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The effects of an annual cull on the sett usage patterns of the Eurasian badger *(Meles meles)*

Submitted by Samuel Alan Marles, to the University of Exeter as a dissertation for the degree of Masters by Research in Biosciences, October 2011.

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Contents

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Literature Review: Wildlife Disease Management

Abstract

This review is a case study based review on the effectiveness of wildlife disease management strategies implemented for three separate reasons; to protect humans, to protect livestock, and for the protection of endangered species. The review highlights successful and un-successful attempts to control diseases in wildlife and emphasises the lessons that have been learned or that need to be learned for the advancement of wildlife disease management.

Introduction

Wildlife disease management is a broad phrase used to describe all manner of methods for fighting diseases, for a variety of different reasons. The sector is rapidly growing due to the realisation of the economical and health benefits of evaluating and fighting wildlife infections (Artois et al, 2001).

The definition of a disease is an impairment of normal functions; however this review will focus on the infectious diseases. Infectious diseases are diseases that can be passed from one individual to another individual excluding heritable diseases, usually via a medium, such as air for the case of tuberculosis or via saliva as for the case of rabies (Buddle et al, 2006, WHO, 2008). Infectious diseases can be split into two groups, the macroparasites, containing the multi-celled pathogens, and the microparasites which include bacteria, viruses and fungi (Hudson et al, 2002). Diseases can have many effects on the infected host ranging from simply being a vector for a disease, to potential lethal consequences. There are thousands of known diseases, with 1,400 found in humans alone. Up to 60% of these diseases are zoonotic, and although the diseases of wildlife are an important part of disease transmission, little is known about the ecology of these pathogens (Delahay, 2009).

Whilst diseases almost invariably cause a decrease in the welfare of the animals they infect, they are a natural part of ecosystems, and therefore should not necessarily be removed. This is an essential point for wildlife disease managers, and evaluations of such factors as health issues, economic effects or conservation aims need to be weighed up with the potential success of the management plan. This is true of most diseases infecting wildlife, however there are many cases where human interference is necessary, and a definite benefit for implementing management strategies is predicted (Artois et al, 2001). These situations tend to be skewed, as management plans are more often implemented when there is a benefit to humans, either through improved health or the reduction of economic costs. These are the diseases that tend to have the most concerted management effort applied, due in no small part to the extra funding accrued (Pastoret and Brochier, 1998). These strategies can improve wildlife welfare, however there are no doubts the main benefactors are people and their investments. Situations when strategies are devised for the exclusive benefit of wildlife tend to be emergency measures for the protection of endangered species when the management of wildlife diseases is key to the survival of the species (Randall et al, 2006).

Once the decision has been taken to manage a disease, the target of the management plan must be decided. The three targets are the host population, the environment or targeting the pathogen itself (Delahay, 2009). Practically, there is a greater chance of success if targeting a combination of all three. There are multiple methods that convey varying efficacy depending on the target, from the culling of the host population, to more novel vaccination programmes as two such examples (see Donnelly et al, 2006, Cross et al, 2007). Each situation requires a tailor made solution, meaning all the factors and the predicted results must be examined before deciding on a course of action.

Three of the major reasons for implementing control measures are for the protection of humans against zoonotic diseases, the protection of livestock or the protection of endangered species. These three reasons are reviewed with appropriate case studies, highlighting the successful and unsuccessful control measures.

Protection of humans

Humans are vulnerable to a number of zoonotic diseases, and this has played a major part in the development of modern wildlife management techniques. There are a number of diseases that occur as a reservoir in wildlife species and can regularly be spread to humans. These diseases are certainly a risk to human health and were one of the first types of disease to be targeted. The rabies virus is a prime example of this.

Rabies was first recorded from around 1900 B.C and has been an ever-present threat around the world ever since (Dunlop and Williams, 1996). Rabies is a neuroinvasive virus that causes acute encephalitis of the brain and can infect any warm blooded animal, though typically the canids are most susceptible to the virus (Bacon and Macdonald, 1980). It is transmitted zoonotically, usually via a bite from an infected individual, and is nearly always fatal if not treated before symptoms begin to show. 55,000 people per year die from rabies (WHO, 2008).

Traditionally the rabies virus has been found in the domestic dog *(Canis familiaris)*, more recently in Europe a strain of sylvatic rabies has developed. This strain of rabies is thought to have developed on the Polish-Russian border in 1939 and spread at a rate of 20-60km per year until the virus became endemic to the vast majority of the red fox *(Vulpes vulpes)* population in Europe (Pastoret and Brochier, 1998). As well as the obvious implications for the fox population, there was also a serious human health risk, as the cases of human rabies began to steadily increase.

European governments decided to attempt to control the disease, and as with most early cases of managing wildlife diseases, the first method tried was culling, aiming to reduce the density of the fox population so that on average each rabid fox would only infect one susceptible fox (Smith and Harris, 1989). This critical density was estimated to be between 0.25 and 1 adult fox/km^2 (Anderson et al, 1981).There were some successes with fox culling, such as the case of the culls that took place on the border between Denmark and the former Federal Republic of Germany in the late 1970’s. Here the Danish government implemented a quarantine zone of 60km^2 and the authorities were able to prevent the spread of rabies into Denmark, managing to lower the number of infected animals from its peak of 165 in 1979 to only 37 in 1980 (Westergaard, 1982). On a continental scale, this method was ineffective due to being vastly cost inefficient due to the geographical spread of the disease, the inability to cull large-scale over certain regions, and the fact that culling produced only a transient reduction of rabies. The method was replaced in the mid-1970’s by the novel idea of oral vaccination programmes.

Oral vaccination was first tested in 1975, and critically it was shown that oral route vaccination could lead to resistance in canids. The original vaccine proved to have a lack of efficacy, and so by 1986 the recombinant vaccinia-rabies glycoprotein virus (VRG) was developed (Pastoret and Brochier, 1998). This vaccine proved to be more efficient at conferring resistance than the original vaccine, furthermore, it was discovered that the vaccine was safe in non-target species and could easily be incorporated into wildlife baiting strategies. This led to the first widespread field trials in Southern Belgium. Mathematical models carried out estimated that a threshold uptake of 75% was needed to prevent any further epidemics. The uptake was found to be 81% in the fox population, far higher than the proposed threshold (Brochier et al, 1995). After the successful field trial, 8.5 million baits were dropped over Europe, and subsequently large parts have now been declared rabies free (Cross et al, 2007).

This strategy proved very successful in reducing the risk of infection to humans, achieving its primary aim of reducing the rates of infection in humans. The success of this vaccination is in no small part to the development of an effective oral vaccine. This initial success paved the way for a full-scale vaccination campaign and due to the potential benefits of the programme and the relative wealth of the European countries, the programme was well organised. In many ways the oral bait vaccination scheme was a benchmark for the vaccine projects, and gave a good model for future vaccination programmes. This example showed the prudency of planning an effective campaign, whereby an effective strategy was devised and followed to a high standard. The early planning stages were essential to the success of the strategy, because there was a unified direction throughout the programme, meaning that the appropriate procedures were performed correctly, vastly increasing the chance of success. Of course, most projects do not command the financial clout of the rabies vaccination programme, but this programme still stands up as one of the most meticulously and cohesively planned strategies, and the benefits of such planning were obvious at the culmination of the programme.

Protection of Livestock

Livestock has long been heavily affected by the transmission of diseases from wildlife, not only because most diseases are zoonotic, but also because there is very little control over the interactions between livestock and infected wildlife (Woodroffe, 1999). This is a major problem for the agricultural industry causing untold economical damage. As an extreme economical problem, there are many cases of the control of wildlife diseases with the primary aim of reducing the levels of infection in livestock.

The case of bovine tuberculosis (bTb) infection in the Eurasian badger *(Meles meles)* in Great Britain is a prime example of this. The causative agent of bTb is *Mycobacterium bovis*, an aerobic slow-growing bacterium that can cross inter-species barriers. It has been suggested that the main wildlife reservoir of the disease in Britain is the badger, with cattle *(Bos primigenius)* being particularly susceptible to the disease (Cross et al, 2007). In Britain the disease is geographically localised, but due to governmental policy of culling cattle with confirmed bTb and the subsequent compensation schemes and the imposition of trade restrictions upon infected farms, lends it large economic significance. BTb is also localised within the badger population, and the areas of infected badgers and infected cattle overlap, suggesting that badgers can potentially pass the infection onto cattle (ISG on cattle Tb, 2007).

The British government has been fighting the disease in badgers since the mid-1970's, with the first method implemented being a cull to reduce badger numbers. The culling regimes of the 1970's and 1980's followed a similar pattern, whereby badgers were culled within a certain radius of a confirmed case of bTb in cattle (Krebs, 1997). This was very much a reaction to the disease, and these strategies appear to have reduced the levels of cattle bTb in these areas; however bTb returned within years after the cessation of culling. The publication of the Krebs report (1997) recommended that a widespread culling trial should be implemented. The Randomised Badger Culling Trial (RBCT) was planned.

The aim of the trial was to analyse the effect of badger culling on the incidence of bTb in cattle. The trial procedure was to form ten triplets consisting of: a pro-active culling area where all badgers were culled regardless of bTb incidence, reactive areas where culling was carried out only when there was confirmed bTb incidence in cattle and a control group where no culling was carried out. In the proactive areas, badger activity was reduced by 70%, however the breakdown of the social group structure and territories led to an increase in perturbation (Donelly et al, 2006). It was found that the badger cull caused a higher level of movement over territorial boundaries than previously thought (Pope et al, 2007). So although there was a 23% reduction in the number of herd breakdowns within the proactive culling area, there was an increase of 25% in the number of herd breakdowns in areas bordering the proactive area. In the reactive area, the number of herd breakdowns increased by an estimated 20% (Donnelly et al, 2006). The Independent Scientific Group (ISG), which oversaw the RBCT, concluded that the economic costs of the cull were forty times higher than the economic benefits derived (ISG on cattle bTb, 2007). Mixed results and the unpopularity towards culling with the British public caused the cessation of the culling programme, with the government implementing a new vaccination policy.

At the time of writing the oral bait vaccine for *M.bovis* is in its early stages of development, both in the development of a vaccine that can survive the digestive system and the development of a suitable vehicle for the vaccine (Buddle et al, 2006, Cagnacci et al, 2007).This has left only one effective deployment method of spreading the vaccine in significant numbers to wild animals, either an intra-muscularly or subcutaneously injected vaccine. The Bacille Calmette-Gué´rin (BCG) vaccine is used extensively for the vaccination of humans against *M. tuberculosis* and in 1994 a joint WHO/FAO/OIE consultative group recommended that a strain of BCG should be used in animal vaccine efficacy studies (Corner et al, 2008). Extensive laboratory tests have since been carried out and it has been shown that not only is the vaccine safe in the badger but also that it confers a degree of resistance to the *M. bovis* bacterium (Lesellier et al, 2006). This led to a field trial to assess safety, and with the expectation that the results will be similar to those reported from the laboratory, the British government has implemented a new vaccination campaign in England to begin in the summer of 2010. The aims of this programme are to learn lessons about vaccine deployment and the generation of a vaccine industry in Britain which could be accepted by farmers as a viable alternative to culling (Defra, 2009).

The example of the badger culls highlights some potential problems with culling strategies for disease control. Firstly, when it was decided that the control strategy was aimed at the host species, the initial reaction was to authorise a culling programme in the anticipation that lowering the host population will lower the incidence of disease. As the RBCT proved, there are more considerations that need to be taken into account in order to effectively manage wildlife diseases, such as the behaviour of the host population (Delahay et al, 2009). The potential for disease transmission through the alteration of the natural behaviour of the host species is often overlooked when devising plans, as shown by this scenario where the management plan led to an increase in perturbation of badgers and dispersed the disease over a larger scale. With the findings of the RBCT, culling was withdrawn as a primary management tool for badgers and bTb. The RBCT should have wider reaching consequences, whereby new management techniques should be considered in situations where the behaviour of the host population is a major factor for the transmission of diseases. Badger vaccination aims to avoid the problems discovered during the RBCT due to the minimal effect that is predicted on badger behaviour.

Solutions can be simpler than having to treat a reservoir of infection; it can be relatively easy to manipulate the environment to minimise contact rates between wildlife and livestock. Levels of contact between livestock and wildlife are crucial to the management of disease, as most diseases currently inflicting livestock are spread through either direct contact with an infected individual or contact with infected excrement, thus if the potential for contact is reduced by the manipulation of the environment, then a reduction in the rates of infection will be predicted.

A good example of this is the case of Chronic Wasting Disease (CWD) in cervid species in the U.S. Deer are farmed for their meat in the U.S, but there is limited control of contact rates between farmed deer and the wild deer that are common throughout the U.S. CWD has been confirmed in farmed populations in 11 states and the disease is present in wild populations of elk *(Cervus elephas)*, mule deer *(Odocoileus hemionus)* and white-tailed deer *(Odocoileus virginianus)* (USGS, 2002). Contact rates between the farmed and wild populations are high in an uncontrolled area; therefore it is essential that the proper barriers are put in place to limit this. An evaluation of different fences was carried out by the U.S Department for Agriculture (USDA) and published advice is now available to guide farmers on the best protection for their livestock, for example, with farmed elk populations it is advisable to have 2 rows of fences, thereby excluding all contact (VerCauteren, per. comm.). These simple measures are extremely valuable in stopping the transmission between the wild reservoir of disease and the valuable farmed cervids.

A comparable situation occurs with the badger in Britain. The Department for Environment, Food and Rural Affairs (Defra) initiated a review into the use of farm buildings by wildlife, finding that many animals including badgers regularly visit farm buildings in search of food (Ward et al, 2006) and there is video evidence of badgers feeding from the same troughs as cattle, less than a metre apart (Ward et al, 2008). The improved husbandry measures recommended by Defra; such as improving barn security, locking up food stores (CSL, 2006), can prevent badgers from entering barns, or deter them and force them to forage in other areas.

These simple measures advised by both the USDA and Defra can drastically reduce the transmission rates of diseases and can therefore negate the responsibilities of having to deal with the reservoir of infection in wildlife. These examples are shown to be effective and therefore are examples to other organisations planning to manage diseases. Simple and cheap measures such as erecting a fence can have long-term consequences on the transmission of diseases. This is pivotal for managing wildlife diseases for the benefit of livestock, because the underlying reason is to minimise any economic effects, and therefore any management plan implemented must be economically viable. Thus, the re-evaluation of a situation may lead to the discovery that implementing simple and cheap measures, such as erecting a fence, can be a far more cost effective strategy than the expensive management strategies for targeting the host population, such as a vaccination programme.

Protection of Endangered species

Endangered species are often the most vulnerable animals to the spread of disease due to low population sizes which make them vulnerable to any environmental changes, and diseases can significantly lower the chance of survival. Thus it is important to constantly monitor endangered species for any indication that there is a threat from disease. Where such a threat does exist then rapid action has to be taken to reduce the potential effects of any disease.

In most scenarios, a species specific disease will not persist in small, isolated populations due to the reduction of the population and therefore the reduction in host density and the greater isolation of the resulting population (Lyles and Dobson, 1993). In cases where endangered species are vulnerable to disease, there is typically a reservoir of disease in a more common species that has the potential to "spill-over" into the endangered species (Woodroffe, 1999, Daszak et al, 2000). This situation is potentially devastating as the disease will be an ever-present threat to the species, regardless of the population density. This is particularly true of endangered wild canids such as the Ethiopian wolf *(Canis simensis)*, due to the fact that these animals share a close common ancestry and high rates of contact with the domestic dog *(Canis familiaris)*, the most common carnivore in the world and a vector for multiple diseases (Randall et al, 2006).

The Ethiopian wolf is a medium sized canid originating in the highlands of Ethiopia. They were once common over the entire region; however now they are limited to only seven isolated Afro-alpine ranges (Marino 2003), an estimated total of 600 adults persist, split between two regions, the Semien Mountains and the larger population of the Bale Mountains National Park. Due to the fracturing of the population and small population sizes, the wolves are particularly vulnerable to rabies spread by feral domestic dogs that live either within or on the borders of the wolves' territory. This has proved the case before, with at least two confirmed rabies outbreaks in the Bale Mountains National Park alone. In 1991-92, 77% of known wolves from 5 study packs died or disappeared (41 of 53) within four months, causing 3 packs to go extinct. Brain samples taken from 3 carcasses recovered tested positive for rabies (Sillero-Zubiri et al, 1996). A second outbreak of rabies occurred in 2003-04, where 76% of known wolves from 10 packs died or disappeared (72 of 95) within six months, again the rabies virus was isolated from 13 of 15 brain samples (Randall et al, 2004).

As mentioned before, spill-over from the domestic dog population is the accepted source of infection with the rabies virus endemic and widespread throughout the domestic dog population (Tefera et al 2002), especially in the neighbouring regions (Johnson et al, 2004). It has been calculated that dog densities varied from 9.5 to 380 dogs/km^2 (Randall et al, 2006), depending on the size of the civilisation, far higher than the calculated threshold for rabies to persist (7.5 hosts/km^2) (Cleveland and Dye, 1995). Wolves normally avoid dogs, though there are observations of dogs chasing and competing for food with wolves and several cases where domestic dogs and Ethiopian wolves have bred to create fertile hybrids (Gotelli et al, 1994). Phytogenetic analyses of rabies virus samples isolated from the two separate outbreaks have showed that the strains were associated with the domestic dog strains of the rabies virus (Sillero-Zubiri et al, 1996, Randall et al, 2004).

Since 1996, the Ethiopian Wolf Conservation Programme (EWCP) began to vaccinate domestic dogs against rabies, with a particular focus in the Bale Mountains National Park. The aim was to reduce the number of susceptible hosts and therefore the chance of dog to wolf transmission. This vaccination programme appeared to be successful, as the number of cases of rabies dropped drastically. Theoretical analyses led to a recommendation that vaccinating 70% of the domestic dog population would stop an epidemic 95% of the time (Randall et al, 2006). However when the wolf epidemic began in 2003-04, the population vaccinated within the last three years (the period of resistance conferred by the vaccine, (Schultz, 1998)) had dropped to an estimated 43% within and adjacent to wolf habitat, far below the threshold calculated. This drop in the numbers of individuals vaccinated was due to the logistical difficulties of vaccinating the domestic dog population, specifically the seasonal movements of the dog population. A trace-back of the 2003 epidemic suggests it was initiated by a rabid dog that was seasonally present in wolf habitat (Randall et al, 2004).

With the onset of the rabies epidemic of August 2003, only one of the isolated populations became infected, and in response to this, the Ethiopian government gave permission for a trial emergency vaccination programme to vaccinate the adjacent wolf populations (Randall et al, 2004). In total, 37% of individuals from 16 packs (36 wolves) in the area adjacent to the outbreak were vaccinated and 48% of the individuals from a long-term study population were vaccinated (36 wolves), beginning with those closest to the disease front. During subsequent follow-up phases, 8 more wolves were given the primary injection, making the total wolves vaccinated as 77 individuals. It is almost certain that the vaccination programme reduced the spread of the disease throughout the wolf population, with individuals dying or disappearing recorded at only a single pack within the vaccine control area. This pack bordered an infected pack and the vaccine programme came too late to protect this pack, only a single member of the pack was vaccinated, this member survived the outbreak. Other than the deaths in this pack, no rabies related deaths were recorded in the vaccine control area, and all but two wolves were present 6 months after trapping, a level below the background mortality rate (Randall et al, 2006).

During later studies, it was discovered that the vaccine only provided resistance to the rabies virus for a maximum of 6 months, and that to provide further cover then follow up vaccines would be necessary (Randall et al, 2006). This has led to it being suggested that the vaccine is only a short-term preventative solution, and that the logistical difficulties in administering booster vaccines to the population would appear to constrict this strategy to emergency response only.

The effect of some diseases can have such a great effect on some endangered species that the only option left may be to capture the remaining animals and begin a captured breeding plan. This is used only as a last resort as the cost and effects on the population often outweigh the benefits to implementing such programmes. The case of the black-footed ferret *(Mustela nigripes)* is a prime example of this.

The black-footed ferret is a critically endangered mustelid found in North America. Its range was once spread right across the continent, but due to reduction of their habitat and specifically the loss of their main prey, prairie dogs, meant the species was reduced to a single known population found in South Dakota (Forrest et al, 1988). This population was under threat from the Canine Distemper virus, a virulent pathogen spread via infected canids (Biggins and Godbey, 2003). This population was discovered in 1964, and in early 1971 the decision was taken to remove the remaining ferrets from the wild to protect the remaining population. 6 animals were originally captured in the mid-1970's, and these were given a modified live virus vaccine previously tested on the closely related Siberian polecat *(Mustela eversmanni)* (Thorne and Williams, 1988). The black-footed ferret proved to be more susceptible to the virus and shortly all 6 animals vaccinated died of CDV (Carpenter et al, 1976). By the end of the 1970's, the South Dakota population had disappeared.

Following the disappearance of the South Dakota population, the black-footed ferret was thought to be extinct until a small population was discovered in Wyoming in 1981. This population was observed between 1981-85, however in late 1985 it was decided that a number of individuals should be collected as an insurance policy. This collection took place in late September and October 1985, where 4 females and two males were collected, however the feared CDV outbreak had already begun to effect dramatic reductions in the wild population, and all 6 captured animals shortly died. In late 1985, an emergency trapping effort began, with all remaining wild ferrets collected. After 1987 no free-ranging ferrets were reported and there were only 18 animals in captivity (Biggins and Godbey, 2003).

Since the beginning of the captive breeding campaign, the story has been a great success; the early birthing numbers were 34, 58, 66 in 1988, 89, and 90 respectively (Dobson and Lyles, 2000). From the period between 1987 and 1999, 3000 ferrets were born in captivity and have subsequently been released into five separate sites. As of 2007, there are 750 wild living ferrets in 7 separate population areas and with the spread of these populations, there is a buffer against any further CDV outbreaks. The black-footed ferret was downgraded from Extinct in the Wild to Globally Endangered as of 2008 (IUCN, 2008), emphasizing the success of this management strategy for the survival of the black-footed ferret.

Whilst the captive breeding project was being coordinated, there was a serious sylvatic plague outbreak detected in the ferrets' main prey, the various species of North American prairie dogs in the spring of 1985. The North American populations of prairie dogs are particularly susceptible to sylvatic plague; it is generally believed that a plague infection causes the complete extirpation of prairie dogs from that location (Barne, 1982). In order to prevent this extirpation, 80,000 prairie dog burrows were individually dusted with insecticide to kill the flea vector of the plague virus. This effort reduced the effect of the plague to a population reduction of only 20% by 1986 (Thorne and Williams, 1988), a far smaller margin than predicted had there been no human intervention.

One of the more recent diseases to occur, and certainly one of the most devastating in terms of its potential impact on the ecosystems of the world, is the infection of amphibian populations with the fungus *Batrachochytrium dendrobatidis* (Bd) (Berger et al, 1999). This fungus is spread throughout the world, and has been linked with the extinction and dramatic population declines of many species (Skerratt et al, 2007) making fighting the disease a priority for conservation groups. Due to the disease being a fungal infection, it removes the ability to vaccinate; and the notion of individually treating every individual is logistically impossible. Currently multiple separate studies are being undertaken as to how best to fight this infection, with potentially important findings for the future of fighting a Bd infection. One such study on Archey's frog *(Leoipelma archeyi)* has shown that the washing of the frogs in a fungicide can eradicate the infection from individuals and is safe for use with this species (Bishop et al, 2009), however the sample sizes are very small and it has been suggested that the fungicide can have some potentially harmful effects, such as inducing leukaemia (El-Mofty et al, 2000).

The fungal infection appears to favour cool, humid conditions and studies have shown that normally susceptible frogs can eradicate the fungal infection when kept at higher temperatures. The study by Woodhams et al (2003) found that experimentally infected *Litoria chloris* cleared their infection when held at 37°C for less than 16 hours, whereas individuals held below 24°C died. Similar results were found with experimentally infected *Pseudacris triseriata*, whereby the individuals cleared a Bd infection if held at 32°C for 5 days (Retallick and Miera, 2007). Although this is not useful for management in the field, it has potential uses for the captive breeding programmes of endangered amphibian species.

Many techniques have been used to limit the impact of diseases on endangered populations, with varying degrees of success. The example of the Ethiopian wolf and the emergency vaccination is a model of how to administer a vaccine, with the due care and the necessary tests being carried out. Not only this, but it also illustrates the usefulness of modelling a disease outbreak because the models provided a threshold frequency for the vaccination of dogs, and therefore provided a preliminary aim for the project. Modelling diseases has been used in a wide variety of cases, and has proven to be a useful tool in predicting the possible effects of a disease outbreak. Many organisations have used this information as a basis for their management plans. The use of retrospective analysis techniques was proved useful for the identification of the rabies virus in a number of corpses discovered. Disease analysis can be essential in managing wildlife diseases for the correct identification of the disease and the identification of the route of infection and can lead to the honing of any management plan.

The failure of basic planning and testing when vaccinating the black-footed ferret caused the extinction of the last known population at the time, and must go down as one of the worst decisions made when attempting to protect a species. Thankfully, the team behind the Wyoming captive breeding programme learned from this mistake, although the delay between the finding of the population and the initiation of the captive breeding programme appears mystifying, and could potentially have caused a second extirpation, resulting with extinction of the species. The novel approach to the protection of the ferrets prey species appears to have been effective, and is something that should be considered for future conservation projects. The research carried out on the Bd fungal infection is still in its early phases, though there is progress being made. There is a fear that the speed with which the disease is spreading and the speed in which the disease kills means that by the time any concerted management technique is developed, it could be too late.

Conclusion

There are many different reasons why diseases are controlled in wild animals, and there are many different techniques as to fighting them. Each separate situation needs to be analysed separately and the potential consequences must be weighed up equally with the costs involved. As described in this review each reason has its own measure of success, for instance in protection of livestock, there has to be an economic benefit, whereas with the protection of endangered species the success is measured in the survival of the population. This leads to differing management strategies used, and differing plans being implemented. A key issue is to plan an effective management strategy and to not rush blindly into a plan. Having said this, in certain situations it is advisable to work with haste, especially when working with endangered species, because delaying could cause catastrophic and possibly irreversible effects to occur.

The measure of success may change, but the effectiveness of a well thought and well-coordinated management plan will always be constant, and will lead to the greatest success.

References

Anderson R.M, Jackson H.C., May R.M., Smith A.D.M. (1981) Population dynamics of fox rabies in Europe, *Nature*, vol. 289, 765-771

Bacon P.J., Macdonald D.W. (1980) To control rabies: vaccinate foxes, *New Scientist*, vol. 87, 640-645

Barnes A.M. (1982) Surveillance and control of bubonic plague in the United States, *Symposium of the zoological society of London*, vol.50, 237-270

Berger L., Speare R., Hyatt A. (1999) Chytrid fungi and amphibian declines: Overview, implications and future directions, In: Campbell *A. (ed), Declines and disappearances of Australian frogs*, Environment Australia, Canberra

Biggins D.E. and Godbey J.L (2003) Challenges to reestablishment of free-ranging populations of black-footed ferrets, *C.R. Biologies*, vol.326, 104-111

Bishop P.J., Speare R., Poulter R., Butler M., Speare B.J., Hyatt A., Olsen V., Haigh A. (2009) Elimination of the amphibian chytrid fungus by Archey's frog, *Diseases of Aquatic organisms*, vol.84, 9-15

Bourne J. (2007) Bovine TB: The scientific evidence, *Independent Scientific group on cattle TB*, London, UK

Brochier B. Costy F. Pastoret P.P. (1995) Elimination of fox rabies from Belgium using a recombinant vaccinia-rabies vaccine: an update, *Veterinary Microbiology*, vol.46, 269-279

Buddle B.M., Wedlock D.N., Denis M. (2006) Progress in the development of tuberculosis for cattle and wildlife, *Veterinary Microbiology*, vol.112, 191-200

Carpenter J.W. Appel M.J.G., Erickson R.C., Novilla M.N. (1976) Fatal vaccine-induced canine distemper virus infection in black-footed ferrets, *Journal of the American Veterinary Medical Association*, vol.169, 961-964

Central Science Laboratory (2006) *An investigation of potential badger/cattle interactions including the extent of badger visitations to farm buildings and food stores, and how cattle husbandry methods may limit these*, Report to DEFRA, DEFRA, London, UK

Cleaveland S., Dye C. (1995) Maintenance of a microparasite infecting several host species: rabies in the Serengeti, *Parasitology*, vol.111, 533–547

Cagnacci F., Massei G., Cowan D.P., Walker N., Delahey R.J (2007) Effects of bait type on uptake by free-living badgers, *Wildlife Research*, vol. 34, 454-460

Corner L.A.L., Costello E., Lesellier S., O'Meara D., Gormley E. (2008) Vaccination of European badgers with BCG by the subcutaneous and mucosal routes induces protective immunity against endobronchial challenge with Mycobacterium bovis, *Tuberculosis*, vol. 88, 601-609

Cross M.L. Buddle B.M. Aldwell F.E. (2007) The potential of oral vaccines for disease control in wildlife species, *Veterinary Journal*, vol.174, 472-480

Daszak P., Cunningham A.A., Hyatt A.D., (2000) Emerging infectious diseases of wildlife: threats to biodiversity and human health, *Science*, vol.287, 443–449

Defra (2009) Badger vaccine deployment project, http://www.fera.defra.gov.uk/wildlife/ecologyManagement/bvdp/, accessed 11/2/10

Delahey R.J., Smith G.C., Hutchings M.R. (2009) *Management of disease in mammals*, Springer, New York, US

Dobson A. Lyles A. (2000) Black-footed ferret recovery, *Science*, vol.288, 985-988

Donnelly C.A., Woodroffe R., Cox D.R., Bourne J., Cheeseman C.L., Clifton-Hadley R.S., Wei G. (2006) Positive and negative effects of widespread badger culling on tuberculosis in cattle, vol.439, 834-837

Dunlop, Robert H.; Williams, David J. (1996). *Veterinary Medicine:An Illustrated History*. Missouri, U.S

El-Mofty M.M., Abdelmeguid N.E., Sadek I.A., Essawy A.E., Abdel Aleem E.A. (2000) Induction of leukaemia in chloramphenicol-treated toads, *La Revue de Sante de la Mediterranee Orientale*, vol.6, 1026–1033

Forrest S.C., Biggins D.E., Richardson L., Clark T.W., Campbell T.M., Fagerstone K.A., Thorne E.T (1988) Population attributes for the black-footed ferret at Meeteetse, Wyoming, 1981-1985, *Journal of Mammology*, vol.69, 261-273

Gottelli D., Sillero-Zubiri C., Applebaum G.D., Roy M.S., Girman D.J., Garcia-Moreno J., Ostranders E.A., Wayne R.K. (1994) Molecular genetics of the most endangered canid: the Ethiopian wolf, *Molecular Ecology*, vol.3, 301–312

Hudson P.J., Rizzoli A., Grenfell B.T., Heesterbeek H., Dobson A.P. (2002) *The ecology of wildlife diseases*, Oxford University Press, New York, US

IUCN (2009) Black footed ferret *(Mustela nigripes)*, http://www.iucnredlist.org/apps/redlist/details/14020/0, accessed 9/2/10,

Johnson N., McElhinney L.M., Ali Y.H., Intisar K.S., Fooks A.R. (2004) Molecular epidemiology of canid rabies in Sudan: evidence for a common origin of rabies with Ethiopia, *Virus Research*, vol.104, 201–205

Krebs J.R. (1997) *Bovine tuberculosis in cattle and badgers*, Ministry of Agriculture, Fisheries and Food, London, UK

Lesellier S., Palmer S., Dalley D.J., Dave D., Johnson L., Hewinson R.G., Chambers M.A. (2006) The safety and immunogenicity of BCG vaccine in European Badgers, *Veterinary Immunology and Immunopathology*, vol.112, 24-37

Lyles A.M., Dobson A.P. (1993) Infectious-disease and intensive management population-dynamics, threatened hosts and their parasites, *Trends in Ecology and Evolution*, vol.24, 315-326

Marino J, (2003) Threatened Ethiopian wolves persist in small isolated Afroalpine enclaves, *Oryx*, vol.37, 62–71

Pastoret P.P. and Brochier B. (1998) Epidemiology and Elimination of Rabies from Western Europe, *Veterinary Journal*, vol. 156, 83-90

Pope L.C., Butlin R.K., Wilson G.J., Woodroffe R., Erven K., Conyers C.M., Franklin T., Delahay R.J., Cheeseman C.L., Burle T. (2007) Genetic evidence that culling increases badger movement: implications for the spread of bovine tuberculosis, *Molecular Ecology*, vol.16, 300-(FIND)

Randall D.A., Marino J., Haydon D.T., Sillero-Zubiri C., Knobel D.L., Tallents L.A., Macdonald D.W., Laurenson M.K. (2006) An integrated disease management strategy for the control of rabies in Ethiopian wolves, *Biological Conservation*, vol. 131, 151-162

Randall D.A., Williams S.D., Kuzmin I.V., Rupprecht C.E., Tallents L.A., Tefera Z., Argaw K., Shiferaw F., Knobel D.L., Sillero-Zubiri C., Laurenson M.K. (2004) Rabies in endangered Ethiopian wolves, *Emerging Infectious Diseases*, vol.10, 2214–2217

Retallick R.W.R., Miera V. (2007) Strain differences in the amphibian chytrid and non-permanent, sub-lethal effects of infection, *Diseases of Aquatic Organisms*, vol. 75, 201–207

Schultz R.D. (1998) Current and future canine and feline vaccination programs, *Veterinary Medicine*, vol.3, 233–254

Sillero-Zubiri C., King A.A., Macdonald D.W. (1996) Rabies and mortality in Ethiopian wolves, *Journal of Wildlife Diseases*, vol.32, 80–86

Skerratt L.F., Berger L., Speare R., Cashins S., Macdonald K.R., Phillott A.D., Hines H.B., Kenyon N. (2007) Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs, *Ecohealth*, vol.4, 125-134

Smith G.C. and Harris S. (1989) The control of rabies in urban fox populations, in *Mammals as Pests ed. Putman R.J.*, Suffolk, UK

Tefera G., Yimer E., Geyid A. (2002) Endemic existence of rabies in Ethiopia, *Ethiopian Medical Journal*, vol.40, 163–170

Thorne E.T. and Williams E.S. (1988) Disease and endangered species: the black-footed ferret as a recent example, *Conservation Biology*, vol.2, 66-74

Ward A.I., Tolhurst B.A., Delahey R.J. (2006) Farm husbandry and the risks of disease transmission between wild and domestic mammals: a brief review focusing on bovine tuberculosis in badgers and cattle, *Animal Science*, vol.82, 767-773

Ward A.I., Tolhurst B.A., Walker N.J., Roper T.J., Delahey R.J. (2008) Survey of access to farm buildings and facilities in relation to contact with cattle, *Veterinary Record*, vol.163, 107-111

Westergaard J.M. (1982) Measures applied in Denmark to control the Rabies epizootic in 1977-80, Comparative Immunology, *Microbiology and Infectious Diseases*, vol.5, 383-387

World Health Organization (2008) *Rabies*, http://www.who.int/mediacentre/factsheets/fs099/en/, accessed 20/1/10

Woodhams D.C., Alford R.A., Marantelli G. (2003) Emerging disease of amphibians cured by elevated body temperature, *Diseases of Aquatic Organisms*, vol.55, 65–67

Woodroffe R. (1999) Managing disease threats to wild mammals, *Animal Conservation*, vol.2, 185-193

Wright S. (2002) *Chronic wasting disease*, USGS-NWHC Information Sheet, US

The effects of an annual cull on the sett usage patterns of the Eurasian badger *(Meles meles)*

Sam Marles

Abstract

In this study we have looked at the effect of an annual cull on the Eurasian badger and have found that there is no statistically significant overall effect of culling, however there is a large seasonal effect, whereby badgers in the culling area are using the main setts significantly less than badgers in an un-culled area in spring, autumn and winter. The results from this study show that at these times badgers are using outlier setts for resting during the day. This study concludes that the disturbance around badger setts and the disruption to badger social groups at these times is causing animals to use the outlier setts as resting sites during the day. This information is important because it can lead to the development of better culling procedures with consideration for season and the structure of badger territories.

Introduction

During the last century it became increasingly apparent that wild species can act as a reservoir or vector of diseases transmissible to man or domestic animals (Artois et al, 2001). The problem is a global one and some good examples of the issues of wildlife diseases are found in New Zealand, whereby bTB is spread to domestic cattle (*Bos primigenius)* via the reservoir of the introduced brush-tailed possum *(Trichosurus vulpecula)* (Coleman and Cooke, 2001), or the spread of the rabies virus in Europe by wild canid species (Pastoret and Brochier, 1998). These wildlife diseases cost untold millions of pounds per year to the respective economies, for example in New Zealand, the cost of possum control and related research is 117 million NZ$ per year (Report, 2000); therefore there has been a recent rapid growth in the wildlife disease management sector. There are problems to managing wildlife, with the lack of access to wild free-ranging animals and the lack of any kind of ownership being a major hurdle to overcome (Artois et al, 2001). Another problem is the fact that wildlife are the focus of affection from the general public, and any management plans implemented are scrutinized by the media. This is especially a problem with the traditional methods of wildlife disease management.

During the late 20th century, when the effect of wildlife reservoirs was first being discovered, the management plans were invariably to remove the wildlife carrying the disease. This can be very effective as found in the example of possums in New Zealand. Here, there was a large concerted effort to successfully remove the maximum number of possums, reducing bTB in many areas to almost negligible levels (Porphyre et al, 2008). This is an example of the successes of culling operations; however culling has not always been a successful answer to wildlife diseases. In Europe, red foxes *(Vulpes vulpes)* were culled until the 70's in an attempt to reduce the levels of sylvatic rabies (Smith and Harris, 1989). This method was dropped due to the high costs of culling over a continental scale and the fact that there was only a transient reduction in the virus. This failure led to the first use of wildlife vaccinations. Over a 20-year period, 8.5 million vaccine containing baits were dropped in Europe, leading to much of Europe being deemed rabies free (Cross et al, 2007). Another, rather simpler method of wildlife disease control is to separate wildlife and livestock, as has been successfully employed in separating deer and livestock in the USA (VerCauteren, per. comm.).

All of these methods are particularly relevant when referring to the focus of this study, the effect of culling on the spread of bTB in Eurasian badgers *(Meles meles)* in Britain. BTB is a disease caused by the bacterium *Mycobacterium bovis*, an aerobic slow-growing bacterium that can cross inter-species barriers and can infect many livestock species; however cattle are particularly susceptible to the disease (Cross et al, 2007). The disease is particularly prevalent in South-west Britain (Report, 2000), and cost the government £87 million in cattle testing, compensation and research costs in 2010 alone (DEFRA, 2010). The disease was first identified in badgers in 1971 at a study site in Gloucestershire (Muirhead et al, 1974). BTB has since been found in many British mammals, including roe deer, wild boar, ferrets and polecats (Delahey et al, 2002), however bTB's prevalence and the vulnerability of badgers to bTB has resulted in the badger being labelled as the main wildlife reservoir in Britain and it is accepted that badgers spread bTB to cattle (Nolan and Wilesmith, 1994). Along with the prevalence of the disease in badgers, there is also the fact that badger territories often overlap cattle pastureland; in fact their preferable habitat consists of pasture mixed with patches of woodland (Cresswell et al, 1990). Little et al, 1982, kept infected badgers and cattle together in the same cages for six months and found that the disease could be transferred between badgers and cattle. Although it should also be noted that cattle-to-cattle transmission is still considered to be one of the most important routes of infection (Gilbert et al, 2005). Because of this link, a full investigation into the effect of culling strategies on cattle bTB infection rates was ordered by the British government in 1997 (Krebs, 1997).

The study was called the Randomised Badger Culling Trial (hereafter RBCT) and was a fully independent scientific trial. The experimental design involved thirty 100-km² study areas throughout southern and western England, grouped into 10 triplets. In one area of each triplet, no culling was performed; in a second area, reactive localized badger culling took place in response to cattle herd TB infections (average area, 5.3 km²), and in the third area, badgers were proactively culled, roughly annually, over an area of 100 km² (Donnelly et al, 2003). During the reactive culls it was found that bTB incidence only marginally decreased in some areas and actually increased in others, leading to the abandonment of the reactive culling in 2003 (Bourne, 2007). The results of the study found that the bTB incidence in cattle decreased within the trial area, but increased in areas immediately adjacent (Donnelly et al, 2006). Smith (2001) theorised that culling-induced alteration to social organisation, dispersal and compensatory reproduction could cause an increase in contact rates and therefore the potential for disease transmission. Woodroffe et al, 2006, found that in areas where badgers were culled there was an increase in the overlap of social territories, this was supported by work carried out by the Central Science Laboratory (CSL; now the Food and Environment Research Agency), finding that radio-collared badgers in the proactive culling areas travelled significantly further than badgers from an adjacent un-culled area (Report, 2007). Post-cull, genetic evidence was gathered from culled badgers and found that there was a significant increase in post-cull dispersal, especially in long distance movements (greater than 1km) (Pope et al, 2007).

Although there has been much research the effects of culling on social structure and movement, there has been very little research into the effect on badgers sett use. It is important when studying sett use patterns to consider the social structure of badgers. Studies have shown that British badgers live in mixed sex social groups with up to 23 individuals (Harris and Yalden, 2008), with an average of 5-6 individuals inhabiting the same territory (Kruuk, 1989). Territories are defended by its social group using shared defecation sites or latrines and scent-marking at the boundaries between territories (Stewart et al, 2002), and it is accepted that there is very little movement between social groups (Cheeseman et al, 1988). The few movements that do take place tend to be by sexually mature adult males (i.e. males over two years of age (Ahnlund, 1980) and is essential to keeping a healthy gene pool, thus reducing the effects of inbreeding.

Typically, British badger territories contain up to 13 setts (Ostler and Roper, 1998), however in most cases there will be a solitary “main sett” (Neal and Roper, 1991). The main sett tends to be larger in relation to area, volume, tunnel length, number of chambers and number of latrines than other setts (Roper, 1992). Main setts comprise of multiple entrances (mean 10.5, Neal, 1977) and an interlocking series of underground tunnels and nest chambers. The remainder of the setts in a territory are known as “outlier setts”. The number of these setts varies (mean 2-3 but up to a dozen, Cresswell et al, 1989, Ostler and Roper, 1998) and the size of these setts also varies, with some being simple blind ended tunnels and others containing multiple entrances and interlocking tunnels and nest chambers (Roper, 1992). Due to the added size and security of main setts, these tend to be the site of breeding, and it is extremely rare for litters to be born at outlier setts (Neal and Roper, 1991).

There are many hypotheses as to why badgers dig and maintain multiple setts. One suggestion is that badgers use all of the available underground space to reduce ectoparasite burdens (Neal and Roper, 1991, see Butler and Roper, 1996). It has also been suggested that setts are an extension of the communal latrine sites, whereby they are of use in marking territories. It was found that in a low-density badger population in Spain that 80% of scats found were associated with setts (Revilla and Palomares, 2002) and it has also been noted that badgers sometimes defecate within a sett (Kruuk, 1978). In larger territories it has been proposed that outlier setts are of use to badgers in reaching all of their sett boundaries (Kowalczyk et al, 2004). Outlier setts could also be useful in reaching food sources dispersed far from the main sett. This hypothesis has been called efficient travel (Kruuk, 1978). Similar to efficient travel, it might prove to be practical for badgers to have a number of setts spread over a territory for emergency shelter (Butler and Roper, 1995).

Studying the effects on sett usage is important because it is key to consider all consequences of any culling plans implemented. This study should give an insight into the effect of an annual culling strategy on badger sett use patterns, and if there is a significant effect, then this information can be used to adjust culling techniques to maximise the number of animals caught, and therefore increase the effectiveness of culling strategies. This study uses data gathered by CSL between the years 2004 and 2007 as part of their research into the effects of culling on badger movement but will be looking at how an annual badger cull affects the sett use of badgers. This study will also analyse the other main factors that affect sett use by badgers.

Methods

Study Area

For the RBCT, each study triplet was chosen from within the Tb “hotspot” regions of West and South West England. Each of the three 100km² study areas were surveyed prior to the commencement of the study and then the treatment for each area was selected randomly (see Bourne, 2007). An area of approximately 27 km² within and adjacent to one of the Gloucestershire RBCT proactive culling areas (I2) (Centred on coordinates 2°26’W, 51°35’N), the perturbation study area, was selected for an intensive study of the effects of proactive culling on badger movement and demography The culling effort focussed on a 16.47km² area hereafter the culled area) and the non-culled area comprised of 10.87km². The former area is referred to as the culled area and the latter as the un-culled area. The culled area was subjected to annual culls between the years 2002 and 2005 inclusive. The study area was relatively flat and comprised predominantly of agricultural grassland and cereals.

Surveying and Bait-marking

At the commencement of the project in April 2004 the study area was initially surveyed for signs of badger activity by members of the CSL wildlife disease team. During this process all of the land was searched for badger activity, involving a team member following the boundaries of fields or sweeping woods for any signs of badger use. All signs of badger activity were recorded, particularly setts, which were assessed for their size and activity levels (number of well used, partially used and disused holes), as well as for the presence of latrines and badger runs. This information formed the basis of the study. The configuration of badger social groups was determined by using bait-marking (see Delahey et al, 2000). Bait marking provides an estimate of the home range of a social group and was used to map social group territories using a geographic information system (ArcGIS 9.1: Environmental Systems Research Institute (ESRI), Redlands, California, USA, 2005). The establishment of social group territories allowed each sett to be attributed to a specific social group. As badger territories are dynamic, it was necessary to bait mark every spring between 2005 and 2007 in order to monitor if any change of sett ownership occurred. The study began in April 2004; consequently the first bait-marking was not carried out until the spring of 2005.

Live-trapping

Demographic information on the resident badger population was collected by means of a routine capture-mark-release (CMR) programme, consistent with that carried out at Woodchester Park since 1981 (see Rogers et al, 1997).Trapping took place throughout the year, except for a close season from February to April when female badgers may have small dependent cubs that cannot be left alone for protracted periods (see Woodroffe et al, 2005). Badger social groups in the area were trapped on average four times a year between 2004 and 2006. Each sett identified by the initial survey, both active and inactive, was visited prior to each trapping operation to determine the levels of activity. Levels of activity and previous knowledge of number of animals caught was used as a guide to the number of traps set, although the general approach was to put down more traps than were expected to be needed (saturation trapping). Remote trapping on badger runs away from active setts was used in the culled area in 2004 in an attempt to increase the number of radio-collared badgers in the culled area. (For full trapping methods of CSL, see Report,2007).

Main setts were identified from activity levels found during the field surveys undertaken at the commencement of the study, however where this was not possible, the presence of cubs during live-trapping was used to identify main setts. This technique was used because cubs are usually only born at the main sett (Neal and Roper, 1992), and in the rare occasion there was a social group with more than one sett containing cubs, the main sett was determined as the more active sett using such indicators as number of active holes, number of well used runs and active latrines. All other setts were labelled outlier setts.

Clinical sampling

Techniques developed at Woodchester Park to investigate population structure were employed to study the population in the perturbation study area. Trapped badgers were anaesthetised with a mixture of ketamine hyrdrochloride, medetomidine hydrochloride and butorphanol tartrate (de Leeuw et al, 2004) and on first capture each badger was given a unique identifying tattoo (Cheeseman and Harris, 1982). Not only this, but each badger had its characteristics noted, such as age, sex, length and weight. This information was used to assess each animal's general condition.

Radio-tracking

All adult badgers captured in the study area between June 2004 and November 2006 were fitted with radio-collars to determine sett use in relation to culling operations. Radio-collars consisted of TW-3 transmitters with a closed loop antenna (Biotrack Ltd, Furzebrook, Wareham, Dorset, UK), encased in epoxy resin and set into a leather collar. Collars were not fitted to badgers with severe lesions or wounds to their neck. Collar weight was well below the 5% of an animal's body weight as recommended for radio-tracking studies (Cochran, 1980). Radio-tracking was carried out on foot using a hand-held Yagi-flexible element antenna (Biotrack Ltd, UK) connected via a coaxial cable to a TR-4 receiver (Telonics Inc., 923E Impala Avenue, Mesa, Arizona, USA). Daytime location data for each collared badger was recorded by visiting all known setts in the study area once a week and recording the individuals located at each sett for the duration of the study. Over the 3 years of the study, there were a total of 30 badgers tracked from 11 social groups. The culled area consisted of a total of 10 badgers tracked from 5 social groups and from the un-culled area a total of 20 badgers from 6 social groups.

Culling Method

Cage trapping, followed by humane dispatch (shooting) was the method selected for culling badgers in the RBCT (Bourne, 2007). All fieldwork was carried out by the Ministry of Agriculture, Fisheries and Food's (MAFF) Wildlife Unit (WLU). The initial cull to remove badgers in the I2 proactive culling area was completed in October 2002, and the follow up culls continued annually until July 2005. The live-trapping method used by the WLU was similar to CSL's live-trapping procedure as described above, however once traps were placed; they were pre-baited using peanuts for 1-2 weeks. On the initial cull, traps were set for 11 nights consecutive to maximise the capture rates, follow-up culls were carried out over 8 nights. Badgers captured were dispatched humanely with a single gunshot to the head. All culling activities ceased with the onset of the closed season (Feb-April inclusive) (Woodroffe et al, 2005).

Statistical Analysis

Data Analysis

Once all data had been collected, the data was screened for any extra-social group movements as this was considered a potentially confounding effect of any potential movement. To analyse the data, the daytime location fixes were transformed into numerical data points, whereby a daytime location fix at a main sett was 1 and a fix at an outlier was 0. To analyse the data, the proportion of time spent at the main sett for each individual, in each season for every year of the study was calculated. When looking at the distribution of the data it was found that there were non-normal errors, so the data were subjected to an arcsine transformation.

Group size was estimated from a combination of factors. The main method used was the capture rates over a given year. As each badger had been marked, it was possible to count the number of badgers in the social group over the year. Where any active collared badgers were present, but were not recorded during the live-trapping of that year then these were added to the group size. Also, in the culled area; the area where the badgers were proactively culled, each badger killed had a grid reference associated to it, so this was used to assign each badger to its social group, assuming that the badgers were not crossing into neighbouring territory. This measurement for group size is not an absolute value; it is used only as a proxy for relative group size.

Using the data collected from the culled badgers, it was possible to not only test the overall effect of the cull on all the social groups using the total number of badgers culled, but also to test the effect that removals had on specific social groups. This was possible because as mentioned above, the number and location of culled badgers was recorded and it was therefore possible to assign each culled badger to a social group.

Also analysed was the number of outlying setts in each social group's territory. This was measured using the survey data and the bait marking maps where it was possible to attribute the number of outlying setts to each social group on a year by year basis.

Model Analysis

Due to the lack of data on the age of animals in the culled area, two separate models were carried out, one that compared the sett use of badgers across the culled area and the un-culled area with the other model comparing the effects of age on sett use within the un-culled group. Data for the ages of badgers in the culled area was only available for one animal, and therefore no analysis could be carried out.

Both models were carried out using Genstat v.13 (VSN International) using a linear mixed model (REML). The first model testing for the effect of the treatment was analysed with the proportion of time spent at the main sett as the response variate and individual and social group as the random factor. The explanatory variables tested were group size, treatment, total number of badgers culled, the number of badgers culled in each social group, season, sex, year and the number of outliers. The interactions tested were group size and treatment, treatment and season, treatment and sex, treatment and year, treatment and number of outliers, season and sex, group size and sex and group size and number of outliers.

For the second model testing the effects of age was analysed with the response variate being the proportion of times spent at the main sett and the random factors fitted were individual and the social group of the badger. The explanatory variables fitted to this model were age, group size, season, year and sex. The interactions fitted were the effect of group size and age, age and season, age and sex, sex and season, and group size and sex.

Results

Effects of Treatment on Sett Usage

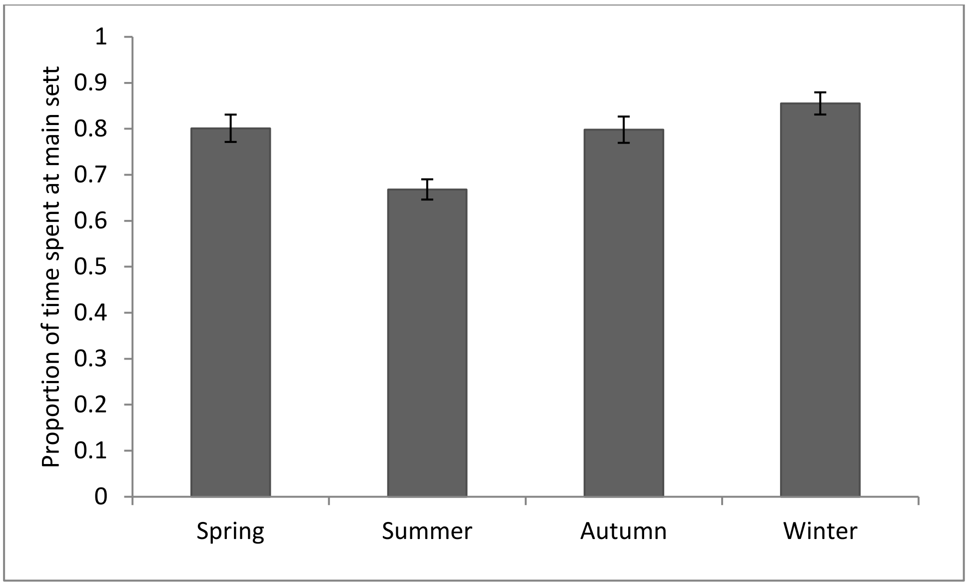

Figure 1. The effect of season on the proportion of time spent at the main sett over the entire population from the perturbation study area. Error bars ±1SE.

As mentioned in the methods, there were a total of 30 badgers tracked from 11 social groups. The culled area consisted of a total of 10 badgers tracked from 5 social groups and from the un-culled area a total of 20 badgers from 6 social groups. There were a total of 132 proportions analysed from a total of 1049 inactive fixes. For the culled area, there were a total of 26 proportions analysed, gathered from 161 inactive fixes, and for the un-culled area, there were a total of 106 proportions used, gathered from 888 inactive fixes.

The first measurement tested was the effect of year but it was found that there was no significant difference between the years (*df*= 1, *F-statistic*= 0.00, *P*= 0.947), whereas season had a significant effect on sett usage (*df* = 3, *F-statistic*= 5.00, *P*= 0.003) (Figure 1) with badgers spending the lowest

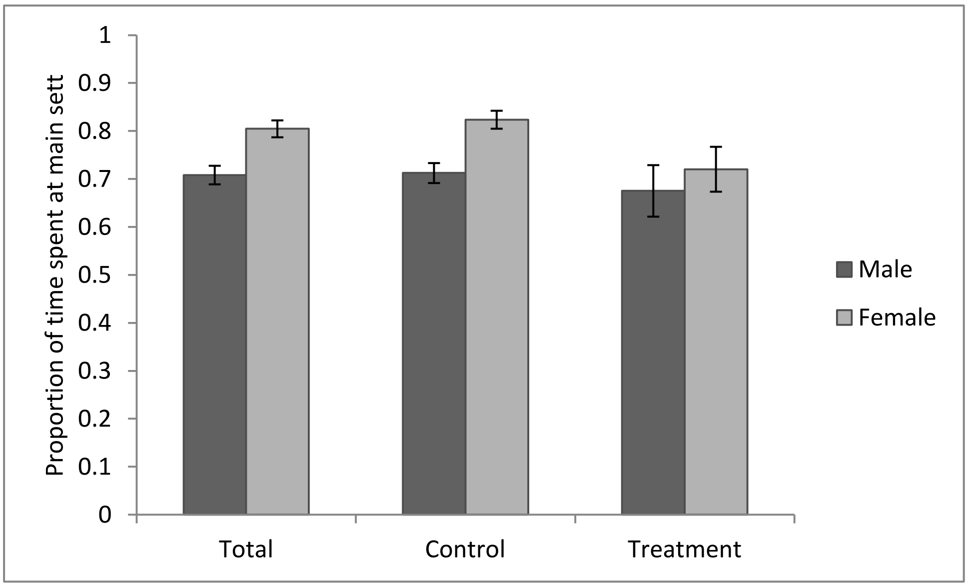

Figure 2. The effect of the interaction between treatment and sex on the proportion of time spent at the main sett. Error bars ±1SE.

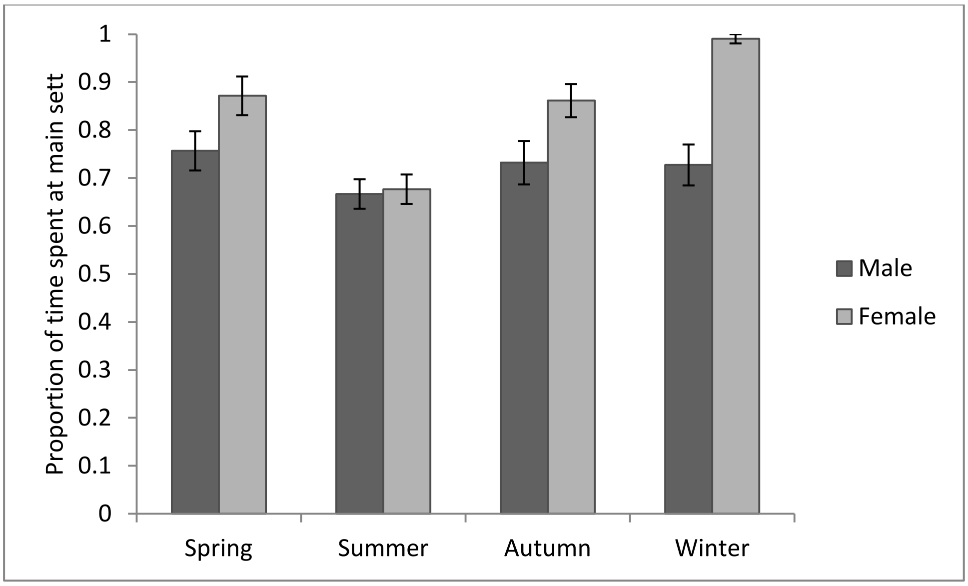

Figure 3. The effect of ex on the seasonal sett use patterns. Error bars ±1SE.

proportion of time at main setts in summer (0.66±0.022) and the highest in winter (0.85±0.024) (spring 0.80±0.029, autumn 0.79±0.028).

Sex had no significant effect (male 0.82±0.041, female 0.85±0.043, *df*= 1, *F-statistic*= 1.90, *P*= 0.182) (Figure 2) and the interaction between sex and treatment was also not statistically different (*df*=1 *F-statistic*=1.15, *P*= 0.296) (Figure 2). The interaction between sex and season was also measured, finding a significant interaction (*df* = 3, *F-statistic*= 2.74, *P* = 0.047) (Figure 3) with the greatest difference between the sexes found in winter (male 0.72±0.042, female 0.99±0.009) and the least difference found in summer (male 0.66±0.031, female 0.67±0.031) (spring, male 0.75±0.041, female 0.87±0.041, autumn, male 0.73±0.045, female 0.86±0.034).

When tested as a main factor, treatment had no effect on sett usage (*df*=1, *F-statistic*= 1.22,

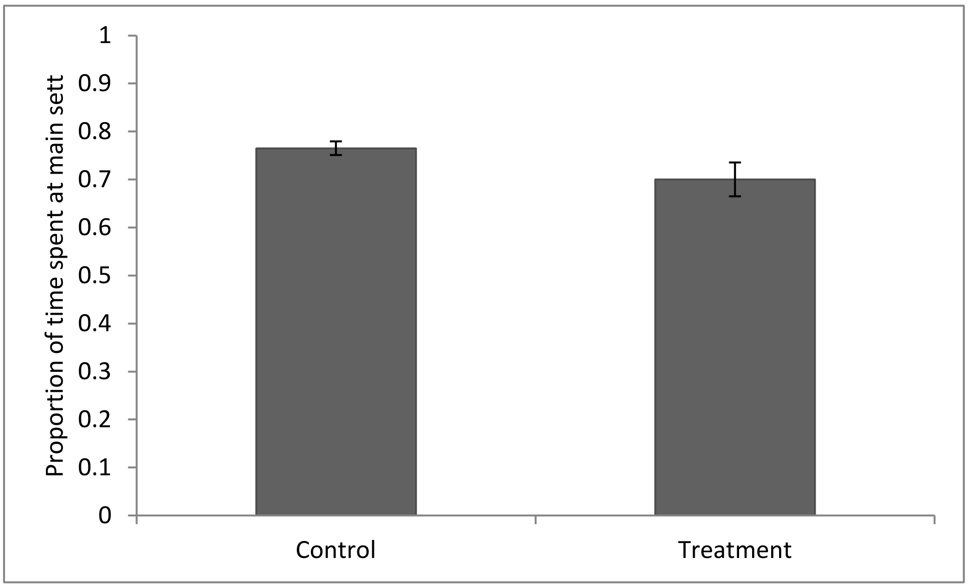

Figure 4. The effect of treatment on the proportion of time spent at the main sett. Error bars ±1SE.

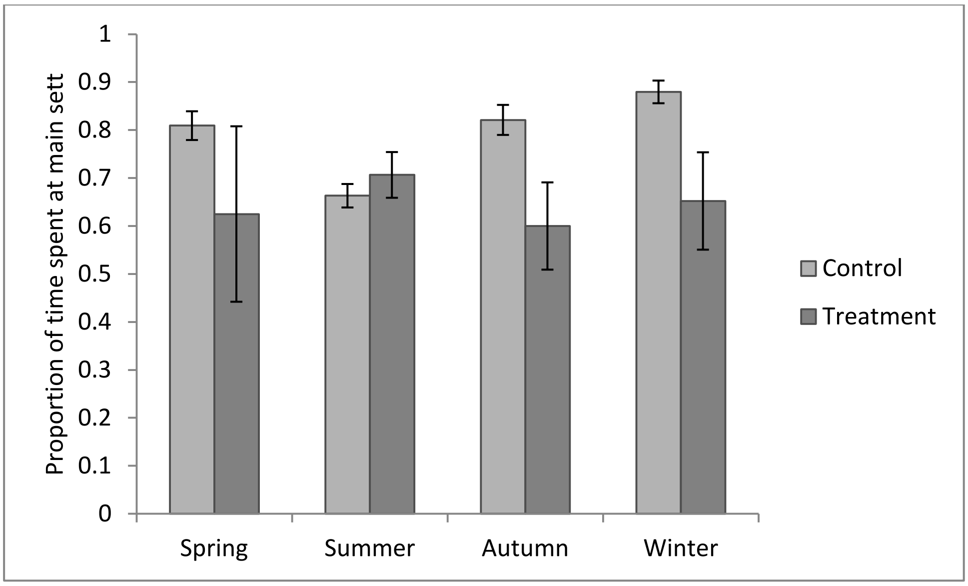

Figure 5. The effect of treatment on the seasonal sett use patterns. Error bars ±1SE.

P=0.303) (Figure 4), but when tested as an interaction with season, it was found to have a strong effect (*df*=3, *F-statistic*= 7.90, *P*= 0.001) (Figure 5) with spring (culled, 0.63±0.183, un-culled 0.80±0.029), autumn (culled 0.6±0.091, un-culled 0.82±0.031) and winter (culled 0.65±0.102, un-culled 0.87±0.024) showing a much reduced use of main sets in the culled area compared to the un-culled area, whereas in summer the badgers in the culled area (0.70±0.047) used the main sett proportionally more than the badgers in the un-culled area (0.66±0.024). When treatment was tested as an interaction with group size there was also a significant effect (*df*=1, *F-statistic*= 8.53, *P*=0.011)(Figure 6) with group size having a strong negative effect on proportion of time spent at main sett (-0.0268) for the badgers located in the un-culled area whereas with the culled area, there was a positive effect of group size on proportion of time spent at the main sett (0.0146).

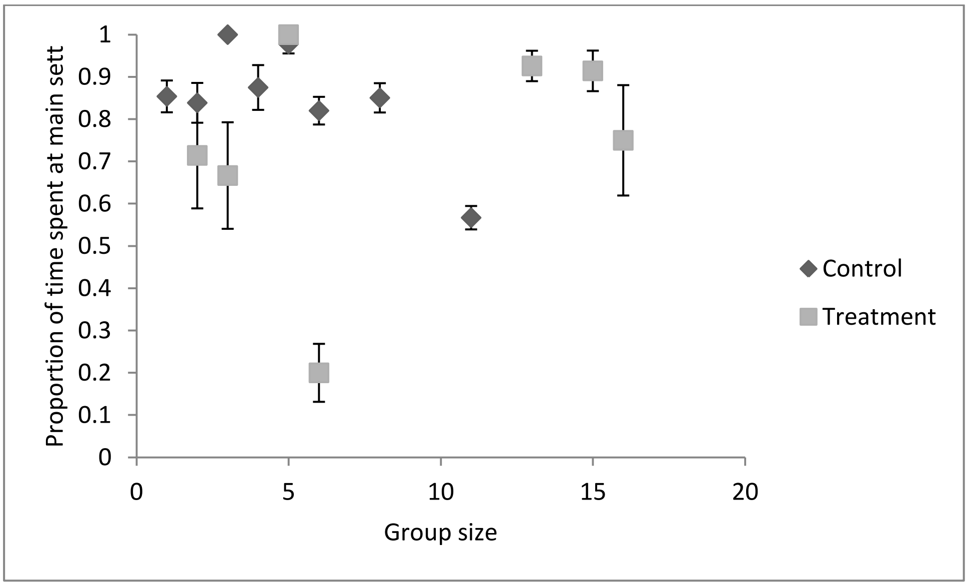

Figure 6. The effect of the interaction between group size and treatment on the proportion of time spent at the main sett. Error bars ±1SE.

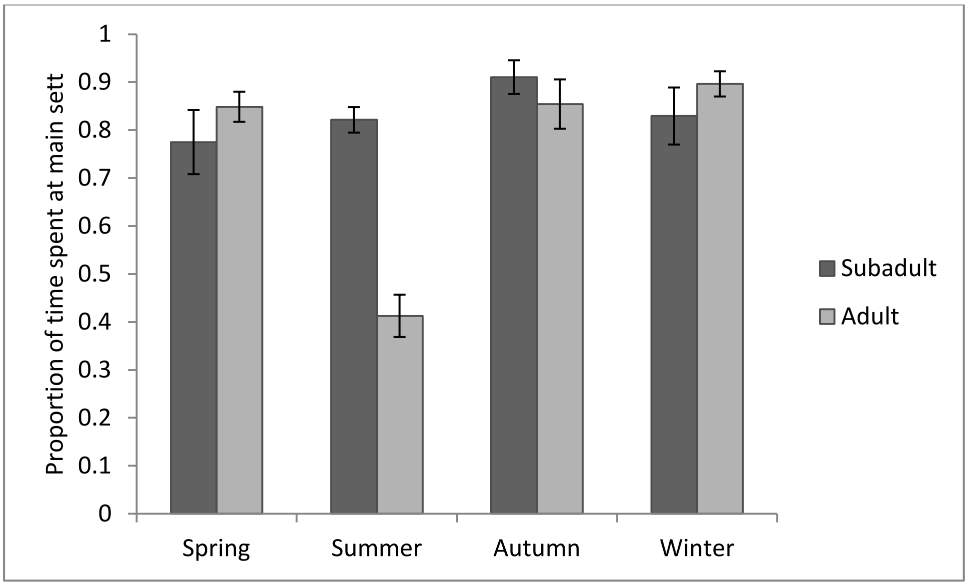

Figure 7. The effect age on the seasonal sett use patterns. Error bars ±1SE.

Both the number of culled badgers in total and the number of culled badgers from each social group had no effect (*df*= 1, *F-statistic*= 3.52, *P*= 0.064, *df*=1, *F-statistic*= 0.03, *P*= 0.868 respectively). The number of outliers also had no effect (*df*=1, *F-statistic*= 0.00, *P*= 0.949). The same was true of group size, which had no significant effect (F-statistic= 3.65, p-value= 0.068).

<u>Effects of age on the sett use of badgers</u>

In the un-culled area, there were a total of 20 badgers tracked from 6 social groups. Over the course of the study, it was impossible to accurately age the badgers, so each badger was divided into two groups, either adult or sub-adults. Over the course of the study, there were 9 sub-adults tracked and 15 adults. There were a total of 31 proportions for sub-adults from 344 inactive fixes, and for adults there were 51 proportions from 444 inactive fixes.

The first major effect tested was the effect that age had on sett usage and it was found that there was no significant effect (sub-adult 0.83±0.019, adult 0.73±0.021, *df*= 1, *F-statistic*= 0.06, *P*= 0.800). The effect of the interaction between age and sex was also not significant (sub-adult male 0.8±0.026, sub-adult female 0.9±0.027, adult male 0.67±0.033, adult female 0.8±0.026, *df*= 1, *F-statistic*= 0.59, *P*=0.446). The effect of the interaction between group size and age was also not significant (*df*= 1, *F-statistic*= 2.10, *P*= 0.153). The interaction between season and age was significant (*df*= 3, *F-statistic*= 5.81, *P*= 0.001) (Figure 7) with the greatest difference found in summer (sub-adult 0.82±0.026, adult 0.41±0.044) whereas there was very little difference between the two age groups in the other seasons (spring, sub-adults 0.78±0.067, adult 0.85±0.031, autumn, sub-adult 0.91±0.035, adult 0.85±0.051, winter, sub-adult 0.83±0.059, adult 0.9±0.026).

<u>Discussion</u>

From the analysis of the effects of treatment there was no overall significant effect from annual culling operations on badger sett usage in this study group (Fig. 4), but the effect of treatment varies significantly over seasonal patterns (Fig. 5) with badgers in the culled area showing a much reduced use of main setts in spring, autumn and winter. This information could be used to effectively hone any culling strategies and increase the trapping efficiency. Interestingly, there is a positive correlation between group size and the proportion of time spent at the main sett, whereas in the un-culled area there was a negative correlation (Fig. 6) although comparisons are hard to make between the two study groups due to a lack of correlating data. The number of badgers culled also had no effect either as a total from the entire culling area or for each individual social group.

This study group show that the season has a major effect on the patterns of sett usage, with summer being the time when badgers use the main sett least, and the highest use of the main sett found in winter (Fig. 1). This seasonal effect was also found to affect the two sexes differently, with males using the main sett significantly less in spring, autumn and winter, whereas in summer there was very little difference (Fig. 4).

This analysis also showed that badger social organisation has an effect on the sett usage; again there was a seasonal effect, with sub-adults using the main sett drastically more in summer than the adults (Fig. 7) with little difference in the other seasons. Interestingly, there was no difference between sub-adults and adults despite the disparity in the summer months.

The effect of culling on badger sett use patterns

The hypothesis states that the annual cull of badgers should have the overall effect of reducing the proportion of time spent at the main sett, based upon the fact that when the culls were taking place, there was a larger trapping effort concentrated on main setts, therefore it is hypothesised that to avoid persecution badgers were expected to utilise outlying setts as a safer alternative, an expansion of the harassment avoidance theory suggested by Neal (1977). As figure 4 shows, the results gathered from this study do not support this theory, with no significant difference found between the treatment group and the study group. Although there was no significant difference between the total sett use patterns of both study groups, figure 5 shows that there was a seasonal effect of treatment.

Badgers located in the treatment area spent significantly less time in the main sett in spring, autumn and winter (Fig. 5). In summer there was a slight rise in the use of the main sett by badgers in the treatment area, however this effect is very slight and therefore is not significant. These data show that badgers are affected by the cull on a seasonal basis, with the greatest effect being found in autumn and winter. This effect correlates with the culling schedule, as the culling effort was focused during the autumn and to a lesser degree, early winter. This would appear to show that the time-scale when the vast majority of the trapping took place coincided with the most disturbance to the badgers sett use patterns. During the badger culls, it was necessary for the wildlife unit to place multiple traps, and regularly visit the setts in order to keep pre-baiting traps. This disturbance would probably affect badgers and cause some individuals to move to outlying setts where there would be less disturbance.

The evidence here appears to support an extension of the harassment avoidance theory (Neal, 1977, Davison et al, 2008). Although Neal proposed this theory to explain the use of outlying setts by young animals harassed by older animals, or even the effect of males leaving the main setts during spring, it can still apply to the results gathered by this study. Although the harassment does not originate from badger to badger contact, it is possible that badgers, especially rural and relatively undisturbed populations, can feel stressed when there are repeated human visits. It is probable that the introduction of traps and novel food sources along with the smell of humans could cause some individuals to leave the vicinity of the main sett and thus use outlying setts proportionally higher. This effect could continue over the course of the rest of the following year, with badgers staying away from the main sett throughout the winter and into the spring.

Not only will the presence of humans affect the sett use patterns of badgers, but the removal of individuals from a social group should affect the badger sett usage during the autumn. This removal lowers the population of each social group before the winter inactivity and as social groups overwinter communally there should be a resultant effect into the winter sett usage. The removal of individuals from social groups could remove the need for the extra space a main sett affords, meaning that there is no advantage derived from hibernating in the large main setts. Conversely, it could be considered a hindrance because main setts tend to be large and have many entrances, and possibly smaller social groups could struggle to maintain thermoregulation. In this situation, it is conceivable that using a smaller outlier sett could be an advantage due to the smaller size and fewer entrances meaning that, in theory, it would be less energetically exacting to maintain thermoregulation. As figure 5 shows, in winter, 65% of the day fixes were found in the main sett, showing that this theory is not substantiated by the data gathered from this study. In fact, 60% of the day fixes were recorded at the main sett no matter what the season, showing that the main sett is still important to a social group, with activities such as breeding and mating still taking place at this time. From the trapping data carried out, it was evident that the treatment groups were still breeding with cubs born at these main setts. Even with the added disturbance and the reduction in the population of each social group in the treatment area, the main sett is an important centre for each individual's life, and it is doubtful that this effect would disappear immediately, possibly continuing to use the main sett as a diurnal resting place partially out of habit.

With the reduction of the population sizes of each social group, it is possible the main sett could lose the impact of being the centre a groups social interactions This would be important because if there are fewer animals in a social group, there is less need to constantly reaffirm the social bonds, and consequently less need to visit the main sett. Winter would be expected to be the time when this effect would be strongest, due to the communal hibernation and the mating that takes place underground, although this effect should be felt throughout the year. This could be a reason why the animals in this study spent proportionally less time at the main sett.

Data gathered from the wildlife unit about the number and location of the badgers culled allowed the testing of the hypotheses that; 1) the total number of badgers culled should encourage a lower proportion of time spent at main setts, 2) that the number of badgers culled within a social group should lower the proportion of time spent at the main sett. Both of these hypotheses were shown to have no effect on the proportion of time spent at the main sett, although this could be due to the small data sets gathered. The total number of culled badgers possibly had no effect due to the fact that although many studies have shown that there can be a breakdown of social structure and resultant wide-ranging behaviour by badgers (Report, 2007), this appeared to have no effect on the badgers in this study. Over the course of the study only 7 inter-group movements were detected, and none of these occurred in the treatment group, however this study commenced a year after the initial cull, when badger social organisation is most disorganised. It is possible that the reason for this is that the removal of badgers was inefficient within the study area and that in fact there was a healthy population remaining within the treatment area. This would seem unlikely because within the treatment area, the number of badgers trapped for each social group was lower than the average group size, although it is possible that there were a high proportion of neophobic badgers in the population. This effect would need to be studied rigorously before being proven, and should be the focus of more studies in the future using camera traps to estimate population sizes as well as the traditional live-trapping methods of population size estimates.

The number of badgers removed from each social group was also hypothesised to have an impact on the proportion of time spent at the main sett, this was to be expected because with an increase in the number of individuals taken, it was expected to disturb the animals social behaviour causing a disruption to the sett usage. This hypothesis is based on the fact that the highest trapping activity was present at the main sett, shown by the trapping records submitted by the wildlife unit staff. There was no significant effect of this, however the data set is small and this effect should be studied further.

When a comparison of the effect of treatment on varying group sizes was carried out, it was found that treatment had a significant effect. The data for group size is varied and it is difficult to make any direct comparisons between the treatment groups and the control groups. This is especially true of the higher group sizes because there are few cases of both the control groups and the treatment groups having the same number of individuals per social group. Comparisons between groups of an average or smaller size shows that the social groups within the treatment area spent less time at the main sett than groups of a comparable size (see figure 6). The effect is stronger for animals in smaller groups, whereas the larger groups appear to be more resistant to the effect of disturbance, appearing to contradict the conclusions drawn from the analysis of the number of badgers culled per social group, where these data appeared to suggest that badgers react comparably to removal of animals.

Implications for future wildlife management

This study is centred around the effects of an annual cull on badger sett usage, and therefore the results can be applied to wildlife management plans. As this study shows, annual culling has a minimal effect to the overall sett use patterns; however there are many factors from this study which can influence any future planned culling operations. The most important factor has to be the influence that season has on culling procedures. The data shows that in the control population, badgers are present at the main sett for the highest proportion of time during winter, suggesting that trapping at the main setts would be more effective at this time. It should be noted, however, that this time is when badgers are least active and are not foraging for food and therefore this should not be considered a peak time for trapping. It has been suggested that the times around the winter lethargy would be a good time to trap at the main sett because in late autumn the badgers will be highly active foraging to put on fat reserves and may also be in the vicinity of the main sett preparing for hibernation. Badgers in the treatment area of this study were present at the main sett least in autumn, therefore it cannot be advised that autumn is the best period to trap. During summer the badgers subjected to an annual cull are present most at the main sett, although there is very little differentiation between the four seasons. Figure 5 shows that any disturbance will result in badgers using outlying setts around 30-40% of the time. Future management plans should factor for the increase outlying sett use, ensuring that outlying setts are also trapped, not just focusing on main setts. This tactic may prove to be costlier due to the extra effort involved in finding outlying setts and subsequently trapping them, however there is a potential to increase the number of badgers culled by 30-40%. If the aim is to remove badgers from an area to reduce the opportunity for transmission of bovine TB to cattle, then these extra badgers could have a significant effect on the effectiveness of such a plan.

This study could be used as a guide for large scale vaccination projects, such as the Badger Vaccination Deployment Project (hereafter BVDP) currently being run by DEFRA (DEFRA 2010), where season needs to be carefully considered at the planning stage. The BVDP is currently in operation in a 100km^2 area in Gloucestershire, and although the aim is to vaccinate every animal in this area, the cubs and sub-adults are the main targets for vaccination as these animals are less likely to have been subjected to tuberculosis, but are arguably more susceptible to the disease, thereof to vaccinate early will decrease the number of badgers that can be infected. Sub-adults are most often found in the vicinity of the main sett throughout the year. This information can be used to specifically target the sub-adults, as figure 8 shows that during summer the sub-adults are most often to be found around the main sett, whereas the adults are more likely to be found in the outlier setts. Summer is therefore optimum for any management plan targeting sub-adults. An additional benefit is that studies have shown that the cubs remain around the main sett during the summer months, therefore plans targeted at the relatively naive cubs and sub-adults would benefit the most by being targeted at the main setts in summer.

The effects of environmental and badger social behaviour on sett use patterns

Previous studies (Roper et al, 2001, Cresswell and Harris, 1988) have found that sett usage of badgers is often affected by the changes of season, and the same is true of this study with figure 1 showing that the highest proportional use of main setts was found in winter, and the lowest found in summer. This was to be expected as there have been many studies to highlight this variation. There are two main factors that are often used to explain this seasonal variation; winter lethargy and the reproductive cycle.

Although badgers are not true hibernators, as they often leave setts during the winter to drink and sometimes to forage, they do spend a very high proportion of time inactive (Cresswell and Harris, 1988). This decrease in activity is, however, not coupled with a decrease in a badgers metabolic rate (Harris and Yalden, 2008), and with all mammals the majority of energy is used for body temperature maintenance. This could be why the main sett is used for over-wintering, because they are bigger and deeper, meaning that less cold can prevail into the sett, but also it is possible to fit all members of the social group into the same sett. This communal inactivity leads to greater thermal insulation, and the ability to resist cold weather with greater ease (Roper et al, 2001). The inactivity of badgers in winter and the subsequent use of the main sett for over-wintering is also useful for explaining the greater movements away from the main sett in summer. It is during this time that a badger must forage to put on the fat reserves necessary to survive the long winter inactive, and when they spread out most over their territory, thus necessitating the extra use of outlier setts to reach all parts of their territory (Roper et al, 2001).

The other major factor for the additional use of main setts in winter is tied in with the badgers breeding cycle. Cubs are born between mid-January to mid-March, staying underground for a period of about 8 weeks, before finally emerging in late spring (Harris and Yalden, 2008). The requirement for females to suckle dependent young is often cited as the reason they remain at main setts in spring. Females are only in oestrus for between 4-6 days typically focused in early spring (Cresswell et al, 1992), thus males spend proportionally more time in the main sett in spring rather than in any other season to ensure copulation.

When the two sexes are compared over the seasons, there are marked differences in the proportion of time spent at the main sett, and as figure 3 shows, females residing in the main sett to a greater degree than the males in winter (male 0.72±0.042, female 0.99±0.009) and spring(spring, male 0.75±0.041, female 0.87±0.041). Although this is partially explained by the fact that females have to stay at the main sett to care for their offspring, the nature of the male's behaviour has to be taken into account. Studies into the patterns of bite wounding (Delahey et al, 2006) and the frequency of visits to boundary latrines (Brown et al, 1992) suggest that males are most active in territorial defence and therefore they are wider ranging. This would especially explain the difference between females and males during spring, as at this point the females are still attempting to wean their young, whereas the males range across the entire territory, both foraging and actively marking territorial boundaries.

There is a possibility that the males leave the main setts in spring due to harassment from the cubs. Badger males have no input into the raising of the offspring and it is quite likely that the males will be the focus of some defensive females and that this coupled with the effect of having cubs around could lead to males residing in outlier setts.

One point of note is that although badgers use outlying setts more in summer, they are still using main setts to sleep 65% of the time (Fig. 3). In this study it is hypothesised that the main sett is the centre for social activities, and that regular visits are necessary for the maintenance of the social bonds of the group. This effect has not been studied in any depth and a study on the social interactions between badgers at main setts and outlying setts could provide some interesting data on the mechanics of badgers social structure.

Although male and female badgers have differing sett use patterns over seasons, there is no discernable difference as a total proportion of time spent at the main sett. This is possibly due to spread of the daytime location fixes recorded, with the vast majority being recorded in the summer when it would be expected that male and female badgers would have the most similar sett use patterns due to the need for extra foraging. This skew in the data collection may have caused the results for sex to be more similar than if there was an even spread of data collection, therefore this affect should be investigated further.

Two other main factor effects were tested in this study; the effect of the group size and the effect of the number of outlying setts per territory. It was expected that with an increase in group size there would be a decrease in the proportion of time spent at the main sett. This prediction was based upon the theory that badgers, although being communal, are not truly altruistic and would therefore need to spread out over a territory to maximise the resource usage (Roper et al, 201). As the data shows, the effect group size was marginally not-significant, meaning that in these populations it appears that badgers are equally tolerant of the other individuals in the social group, regardless of the number of individuals in said social group.

The number of outliers was also predicted to have a negative correlation with the proportion of time spent at the main sett; however this too had no significant effect. This prediction was based on two theories; the theory of resource dispersion (Revilla, 2003) and the theory of efficient travel (Kruuk, 1978, Roper, 1992). Resource dispersion theory hypothesises that badgers build outlying setts near to specific resources, for example maize fields or orchards. These outlying setts can then be used when accessing these resources. This theory is further supported by the theory of efficient travel, because these resources can often be located a long way from the main sett, therefore an outlying sett near this resource, especially located near to a core foraging area, will reduce the energy expenditure used obtaining such a resource (Kruuk, 1989). These outlying setts should be better used than other non-associated outliers, as it is easier for a badger to utilise these core foraging areas (Davison et al, 2008). The fact that the number of outliers had no significant effect on the sett use patterns could be due to the fact that all social groups use outliers for the same reasons. This means that all the badgers will use outlying setts for the same purpose, and barring individual variation, which was controlled for in the models, they should spend similar proportion of times away from the main sett.

From the data collected during the course of this study, it was possible to look compare the effect that adults and sub-adults had on sett usage in the un-culled area. Figure 6 shows that there was no significant effect between the separate groups. When analysing the effect age had on seasonal sett usage, figure 7 shows that spring, autumn and winter had no significant effect, however during summer the sub-adults used the main 82% of the time compared to adults which were only found in the main sett 41% of the time. Being a sub-adult only lasts for a solitary year; therefore the summer data gathered for the sub-adults was their first summer without the protection and guidance of their mothers. The mothers would separate themselves from their cubs during late autumn and the winter hibernation (Harris and Yalden, 2008). Up until this point the sub-adults would likely have spent the vast proportion of their time at the main sett, meaning the main sett and the area around it would be familiar and safe, thus leading to them staying at the main sett more. As figure 7 shows, for adults the summer months are peak foraging time, and adults are at their most active to put on the fat reserves needed for the winter inactivity, using outlying setts for the reason explained above.

The sex of the two age groups had no effect on the proportion of time spent at the main sett, and the same was true of the group size. Sex would have had no effect because the young badgers were learning at the same time; therefore both sexes would remain close to the sett for protection during their first independent year. Only once the sub-adults had reached true adulthood and sexual maturity would it be expected that they would range further from the main sett.

Limitations of the study

There are limitations to this study, mainly due to the nature of the study. There is a small sample size for the treatment area, with only 10 badgers tracked across the whole of the three year study period, potentially causing some confounding data due to individual preferences of the badgers. This problem is inherent when studying a post-cull population, and other than expanding the study site to include more animals there was very little that could have been done to minimise this effect. Another limitation that arose during data analyses was the fact that the majority of the day fixes were taken during the summer months, with the study showing this is the time when the control and treatment group are most similar. This could have skewed the data and resulted in hiding the true effects of an annual cull. In future studies, the data should be collected evenly across all seasons to clarify the data.

The main limitation with the group size data is that it is only a proxy of group size, and is gathered from the number of individuals trapped, culled and radio-tracked. For groups within the treatment area the number of culled badgers was added to the group size, however it is probable that due to any breakdown of territoriality, many roaming badgers from outside the treatment area were caught and attributed to these social groups. This could have potentially inflated the population size, as can be seen in figure 6. Not only this, but it is possible that there were neophobic badgers that were not caught, therefore the data on group sizes has been analysed cautiously, and should be studied more in the future to establish any effects.

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References

Ahnlund H. (1980) Sexual maturity and the breeding season of the badger in Sweden, *Journal of Zoology*, 190: 77-95

Artois M. Delahey R. Guberti V. Cheeseman C. (2001) Control of Infectious diseases of wildlife in Europe, The Veterinary Journal, 162: 141-152

Bourne J. (2007) Bovine TB: The scientific evidence, *Independent Scientific group on cattle TB*, London, UK

Brown J.A. Cheeseman C.L. Harris S. (1992) Studies on the spread of bovine tuberculosis from badgers to cattle, *Journal of Zoology*, 227: 694-696

Butler J. M. Roper T.J. (1996) Ectoparasites and sett use in European Badgers, *Animal Behaviour*, 52: 621-629

Butler J.M. Roper T.J. (1995) Escape tactics and alarm responses in badger – a field experiment, *Ethology*, 99:313-322

Cheeseman C.L. Burke T. (2007) Genetic evidence that culling increases badger movement: implications for the spread of bovine tuberculosis, *Molecular Ecology*, 16: 4919-4929

Cheeseman C.L. Cresswell W. J. Harris S. Mallinson P. J. (1988) Comparison of dispersal and other movements in two badger populations, *Mammal Review*, 18: 51-59

Cheeseman C.L. Harris S. (1982) Methods of marking badgers, *Journal of Zoology*, 197: 289-292
Cochran W.W. (1980) Wildlife telemetry, In S.D Schemnitz (ed), *Wildlife Management Techniques Manual 4th Edition*, 507-520, Wildlife Society, Washington, USA

Coleman J. Cooke M. (2001) Mycobacterium bovis infection in wildlife in New Zealand, *Tuberculosis*, 81: 191-202

Cresswell P. Harris S. Bunce R.G.H. Jefferies D.J. (1989) The badger *(Meles meles)* in Britain: present status and future population changes, *Biological Journal of the Linnean Socirty*, 38: 91-101

Cresswell P. Harris S. Jeffries D.J. (1990) The history, distribution, status and habitat requirements of the badger in Britain, In Neal E. Cheeseman C.L. (1996) Badgers, T and A D Poyser Ltd, UK

Cresswell W.J. Harris S. (1988) Foraging behaviour and home-range utilization in a suburban badger population, *Mammal Review*, 18: 37-49

Cresswell W.J. Harris S. Cheeseman C.L. Mallinson P.J. (1992) To Breed or not to breed: An analysis of the social and density-dependent constraints on the fecundity of female badgers, *Philosophical Transactions of the Royal Society B*, 338: 393-407

Cross M.L. Buddle B.M. Aldwell F.E. (2007) The potential of oral vaccines for disease control in wildlife species, *Veterinary Journal*, vol.174, 472-480

Davison J. Huck M. Delahey R.J. Roper T.J. (2008) Urban badger setts: characteristics, patterns of use and management implications, *Journal of Zoology*, 275: 190-200

De Leeuw A.N. Forrester G. Spyvee P.D. Brash M. Delahey R.J. (2004) Experimental comparison of ketamine, butorphanol and medotomidine for general anaesthesia of the European badger, *Veterinary Journal*, 167: 186-193

DEFRA, (2010) http://www.defra.gov.uk/foodfarm/farmanimal/diseases/atoz/tb/vaccination/bvdp.htm, accessed 2/3/2011

Delahey R. De Leeuw A.N.S. (2002) The status of *Mycobacterium bovis* infection in UK wild mammals: A review, *The Veterinary Journal*, 164: 90-105

Delahey R.J. Brown J.A. Mallinson P.J. Spyvee P.D. Handoll D. Rogers L.M. Cheeseman C.L. (2000) The use of marked bait in studies of territorial organisation of the European badger, *Mammal Review*, 30: 73-87

Delahey R.J. Walker N. Forrester G.J. Harmsen B. Riordan P. Macdonald D.W Newman C. Cheeseman C.L. (2006) Demographic correlates of bite wounding in European badgers in stable and perturbed populations, *Animal Behaviour*, 71: 1047-1055

Donnelly C A. Woodroffe R. Cox D. R. Bourne J. Gettinby G. Le Fevre A.M. McInerney J.P. Morrison W.I (2003) Impact of localized badger culling on tuberculosis incidence in British cattle, *Nature*, 426: 834–837

Donnelly C.A. Woodroffe R. Cox D.R. Bourne J. Cheeseman C.L. Clifton-Hadley R.S. Wei G. Gettinby G. Gilks P. Jenkins H. Johnston W.J. Le Fevre A.M. McInerney J.P. Morrison W.I. (2006) Positive and negative effects of widespread badger culling on tuberculosis in cattle, *Nature*, 439: 843

Gilbert M. Mitchell A. Bourn D. Mawdley J. Clifton-Hadley R. Wint W. (2005) Cattle movements and bovine tuberculosis in Great Britain, *Nature*, 435: 491

Harris S. Yalden D.W. (2008) Mammals of the British Isles: Handbook 4th ed. *Mammal Society*

Kowalczyk R. Zalewski A. Jedrzewska B. (2004) Seasonal and special pattern of shelter use by badgers in Bialowieza Primeval forest, *Acta Theriologica*, 49: 75-92

Krebs J.R. Anderson R. Clutton-Brock T. (1997) *Bovine tuberculosis in cattle and badgers*, The Ministry of Agriculture, Fisheries and Food Publications, London

Kruuk H. (1989) *The Social Badger*, Oxford Univeristy Press, Oxford

Kruuk, H. (1978) Spatial organization and territorial behaviour of the European badger *(Meles meles)*, *Journal of Zoology, London,* 184: 1-19

Little T.W. Naylor P.F. Wilesmith J.W. (1982) Laboratory study of *Mycobacterium bovis* infection in badgers and calves, *Veterinary Record*, 11: 550–557

Muirhead R.D. Gallagher J. Burn K.J. (1974) Tuberculosis in wild badgers in Gloucestershire: epidemiology, *The Veterinary Record*, 95: 552-555

Neal E. Roper T.J. (1991) The environmental impact of badgers and their setts, Symp. Zool. Soc., London, 63: 89-106

Nolan A. Wilemith J.W. (1994) Tuberculosis in badgers, *Veterinary Microbiology*, 40: 179-191
Ostler J.R. Roper T.J. (1998) Changes in size, status and distribution of badger *(Meles meles) setts during a 20-year period, Z. Saugetierkunde, 6 3: 200-209.*

Pastoret P.P. and Brochier B. (1998) Epidemiology and Elimination of Rabies from Western Europe, *Veterinary Journal*, 156: 83-90

Pope L.C. Butlin R.K. Wilson G.J. Woodroffe R. Erven K. Conyers C.M. Frankin T. Delahey R.J. Porphyre T. Stevenson M.A. McKenzie J. (2008) Risk factors for bovine tuberculosis in New Zealand cattle farms and their relationship with possum control strategies, Preventative Veterinary Medicine, 86: 93-106

Report (2000) *Animal Health 1999. The report of the Chief Veterinary Officer*, Ministry of Agriculture, Fisheries and Food, Scottish Agriculture, Environment and Fisheries Department and the Welsh Office Agriculture Department, p118, HMSO

Report (2000) *Possum control*, produced for the New Zealand Government, accessed 24/4/2011, http://www.parliament.nz/NR/rdonlyres/C5AA4332-F028-448E-A659-72DF0F5F27FE/422/002Possum1.pdf

Report (2007) *Project report to DEFRA: The demographic, ecological and epidemiological consequences of culling badgers*, Central Science Laboratory, York

Revilla E. (2003) What does the resource dispersion hypothesis explain, if anything? *OIKOS*, 101: 428-432

Revilla E. Palomares F. (2002) Spatial organization, group living and ecological correlates in low density populations of Eurasian badgers, *Journal of Animal Ecology*, 71: 497-512

Rogers L.M. Cheeseman C.L. Mallinson P.J. Clifton-Hadley R. (1997) The demography of a high density badger population in the west of England, *Journal of Zoology*, 242: 705-728

Roper T. J. (1992) Badger setts – architecture, internal environment and function, *Mammal Review*, 22: 43-53

Roper T.J. Ostler J.R. Schmid T.K. Christian S.F. (2001) Sett use in European Badgers, *Behaviour*, 138: 172-187

Smith G.C. and Harris S. (1989) The control of rabies in urban fox populations, in *Mammals as Pests ed. Putman R.J.*, Suffolk, UK

Smith G.C. Cheeseman C.L. Clifton-Hadley R.S. Wilkinson D. (2001) A model of bovine tuberculosis in the badger *Meles meles*: an evaluation of control strategies, *Journal of Applied Ecology*, 38: 509–519

Stewart P.D. Macdonald D.W. Newman C. (2002) Behavioural mechanisms of information transmission and reception by badgers at latrines, *Animal Behaviour*, 63: 999-1007

Woodroffe R. Bourne F.J. Cheeseman C.L. Cox D.R. Donelly C.A. Gettinby G. McInnery J.P. Morrison W.I. (2005) Welfare of badgers subjected to culling: development and evaluation of a closed season, *Animal Welfare*, 14: 19-25

Woodroffe R. Donnelly C.A. Cox D.R. Bourne J. Cheeseman C.L. Delahey R.J. Gettinby G. McInerney J.P. Morrison W.I. (2006) Effects of culling on badger *Meles meles* spatial organization: implications for the control of bovine tuberculosis, *Journal of Applied Ecology*, 43: 1–10