e.g. Donnelly et al. 2003;M. Vervaeke, unpublished data), and immigrating individuals may also exert higher levels of predation relative to resident individuals (Althoff and Gipson 1981; Frank and Woodroffe 2001).

**Demography of rural foxes (Vulpes vulpes) in relation to cull intensity in three contrasting regions of Britain**

**Heydon et Reynolds, 2000**

Although a local (< 10 km2) impact has been accepted, previous authors have denied that culling has any impact on a larger scale because local losses are compensated through immigration. Rather, it has been claimed that at this scale fox density is determined by resources, mediated through social behaviour and breeding suppression.

We conclude that the impact of culling in different regions of Britain is variable, dependent on the regional prevalence, methods, and history of culling. However, it is clear that in a range of circumstances culling can substantially depress fox numbers, and that current fox densities reØect a history of culling.

It has been demonstrated experimentally (Tapper, Brockless & Potts, 1991; Reynolds, Goddard & Brockless, 1993) that local (< 10 km2), seasonal (March±September) culling of foxes (amongst other predator species) can substantially reduce predation by foxes even if its impact on fox numbers is likewise local and temporary. It remains unclear whether on a larger geographical scale (`regional', regions > 1000 km2) fox numbers are inØuenced by widespread culling effort.

Pye-Smith (1997) estimated that collectively gamekeepers, fox hunts, farmers and others kill 190 000 foxes annually in Britain, a Ægure that is unavoidably speculative and which Baker & Harris (1997) claim is a signiÆcant underestimate.

Biological studies of fox populations and culling have given rise to mixed conclusions. Hewson (1986) concluded that culling in Scotland during the 1970s was unable to prevent regional population increases, and Macdonald & Johnson (1996) argued that culling by one widespread method (hunting with hounds) was not sufÆcient in itself to achieve regional suppression. Baker & Harris (1997) denied that present-day culling intensity was sufÆcient to suppress fox abundance, claiming that foxes `regulate their numbers naturally' and that `fox numbers are in balance with their food supply'. On the other hand, Harris & Smith (1987) concluded that fox culling in London (1580 km2) on behalf of Borough Councils reduced the adult breeding population by 20% and juvenile survival by 12%.

Furthermore, many authors (Lloyd & Jensen, 1976; Lindstro» m, 1982; Harris & Smith, 1987; Macdonald, 1987; Reynolds & Tapper, 1995) have concluded that anthropogenic mortality, whether deliberate or accidental, was the commonest cause of death in foxes.

Productivity differed signiÆcantly between regions and only in region B was there evidence of lowered productivity normally associated with competition for resources.

Population dynamics of foxes during restricted-area culling in Britain: Advancing understanding through state-space modelling of culling records

Porteus et al, 2019

Lethal control iswidely employed tosuppress the numbers oftarget wildlife species within restricted management areas. The success ofsuch measures isexpected tovary with local circumstances affecting rates ofremoval and replacement.

In Britain, red fox (Vulpes vulpes) populations are culled within the confines of shooting estates to benefit game and wildlife prey species. We developed a Bayesian state-space model for within year fox population dynamics within such restricted areas and fitted it to data on culling effort and success obtained from gamekeepers

informative priors for key population processes—immigration, cub recruitmentand non-culling mortality–that could not be quantified inthe field

All estates achieved suppression of the fox population,with pre-breeding fox density on average 47% (range 20%–90%) ofestimated carrying capacity. As expected, the number of foxes killed was apoor indicator of effectiveness. Estimated rates of immigration were variable among estates, but in most cases indicated rapid replacement of culled foxes so that intensive culling efforts were required to maintain low fox densities.

During the critical March-July breeding period, mean fox densities on all estates were suppressed below carrying capacity, and some maintained consistently low fox densities throughout this period.

enefits may be evidenced by showing increased prey survival or breeding success where predators are culled, but because of variation in these parameters by site and year, unequivocal demonstration of the effect of predator control requires acostly experimental approach

The fact that predator culling benefits prey in one context does not imply that itwill do so in another.

Predator-removal experiments generally avoid the use of research techniques that might interfere with the outcome, and consequently provide little detail on the human-predator-prey interactions that contribute to their success or failure.

Acommon perception isthat culled predators are rapidly replaced through immigration, and this isused to argue both the futility of predator control, and its difficulty and importance [6–9]. With few exceptions (e.g. mink [10]) almost nothing isknown of the dynamics of predator numbers during control efforts.

red foxes (Vulpes vulpes) are commonly culled within the boundaries of game-shooting estates or wildlife reserves, with the aim of suppressing fox density locally

At larger, regional scales (>1,000 km2)there isconsiderable variation in fox density and demographics attributable to regional differences in food availability and fox culling intensity

Cull data from individual estates suggest that the rate at which culled foxes are replaced by immigration may vary greatly among estates due to local circumstances

Most established field methods to estimate population density and demographic parameters (e.g. mark-recapture), have limitations when applied at the local scale, or in the rapidly changing situation expected where culling isintensive and replacement of culled animals through immigration israpid. In these circumstances, index methods

Previous modelling of culled fox populations on restricted areas has shown that immigration was important on those sites studied. Lieury et al. [7] sought to explain observed removals from culling by fitting models accounting for immigration to fox densities estimated from costly site-specific surveys. Harding et al. [23] and McLeod and Saunders [24] used parameter values from the literature to reconstruct fox populations with density similar to those observed, then inferred the rate of replacement which explained the known removals.

daily records in apro-forma diary of lamping effort; foxes seen; and foxes culled (categorised by culling method). These data allowed calculation of lamping detection rate for use as an abundance index.

This required us to aggregate the data. Modelling data on too short atime step (e.g. daily) would result in an over-parameterised model that would exhibit prohibitively slow convergence

The lack of age- or sex-structured information in the culling data limited our choice of population dynamics modelling approach, i.e. matrix models were unsuitable.

In Britain, most cubs are born between midMarch and mid-April

We assumed a50:50 sex ratio with all females breeding, and that productivity was similar across ages.

Culling was expected to be asubstantial additive component of overall fox mortality [13], but local fox density will also be determined by non-culling mortality factors including natural risks, e.g. from disease or starvation, and non-natural risks, e.g. from road traffic collisions or secondary poisoning

oth recruitment of weaned cubs and net immigration into the observable fox population were assumed to be density-dependent processes

density-dependence in seasonal reproduction and/ or immigration was modelled using logistic terms with acarrying capacity, K, describing the fox density above which no cubs are recruited and there isno immigration into the population.

The contribution of estimated non-culling mortality to total mortality was small relative to the culling mortality on all estates

Cumulative non-culling mortality typically exceeded carrying capacity after about four years, which given our model assumptions implies apopulation turnover of four years in the absence of culling.

Indeed, the responses of the population to removals, e.g. through compensatory immigration, may result in control being ineffective and inefficient.

the estimated immigration rate on some estates was particularly high. The immigration rate parameter is a maximal rate, reflecting the maximum number of foxes that would move onto the estate if the fox density was maintained near zero throughout the year.

landscape alone is not a satisfactory predictor of regional fox density in Britain

The impacts and management of foxes Vulpes vulpes in Australia

Saunders et al, 2010

The successful introduction of the red fox Vulpes vulpes into Australia in the 1870s has had dramatic and deleterious impacts on both native fauna and agricultural production.

Recent analyses suggest that native fauna can be successfully reintroduced to their former ranges only if foxes have been controlled, and several replicated removal experiments have confirmed that foxes are the major agents of extirpation of native fauna. Predation is the primary cause of losses, but competition and transmission of disease may be important for some species.

In agricultural landscapes, fox predation on lambs can cause losses of 1–30%; variation is due to flock size, health and management, as well as differences in the timing and duration of lambing and the density of foxes

baiting can reduce fox activity by 50–97%. We review patterns of baiting in a large sheep-grazing region in central New South Wales

he variable reduction in fox density within the baited area, together with the ability of the fox to recolonize rapidly, suggest that current baiting practices in eastern Australia are often ineffective

foxes were favoured in this area by the availability of both open pastures and denser shrub cover for shelter, but establishment was probably facilitated primarily by the earlier introduction and spread of the European rabbit Oryctolagus cuniculus (Long 1988).

The impacts of foxes on poultry and livestock were recognized within a few years of their establishment.

The only positive ecological impact of the fox that has been reported in the literature is its role in the regulation of rabbit populations; this is thought to be significant, but only at low to medium rabbit densities (Catling 1988, Newsome et al. 1997).

Three factors are likely to have assisted the establishment of the fox in Australia.

the fox occupies the largest geographical range outside Australia

It is therefore climatically adaptable, and much of the southern mainland of Australia and Tasmania are within its preferred climatic range.

the fox is ecologically flexible, as demonstrated throughout its global range; it exploits divergent habitats ranging from dense forest to desert, alpine and suburban landscapes, and consumes an enormous range of live prey, carrion and plant material (Macdonald 1987, Corbet & Harris 1991)

population densities in Australia range from 0.2 to 7.2km2 in rangelands, timbered areas and temperate grazing areas, up to 12km2 in suburban Melbourne (Saunders et al. 1995)

humans had modified large areas of the Australian environment by the second half of the nineteenth century, making it even more suitable for foxes to survive and spread. Rabbits had become established

Native Australian species did not evolve with the fox and hence have few fox-specific predation avoidance strategies (Salo et al. 2007)

active suppression of the dingo Canis lupus dingo in much of south-eastern Australia throughout the 1860s, and earlier, would also have reduced the chance of foxes succumbing to competition or predation upon their arrival (Glen & Dickman 2005).

the red fox eats native Australian fauna: representatives of all five vertebrate classes and many invertebrates are included in its diet (e.g. Newsome & Coman 1989, Saunders et al. 2004, Mitchell & Banks 2005)

the first arrival of the fox at a locality usually coincided with the decline and disappearance of conspicuous, medium-sized marsupials (White 1952, Leake 1962, Jenkins 1974)

Species that were once widespread and common and are now extinct or rare on the Australian mainland, still survive in numbers on offshore islands not colonized by foxes (Burbidge & Manly 2002, Short et al. 2002).

Observations such as the above suggest that foxes have strong negative effects on native fauna, but, because they do not rule out plausible alternative explanations (e.g. predation by cats, impacts from rabbits, overgrazing and loss of habitat), cannot be taken as unambiguous evidence of impact.

Reintroduction programs frequently fail because of fox predation (Short et al. 1992).

Short et al. (1992) documented a success rate of just 8% if foxes and other predators were present, compared with 82% when they were absent.

Controlled and replicated field manipulations have revealed that populations of several native species increase quickly after the removal of foxes

Banks (1999) found no evidence that removing foxes affected populations of either bush rats Rattus fuscipes or Antechinus spp., perhaps because foxes ate animals that contributed little to effective population size, while Mahon (1999) reported weak effects on the numbers of sandy inland mice Pseudomys hermannsburgensis.

apparently because numbers of feral cats Felis catus increased, and cats replaced foxes as the dominant predator (Risbey et al. 2000).

Competition and transmission of disease from foxes are the two additional processes most likely to affect native fauna, although direct evidence for either process is weak

foxes contribute to both interaction chains and interaction modifications

depletion by foxes of herbivore populations ‘releases’ vegetation from grazing pressure, and so facilitates populations of preferred forage species (Newsome et al. 1997).

Further interaction chains can be expected if foxes remove functionally important species from the environment. For example, depletion by foxes of pollen vectors such as small mammals and honeyeaters (passerine birds) could be expected to reduce pollination and seed production, and hence slow plant recruitment (Dickman 2006).

By contrast, foxes have been identified as major vectors of the seeds of exotic and invasive plants (Twigg et al. 2009)

In suburban and agricultural landscapes, human activity provides foxes with extra food (e.g. at rubbish tips, dead livestock, dead kangaroos) and abundant shelter.

fox predation events have regularly been reported on lambs, kids, piglets, calves, cows in birthing difficulties, deer, ostrich and emu chicks, and free-range poultry, including chickens, ducks, geese and turkeys (Saunders & McLeod 2007).

Dietary studies in Australia suggest that foxes do not eat freshly killed livestock as commonly as they eat carrion, notably sheep and lamb carcasses, particularly in winter (Catling 1988).

The fox in rural Australia carries no diseases of serious economic or public health significance

In 2004, foxes were estimated to cost the Australian agricultural industries and the environment in excess of $AUS227 million annually (McLeod 2004), topping the list of costs incurred by introduced vertebrate pest species.

The most commonly used fox control technique is lethal baiting, followed by shooting, trapping, den fumigation, den destruction and exclusion fencing (Saunders et al. 1995, West & Saunders 2003). Fertility control through immunocontraception has also been investigated as an alternative or supplementary means of fox control (Bradley et al. 1997), as has chemical fertility control (Marks et al. 1996, Marks 2001).

Research focused on two main systems that would deliver antigens to induce an immunocontraceptive response: bacterial vectors and recombinant viruses including vaccinia and canine herpes virus (CHV; Brochier et al. 1990, Reubel et al. 2001).

shooting is labour intensive, especially as fox density decreases, and there is also evidence that shooting can selectively target juvenile foxes because more wary, older animals often escape (Englund 1980, Coman 1988, Parker 2002).

It is also ineffective at reducing populations significantly, particularly in the longer term, due to rapid immigration and demographic compensatory processes (Coman 1988, Newsome et al. 1989 Fleming 1997).

no study linking the shooting of foxes to environmental recovery has yet been reported in the scientific literature (McLeod et al. 2008).

Options include local eradication, sustained management and no control (Saunders et al. 1995).

Local eradication is an option potentially suitable for islands. Tasmania, Kangaroo Island, and a number of small islands off the coasts of South Australia and Western Australia are the primary refuges of mammal species that are extinct or very rare on the mainland (Dickman 1992, Burbidge & Manly 2002).

The other case for local eradication involves the use of exclusion fencing. Many Australian governments and private conservation organizations now rely on this technique for in situ protection or reintroduction of threatened species (Moseby & Read 2006). These sanctuaries, which are becoming numerous across Australia, can be spectacularly successful in enhancing the survival of selected species within the critical weight range (CWR) for fox predation. However, it remains unclear if they are serving as open range zoos for a small number of iconic species, or if they are preserving ecosystems and wildlife assemblages in a fox-free environment.

Sustained management involves an initial widespread and intensive control campaign to reduce fox populations followed by maintenance control (sometimes equivalent to the initial campaign) to prevent fox population recovery.

The relationship between hunting methods and sex, age and body weight in a non-trophy animal, the red fox

Tryjanowski et al, 2009

knowledge of potential sources of bias in these kinds of data is lacking

Taking account of seasonal differences in hunting methods used, shooting assisted by beating gave a higher proportion of male foxes, whereas individual hunting resulted in smaller foxes in shot samples. Hunting with dogs resulted in heavier female foxes, with the results being skewed towards females

he recent discussion on red fox hunting in the popular media has been emotive and polarised, with animal welfare and animal rights groups on one side, and hunters and pragmatic conservationists on the other

hunting represents a major source of mortality in many red fox populations (Goszczynski 1989; Aebischer et al. 2003; Ewald et al. 2006).

in recent decades the numbers of red foxes have increased rapidly in parts of Europe, often as a consequence of vaccination programs following an outbreak of rabies, human abandonment of the countryside and dump proliferation (Chautan et al. 2000)

Males would be more likely to be shot by all methods because they are more mobile than females and, moreover, because females spend a longer time in safe places such as dens

The methods were not used equally throughout the year. Hunting with beating and hunting with dogs were more popular in winter, when foxes are both more likely to be encountered and more easily tracked because of prints

**Lessons from long-term predator control: a case study with the red fox**

**Kirkwood et al., 2014**

Predator-control aims to reduce an impact on prey species, but efficacy of long-term control is rarely assessed and the reductions achieved are rarely quantified.

the changing efficacy of a 58-year-long campaign against red foxes (Vulpes vulpes) on Phillip Island, a 100-km2 inhabited island connected to the Australian mainland via a bridge. The campaign aimed to eliminate the impact of foxes on ground-nesting birds, particularly little penguins (Eudyptula minor).

The campaign began as a bounty system that ran for 30 years and was ineffective. It transitioned into a coordinated, although localised, control program from 1980 to 2005 that invested considerable effort, but relied on subjective assessments of success. Early during the control period, baiting was abandoned for less effective methods that were thought to pose fewer risks, were more enjoyable and produced carcasses, a tangible result. Control was aided by a high level of public awareness, by restricted fox immigration, and by a clear, achievable and measurable target, namely, to prevent little penguin predation by foxes.

In 2006, the campaign evolved into an eradication attempt, adopting regular island-wide baiting, and since then, has achieved effective knock-down of foxes and negligible predation on penguins.

Conclusions. Effective predator control was achieved only after employing a dedicated team and implementing broadscale baiting. Abandoning widespread baiting potentially delayed effective control for 25 years. Furthermore, both predator and prey populations should be monitored concurrently because the relationship between predator abundance and impact on prey species is not necessarily density dependent.

They have contributed to population declines and extinctions of native fauna (Dickman 1996; Kinnear et al. 2002) and severely affected livestock industries (Rowley 1970).

Several short-term studies have correlated reductions in fox sign with immediate increases in prey abundance (Banks et al. 1998; Harding et al. 2001)

Foxes readily travel tens of kilometres in a night (Voigt and Macdonald 1984; Goszczynski 1989; Adkins and Stott 1998) and can migrate further to establish in unoccupied territories (Trewhella et al. 1988). Where fox immigration is restricted, control actions tend to have a more lasting effect (Lokemoen and Woodward 1993; Ebbert and Byrd 2002; Kinnear et al. 2002). Generally, only sustained and intense control efforts supress fox populations (Heydon et al. 2000; Harding et al. 2001).

The minimum number of foxes known to be alive (KTBA) climbed between 1994/95 and 1999/2000, despite intensive efforts to remove foxes.

There was no clear trend toward a reduction in penguin kills during daytime searches until 2008/09, from when just two penguins were killed by foxes in a 3-year period

The early attempts of fox control on Phillip Island reflect a history of failures in fox-control methods more generally found in Australia.

The vulnerability of penguins to fox predation and the economic value of penguin tourism meant that fox control received the support and focus it ultimately needed to be effective. However, the control program relied on subjective interpretations of efficacy, which led to the incorrect conclusion that foxes were under control and that harvesting foxes was useful

Monitoring of little penguins on Phillip Island suggested that the impact of foxes was being reduced during the 1980–2006 foxcontrol program; however, it did not eliminate the depredation of penguins. Little penguins continued to be killed in large numbers because, even at lowered densities, individual foxes could surplus kill many birds

The program goals changed from fox control to eradication, once it was recognised that the number of penguins killed was not reduced in a density-dependent relationship with foxes.

Restricting fox immigration allows single control efforts to sustain population reductions for longer than would be possible if migration was open (Algar and Smith 1998; Risbey et al. 2000)

In our case study, urban foxes may not be subjected to effective control and further development is required for effective and safe control techniques in urban environments.

**Slow recruitment in a red-fox population following poison baiting: a non-invasive mark–recapture analysis**

**Berry et al., 2014**

non-invasive DNA sampling of fox hairs in semi-arid Western Australia where the population was subject to two episodes of aerially delivered sodium fluoroacetate (1080) poison baits within 12 months. Sampling took place at ~45-day intervals and individual foxes were identified by genotyping eight microsatellite DNA markers and a genderspecific marker. Open-population and spatially explicit mark–recapture models were used to estimate the density, apparent survival and movements of foxes before and following baiting.

Baiting with 1080 poison significantly reduced the density of foxes, and the low density was sustained for more than 6 months. Foxes moved significantly further between recaptures after baiting when at low densities.