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The avoidance of farmyards by European badgers *Meles meles* in a medium density population

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ABSTRACT

Mycobacterium bovis (TB) in cattle is a disease with far-reaching economic effects throughout Europe but especially in Great Britain and Ireland. Wildlife reservoirs, in particular the European badger *Meles meles*, continue to play an important role in the transmission of the disease, although the pathways of transmission are still poorly understood. The badger is an opportunistic feeder that takes advantage of seasonally abundant foods, such as fruits and insect larvae. Badgers might therefore be expected to enter farmyards to exploit grain stores or feed concentrates. This would bring them into close proximity with livestock present in those yards, potentially increasing the likelihood of disease transmission.

This Irish study is the first to have looked at the use of a variety of farmyard types by free-ranging, GPS collared badgers from a medium-density population over a 3 years period.

We found that badgers in our study area avoided all types of farmyards but particularly those where cattle were present.

We investigated the influences of seasonality, social group members and badger gender on these preferences and found that they had no impact on this behaviour.

As our results differ from the findings of studies carried out in high-density badger populations in Great Britain it is probable that different farming practices as well as differences in badger behaviour and ecology must be taken into account when designing measures to control this disease. Increasing our knowledge of the interactions between badgers and cattle in a variety of ecological situations will assist in proactive and general control of the disease in both species.

1. Introduction

Mycobacterium bovis causes tuberculosis (TB) in cattle, a disease with far-reaching economic effects throughout Europe but especially in Great Britain and Ireland (Abernathy et al., 2013). Wildlife reservoirs, in particular European badgers *Meles meles*, continue to play an important role in the transmission of the disease (Wilson et al., 2011; Biek et al., 2012). This type of TB is primarily a respiratory disease in badgers (Corner et al., 2011), and remains endemic in the badger population (O'Connor and O'Malley, 1989). Considerable research has been undertaken in Ireland to address the role played by badgers in the endurance of TB in cattle (Ward et al., 2010; Aznar et al., 2011; Gormley and Corner, 2011). Although huge financial resources are spent each year in the fight to control this disease in cattle and badgers, the transmission pathways between these two key species remain largely unknown (Wilson et al., 2011; Biek et al., 2012).

European badgers are nocturnal mammals, whose underground setts and lifestyle make them difficult to study. Consequently their behaviour is relatively poorly understood. They are opportunistic omnivores that take advantage of seasonally abundant foods, such as fruits and insect larvae (Cleary et al., 2009; Roper, 2010). They might therefore be expected to enter farmyards to feed on

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grain stores or feed concentrates, particularly at times of year when other foods may not be abundant (Garnett et al., 2002). In Ireland food is seasonally chosen with abundant insect larvae in Spring and Autumn but less food available in Summer and Winter (Cleary et al., 2009). The presence of badgers in farmyards would bring them into close proximity with any livestock present in those yards, potentially increasing the likelihood of disease transmission.

The focus of disease transmission studies has been on one of two routes; either the interactions between cattle and badgers at pasture (Benham and Broom, 1989; Benham, 1993; Sleeman and Mulcahy, 1993; Hutchings and Harris, 1997; Olea-Popelka et al., 2006; Mullen et al., 2013), or in farmyards and buildings (Cheeseman and Mallinson, 1981; Garnett et al., 2002, 2003; Scantlebury et al., 2006; Sleeman et al., 2008; Tolhurst et al., 2009; Anon, 2013). Previous Irish studies of farmyard use by badgers have tended to focus on the relationship between the presence of active badger setts on farmland and the likelihood of a TB breakdown in the herd (Olea-Popelka et al., 2006; Menzies et al., 2011). Previous work investigating badger behaviour in and around farms has relied on radio-tracking, speculative filming of farmyards or finding their tracks as they come into farms (Garnett et al., 2002; Sleeman et al., 2008; Tolhurst et al., 2009). British studies have found high levels of badger activity in and around farm buildings. Irish studies have found less evidence of badger activities in farm yards (Sleeman et al., 2008) but detailed quantitative data covering a wide variety of farm types was lacking before the present study. The strong link between TB in badgers and TB in cattle (Biek et al., 2012) makes it important to understand the full range of possible interactions between badgers and cattle and, therefore, the potential opportunities for disease transmission.

Although most work on badger ecology has been conducted in Great Britain (GB), it is important to consider Irish populations for two reasons. Firstly, Irish populations are at a lower density than the best studied populations in England (Roper, 2010; Byrne et al., 2012), but may be more typical of the densities in the north of GB and the rest of Europe. Potentially, population density may influence the likelihood of individuals to enter farmyards. Secondly, as researchers continue to document differences between British badgers and other European populations, it is becoming clear that there are morphological and behavioural differences between the British and Irish populations (Lynch et al., 1997; O'Meara et al., 2012; MacWhite pers comm). Therefore, it may not be safe to extrapolate the findings from British studies to the Irish population.

This study concentrated on the use of farmyards by free-ranging, GPS-collared badgers (MacWhite et al., 2013) across an area of approximately 41 km^2 of mixed farmland and woodland in Co. Wicklow, Ireland (N52.9107200 W6.1035767) from 2010 to 2013. The landscape and farming practices are typical of most agricultural land in Ireland. Badger density for the study area 2010–2013, based on minimum number alive, (using the GPS collared badgers), was estimated to be 1.1 per km^2. This is slightly lower than the national estimate of 1.9 badgers per km^2 (Sleeman et al., 2009).

Our expectation, based on the adaptable, seasonal nature of badger foraging behaviour found in Ireland (Cleary et al., 2009), was that badgers would rely on farmyards as a food source, particularly when other food was scarce. The research aimed to establish whether the recorded visits made by badgers to farmyards in the study area were as frequent as would be expected given the availability of farmyards to the badgers. It examined the possible influence of season, sex of the badger, social group and farm type on the pattern of visits. Understanding the factors which influence the use of farmyards by badgers will help our understanding of interactions between badgers and livestock, and its relevance to disease spread.

2. Material and methods

This study used 30,764 GPS fixes, obtained from 40 collared badgers from 12 social groups, each contributing to the data set for part of the study over a 3 years period (Table S1). The study ran from April 2010 to February 2013 as part of an ongoing study (MacWhite et al., 2013). The badgers had been fitted with Tellus 1C (Followit, Sweden) collars which sent GPS fixes by SMS message that were downloaded from the Followit website and converted to Irish Grid location data. The collars were programmed to record four fixes per night at 22:00, 23:00, 01:00 and 02:00 except in April, May and September when the collars were set to give eight at 21:00, 22:00, 23:00, 00:00, 01:00, 02:00, 03:00 and 04:00 to facilitate trapping. Fixes were recorded when the badgers were above ground and able to communicate with a satellite (MacWhite et al., 2013). These fixes were mapped using ArcView GIS 3.2 (ESRI, Redlands, California) and allocated a season within each year as follows: Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November), Winter (December, January, February). Using these categories 95% Minimum Convex Polygon (MCP) home ranges were calculated for each badger in each season for the 3 years of the study.

There were 58 farmyards in the study area which were mapped and the area of each farmyard calculated. The farmyards were sorted into 10 categories according to the type of farming activities carried out (Table 1). This categorisation was then verified by means of site visits. Using GPS data from individual badgers, within ArcView, it was possible to determine which farmyards fell within each home range and to calculate the proportion of each range represented by that farmyard. We observed that badgers can cover distances of up to 6 km per night and so a badger could easily visit any part of its range on any given night. Therefore we made the assumption that farmyard distance from the sett would not affect the badger's likelihood of visiting any given farmyard over the course of a season. We calculated the chance of a fix happening to be in a farmyard if the badger used all areas of its home range at random. We then compared this to how often badgers really did record a fix in a farmyard. An expected number of records from each farmyard by each badger was calculated using the proportion of the area of the badger's home range (95% MCP) represented by each farmyard, assuming that badgers showed no preference for entering or avoiding farmyards. This was done for each badger during each season for which it provided data. The expected number of badger records was subtracted from the actual number of records to identify a preference for, or avoidance of, farmyards. This value was referred to as the 'farm bias index'. Positive index values indicated a preference for the farmyard, compared to other parts of the badger's home range, and negative values indicated avoidance of the farmyard (Neu et al., 1974).

We made no distinction between farm buildings and the uncovered areas of farmyards immediately surrounding those buildings, as the maximum margin of error of the GPS readings from the collars was 15 m, so the resolution was not accurate enough to distinguish inside and immediately outside a given building. Field trials showed that the collars were capable of connecting to satellites while they were inside a cattle feed store. We were therefore satisfied that we were not missing readings from badgers that spent time within farm buildings.

For the purposes of this paper, a social group was defined as the group of badgers which used the same main sett and whose home ranges overlapped during the season in question. This allowed for the dispersal of some badgers from their original social group over the 3 years of the study. Dispersing badgers were assigned to their original social group for the seasons in which their home ranges overlapped with others in that group. They were considered to have

Table 1
Summary of farms in the study area arranged by livestock and land use.

Type of farm	Total area (ha)	No. of farms	Farms visited by badgers	% farms of this category visited	No. of Badger records from this category	No. of individual Badgers which visited this category
Cattle	10.7	24	7	29	12	10
Cattle/tillage	1.4	3	1	33	1	1
Disused	1.4	3	2	66	14	5
Equestrian	6.5	11	3	27	30	5
Sheep	1.6	4	2	50	6	2
Tillage	2.6	7	2	28	3	3
Animal shelter	0.5	1	0	0	0	0
Machinery	0.4	1	0	0	0	0
Horse/sheep	0.4	1	0	0	0	0
Cattle/horse	1.9	3	0	0	0	0

joined a new social group in subsequent seasons if their home range overlapped with that of members of the new group.

Statistical analyses were performed in 3.1.1 (R Core Team, 2014). The overall preference for farmyards of the study population in each season was calculated using paired T tests comparing the expected farm visits with the actual number of visits (i.e. the farm bias index) in each season (cf. Neu et al., 1974). As similar tests were applied for each of the 12 seasons, a Holm adjustment for multiple tests (Holm, 1979) was applied to all *P* values from these tests. In addition, we conducted a more detailed analysis by month across the whole of the study period, including all GPS fixes for all badgers in the study area between 21/04/2010 and 28/02/2013. Each GPS fix was scored as either 0 (no visit) or 1 (visit) depending on whether the fix placed the badger in a farmyard or not. These data were subjected to a further analysis using a generalized binomial mixed model framework (using the glmer function from the lme4 package) (Bates et al., 2013). For the saturated model, visit was the dependent variable, gender and season were fixed factors and individual badger was a random factor. We ran all legitimate combinations of random and fixed factors using the dredge function from the MuMin package (Barton, 2013). Results from the better-performing models (dAIC <5) were averaged using the model.avg function (also from the MuMin package).

2.1. Ethical standards

No experiments were carried out on the badgers in this study. The trapping, marking and collaring of the badgers was completed under licence from the National Parks and Wildlife Service (Licence No. C005/2013 held be Teresa MacWhite and Nominees).

3. Results

There were a total of 30,764 records (GPS fixes) from the badgers during the study period. Of these, only 66 records (0.21%) were located within a farmyard. During the study, GPS fixes were collected for 40 badgers of which 21 were male and 19 female. Twenty badgers, 10 of each gender, (48% of the males and 53% of the females) provided at least one fix from within a farmyard. There was at least one fix recorded within a farmyard for each of the four seasons in each year of the study period, with the exception of Winter 2010. During that season badger activity was greatly reduced, most likely due to the unusually cold weather. December 2010 was one of the coldest months on record in Ireland ever. The nearest meteorological station recorded snow for 13 days, a minimum temperature of −12.2 °C and 42 days of air frost (Met Éireann, 2011).

Median farm bias index scores were negative for both male and female badgers in all seasons (Fig. 1). This shows that of the badgers which did visit farmyards, the average rate of visiting farmyards was never above that predicted by chance encounter, and indeed, in most cases they actively avoided the farmyards. The nature of this avoidance was tested for each season using paired *T*-tests (Table 2). The badger population demonstrated an active avoidance of farmyards in all but four seasons – Autumn 2010, Winter 2011, Summer 2012 and Autumn 2012. However, this population level avoidance was not shared by all individuals. In Autumn 2012 one female badger (No. 1880) provided 18 records in the same farmyard over nine nights. Her behaviour regarding the frequency of fixes from this one farmyard was unique in this dataset, and appeared idiosyncratic so was excluded to allow the population level avoidance behaviour of the badgers to be investigated. When the data for this badger were omitted the avoidance of farmyards during Autumn 2012 became significant (Table 2). Thus, when her data was included there was significant avoidance of farmyards in eight out of 12 seasons. By excluding her data the significant avoidance of the farmyards by the badgers occurred in nine of the 12 seasons. In Winter 2011 the number of records from farmyards matched that which would be expected if the badgers' use of the farmyards had been random. Winter 2011 was a relatively mild winter. The nearest weather station recorded only 12 days of air frost and 4 snow days. The average temperature was 0.8 °C above normal. It was also the driest winter recorded in the Dublin region for 5 or 6 years (Met Éireann, 2012). The seasonal mixed model provided no evidence of season or badger gender influencing farm visit likelihood when badger 1880 was included in (Table S2) or excluded from (Table S3) the dataset.

A total of 17 farmyards were visited by the collared badgers. This was 29.3% of the 58 farmyards falling within the study badger home ranges. The area of each category of farm available to the badgers was used to calculate the expected number of records for that particular category. When compared to the actual number of records of badgers entering that type of farmyard, the pattern of usage could be clearly seen (Table 1). Badgers showed a general avoidance of farmyards but showed a particularly strong avoidance of yards on cattle farms (Fig. 2). In contrast to this, among the farms visited, the badgers showed a greater usage of equestrian yards and disused farmyards than that which was expected from the availability of those categories (Fig. 2).

It was possible to ascertain whether the badgers from a given social group tended to visit or avoid the same farms i.e. whether badgers in a social group were influencing the decisions of other members of that group. Badgers belonging to the same social group had the opportunity to visit the same farmyards. Of the nine social groups in the study containing more than one collared badger, six groups contained some badgers which visited farmyards and some which did not. In all but one social group, badgers did not habitually use the same farmyards as others in their group. In two social groups none of the badgers were recorded as visiting any farmyard for the duration of the study. Thus there was no discernible evidence that social group members positively influenced the use of farmyards by other badgers in their social group.

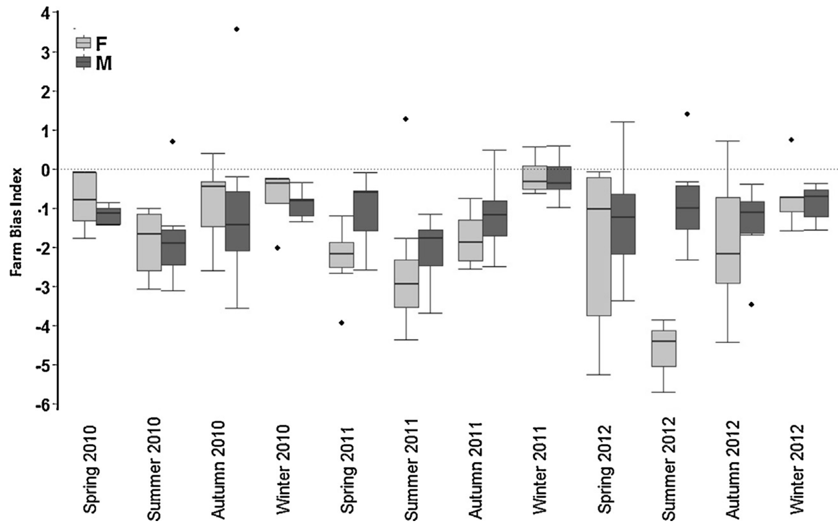

Fig. 1. Boxplot to show the farmyard visit preference scores for male (dark grey bars) and female (pale grey bars) badgers, by season, during the study period (date range). Negative scores represent an avoidance of farmyards, positive scores represent a preference for farmyards. The dotted line at zero represents the predicted rate of farmyard visitation by badgers, if they were moving randomly through their home ranges. Dots outside the line and whisker plots indicate data points >2*SD from the median values of that cohort.

Table 2
The paired *T*-tests for expected number of farm visits versus actual number of farm visits for each season, with adjusted *P* values (Holm correction). These analyses exclude badger no. 1880.
* indicates <0.05 > 0.01 ** indicates <0.01 > 0.001 ***indicates <0.001

Season	df	*T* value	Original *P*	Adjusted *P*	Significance	Preference
Sp10	9	−5.55	0.000355	0.003	**	Avoidance
Su10	10	−5.41	0.000298	0.003	**	Avoidance
A10	12	−1.96	0.073172	0.157	NS	No preference
W10	8	−4.18	0.003089	0.012	*	Avoidance
Sp11	13	−5.97	0.000046	0.000	***	Avoidance
Su11	12	−5.72	0.000097	0.001	***	Avoidance
A11	15	−6.97	0.000005	0.000	***	Avoidance
W11	14	−1.61	0.130739	0.157	NS	No preference
Sp12	16	−3.64	0.002207	0.011	*	Avoidance
Su12	7	−2.33	0.052231	0.157	NS	No preference
A12	13	−4.32	0.000836	0.006	**	Avoidance
W12	11	−4.37	0.001125	0.007	**	Avoidance

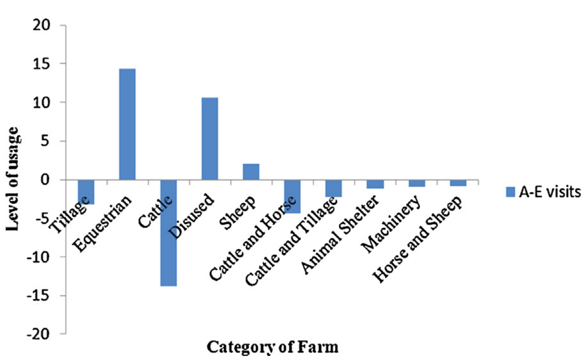

Fig. 2. Relative usage of each farm type calculated from the actual number of badger visits minus the expected number of visits based on the proportion of farmyard area of each category available. Positive values indicate that when badgers visited farms, they visited these farm types more often than their availability would predict, while negative values indicate those farm types avoided more than their availability would predict.

4. Discussion

This study represents the first quantitative study of badger ranging behaviour with respect to farmyards and farm buildings in Ireland. It is also the first study to examine how badgers use the variety of farmyards available to them within their home ranges rather than focusing on cattle farms alone.

4.1. Irish badgers avoid farmyards

Our data show that Irish badgers generally avoid farmyards. In eight out of 12 seasons during the study period the badgers showed a strong avoidance of farmyards. In addition, there were no seasons when the badgers showed any preference for farmyards. British studies have shown regular and frequent badger visits to farm buildings (Garnett et al., 2002; Tolhurst et al., 2009; Judge et al., 2011). Only one previous study (Sleeman et al., 2008) has investigated badger visits to farmyards in Ireland but that study was limited to a single season (winter). The study found a very low incidence of badger visits to farmyards.

Behavioural observations (Benham and Broom, 1989), as well as the use of proximity collars (Drewe et al., 2013) and GPS tracking (Mullen et al., 2013), suggest that badgers avoid cattle at pasture in both Ireland and GB, although this does not preclude the risk of infection at latrines (Hutchings and Harris, 1997). These behavioural studies, together with the evidence of badger visits to farm buildings in GB (Garnett et al., 2002; Tolhurst et al., 2009), have generated a shift in thinking, such that direct and indirect interactions between badgers and cattle in farmyards and farm buildings have been considered the most likely route for TB cross-infection

(Allen et al., 2011). Our results show that the opportunity for direct transmission of the disease is less likely to occur in Irish farmyards and so the opportunities for transmission via fomites within those yards are also reduced compared with British studies. However, as one individual (Badger 1880) made repeated visits to a farmyard, the potential for transmission does nonetheless exist (Conner and Miller, 2004).

British studies frequently show a seasonal trend in farmyard visits. Garnett et al. (2002) demonstrated a peak in visits during July, while Tolhurst et al. (2009) and Judge et al. (2011) recorded most visits in April, May and June. We found very few visits and no seasonal peaks within these periods. Instead our study badgers showed a strong avoidance of farmyards for all but one of the spring and summer seasons during the study (Table 2). Tolhurst et al. (2009) suggested that the peak in visits during spring/summer might be related to changes in earthworm availability. Garnett et al. (2002) in GB found that drier conditions increased the likelihood of a farm visit. They suggested that as dry weather made it difficult for badgers to capture earthworms farmyards provided easier foraging during dry conditions. Irish badgers are not dependent on earthworms in the same way as British badgers, although they are still dependent on soil invertebrates at some times of year (Cleary et al., 2009). Thus a dearth of earthworms during dry periods may not cause food shortages for Irish badgers and this may go some way to explain why our study did not show the same seasonal patterns of farmyard use as they switch between earthworms, tipulid larvae and noctuid larvae. However, in the driest winter in our study (Winter 2011) while our study badgers still avoided farmyards there was a slight increase in farmyard usage.

Our mixed models found that the sex of the badger was not a useful predictor of their likelihood to visit farmyards, so we found no evidence that males and females within our study population used farmyards differently. This contrasts with the findings of Tolhurst et al. (2009) who found males in farm buildings more frequently than females.

Irish badgers may differ from badgers in GB genetically (Marmi et al., 2006; Del Cerro et al., 2010; O'Meara et al., 2012 but cf Frantz et al., 2014) and they clearly differ behaviourally (Cleary et al., 2009). Badger densities are lower in Ireland (Sleeman et al., 2009; Byrne et al., 2012), their social groups tend to be smaller and their home ranges larger (unpublished data MacWhite, T.) than those measured by Tolhurst et al. (2009). In GB earthworms form a major part of the badger's diet (Kruuk, 1978; Roper, 2010). It is possible that the dietary differences (Cleary et al., 2009) and lower densities of Irish badgers (Byrne et al., 2012) mean that farmyards are not as important a source of food for badgers in Ireland as they are in GB (Garnett et al., 2002; Tolhurst et al., 2009; Judge et al., 2011; Drewe et al., 2013). In addition, both cattle and dairy farming in Ireland are largely grass-based systems. By comparison, in the study by Tolhurst et al. (2009) four of the six farms fed their cattle in buildings all year round, and some housed their cattle all year round. On only one of the farms in Tolhurst's study were the cattle completely at pasture, but that was just for 6 months from April to September. Cattle in our study were at pasture from April or May through to late November or early December each year. This regime means that there is likely to have been less cattle feed stored in Irish farmyards during these months. As a consequence the farmyards may be less attractive to Irish badgers at this time. The peak of visits to farmyards in British studies (Garnett et al., 2002; Tolhurst et al., 2009; Judge et al., 2011) occurred between April and July, a time of year when most Irish cattle are at pasture. While Mullen et al. (2013) found that badgers avoid cattle at pasture they still foraged in pastures when the cattle were not present. The presence of cow dung may offer improved feeding opportunities for badgers in cattle pastures. The removal of cattle from pasture (in GB) may be reducing the availability of cow dung as a source of invertebrate prey for badgers and thus increasing the attractiveness of farmyards to badgers in that country.

Our 3-year study comprised a large number of badgers (40) from 12 social groups, and also a large number of farms (58). The GPS collars enabled us to monitor changes in home ranges of the badgers across the study period. This meant that we could look at the use of all the farms present in each badger's home range even when that home range varied from season to season. As our data were collated from snapshots in time it is possible that we did not record some visits to farmyards which a continuous recording method would have identified. However, if the badgers were spending prolonged periods of time in farmyards we would have expected the fixes from the collars to identify this activity. Only one badger sent multiple fixes from a farmyard in the same night (Badger 1880). Farmyards being mostly buildings and concrete will not yield much in the way of normal wild food so the presence of a badger there means it is either transitioning the yard or it is there for stored food.

4.2. Badger visits to different farm types

Our study has been the first to examine badgers' usage of different farm types, rather than concentrating exclusively on cattle farms. While badgers generally avoided farmyards they seem to have avoided some types of farmyard less than others. Of the 10 categories of farm described, the badgers showed greater usage of three types: sheep farms, equestrian farms and disused farmyards.

The lesser avoidance of disused farmyards by the badgers could be because these yards were overgrown, providing many microhabitats for invertebrates. Badgers could forage in these yards without fear of being disturbed. However, these farmyards did not provide a source of cattle feed, which was suggested by Garnett et al. (2002) to be the reason badgers visit farmyards and we have no behavioural data for our badgers at farmyards.

In our study, although the badgers avoided all types of farmyards, they unexpectedly showed greater usage of equestrian yards than other farmyard types. The reasons for this finding are unclear but may relate to differences in the food types offered to cattle and horses. There may also be differences in spillage rates during feeding by these two species.

Of the categories of farmyards available to the badgers, those farmyards associated with cattle were visited least by the badgers despite the food resources available within them. Of the 66 GPS fixes in farmyards recorded during our study only 13 were in cattle farmyards. When this value is corrected for the proportion of cattle farmyards, it shows a greater avoidance of cattle farmyards than of any other category. We know that badgers in Ireland do occasionally visit buildings on cattle farms, as Sleeman and Mulcahy (1993) reported following a radio-tracked badger into a milking parlour. In the Department of Agriculture Food and Marine's (DAFM) badger vaccine research facility some badgers have been recorded in sheds and have also been observed to instigate nose-to-nose contact with cattle in buildings (E. Gormley, pers. comm.). Prior to this study, a badger (which was clear of TB) was found living in a farm building on one of the study farms and one badger during this study frequently visited a farmyard over a short period. Our findings of strong avoidance of cattle farms among most of the badger population are consistent with the results of an earlier study showing that badgers avoid cattle at pasture (Mullen et al., 2013). Badgers in GB and Ireland have the same opportunities to gain access to farms and farmyards. It is highly unlikely that Irish farmers employ more biosecurity measures on farms than their counterparts in GB. However, ecological pressures (food availability and population density concerns) appear to differ between the islands. Therefore, it is likely to be these differences that explain the difference in the behaviour of the badgers towards farms and farmyards.

4.3. Social group co-ordination

This study was the first to investigate the effect of sociality on farmyard visits. We found no evidence that the behaviour of one badger increased or decreased the likelihood of farmyard visits in other members of the same social group. Roper (2010) reports that there is little interaction or social facilitation between the adult foraging members of the same social group of badgers. As the badgers in our study were all adults, our results correspond with this view of independent foraging. Our findings are also consistent with Robertson et al. (2014) who demonstrated that individual badgers occupied distinct foraging niches within the common social group range, in spite of the fact that the resources were available to all members of the social group.

4.4. Implications for TB

Woodroffe et al. (2006) argued, in their GB study, that researchers need to think in terms of a dynamic picture of infection between cattle and badgers, with disease transfer likely to occur from cattle to badger and from badger to cattle as well as within the species themselves. Incursions by badgers to farmyards and sheds would increase the chance of inter-species transmission of TB if either species were infected. As Irish badgers appear to avoid cattle in farmyards (this study) and at pasture (Mullen et al., 2013), this clearly minimises the opportunities for direct transmission of TB between badgers and cattle. It also reduces the opportunities for indirect contact between them in the farmyards through contamination with faecal matter or other fomites. There is some evidence that TB-infected badgers might behave differently from healthy individuals (Garnett et al., 2005) but the badgers in our study were all vaccinated against the disease. While evidence for the transfer of TB between badgers and cattle is overwhelming (Biek et al., 2012), it will not be possible effectively to mitigate against this until the mechanisms of disease transfer are more clearly understood. This study shows that the opportunities for inter-species transmission of the disease within farmyards in Ireland are more likely to be indirect than direct and may be fewer than previously suspected.

5. Conclusion

This study demonstrates a strong avoidance of farmyards by Irish badgers, which is particularly marked on cattle farms. While our findings contrast with the much more frequent use of farmyards identified by studies of British badgers, these findings are essential for a clearer understanding of the transmission of TB between badgers and cattle in Ireland. Our study suggests that ecological differences may be driving behavioural differences in British and Irish badger populations. Future considerations of TB transmission and its control may require a more careful deliberation of these differences.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.applanim.2015.08.021.

References

Abernathy, D.A., Upton, P., Higgins, I.M., McGrath, G., Goodchild, A.V., Rolfe, S.J., Broughan, J.M., Downs, S.H., Clifton-Hadley, R., Menzies, F.D., de la Rua-Domenech, R., Blissitt, M.J., Duignan, A., More, S.J., 2013. Bovine tuberculosis trends in the UK and the Republic of Ireland, 1995-2010. Vet. Rec. 172 (12), 312, http://dx.doi.org/10.1136/vr.100969.

Allen, A.R., Skuce, R.A., McDowell, S.W.J., 2011. Bovine TB: A Review of Badger-to-Cattle Transmissions. http://www.dardni.gov.uk

Anon, 2013. Caught on camera: surveillance monitors badgers' visits to farms. Vet. Rec. 173, 105, http://dx.doi.org/10.1136/vr.f4806.

Aznar, I., McGrath, G., Murphy, D., Corner, L.A.L., Gormley, E., Frankena, K., More, S.J., Martin, W., O'Keeffe, J., DeJong, M.C.M., 2011. Trial design to estimate the effect of vaccination on tuberculosis incidence in badgers. Vet. Microbiol. 151, 104–111.

Barton, K., 2013. MuMIn: Multi-Model Inference. R Package Version 1.9.13. http://CRAN.R-project.org/package=MuMIn

Bates, D., Maechler, M., Bolker, B., 2013. The Comprehensive R Archive Network lme4: Linear Mixed-Effects Models Using Eigen and S4. R Package – Version 1.0-5, Accessed July 31st 2013 http://CRAN.R-project.org/package=lme4

Benham, P.F.J., 1993. The interactive behaviour of cattle and badgers with reference to transmission of bovine tuberculosis. In: Hayden, T.J. (Ed.), The Badger. Royal Irish Academy, Dublin, pp. 189–195.

Benham, P.F.J., Broom, D.M., 1989. Interactions between cattle and badgers at pasture with reference to bovine tuberculosis transmission. Br. Vet. J. 145, 226–241.

Biek, R., O'Hare, A., Wright, D., Mallon, T., McCormick, C., Orton, R.J., McDowell, S., Trewby, H., Skuce, R.A., Kao, R.R., 2012. Whole genome sequencing reveals local transmission patterns of *Mycobacterium bovis* in sympatric cattle and badger populations. PLoS Path 8 (11), e1003008, http://dx.doi.org/10.1371/journal.ppat.1003008, Accessed 17 August 2014.

Byrne, A.W., Sleeman, D.P., O'Keeffe, J., Davenport, J., 2012. The ecology of the European badger (*Meles meles*) in Ireland: a review. Biol. Environ. Proc. R. Ir. Acad. 112B, 105–132.

Cheeseman, C.L., Mallinson, P.J., 1981. Behaviour of badgers (*Meles meles*) infected with bovine tuberculosis. J. Zoolog. 194, 284–289.

Cleary, G.P., Corner, L.A.L., O'Keeffe, J., Marples, N.M., 2009. The diet of the badger *Meles meles* in the Republic of Ireland. Mamm. Biol. 74 (6), 438–447.

Conner, M.M., Miller, M.W., 2004. Movement patterns and spatial epidemioology of a prion disease in mule deer population units. Ecol. Appl. 14, 1870–1881.

Corner, L.A.L., Murphy, D., Gormley, E., 2011. *Mycobacterium bovis* infection in the Eurasian badger (*Meles meles*): the disease, pathogenesis, epidemiology and control. J. Comp. Pathol. 144, 1–24.

Del Cerro, I., Marmi, J., Ferrando, A., Chashchin, P., Taberlet, P., Bosch, M., 2010. Nuclear and mitochondrial phylogenies provide evidence for four species of Eurasian badger (Carnivora). Zool. Scripta 39, 415–425.

Drewe, J.A., O'Connor, H.M., Weber, N., McDonald, R.A., Delahay, R.J., 2013. Patterns of direct and indirect contact between cattle and badgers naturally infected with tuberculosis. Epidemiol. Infect., http://dx.doi.org/10.1017/S0950268813000691, Accessed 17 August 2014.

Frantz, A.C., McDevitt, A., Pope, L.C., Kochan, J., Davison, J., Clements, C.F., Elmeros, M., Molina-Vacas, G., Ruiz-Gonzalez, A., Balestrieri, A., Van Den Berge, K., Breyne, P., Do Linh San, E., Ågren, E.O., Suchentrunk, F., Schley, L., Kowalczyk, R., Kostka, B.I., Ćirović, D., Šprem, N., Colyn, M., Ghirardi, M., Racheva, V., Braun, C., Oliveira, R., Lanszki, J., Stubbe, A., Stubbe, M., Stier, N., Burke, T., 2014. Revisiting the phylogeography and demography of European badgers (*Meles meles*) based on broad sampling, multiple markers and simulations. Heredity, http://dx.doi.org/10.1038/hdy.2014.45.

Garnett, B.T., Delahay, R.J., Roper, T.J., 2002. Use of cattle farm resources by badgers (*Meles meles*) and the risk of bovine tuberculosis (*Mycobacterium bovis*) transmission to cattle. Proc. R. Soc. Lond. Biol. Sci. 269, 1487–1491.

Garnett, B.T., Roper, T.J., Delahay, R.J., 2003. Use of cattle troughs by badgers (*Meles meles*): a potential use for the transmission of bovine tuberculosis (*Mycobacterium bovis*) to cattle. Appl. Anim. Behav. Sci. 80, 1–8.

Garnett, B.T., Delahay, R.J., Roper, T.J., 2005. Ranging behaviour of European badgers (*Meles meles*) in relation to bovine tuberculosis (*Mycobacterium bovis*) infection. Appl. Anim. Behav. Sci. 94, 331–340.

Gormley, E., Corner, L.A.L., 2011. Control of tuberculosis in badgers by vaccination: where next? Vet. J. 189, 239–241, http://dx.doi.org/10.1016/j.tvjl.2011.03.007.

Holm, S., 1979. A simple sequentially rejective multiple test procedure. Scand. J. Stat. 6 (2), 65–70.

Hutchings, M.R., Harris, S., 1997. Effects of farm management practices on cattle grazing behaviour and the potential for transmission of bovine tuberculosis from badgers to cattle. Vet. J. 153, 149–162.

Judge, J., McDonald, R.A., Walker, N., Delahay, R.J., 2011. Effectiveness of biosecurity measures in preventing badger visits to farm buildings. PLoS ONE 6 (12), e28941, Accessed 17 August 2014.

Kruuk, H., 1978. Foraging and spatial organisation in the European badger (*Meles meles*). Behav. Ecol. Sociobiol. 4, 75–89.
Lynch, M., Whelan, R., Il Fituri, A.I., Hayden, T.J., 1997. Craniometric variation in the Eurasian badger, *Meles meles*. J. Zool., Lond. 242, 31–44.
MacWhite, T., Maher, P., Mullen, E., Marples, N., Good, M., 2013. Satellite tracking study of badgers *Meles meles*: establishing normal ranging behaviour prior to a road re-alignment. Ir. Nat. J. 32 (2), 99–105.
Marmi, J., López-Giráldez, F., MacDonald, D.W., Calafell, F., Zholnerovskaya, E., Domingo-Roura, X., 2006. Mitochondrial DNA reveals a strong phylogeographic structure in the badger across Eurasia. Mol. Ecol. 15, 1007–1020.
Menzies, F.D., Abernethy, D.A., Stringer, L.A., Jordan, C., 2011. A comparison of badger activity in two areas of high and low bovine tuberculosis incidence of Northern Ireland. Vet. Microbiol., http://dx.doi.org/10.1016/j.vetmic.2011.02.033, Accessed 17 August 2014.
Met Éireann, 2011. Winter 2010/2011 Summary Clim-2011, Accessed 17 August 2014 http://www.met.ie/climate/MonthlyWeather/clim-2011-win.pdf
Met Éireann, 2012. Winter 2011/2012 Summary Clim-2012, Accessed 17 August 2014 http://www.met.ie/climate/MonthlyWeather/clim-2012-win.pdf
Mullen, E.M., MacWhite, T., Maher, P.K., Kelly, D.J., Marples, N.M., Good, M., 2013. Foraging Eurasian badgers *Meles meles* and the presence of cattle in pastures Do badgers avoid cattle? Appl. Anim. Behav. Sci. 144, 130–137.
Neu, C.W., Byers, C.R., Peek, J.M., 1974. A technique for analysis of utilisation-availability data. J. Wildl. Manag. 38, 541–545.
O'Connor, R., O'Malley, E., 1989. Badgers and Bovine Tuberculosis in Ireland. Economic and Research Institute, Burlington Road, Dublin.
O'Meara, D., Edwards, C., Sleeman, P., Cross, T., Statham, M., McDowell, J., Dillane, E., Coughlan, J., O'Leary, D., O'Reilly, C., Bradley, D., Carlsson, J., 2012. Genetic relationships between Eurasian badgers *Meles meles* (Carnivora: Mustelidae) in Europe and implications for the colonisation history of Ireland. Biol. J. Linnaen Soc. 106 (4), 893–909.
Olea-Popelka, F.J., Phelan, J., White, P.W., McGrath, G., Collins, J.D., O'Keeffe, J., Duggan, M., Collins, D.M., Kelton, D.F., Berke, O., More, S.J., Martin, S.W., 2006. Quantifying badger exposure and the risk of bovine tuberculosis for cattle herds in County Kilkenny, Ireland. Prev. Vet. Med. 75, 34–46.
R Development Core Team, 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Robertson, A., McDonald, R.A., Delahay, R.J., Kelly, S.D., Bearhop, S., 2014. Individual foraging specialisation in a social mammal: the European badger (*Meles meles*). Behav. Ecol., http://dx.doi.org/10.10007/s00442-014-3019-2.
Roper, T.J., 2010. Badger. Collins, London.
Scantlebury, M., Harris, S., Allcroft, D.J., Hutchings, M.R., 2006. Individual trade-offs between nutrition and risk of interspecific transmission of disease by grazing cows, badger latrines and bovine tuberculosis. Behaviour 143, 141–158.
Sleeman, D.P., Davenport, J., Fitzgerald, A., 2008. Incidence of visits by badgers to farmyards in Ireland in winter. Vet. Rec. 163, 724.
Sleeman, D.P., Davenport, J., More, S.J., Cleg, T.A., Collins, J.D., Martin, S.W., Williams, D.H., Griffin, J.M., O'Boyle, I., 2009. How many Eurasian badgers (*Meles meles*) are there in the Republic of Ireland? Eur. J. Wildl. Res. 55, 333–344.
Sleeman, D.P., Mulcahy, M.F., 1993. Behaviour of Irish badgers in relation to bovine tuberculosis. In: Hayden, T.J. (Ed.), The Badger. Royal Irish Academy, Dublin, pp. 154–165.
Tolhurst, B.A., Delahay, R.J., Walker, N.J., Ward, A.I., Roper, T.J., 2009. Behaviour of badgers (*Meles meles*) in farm buildings: Opportunities for the transmission of *Mycobacterium bovis* to cattle? Appl. Anim. Behav. Sci. 117, 103–113.
Ward, A.I., Judge, J., Delahay, R.J., 2010. Farm husbandry and badger behaviour: Opportunities to manage badger to cattle transmission of *Mycobacterium bovis*? Prev. Vet. Med. 93, 2–10.
Wilson, G.J., Carter, S.P., Delahay, R.J., 2011. Advances and prospects for management of TB transmission between badgers and cattle. Vet. Microbiol. 151, 43–50.
Woodroffe, R., Donnelly, C.A., Jenkins, H.E., Johnston, W.T., Cox, D.R., Bourne, F.J., Cheeseman, C.L., Delahay, R.J., Clifton-Hadley, R.S., Gettinby, G., Gilks, P., Hewinson, R.G., Mcinerney, J.P., Morrison, W.I., 2006. Culling and cattle controls influence tuberculosis risk for badgers. PNAS 103 (40), 14713–14717.