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**Original article**

# Monitoring and population estimation of the European badger *Meles meles* in Northern Ireland

**Neil Reid, Thomas R. Etherington, Gavin J. Wilson, W. Ian Montgomery & Robbie A. McDonald**

The estimation of animal abundance has a central role in wildlife management and research, including the role of badgers *Meles meles* in bovine tuberculosis transmission to cattle. This is the first study to examine temporal change in the badger population of Northern Ireland over a medium- to long-term time frame of 14-18 years by repeating a national survey first conducted during 1990-1993. A total of 212 1-km$^2$ squares were surveyed during 2007-2008 and the number, type and activity of setts therein recorded. Badgers were widespread with 75% of squares containing at least one sett. The mean density of active main setts, which was equivalent to badger social group density, was 0.56 (95% CI: 0.46-0.67) active main setts per km$^2$ during 2007-2008. Social group density varied significantly among landclass groups and counties. The total number of social groups was estimated at 7,600 (95% CI: 6,200-9,000) and, not withstanding probable sources of error in estimating social group size, the total abundance of badgers was estimated to be 34,100 (95% CI: 26,200-42,000). There was no significant change in the badger population from that recorded during 1990-1993. A resource selection model provided a relative probability of sett construction at a spatial scale of 25 m. Sett locations were negatively associated with elevation and positively associated with slope, aspect, soil sand content, the presence of cover, and the area of improved grassland and arable agriculture within 300 m.

*Key words: abundance estimation, European badger, Meles meles, sett surveys, social group size*

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The European badger *Meles meles* is widespread and common in Great Britain and Ireland (Smal 1995, Wilson et al. 1997). As the estimation of animal abundance has a central role in wildlife management and research, including the role of badgers in bovine tuberculosis transmission to cattle (Collins et al. 1994, O'Keeffe 2006, Kelly et al. 2007), a great deal of effort has been made to estimate the size of local and national badger populations throughout the British Isles (Feore 1994, Smal 1995, Rogers et al. 1997, Wilson et al. 1997, Ostler & Roper 1998, Macdonald & Newman 2002) despite the inherent difficulties of surveying badger numbers (Smith & Cheeseman 2007, Woodroffe et al. 2007).

Badgers are nocturnal and are difficult to observe directly. Live trapping has been used to study focal social groups (Rogers et al. 1997, Tuyttens et al. 1999), but mark-recapture methods are highly labour intensive and time consuming. Recent advances in DNA analyses, including a reduction in cost and increase in computing power, have allowed individual genotyping using faeces or hair to be developed as a more accurate technique in estimating badger social group size (Franz et al. 2006). However, such techniques are still prohibitively expensive at the national scale for the purposes of estimating total populations. Other methods for estimating badger density, such as counting latrines, can be efficient but have poor accuracy (Tuyttens et al. 2001). Consequently, the method of choice for enumerating badgers at large spatial scales remains the relatively crude and labour intensive technique of field surveys. All potentially available habitats within the sample area are searched for the presence of setts, whereupon a multiplicative estimate of the total numbers of badgers can be made, assuming some information is available on likely social group sizes (Cresswell et al. 1990, Feore 1994, Smal 1995, Wilson et al. 1997).

In general, there is a paucity of data on badger populations over most of the species' range (Clements et al. 1988, Cresswell et al. 1990), and even less information about changes in population size over time (Wilson et al. 1997). Recent estimates of badger abundance exist for the Republic of Ireland (Sleeman et al. 2009), but data on their distribution and abundance in Northern Ireland are out-of-date (Feore 1994). During 1990-1993, the total number of badger social groups in Northern Ireland was estimated at 8,800 (95% CI: 6,800-10,700) with an estimated total population of 37,600 badgers (95% CI: 29,000-46,300; Feore 1994). Sadlier & Montgomery (2004) found that locally the number of badger setts and social groups in Northern Ireland had not changed significantly between 1990-1993 and 1997-1998. In Great Britain, comparison of two national surveys demonstrated substantial increases in the number of badger social groups during the same period of time (Cresswell et al. 1990, Wilson et al. 1997).

Here, we reassess the number of badger social groups and badger abundance in Northern Ireland during 2007-2008 by repeating an identical survey to that carried out during 1990-1993 (Feore 1994) with the aim of determining whether any temporal change had occurred over a period of 14-18 years. We also improved previous methodologies by investing greater survey effort in those landscapes in which badgers were deemed most prevalent to refine the precision of our estimates. Finally, we analysed badger resource selection by creating a model of the relative probability of sett construction throughout the Northern Irish landscape at a spatial scale of 25 m. Such data are required to inform wildlife management and research policies, most notably with reference to badgers and bovine tuberculosis.

## Material and methods

### Survey design

To examine variability in badger social group density across Northern Ireland and allow an unbiased analysis of factors influencing badger sett location, it was necessary to sample Northern Ireland's landscape uniformly. We employed two means of sampling the landscape, hereafter referred to as the 'systematic sample' and the 'focal sample'. The systematic sample consisted of 144 1-$km^2$ grids each positioned at the most southwesterly corner of each 10-$km^2$ grid covering the whole of the country. Using this design, we sampled the eight landclass groups of Northern Ireland in proportion to their availability: drumlin farmland, lakelands, marginal lowlands, central lowlands, marginal uplands, settled uplands, high uplands and mountains (see Murray et al. 1992). This systematic sample provided the basis for direct comparison with Feore (1994), hereafter referred to as the 1990-1993 survey.

Badger population densities were likely to vary with environmental factors across landclass groups (Feore 1994, Wilson et al. 1997). Thus, the focal sample consisted of 75 1-$km^2$ grids chosen at random from the three landclass groups determined to have the highest density of badger social groups during the 1990-1993 survey, specifically; drumlin farmland, marginal uplands and settled uplands. This additional sample provided greater precision in areas of high badger density, as precision in areas of lower density was unlikely to affect the overall precision of the total population estimate. Consequently, there was a total of 219 1-$km^2$ surveyed during 2007-2008.

### Sett surveys

We conducted the surveys between late autumn and early spring (19 November 2007 to 14 March 2008) when ground vegetation was minimal and setts were most easily detected. To ensure that all setts were located within each survey square, all linear features such as hedgerows, ditches, stone walls and habitat boundaries were walked. We sampled forest blocks using either a zig-zag transect system where patches were small and the number of surveyors limited, or a line of surveyors spaced out at regular intervals where patches were large and a greater number of surveyors were available. We surveyed dense habitats such as gorse *Ulex europaeus* or bramble *Rubus fruticosus* dominated scrub by walking the habitat boundary, noting badger activity such as runs or latrines with subsequent investigation of the interior of the habitat patch if badger activity was indicated. In the interests of effective biosecurity, land registered as affected with the bacteria *Brucella abortus* was avoided and left unsurveyed. We recorded the extent of each survey square that could not be surveyed due to impenetrable habitat, rough terrain, development (e.g. urban areas and quarries) or biosecurity, and accounted for it during the analysis.

We recorded sett location (10-figure grid reference recorded using a handheld GPS), size (number of entrances), entrance activity (active or disused) and type (main, annex, subsidiary or outlier). We based the criteria for classifying sett type on a combination of sett size and entrance activity, and they were identical to those criteria used during the 1990-1993 survey to ensure data were directly comparable. Specially, well-used holes were characterised by signs of regular use including conspicuous spoil heaps with signs of fresh digging, regular trampling of soil and/or vegetation, deposition of fresh bedding such as dried grass and obvious well-worn paths radiating from the sett. Partially-used holes generally showed evidence of use but not to the same extent as well-used holes including trampling of soil and/or vegetation and the deposition of old bedding. Runs radiating from partially-used holes were not as defined as those associated with well-used holes. Disused holes were often partially or completely filled with debris such as leaf litter and showed no signs of recent activity.

Main setts were those with a large number of entrances (typically about seven) with a greater proportion of well-used holes (typically about four) than other sett types. Badger social groups are territorial and are generally separated by characteristic boundary runs associated with large, frequently used, regularly spaced latrines. Boundary runs, latrines, natural physical barriers such as rivers and anthropogenic features such as roads, were useful when discerning large setts with similar characteristics as the main setts of neighbouring social groups. Annex setts were taken as those adjacent to a main sett, generally within 150 m and typically linked to a main sett by conspicuous well-worn paths. Due to their proximity to a main sett, they may not have been in continuous use and, thus, generally had a greater proportion of partially-used holes than their associated main sett. Subsidiary setts were generally more isolated from main setts than annex setts and were not connected to other setts by paths. A subsidiary sett typically had 2-3 partially-used entrances. Outlier setts usually had just one entrance and were not normally associated with large spoil heaps or worn paths. Outlier setts are liable to fall out of use and were generally characterised by partially-used and disused holes.

We trained all field surveyors in field techniques prior to the start of fieldwork to ensure the consistency and standardisation of the data returned.

### Environmental data

We used a geographic information system (GIS) to compute environmental parameters using ArcGIS version 9.3 (ESRI, California, USA). We based landscape variables chosen for inclusion in analyses (Table 1) on those shown to influence badger distribution and abundance in previous studies (Reason et al. 1993, Neal & Cheeseman 1996, Wilson et al. 1997, Feore & Montgomery 1999, Newton-Cross et al. 2007).

Sett location was likely to be influenced by habitat variables specific to each site (e.g. within 25 m of the sett). Other variables may be important in the context of the surroundings in which a sett is located. However, there was little evidence to suggest the most appropriate spatial scale to use except that candidate scales should be smaller than the average badger territory. Consequently, we tested three candidate scales with respect to available habitats within 100 m, 300 m and 500 m of each sett. We chose these distances to create a range of putative territory sizes roughly representative of those recorded previously in Northern Ireland (Feore & Montgomery 1999).

### Statistical analyses

We examined variation in badger main sett density between surveys and across landclass groups using a repeated measures generalised linear model assuming a Poisson error distribution and a logarithmic link function. We treated the survey square as a repeated measure while survey, landclass group and county were fitted as fixed factors. Initially, we

Table 1. Landscape variables used in resource selection modelling for the probability of badger sett construction.

| Variable | Units | Description |
|---|---|---|
| *Variables within 25 m of each main sett* | | |
| Altitude | Metres | Elevation taken from a Digital Elevation Model of Northern Ireland. |
| Aspect (eastness) | Index | Index that represented the degree to which a slope was easterly. A value of 1 = directly east, a value of 0 = directly north or south and a value of -1 = directly west. |
| Aspect (northness) | Index | Index that represented the degree to which a slope was northerly. A value of 1 = directly north, a value of 0 = directly east or west and a value of -1 = directly south. |
| Cover | Area | The combined area of broad-leaved woodland, coniferous woodland, bracken, dwarf shrub heath and open dwarf scrub heath. The extent of habitat boundaries was also included i.e. area of hedgerows in agricultural areas. Calculated from Land Cover Map 2000. |
| Slope | Degrees | Slope was calculated from a Digital Elevation Model of Northern Ireland using the slope function of ArcGIS Spatial Analyst. |
| Soil sand content | % | Proportion of soil consisting of sand. Calculated from the Soil Survey of Northern Ireland (Cruickshank 1997). |
| *Variables within 100 m, 300 m and 500 m of each main sett* | | |
| Arable | Area | Number of 25 raster cells classed as arable agriculture. Calculated from Land Cover Map 2000 within buffers of differing radii. |
| Broad-leaved woodland | Area | Number of 25 raster cells classed as broad-leaved woodland. Calculated from Land Cover Map 2000 within buffers of differing radii. |
| Improved grassland | Area | Number of 25 raster cells classed as improved grassland. Calculated from Land Cover Map 2000 within buffers of differing radii. |

included all two-way interactions but subsequently removed them if they were found to be nonsignificant.

We used two models to obtain estimates of the total number of main setts: one was directly comparable to the 1990-1993 survey and used data from the systematic sample only, and the second used data from the systematic and focal samples combined. We calculated mean social group density per landclass ($\lambda_i$) as:

$$\lambda_i = \frac{x_i}{a_i} \quad (1),$$

where x equalled the total number of active main setts observed within landclass i and a equalled the area surveyed in $km^2$. The 95% confidence limits were derived as:

$$\text{Confidence limit}_\lambda = \lambda_i \pm 1.96\sqrt{\frac{\lambda_i}{a_i}} \quad (2).$$

We obtained an estimate of the number of social groups in each landclass group by multiplying the mean social group density ($\lambda_i$) by the total land area in each landclass group ($A_i$). In addition, the confidence limits of the mean were also multiplied by the total land area in each landclass group. We obtained the estimated total abundance of badger social groups in Northern Ireland as a whole (T) by summing the estimated abundance of social groups within each landclass group:

$$T = \sum_{i=1}^{8} \lambda_i A_i \quad (3).$$

We derived confidence limits for the estimate of the total number of social groups in Northern Ireland from the standard error as:

$$\text{Confidence limits}_T = \sum_{i=1}^{8} A\left(\lambda_i \pm 1.96\sqrt{\frac{\lambda_i}{a_i}}\right) \quad (4).$$

Finally, we obtained an estimate of the total abundance of badgers within each landclass group and for Northern Ireland as a whole by multiplying the estimates of social group abundance by an estimate of social group size. Few studies have focused on determination of badger social group size and those that have, used varying and incomparable methods (Tuyttens et al. 2001, Palphramand et al. 2007, Scheppers et al. 2007). None of these studies were conducted in Northern Ireland. Consequently, for the sake of comparability, we adopted an identical approach to that of the 1990-1993 survey. Feore (1994) reviewed a total of 13 focal studies of badger group size in various landclass categories in Great Britain and Ireland (Table 2).We produced mean estimates for 1) pastoral areas with significant broad-leaved woodland and scrub (analogous to drumlin

Table 2. Mean badger social group size ± 95% confidence intervals, derived from a review of studies in Great Britain and Ireland, grouped according to similarity of habitat types. NI = Northern Ireland, Eng = England, Scot = Scotland and ROI = Republic of Ireland

| Habitat type | Equivalent NI landclass group | Location | Reference | Sample size (N) | Social group size recorded (N) | Mean social group size N (95% CI) |
|---|---|---|---|---|---|---|
| Pastoral areas with significant broad-leaved woodland and scrub | 1. Drumlin farmland | Down (NI) | Feore (1994) | 3 | 5, 9, 5 | 6.05 (5.10 - 7.00) |
| | | Oxford (Eng) | Kruuk (1978) | 3 | 8, 6, 8 | |
| | | Gloucester (Eng) | Cheeseman et al. (1981) | 6 | 4, 5, 7, 3, 4, 3 | |
| | | Gloucester (Eng) | Cheeseman et al. (1981) | 5 | 5, 5, 4, 7, 8 | |
| | | Aberdeenshire (Scot) | Kruuk & Parish (1982) | 2 | 8, 11 | |
| Pastoral agriculture | 2. Lakelands<br>3. Marginal lowlands<br>4. Central lowlands<br>5. Marginal uplands | Down (NI) | Feore (1994) | 3 | 4, 1, 1 | 4.27 (3.66 - 4.89) |
| | | Cornwall (Eng) | Cheeseman et al. (1981) | 6 | 1, 2, 6, 4, 5, 2 | |
| | | Avon (Eng) | Cheeseman et al. (1981) | 7 | 4, 5, 3, 2, 2, 6, 3 | |
| | | Speyside (Scot) | Kruuk & Parish (1982) | 3 | 4, 2, 6 | |
| | | Staffordshire (Eng) | Cheeseman et al. (1985) | 5 | 4, 7, 4, 11, 6 | |
| | | Offaly (ROI) | O'Corry-Crowe (1992) | 5 | 6, 1, 4, 8, 1 | |
| | | All ROI | Smal (1995) | 19 | 7, 3, 6, 6, 5, 4, 4, 7, 6, 4, 7, 3, 5, 2, 1, 4, 6, 7, 3 | |
| Upland and moorland | 6. Settled uplands<br>7. High uplands<br>8. Mountains | Antrim (NI) | Feore (1994) | 2 | 2, 3 | 3.00 (2.20 - 3.80) |
| | | Inverness (Scot) | Kruuk & Parish (1982) | 2 | 4, 3 | |

farmland), 2) pastoral agriculture (analogous to lakelands, marginal lowlands, central lowlands and marginal uplands) and 3) upland and moorland (analogous to landclass groups settled uplands, high uplands and mountains).

Using the systematic sample only, we created a logistic regression resource selection model (Manly et al. 2002) for the probability of badger sett presence. Although the location of setts in any given survey square was known, treating sett absence as an unsuitable landscape may be problematic. The territorial nature of badger social groups means that main setts are not spatially independent of one another. Most areas that are available are not used for sett construction, not because they are unsuitable, but because of the presence of another social group nearby. Consequently, we considered sett data to consist of presence records only and, thus, we adopted a used versus available resources modelling approach meaning that we did not model the probability of sett occurrence *per se*, but the relative probability of the landscape being used for sett construction (Manly et al. 2002).

We extracted and manipulated landscape variables as raster data sets using a cell resolution of 25 m. To measure resource availability, the use of the whole area available within the systematic sample was impractical as there were 203,612 raster cells. Therefore, we used a subsample of the available resources that was a representative sample of the entire available area (Manly et al. 2002). A random sample of 400 raster cells was taken and tested using Kolmogorov-Smirnov tests to ensure that they were a reliable summary of the whole landscape.

We used a stepwise regression approach, not based on traditional Wald or P-values, but a forward-backward AIC-based technique in which the predictive contribution and damage to the model of the addition and subsequent removal of each variable was explicitly tested. This approach evaluates the ecological plausibility of each model using biologically relevant variables without falling into the trap of all sub-set regression model dredging (Burnham & Anderson 2002). We checked the multicollinearity of environmental variables in the selected model using variance inflation factors (VIF), with VIF values $< 5$

taken to indicate reliable results (Montgomery & Peck 1982).

We tested the model using the independent focal sample to ensure that model predictions were robust. Applying the same approach as Etherington et al. (2009), we binned relative probability values within the focal sample into 10 evenly sized categories of increasing sett probability. We calculated the total area of each bin along with the number of setts observed. We evaluated model predictions using the area-adjusted frequencies of sett observations within each bin (Boyce et al. 2002). Hirzel et al. (2006) have shown that this approach is comparable to more standard presence-absence based modelling techniques. The basic premise is that as the relative probability classes of sett construction increase, there should be a matching increase in the observed area-adjusted sett frequency within the independent focal sample. This was tested using Spearman's rank ($r_s$) correlation.

We conducted all statistical analysis using GenStat v6 or R©.

## Results

A total of 212 of the 219 1-km$^2$ squares were surveyed during 2007-2008 (140 systematic squares and 72 focal squares). Seven squares could not be surveyed, five squares fell within large bodies of water (Loughs Erne, Neagh and Strangford), access was denied to one square by a landowner and another was not surveyed due to the terrain. A total of 13.4 km$^2$ of cumulative land could not be accessed within those squares surveyed (i.e. 6.3% of the total area) due to biosecurity restrictions, denial of access of inaccessible terrain, but this was accounted for when calculating social group densities.

Badgers were widespread throughout Northern Ireland with 75% of survey squares containing at least one sett (Fig. 1). A total of 653 setts was recorded; 154 main setts (24%), 28 annex setts (4%), 156 subsidiary setts (24%) and 315 outlier setts (48%).

To allow direct comparison between the 1990-1993 and 2007-2008 surveys, estimates of the number of social groups were produced using the systematic sample (Table 3A and B). However, the 95% confidence intervals for the estimated density and abundance of social groups in drumlin farmland, marginal uplands and settled uplands were improved substantially (by between 26-33%) with the addition of the focal sample of an additional 72 survey squares during the 2007-2008 survey (see Table 3B and C). Consequently, the precision of the overall estimate of the mean density and total number of social groups in Northern Ireland was substantially increased due to a reduction in the width of the 95% confidence interval by 22%. However, due to uncertainty in the estimates of social group size (see Table 2) this improvement in accuracy was lost when estimating the mean density or total abundance of badgers. Thus, subsequent results will use the systematic and focal samples combined.

The mean density of active main setts, which was equivalent to badger social group density, was 0.56 (95% CI: 0.46-0.67) active main setts/km$^2$ (see Table 3C). The mean density of all types of badger setts during 2007-2008 was 3.29 (95% CI: 3.04-3.54) setts/km$^2$. Main sett (social group) density did not differ

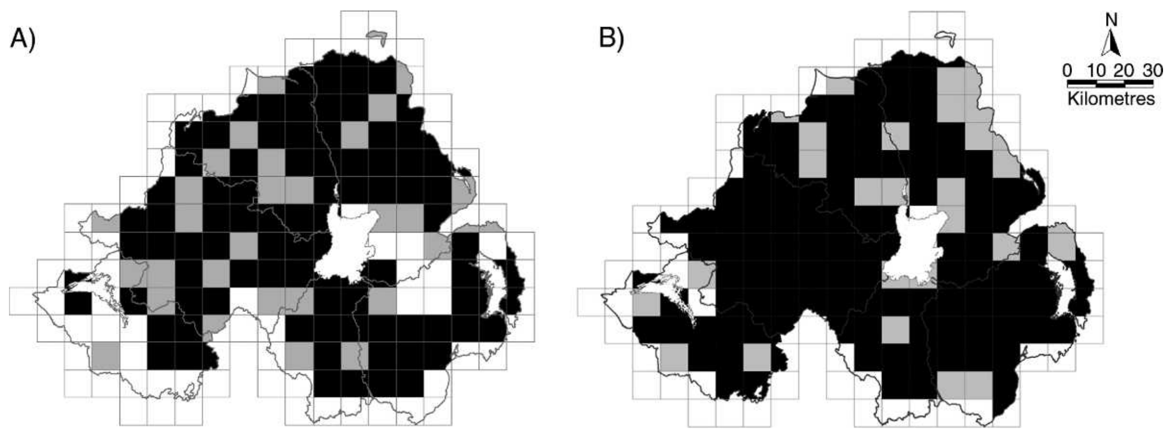


Figure 1. The distribution of badgers in Northern Ireland during 1990-1993 (A) and 2007-2008 (B) defined by the presence of setts within 10-km$^2$ squares showing sett presence (black squares), sett absence (grey squares) and unsurveyed areas (open squares).

Table 3. Estimated density and abundance of badgers in each landclass group in Northern Ireland (NI) during 1990-1993 and 2007-2008. Numbers of social groups and badgers are given to the nearest 100.

| Landclass group | Area in NI km² (%) | No. of squares surveyed N (%) | Mean social group density, active main setts/km² (95% CI) | Estimated abundance of social groups N (95% CI) | Estimated mean social group size N (95% CI) | Estimated badger density badgers/km² (95% CI) | Estimated badger abundance N (95% CI) |
|---|---|---|---|---|---|---|---|
| A) 1990-1993: 129 systematic squares | | | | | | | |
| 1. Drumlin farmland | 2350 (17) | 22 (17) | 0.81 (0.42 - 1.20) | 1900 (1000 - 2800) | 6.05 (5.10 - 7.00) | 4.88 (2.51 - 7.24) | 11500 (5900 -17000) |
| 2. Lakelands | 589 (4) | 6 (5) | 0.68 (0.00 - 1.47) | 400 (0 - 900) | 4.27 (3.65 - 4.89) | 2.92 (0.00 - 6.29) | 1700 (0 - 3700) |
| 3. Marginal lowlands | 1591 (12) | 14 (11) | 0.65 (0.22 - 1.08) | 1000 (300 - 1700) | 4.27 (3.65 - 4.89) | 2.77 (0.92 - 4.62) | 4400 (1500 - 7300) |
| 4. Central lowlands | 2080 (15) | 19 (15) | 0.48 (0.16 - 0.80) | 1000 (300 - 1700) | 4.27 (3.65 - 4.89) | 2.04 (0.68 - 3.41) | 4300 (1400 - 7100) |
| 5. Marginal uplands | 2462 (18) | 30 (23) | 0.80 (0.46 - 1.13) | 2000 (1,100 - 2800) | 4.27 (3.65 - 4.89) | 3.40 (1.98 - 4.82) | 8400 (4900 - 11900) |
| 6. Settled uplands | 1891 (14) | 14 (11) | 0.79 (0.31 - 1.26) | 1500 (600 - 2400) | 3.00 (2.20 - 3.80) | 2.36 (0.94 - 3.78) | 4500 (1800 - 7100) |
| 7. High Uplands | 1454 (11) | 12 (9) | 0.42 (0.04 - 0.79) | 600 (100 - 1200) | 3.00 (2.20 - 3.80) | 1.25 (0.13 - 2.38) | 1800 (200 - 3500) |
| 8. Mountains | 1127 (8) | 12 (9) | 0.33 (0.00 - 0.67) | 400 (0 - 800) | 3.00 (2.20 - 3.80) | 1.00 (0.00 - 2.00) | 1100 (0 - 2300) |
| Total/mean | 13544 (100) | 129 (100) | 0.64 (0.52 - 0.76) | 8800 (6800 - 10700) | 4.16 (3.42 - 4.90) | 2.78 (2.14 - 3.42) | 37600 (29000 - 46300) |
| B) 2007-2008: 140 systematic squares | | | | | | | |
| 1. Drumlin farmland | 2350 (17) | 25 (18) | 0.84 (0.46 - 1.22) | 2000 (1100 - 2900) | 6.05 (5.10 - 7.00) | 5.08 (2.36 - 8.52) | 11900 (5500 - 20000) |
| 2. Lakelands | 589 (4) | 7 (5) | 0.30 (0.00 - 0.73) | 200 (0 - 400) | 4.27 (3.65 - 4.89) | 1.30 (0.00 - 3.56) | 800 (0 - 2100) |
| 3. Marginal lowlands | 1591 (12) | 14 (10) | 0.61 (0.19 - 1.03) | 1000 (300 - 1600) | 4.27 (3.65 - 4.89) | 2.59 (0.68 - 5.02) | 4100 (1100 - 8000) |
| 4. Central lowlands | 2080 (15) | 21 (15) | 0.49 (0.19 - 0.80) | 1000 (400 - 1700) | 4.27 (3.65 - 4.89) | 2.10 (0.68 - 3.90) | 4400 (1400 - 8100) |
| 5. Marginal uplands | 2462 (18) | 33 (24) | 0.71 (0.41 - 1.01) | 1700 (1000 - 2500) | 4.27 (3.65 - 4.89) | 3.02 (1.48 - 4.94) | 7400 (3600 - 12200) |
| 6. Settled uplands | 1891 (14) | 15 (11) | 0.49 (0.13 - 0.86) | 900 (200 - 1600) | 3.00 (2.20 - 3.80) | 1.48 (0.28 - 3.26) | 2800 (500 - 6200) |
| 7. High Uplands | 1454 (11) | 13 (9) | 0.43 (0.05 - 0.80) | 600 (100 - 1200) | 3.00 (2.20 - 3.80) | 1.28 (0.12 - 3.03) | 1900 (200 - 4400) |
| 8. Mountains | 1127 (8) | 12 (9) | 0.08 (0.00 - 0.25) | 100 (0 - 300) | 3.00 (2.20 - 3.80) | 0.25 (0.00 - 0.95) | 300 (0 - 1100) |
| Total/mean | 13544 (100) | 140 (100) | 0.56 (0.43 - 0.69) | 7500 (5900 - 9300) | 4.16 (3.42 - 4.90) | 2.48 (1.92 - 3.04) | 33500 (26000 - 41200) |
| C) 2007-2008: 212 squares (140 systematic plus 72 focal samples) | | | | | | | |
| 1. Drumlin farmland | 2350 (17) | 49 (23) | 0.85 (0.59 - 1.12) | 2000 (1400 - 2600) | 6.05 (5.10 - 7.00) | 5.17 (2.99 - 7.86) | 12100 (7000 - 18500) |
| 2. Lakelands | 589 (4) | 7 (3) | 0.30 (0.00 - 0.73) | 200 (0 - 400) | 4.27 (3.65 - 4.89) | 1.30 (0.00 - 3.56) | 800 (0 - 2100) |
| 3. Marginal lowlands | 1591 (12) | 14 (7) | 0.61 (0.19 - 1.03) | 1000 (300 - 1600) | 4.27 (3.65 - 4.89) | 2.59 (0.68 - 5.02) | 4100 (1100 - 8000) |
| 4. Central lowlands | 2080 (15) | 21 (10) | 0.49 (0.19 - 0.80) | 1000 (400 - 1700) | 4.27 (3.65 - 4.89) | 2.10 (0.68 - 3.90) | 4400 (1400 - 8100) |
| 5. Marginal uplands | 2462 (18) | 63 (30) | 0.76 (0.54 - 0.98) | 1900 (1300 - 2400) | 4.27 (3.65 - 4.89) | 3.24 (1.95 - 4.81) | 8000 (4800 - 11800) |
| 6. Settled uplands | 1891 (14) | 33 (16) | 0.45 (0.21 - 0.68) | 800 (400 - 1300) | 3.00 (2.20 - 3.80) | 1.34 (0.47 - 2.59) | 2500 (900 - 4900) |
| 7. High Uplands | 1454 (11) | 13 (6) | 0.43 (0.05 - 0.80) | 600 (100 - 1200) | 3.00 (2.20 - 3.80) | 1.28 (0.12 - 3.03) | 1900 (200 - 4400) |
| 8. Mountains | 1127 (8) | 12 (6) | 0.08 (0.00 - 0.25) | 100 (0 - 300) | 3.00 (2.20 - 3.80) | 0.25 (0.00 - 0.95) | 300 (0 - 1100) |
| Total/mean | 13544 (100) | 212 (100) | 0.56 (0.46 - 0.67) | 7600 (6200 - 9000) | 4.16 (3.42 - 4.90) | 2.51 (1.93 - 3.11) | 34100 (26200 - 42000) |

Table 4. Estimated density and abundance of badgers within each county in Northern Ireland (NI) during 1990-1993 and 2007-2008. Mean social group size was estimated within each landclass group (see Table 3) before summarising for each county separately. Numbers of social groups and badgers are given to the nearest 100.

| County | Area in NI $km^2$ (%) | No. of squares surveyed N (%) | Mean social group density active main setts/$km^2$ (95% CI) | Estimated abundance of social groups N (95% CI) | Mean social group size N (95% CI) | Estimated badger density badgers/$km^2$ (95% CI) | Estimated badger abundance N (95% CI) |
|---|---|---|---|---|---|---|---|
| A) 1990-1993: 129 systematic squares | | | | | | | |
| Antrim | 2922 (22) | 20 (16) | 0.59 (0.36 - 0.82) | 1700 (1400 - 2000) | 3.92 (3.83 - 3.98) | 2.27 (1.83 - 2.71) | 6600 (5400 - 7900) |
| Armagh | 1253 (9) | 15 (12) | 0.42 (0.15 - 0.69) | 900 (500 - 1300) | 5.03 (4.39 - 5.30) | 3.65 (1.86 - 5.44) | 4600 (2300 - 6800) |
| Londonderry | 2052 (15) | 14 (11) | 0.73 (0.47 - 0.99) | 1200 (904 - 1400) | 3.90 (3.76 - 3.99) | 2.22 (1.66 - 2.78) | 4600 (3300 - 5700) |
| Down | 2430 (18) | 29 (22) | 0.90 (0.53 - 1.27) | 1800 (1000 - 2600) | 5.19 (4.53 - 5.47) | 3.88 (2.01 - 5.74) | 9400 (4900 - 14000) |
| Fermanagh | 1777 (13) | 29 (22) | 0.45 (0.17 - 0.73) | 1200 (900 - 1400) | 4.14 (4.08 - 4.18) | 2.68 (2.08 - 3.29) | 4800 (3700 - 5800) |
| Tyrone | 3104 (23) | 22 (17) | 0.62 (0.34 - 0.90) | 2000 (1600 - 2500) | 3.82 (3.84 - 3.80) | 2.48 (1.97 - 3.00) | 7700 (6100 - 9300) |
| Total/mean | 13544 (100) | 129 (100) | 0.64 (0.52 - 0.76) | 8800 (6400 - 11100) | 4.30 (4.02 - 4.46) | 2.78 (1.90 - 3.66) | 37700 (25800 - 49600) |
| B) 2007-2008: 140 systematic squares | | | | | | | |
| Antrim | 2922 (22) | 30 (21) | 0.49 (0.39 - 0.59) | 1400 (1100 - 1700) | 4.02 (3.94 - 4.08) | 1.97 (1.52 - 2.42) | 5800 (4500 - 7100) |
| Armagh | 1253 (9) | 15 (11) | 0.67 (0.36 - 0.98) | 800 (500 - 1200) | 5.28 (4.61 - 5.53) | 3.53 (1.66 - 5.40) | 4400 (2100 - 6800) |
| Londonderry | 2052 (15) | 23 (16) | 0.49 (0.36 - 0.61) | 1000 (700 - 1300) | 3.96 (3.84 - 4.04) | 1.93 (1.37 - 2.48) | 4000 (2800 - 5100) |
| Down | 2430 (18) | 24 (17) | 0.70 (0.39 - 1.02) | 1700 (900 - 2500) | 5.38 (4.75 - 5.62) | 3.79 (1.83 - 5.75) | 9200 (4400 - 14000) |
| Fermanagh | 1777 (13) | 19 (14) | 0.49 (0.39 - 0.60) | 900 (700 - 1100) | 4.17 (4.13 - 4.20) | 2.06 (1.62 - 2.50) | 3700 (2900 - 4500) |
| Tyrone | 3104 (23) | 29 (21) | 0.53 (0.42 - 0.64) | 1600 (1300 - 2000) | 3.93 (3.90 - 3.95) | 2.08 (1.63 - 2.53) | 6400 (5000 - 7800) |
| Total/mean | 13544 (100) | 140 (100) | 0.55 (0.39 - 0.72) | 7500 (5200 - 9800) | 4.46 (4.14 - 4.63) | 2.47 (1.60 - 3.34) | 33700 (21500 - 45500) |
| C) 2007-2008: 212 squares (140 systematic plus 72 focal samples) | | | | | | | |
| Antrim | 2922 (22) | 39 (18) | 0.50 (0.39 - 0.60) | 1400 (1100 - 1800) | 4.04 (3.95 - 4.09) | 2.00 (1.53 - 2.47) | 5800 (4500 - 7200) |
| Armagh | 1253 (9) | 25 (12) | 0.67 (0.35 - 0.98) | 800 (400 - 1200) | 5.33 (4.66 - 5.66) | 3.55 (1.64 - 5.45) | 4500 (2000 - 6900) |
| Londonderry | 2052 (15) | 32 (15) | 0.50 (0.36 - 0.63) | 1000 (700 - 1300) | 3.98 (3.85 - 4.05) | 1.97 (1.39 - 2.55) | 4000 (2800 - 5200) |
| Down | 2430 (18) | 47 (22) | 0.71 (0.39 - 1.04) | 1700 (900 - 2500) | 5.39 (4.77 - 5.63) | 3.85 (1.85 - 5.84) | 9400 (4500 - 14200) |
| Fermanagh | 1777 (13) | 25 (12) | 0.50 (0.39 - 0.61) | 900 (700 - 1100) | 4.18 (4.14 - 4.21) | 2.11 (1.64 - 2.59) | 3800 (2900 - 4600) |
| Tyrone | 3104 (23) | 44 (21) | 0.53 (0.41 - 0.64) | 1600 (1300 - 2000) | 3.96 (3.92 - 3.99) | 2.09 (1.62 - 2.56) | 6500 (5000 - 8000) |
| Total/mean | 13544 (100) | 212 (100) | 0.56 (0.39 - 0.73) | 7600 (5200 - 10000) | 4.48 (4.16 - 4.65) | 2.51 (1.61 - 3.40) | 34000 (21800 - 46100) |

significantly between 1990-1993 and 2007-2008 ($F_{1, 244} = 0.63$, $P = 0.43$). Social group density varied significantly among landclass groups ($F_{7, 244} = 2.25$, $P = 0.03$). Social group density also varied significantly among counties ($F_{5, 244} = 2.30$, $P = 0.04$), providing varying estimates per county (Table 4). Neither the interaction between survey*landclass group or survey*county contributed significantly to variance in badger social group density, indicating that patterns of variation among landclass groups and county had not changed between the surveys.

The total number of badger social groups in Northern Ireland during 2007-2008 was estimated at 7,600 (95% CI: 6,200-9,000; see Table 3C). The 95% confidence limits for the estimated number of badger social groups during 1990-1993 and 2007-2008 overlapped substantially indicating that there had been no significant change since 1990-1993 (see Table 3A and C). Estimates of social group abundance were similar when derived from landclass groups or counties (see Table 3 and 4). However, because the survey was designed according to landscape, the precision of estimates derived from landclass groups was greater.

During 2007-2008 the total abundance of badgers in Northern Ireland was estimated to be 34,100 (95% CI: 26,200-42,000). The 95% confidence limits for the estimated total abundance of badgers during 1990-1993 and 2007-2008 overlapped substantially indicating that, notwithstanding variation in social group size, there had been no significant overall change in badger abundance since 1990-1993 (see Table 3A and C).

Setts were negatively associated with elevation and positively associated with slope, aspect (northness and eastness), soil sand content, the presence of cover and the area of improved grassland and arable agriculture within 300 m (Table 5). The resolution of spatial modelling was substantially increased from the landclass group scale using a simple multiplicative model (Fig. 2A), to a 25 m scale using a resource selection model of the relative probability of sett construction (Fig. 2B). Predicted relative probability classes exhibited a strong positive relationship with the area-adjusted main sett frequency observed in the focal sample which was used as an independent test set ($r_s = 0.81$, $P < 0.01$) suggesting good representation of badger sett presence.

Table 5. Resource selection model for the probability of badger sett construction as determined by logistic regression.

| Explanatory variable(s) | β ± SE | t | P |
|---|---|---|---|
| Slope | 0.147 ± 0.027 | 5.37 | < 0.001 |
| Improved grassland (300 m) | 0.046 ± 0.012 | 3.91 | < 0.001 |
| Elevation | -0.005 ± 0.001 | -3.82 | < 0.001 |
| Aspect (northness) | 0.383 ± 0.121 | 3.17 | 0.002 |
| Arable agriculture (300 m) | 0.085 ± 0.038 | 2.26 | 0.024 |
| Soil and content | 0.010 ± 0.005 | 2.17 | 0.030 |
| Aspect (eastness) | 0.262 ± 0.124 | 2.12 | 0.034 |
| Cover | 0.457 ± 0.237 | 1.93 | 0.053 |
| Arable agriculture (100 m) | -0.368 ± 0.299 | -1.16 | 0.108 |

## Discussion

This is the first study to examine temporal change in the badger population of Northern Ireland over a medium- to long-term time frame of 14-18 years. The badger population, defined by the estimated number

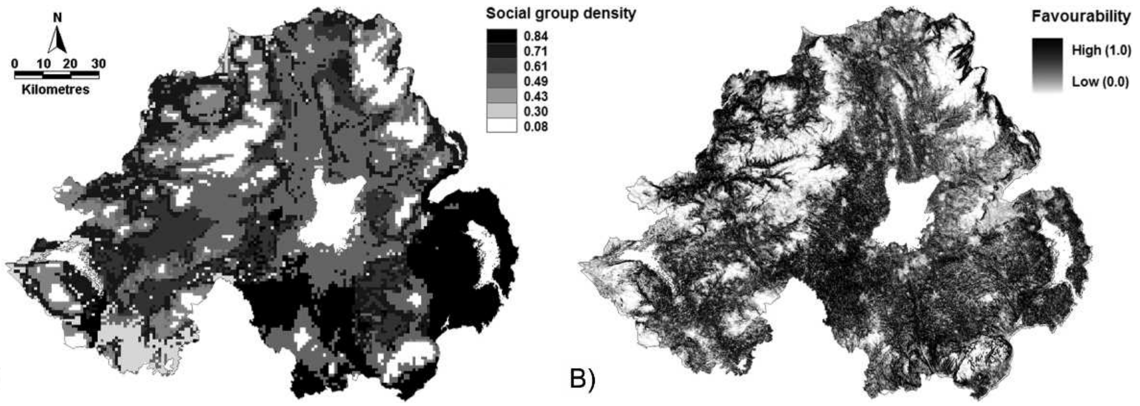


Figure 2. Spatially explicit models of A) mean badger social group density per landclass group (active main setts/km$^2$) and B) the relative probability of badger sett construction at a 25 m scale throughout Northern Ireland during 2007-2008.

of social groups and abundance of individual badgers, has not changed significantly since 1990-1993. This observation is consistent with that made by Sadlier & Montgomery (2004) who found that numbers of badger setts and social group size did not change locally during the 4-8 years between 1990-1993 and 1997-1998.

One major difficulty in attempting to estimate badger population size based on sett surveys is that the abundance of individuals can change independently of the number of social groups. Estimation of badger social group size was not conducted during our study. However, most conservation and management options for badgers are appropriately addressed on the basis of knowledge of the number of social groups, and only under specific circumstances will the effort required to obtain certainty of the number of individuals bring proportional benefits for decision making. The badger population at Woodchester Park, England has been studied in detail for over 30 years (Rogers et al. 1997). During that time the number of social groups within the park boundaries has remained relatively constant. However, the total population of badgers increased threefold from 1982 to 1999 followed by a 44% decline from 1999 to 2006 (Delahay et al. 2006, Food and Environment Research Agency (FERA), unpubl. data). This suggests that the majority of variation in the badger population has resulted from variation in social group size. Consequently, population estimation techniques that generalise social group size are likely to be less reliable than those deriving a contemporaneous estimate of social group size. Our assessments of temporal change in the total number of social groups in Northern Ireland are, therefore, likely to be much more reliable, given the survey effort deployed, than comparisons of overall badger abundance.

Landscapes at low elevations with a high degree of slope and a high proportion of sand in their soil were strongly preferred by badgers for the construction of main setts, which is consistent with previous studies (Reason et al. 1993, Neal & Cheeseman 1996, Wilson et al. 1997, Feore & Montgomery 1999, Newton-Cross et al. 2007). High uplands are generally characterised by wet or boggy conditions which make them unsuitable for living underground.

Less than 6% of Northern Ireland is wooded (EEA 2000). Therefore, setts were almost universally located in field boundary hedgerows. The weak relationship observed between sett presence and the presence of available cover was more likely due to the difficulty in producing an accurate measure of cover than the ecological response to cover by badgers. Habitat boundaries do not provide an exact match with field boundaries and may therefore be a poor proxy for availability of potential sett locations. With most setts located in relatively exposed hedgerows (compared to those sheltered within forest), badgers may avoid the worst of the south-westerly prevailing weather by selecting north-easterly facing slopes.

Badger sett presence was strongly associated with the area of improved grassland and arable agriculture within reasonable foraging distance from the sett (e.g. 300 m). Invertebrate prey including earthworms, Tipulid and Noctuid larvae and Carabid beetles (Cleary et al. 2011) are abundant in agricultural farmland (e.g. Edwards & Lofty 1982) and it, therefore, seems likely that the area of improved grassland may be important in determining badger incidence.

The advantages to population estimation by the inclusion of additional sampling effort were twofold: 1) confidence intervals associated with estimated numbers of social groups were reduced in landscapes in which badgers were most prevalent, and 2) the focal sample provided an independent test for our model of resource selection. Incidentally, the resolution of our modelling at 25 m was a significant improvement on the landclass group resolution of the simple multiplicative model. Despite Fielding & Bell (1997) recommending the retention of a subsample of data for model testing, model validation has remained largely absent from badger-habitat modelling studies (Newton-Cross et al. 2007). Additional sampling effort and new analytical techniques substantially improved the estimation of badger social group density, abundance and the resolution of spatial mapping.

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## References


Boyce, M.S., Vernier, P.R., Nielsen, S.E. & Schmiegelow, F.K.A. 2002: Evaluating resource selection functions. - Ecological Modelling 157: 281-300.

Burnham, K.P. & Anderson, D.R. 2002: Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd edition. - Springer-Verlag, New York, New York, USA, 496 pp.

Cheeseman, C.L., Jones, G.W., Gallagher, J. & Mallinson, P.J. 1981: The population structure, density and prevalence of tuberculosis (*M. bovis*) in the badger (*Meles meles*) from four areas in South West England. - Journal of Applied Ecology 18: 795-804.

Cheeseman, C.L., Little, T.W.A., Mallinson, P.J., Page, R.J.C., Wilesmith, J.W. & Pitchard, D.G. 1985: Population ecology and prevalence of tuberculosis in badgers in an area of Staffordshire. - Mammal Review 15: 125-135.

Cleary, G.P., Corner, L.A.L., O'Keefe, J. & Marples, N.M. 2011: Diet of the European badger (*Meles meles*) in the Republic of Ireland: A comparison of results from an analysis of stomach contents and rectal faeces. - Mammalian Biology 76: 470-475.

Clements, E.D., Neal, E.G. & Yalden, D.W. 1988: The national badger sett survey. - Mammal Review 18: 1-9.

Collins, J.D., Ellis, W., Feore, M., Mulcahy, M.F., Neil, S., Sheridan, M., Sleeman, D.P., Hughes, S. & Rogers, M. 1994: The feasibility of developing a vaccine against tuberculosis for use in the badger (*Meles meles*), report of a steering committee. - Department of Agriculture, Food & Forestry Dublin/Department of Agriculture for Northern Ireland, Belfast, Northern Ireland, 76 pp.

Cresswell, P., Harris, S. & Jefferies, D.J. 1990: The history, distribution, status and habitat requirements of the badger in Britain. - Nature Conservancy Council, Peterborough, UK, 84 pp.

Cruickshank, J.G. 1997: Soil and Environment: Northern Ireland. - Department and Agriculture Northern Ireland, Nicholson and Bass, Belfast. UK, 214 pp.

Delahay, R.J., Smith, G.C., Ward, A.I. & Cheeseman, C.L. 2006: Options for the management of bovine tuberculosis transmission from badgers (*Meles meles*) to cattle: evidence from a long-term study. - Mammal Study 30: S73-S81.

Edwards, C.A. & Lofty, J.R. 1982: Nitrogenous fertilizers and earthworm populations in agricultural soils. - Soil Biology and Biochemistry 14: 515-521.

EEA 2000: CORINE land cover 2000. - European Environment Agency. Available at http://www.eea.europa.eu/publications/COR0-landcover (Last accessed on 22 June 2008).

Etherington, T.R., Ward, A.I., Smith, G.C., Pietravalle, S. & Wilson, G.J. 2009: Using the Mahalanobis distance statistic with unplanned presence-only survey data for biogeographical models of species distribution and abundance: a case study of badger setts. - Journal of Biogeography 36: 845-853.

Feore, S.M. 1994: The distribution and abundance of the badger *Meles meles* L. in Northern Ireland. - PhD thesis, Queen's University Belfast, Belfast, UK, 165 pp.

Feore, S. & Montgomery, W.I. 1999: Habitat effects on the spatial ecology of the European badger (*Meles meles*). - Journal of Zoology (London) 247: 537-549.

Fielding, A.H. & Bell, J.F. 1997: A review of methods for the assessment of prediction errors in conservation presence/absence models. - Environmental Conservation 24: 38-49.

Franz, A.C., Fack, F., Muller, C.P. & Roper, T.J. 2006: Faecal DNA typing as a tool for investigating territorial behaviour of badgers. - European Journal of Wildlife Research 52: 138-141.

Hirzel, A.H., Le Lay, G., Helfer, V., Randin, C. & Guisan, A. 2006: Evaluating the ability of habitat suitability models to predict species presences. - Ecological Modelling 199: 142-152.

Kelly, G.E., Condon, J., More, S.J., Dolan, L., Higgins, I. & Eves, J. 2007: A long-term observational study of the impact of badger removal on herd restrictions due to bovine TB in the Irish midlands during 1989-2004. - Epidemiology and Infection 136: 1362-1373.

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

Kruuk, H. & Parish, T. 1982: Factors affecting population density, group size and territory size of the European badger *Meles meles*. - Journal of Zoology (London) 196: 31-39.

Macdonald, D.W. & Newman, C. 2002: Badger (*Meles meles*) population dynamics in Oxfordshire, UK. Numbers, density and cohort life histories, and a possible role of climate change in population growth. - Journal of Zoology (London) 256: 121-138.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. & Erickson, W.P. 2002: Resource Selection by Animals. 2nd edition. - Kluwer Academic Publishers, Dordrecht, the Netherlands, 240 pp.

Montgomery, D.C. & Peck, E.A. 1982: Introduction to Linear Regression Analysis. - John Wiley & Sons, New York, New York, USA, 504 pp.

Murray, R., McCann, T. & Cooper, A. 1992: A land classification and landscape ecological study of Northern Ireland. - University of Ulster, Coleraine, UK, 254 pp.

Neal, E. & Cheeseman, C. 1996: Badgers. - Poyser Natural History, London, UK, 272 pp.

Newton-Cross, G., White, P.C.L. & Harris, S. 2007: Modelling the distribution of badgers *Meles meles*: comparing predictions from field-based and remotely derived habitat data. - Mammal Review 37: 54-70.

O'Corry-Crowe, G. 1992: The social and genetic structure of a badger (*Meles meles* L. 1758) population in central Ireland. - PhD thesis, National University of Ireland, Dublin, Republic of Ireland.

O'Keeffe, J.J. 2006: Description of a medium term strategy toward eradication of tuberculosis in cattle in Ireland. - In: Costello, E. & Kenny, K. (Eds.); Veterinary network of laboratories researching into improved diagnosis and epidemiology of mycobacterial diseases. Central Veterinary Laboratory Department of Agriculture and Food, Dublin, Republic of Ireland, pp. 2-9.

Ostler, J.R. & Roper, T.J. 1998: Changes in size, status, and distribution of badger *Meles meles* L. setts during a 20-year period. - Zeitschrift für Säugetierkunde 63: 200-209.

Palphramand, K.L., Newton-Cross, G. & White, P.C.L. 2007: Spatial organization and behaviour of badgers (*Meles meles*) in a moderate-density population. - Behavioral Ecology and Sociobiology 61: 401-413.

Reason, P., Harris, S. & Cresswell, P. 1993: Estimating the Impact of Past Persecution and Habitat Changes on the Numbers of Badgers *Meles meles* in Britain. - Mammal Review 23: 1-15.

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

Sadlier, L. & Montgomery, W.I. 2004: The impact of sett disturbance on badger *Meles meles* numbers; when does protective legislation work? - Biological Conservation 119: 455-462.

Scheppers, T.L.J., Frantz, A.C., Schaul, M., Engel, E., Breyne, P., Schley, L. & Roper, T.J. 2007: Estimating social group size of Eurasian badgers *Meles meles* by genotyping remotely plucked single hairs. - Wildlife Biology 13(2): 195-207.

Sleeman, D.P., Davenport, S.J., More, T.A., Cleggs, T.A., Collins, J.D., Martin, S.W., Williams, D.H., Griffin, J.M. & O'Boyle, L. 2009: How many Eurasian badgers *Meles meles* L. are there in the Republic of Ireland? - European Journal of Wildlife Research 55: 333-334.

Smal, C. 1995: The badger and habitat survey of Ireland: The distribution and abundance of the badger *Meles meles* in Ireland, with especial reference to habitat surveys and to bovine tuberculosis *Mycobacterium bovis*. - Report to the National Parks & Wildlife Service and Department of Agriculture & Food, Dublin, Republic of Ireland, 460 pp.

Smith, G. & Cheeseman, C.L. 2007: An assessment of trapping efficacy during the initial proactive culls in the randomised badger culling trial. - Veterinary Record 160: 723-726.

Tuyttens, F.A.M., Long, B., Fawcett, T., Skinner, A., Brown, J.A., Cheeseman, C.L., Roddam, A.W. & Macdonald, D.W. 2001: Estimating group size and population density of Eurasian badgers *Meles meles* by quantifying latrine use. - Journal of Applied Ecology 38: 1114-1121.

Tuyttens, F.A.M., Macdonald, D.W., Delahay, R.J., Rogers, L.M., Mallinson, P.J., Donnelly, C.A. & Newman, C. 1999: Differences in trappability of European badgers in three populations in England. - Journal of Applied Ecology 36: 1051-1062.

Wilson, G., Harris, S. & McLaren, G. 1997: Changes in the British badger population, 1988 to 1997. - People's Trust for Endangered Species, London, UK, 142 pp.

Woodroffe, R., Gilks, P., Johnston, W.T., Le Fevre, A.M., Cox, D.R., Donnelly, C.A., Bourne, F.J., Cheeseman, C.L., Gettinby, G., McInerney, J.P. & Morrison, W.I. 2007: Effects of culling on badger abundance: implications for tuberculosis control. - Journal of Zoology (London) 274: 28-37.