Department of Agriculture and Rural Development

Badger Survey of Northern Ireland 2007/08

Quercus Project QU07-13

Badger Survey of Northern Ireland 2007/08

prepared for

Department of Agriculture & Rural Development (DARD)

by

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Executive Summary

1. The Badger Survey of Northern Ireland 2007/08 was carried out for the Department of Agriculture and Rural Development between November 2007 and March 2008 by surveying badger setts in 212 x 1 km^2 Irish grid squares. Standardised field survey methods and analytical techniques were employed to enable direct comparison with the results of the last survey, conducted between 1990 and 1993 (Feore, 1994).

2. Using the same survey sample and analytical methods as the previous survey, the mean estimated density of badger social groups in Northern Ireland during 2007/08 was 0.56 social groups per 1 km^2 (95% CI 0.43-0.69) giving an estimated total abundance of 7,500 badger social groups (95% CI 5,900–9,300). Sampling additional survey squares in areas of high badger density improved the precision but did not alter the magnitude of these estimates.

3. Using the same survey sample and analytical methods as the previous survey, and not withstanding uncertainty in social group size, the estimated total abundance of badgers in Northern Ireland during 2007/08 was 33,500 badgers (95% CI 26,000-41,200).

4. Neither the density of badger social groups nor the total abundance of badgers (not withstanding uncertainty in social group size) had changed significantly between 1990/93 and 2007/08.

5. Badger setts were significantly positively associated with altitude, gradient and aspect of slope, soil sand content and the area of improved grassland, arable agriculture, and cover.

6. The density of badger social groups was highest in Drumlin farmland and Marginal uplands and lowest in Mountains. Due to the prevalence of favourable landscape features, counties Armagh and Down had the highest density of badger social groups.

Contents

Introduction

Badgers (*Meles meles* L. 1758) are widespread and common in Britain and Ireland but data on their distribution and abundance in Northern Ireland was out of date. During 1990/93, 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 did not change significantly between 1990/93 and 1997/98. In Great Britain, comparison of two national surveys (Cresswell, Harris & Jefferies, 1990; Wilson, Harris & McLaren, 1997) demonstrated substantial increases in numbers of badger social groups during the early 1990s, however there are no large-scale survey data by which to assess population change in Britain since then.

Feore (1994) suggested there were substantial differences in the social and spatial ecology between badgers living in Great Britain and Ireland. Given the significance of badger populations to a range of management issues, including biodiversity conservation and epidemiology of bovine tuberculosis, the DARD Badger Stakeholder Group identified the need to resurvey Northern Ireland to establish the current status of the badger population.

Specifically, the aims of this survey were to:

1. Establish the current distribution and abundance of badgers in Northern Ireland.

2. Provide density estimates for badger social groups according to habitat characteristics and geographic region, and

3. Provide the basis for future monitoring of the status of badgers in Northern Ireland.

Methods

Survey site selection

Two means of sampling the landscape were employed, hereafter referred to as the 'systematic sample' and the 'focal sample'.

The systematic sample

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. The systematic sample consisted of 144 x 1km Irish grid squares each positioned at the most south-westerly corner of each 10km Irish grid square (Fig. 1), sampling the 8 landclass groups of Northern Ireland (Murray, McCann & Cooper, 1997) in proportion to their availability. This systematic sampling regime provided the basis for direct comparison with Feore (1994), hereafter referred to as the 1990/93 survey.

The focal sample

Badger population densities are likely to vary with environmental factors across landclass groups (Feore, 1994; Wilson, Harris & McLaren, 1997). Greater precision is particularly desirable in areas of high density, as precision in areas of lower density is unlikely to affect the precision of the total population estimate. Seventy-five systematic sample squares fell within one of 3 landclass groups determined to have the highest density of badger social groups during 1990/93 (Feore, 1994); specifically landclass groups 1, 5 and 6 (Drumlin farmland, Marginal uplands and Settled uplands). To examine the effect of spatial aggregation on badger incidence each of these 75 systematic squares was paired with a randomly selected focal square within the same high density landclass groups within 5 distance categories including 1, 2, 3, 4 and 5 km (Fig. 2). Fifteen focal squares were selected within each distance category (i.e. 15 x 5 = 75).

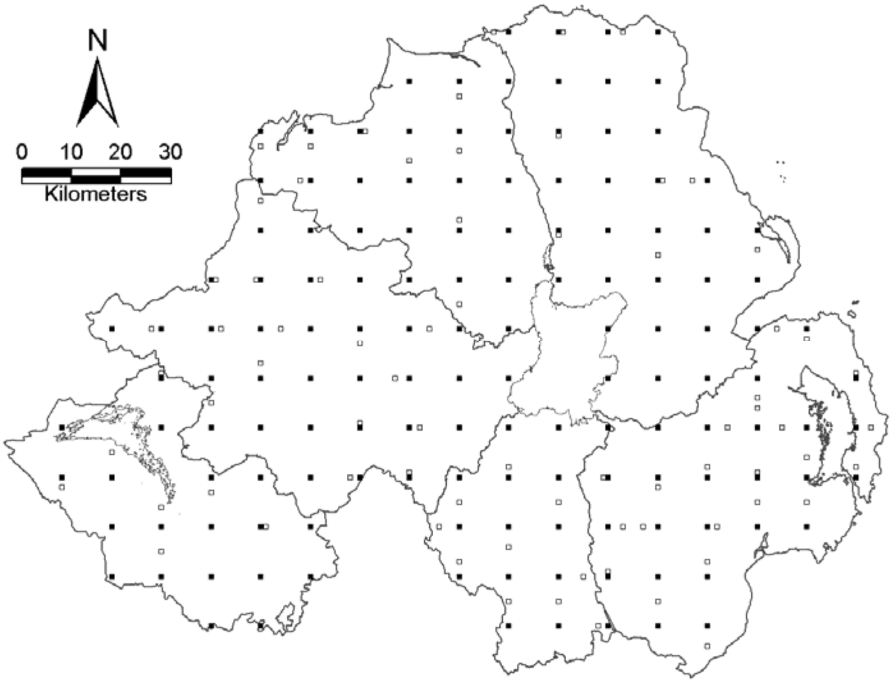


Fig. 1 *The 2007/08 sett survey showing 144 'systematic sample' squares (black squares) and 74 'focal sample' squares (white squares).*

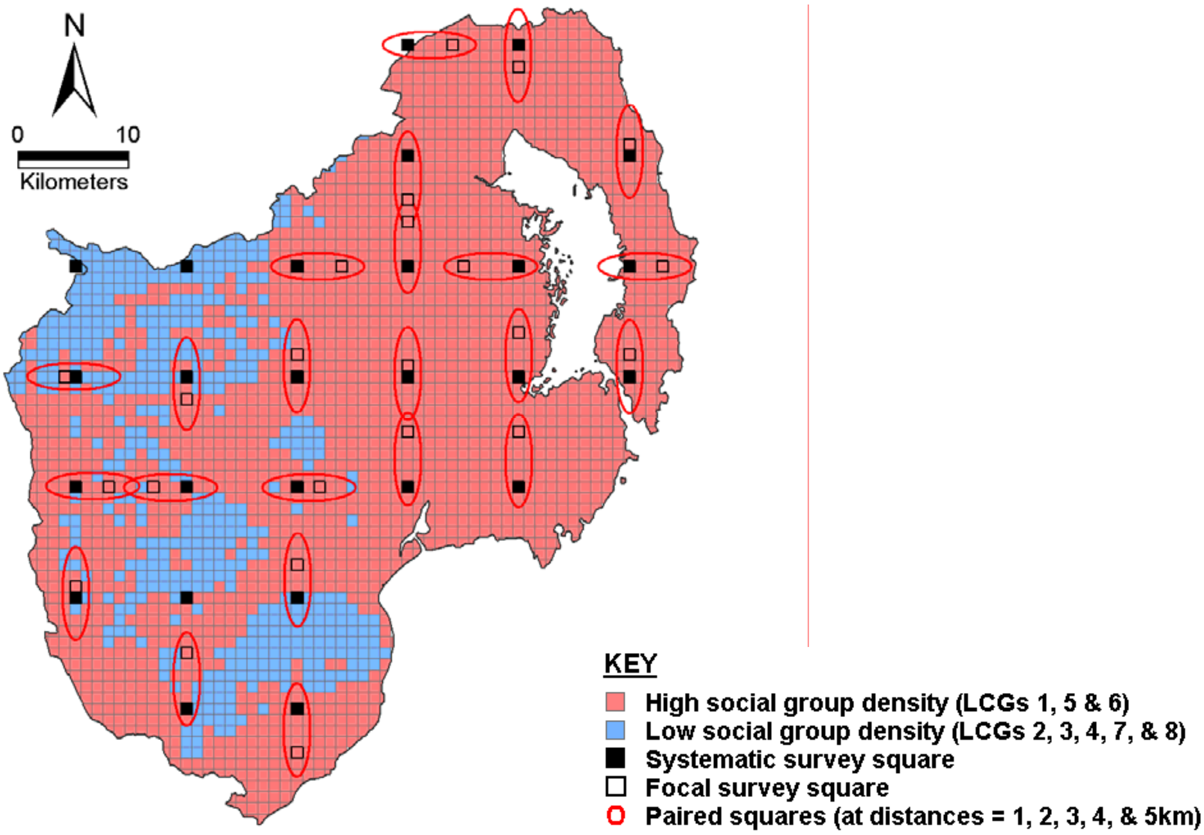


Fig. 2 *Illustration of focal sample square selection in Co. Down. Each systematic sample square was paired with a focal sample square at a range of distances between 1 and 5km within landclass groups shown to have similar badger social group densities during 1990/93 (Feore, 1994).*

Sett surveys

In accordance with the contract specification, surveys of badger setts were conducted in 1 km squares between 19th November 2007 and 14th 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. Forest blocks were sampled 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. Dense habitats such as gorse (*Ulex europaeus* L.) or bramble (*Rubus fruticosus* L.) dominated scrub were surveyed by walking the habitat boundary, noting badger activity such as runs or latrines with subsequent investigation of the interior of the habitat patch if indicated.

In the interests of effective biosecurity, land registered as affected with *brucellosis* was avoided and left unsurveyed. The area of each survey square that could not be surveyed due to impenetrably dense habitat, rough terrain, development (e.g. urban areas, quarries, etc.) or biosecurity was recorded and accounted for during analysis.

The following variables were recorded for each sett following Cresswell, Harris & Jefferies (1990), Feore (1994), Wilson, Harris & McLaren (1997) and Sadlier & Montgomery (2004):

- Location - 10 figure grid reference using a handheld GPS
- Size - Number of sett entrances
- Activity - The number of well-used, partially-used and disused holes
- Sett type - Classified as main, annex, subsidiary or outlier

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.

Different sett types were characterised as:

Main setts - Have a large number of entrances with a greater proportion of well-used holes than other sett types. Main setts were usually surrounded by a number of well-worn paths.

Annex setts - Lie adjacent to the main sett of a social group and are generally within 150m. Annex setts are typically linked to their main sett by conspicuous well-worn paths. Due to their proximity to the main sett they may not be in continuous use and thus generally have a greater proportion of partially-used holes than main setts.

Subsidiary setts - Are generally more isolated from main setts than annex setts and are generally not connected to other setts by paths. A subsidiary sett generally had two or three 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.

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.

A typical example of a completed survey of a 1km square is shown in Appendix 1.

Environmental data

Newton-Cross, White & Harris (2007) demonstrated that field-derived environmental data, such as habitat classifications, are of less utility in modelling badger occurrence than remotely-sensed data from digital databases. Habitat variables collected in the field are generally less accurate, more subjective and thus contain more error than digital data. Furthermore, they are costly to collect due to time spent in the field. Consequently, no environmental variables were collected in the field during the current study.

A geographic information system (GIS) was used to compute environmental parameters using ArcGIS v9.2 (ESRI, Redlands, California, USA). The choice of landscape variables chosen for inclusion in analyses were based on those shown to influence badger distribution and abundance in previous studies (Thornton 1988; Skinner, Skinner & Harris 1991; Roper 1992; Reason, Harris & Cresswell 1993; Macdonald, Mitchelmore & Bacon 1996; Neal & Cheeseman 1996; Wilson, Harris & McLaren 1997; Feore & Montgomery 1999; Wright, Fielding & Wheater 2000; Hammond, McGrath & Martin 2001; Macdonald *et al*. 2004; Jepsen *et al*. 2005; Newton-Cross, White & Harris 2007). Topographical data were derived from a Digital Elevation Model (DEM) of Northern Ireland, soil characteristics were taken from the DANI Soil Survey of Northern Ireland (Cruickshank, 1997) and habitat variables were extracted from Land Cover Map 2000.

Statistical analyses

To ensure direct comparability with the 1990/93 survey, all comparative analyses, unless otherwise stated, included only data from the systematic sample of 140 x 1 km^2 grid squares.

Descriptive statistics were used to describe the prevalence of, and level of activity at, each sett type.

Variation in badger main sett density was examined between surveys and across landclass groups and counties using a repeated measures generalised linear model assuming a Poisson error distribution and a logarithmic link function. The survey square was treated as a repeated measure while survey, landclass group and county were fitted as fixed factors. Initially, all two-way interactions were included but subsequently removed if found to be non-significant.

Two models were used to obtain estimates of the total abundance of main setts: one was directly comparable to the 1990/93 survey and used data from the systematic sample only and the second used data from the systematic and focal samples combined.

Mean social group density per landclass (λ_i) was calculated using the equation:

$$\lambda_i = \frac{x_i}{a_i}$$ **Equation 1**

where x equalled the total number of active main setts observed within landclass i (ranging from 1 to 8) and a equalled the area surveyed in km^2. The 95% confidence limits for mean social group density were derived using:

$$\text{Confidence limit}_{\lambda} = \lambda_i \pm 1.96\sqrt{\frac{\lambda_i}{a_i}}$$ **Equation 2**

An estimate of the abundance of social groups in each landclass group was obtained by multiplying the mean social group density (λ_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. The estimated total abundance of badger social groups in Northern Ireland as a whole (T) was obtained by summing the estimated abundance of social groups within each landclass group:

$$T = \sum_{i=1}^{8} \lambda_i A_i$$ **Equation 3**

Confidence limits for the estimate of the total abundance of social groups in Northern Ireland were derived from the standard error of the overall mean social group density using:

$$\text{Confidence limits}_{T} = \sum_{i=1}^{8} A\left(\lambda_i \pm 1.96\sqrt{\frac{\lambda_i}{a_i}}\right)$$ **Equation 4**

An estimate of the total abundance of badgers within each landclass group and for Northern Ireland as a whole was obtained 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 since the early 1990s and those that have, used varying and incomparable methodologies (Palphramand, Newton-Cross & White, 2007; Scheppers *et al*. 2007; Tuyttens *et al*. 2001). None of these studies were conducted in Northern Ireland. Estimates of badger social group size can only be obtained by detailed study of focal populations using a range of labour intensive and costly survey techniques including bait marking, capture-mark-recapture, direct observations and/or population genetics (Kruuk, 1978; Cheeseman *et al*. 1981; Kruuk & Parish, 1982; Cheeseman *et al*. 1985; O'Corry-Crowe, 1992; Feore, 1994; Smal, 1994). Such methods were beyond the remit of the current study, thus estimates of badger social group size were taken from published literature (Table 1).

Given the potential differences in badger ecology between Great Britain and Ireland (Feore, 1994), greater value should be placed on estimates of social group size from Ireland. As part of a National Bovine Tuberculosis Eradication Programme 'The Four Areas Trial' in the Republic of Ireland identified over 5,000 badger setts and removed almost 2,500 badgers from target areas from 1997 to 2002 (Anon, 2004). However, no attempt was been made to determine the size of social groups from which animals were culled and thus, these data provide a measure of removal effort only. Consequently, culling work in Ireland provides few data of use in updating estimates of mean social group size in Northern Ireland.

Queen's University Belfast has two PhD studentships currently underway examining badger landscape ecology, social group size, density and physiological ecology; one funded by DARD and the other by NIEA. These will employ some of the labour intensive survey techniques already mentioned to assess variability in badger social group size in Northern Ireland, however, no results are currently available.

Therefore, due to the small number of studies conducted since 1990/93 (Palphramand, Newton-Cross & White, 2007; Scheppers *et al*. 2007; Tuyttens *et al*. 2001) and for the sake of comparability we adopted an identical approach to that of Feore (1994) in estimating mean social group size (Table 1).

Table 1 *Mean badger social group size ± 95% confidence intervals, derived from a collation of studies in Great Britain and Ireland, grouped according to similarity of habitat types.*

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 & 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	Down (NI)	Feore (1994)	3	4, 1, 1	4.27 (3.66 - 4.89)
	3. Marginal lowlands	Cornwall (Eng)	Cheeseman *et al.* (1981)	6	1, 2, 6, 4, 5, 2	
	4. Central lowlands	Avon (Eng)	Cheeseman *et al.* (1981)	7	4, 5, 3, 2, 2, 6, 3	
	5. Marginal uplands	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 (1994)	19	7, 3, 6, 6, 5, 4, 4, 7, 6, 4, 7, 3, 5, 2, 1, 4, 6, 7, 3	
Upland & moorland	6. Settled uplands	Antrim (NI)	Feore (1994)	2	2, 3	3.00 (2.20 - 3.80)
	7. High uplands	Inverness (Scot)	Kruuk & Parish (1982)	2	4, 3	
	8. Mountains					

[Modified from Feore, 1994]

The GIS biogeographical model

A GIS biogeographical model of active main sett density was created to assess relationships between habitat and landscape features and the detection of badger setts.

Spatial autocorrelation

Prior to building a predictive model it was necessary to establish whether badger incidence or social group density was spatially autocorrelated, i.e. badger populations were spatially aggregated to an extent that could not be explained by similarity of habitat. It was not enough to correlate badger social group density within the pairs of systematic and focal squares as this would not account for spatial autocorrelation of environmental variables. Instead a single analysis was needed to account for the contribution of distance between the paired squares whilst simultaneously assessing the contribution of environmental variables.

First, a generalised linear model assuming a binomial error distribution using a logit link function was used to describe the factors associated with the similarity of badger main sett occurrence between paired sample squares using *differenced* variables. A differenced variable quantifies the degree of similarity, or conversely the degree of dissimilarity, between the same factor measured at two sites; in this case paired 1km squares. In each pair, the systematic square is used as our reference sample and its paired focal square as the test sample. Using the area of improved grassland as an example, two squares which have the same coverage of improved grassland will have a *differenced* improved grassland variable equal to zero (e.g. 50ha-50ha= 0ha). If, however, the systematic square has a greater area of improved grassland than its paired focal square then the *differenced* improved grassland variable will be a positive integer (e.g. 75ha-50ha = 25ha). Conversely, if the opposite is true then the *differenced* improved grassland variable will be a negative integer (e.g. 50ha-75ha= -25ha). Negative differenced badger occurrence was converted to a positive integer to provide a binomial response variate; 0 when a main sett was either present or absent in both squares within the same pair or 1 when a main sett was present in one square but absent in the other (i.e. 0 = the same, 1 = different).

Second, a generalised linear model assuming a normal error distribution using an identity link function was used to describe the factors associated with the similarity of badger social group density between paired sample squares also using differenced variables. The variables used in both these analyses are listed in Table 2.

A forward-backward stepwise model selection technique based on Akaike's Information Criterion (AIC) was used. The most parsimonious model was taken as that with the lowest AIC value.

Biogeographical modelling

Some landscape variables will be specific to the location of the sett itself, hereafter referred to as 'immediate variables'. Other variables will be important in the context of the surroundings in which a sett is located, hereafter referred to as the 'proximate variables'. Whilst immediate variables are specific to the sett, there is no evidence of the relevant spatial scale for proximate variables. Nevertheless, it is evidently important that candidate scales are smaller than the average badger territory. We tested three candidate spatial scales with respect to available habitats within 100, 300 and 500m of a sett. These distances were chosen to create a range of putative territory sizes roughly representative of that which occurs in the wild (Neal & Cheeseman 1996).

Using the systematic sample only, a model of landscape favourability for badger setts was developed. All areas were surveyed, thus the presence or absence of setts in any given area was known. However, treating sett absence as landscape unsuitability 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, sett data were considered to consist of presence records only and thus a presence only modelling approach was adopted.

Table 2 *Differenced landscape variables included in models designed to detect spatial autocorrelation of badger incidence or social group density. All variables, except distance between paired squares, are the taken as the difference between the named variable in the systematic sample square and the same variable in the focal sample square.*

Differenced variable(s)	Description
Altitude	Mean elevation taken from a Digital Elevation Model (DEM) of Northern Ireland.
Arable	Proportion of an area classed as arable agriculture. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Broad-leaved woodland	Proportion of an area classed as broad-leaved woodland. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Coniferous woodland	Proportion of an area classed as coniferous woodland. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Dense dwarf scrub heath	Proportion of an area classed as dense dwarf scrub heath. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Distance between squares	Distance between the centre of the systematic sample square and its paired focal sample square including 1, 2, 3, 4 and 5km.
Hedgerow density	Length of habitat patch edge in kilometres within each 1km square.
Hilliness Index	An index of average landscape ‘roughness’ indicating the prevalence of hills and, therefore, slopes within each square. Details on how this metric was calculated can be obtained from Newton-Cross, White & Harris (2007).
Improved grassland	Proportion of an area classed as improved grassland. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Open dwarf scrub heath	Proportion of an area classed as dense Open scrub heath. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.
Soil sand content	Proportion of soil consisting of sand. Calculated from the Soil Survey of Northern Ireland. The coarse resolution of the data (1:50,000) was transformed into a 25m raster and averaged over a radius of 500m to ensure avoid problems associated with hard categorical boundaries.

Landscape variables were extracted and manipulated as raster datasets using a cell resolution of 25m (n= 203,612 cells within Northern Ireland). To develop a landscape suitability model using this sample size was impractical and thus a representative sub-sample of available resources was taken (Manly *et al*. 2002). A random sample of 400 cells was selected and tested to ensure valid representation of the landscape. Sett data were coded as 1 = used and 0 = available.

A list of landscape variables included in this analysis is provided in Table 3. To account for the potential locational error in georeferencing sett locations, the immediate landscape variables were extracted as the mean value within 25m of the

Table 3 *Landscape variables included in biogeographical models of badger sett presence.*

Explanatory variable(s)	Units	Description
Immediate variables (within 25m of the main sett)		
Altitude	Metres	Elevation taken from a Digital Elevation model of Northern Ireland.
Aspect (Eastness)	Index	Index that represents the degree to which a slope is 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 represents the degree to which a slope is northerly. A value of 1 = directly north, a value of 0 = directly east or west and a value of -1 = directly south.
Cover	Index	Area that provided cover included broad-leaved woodland, coniferous woodland, bracken, dwarf shrub heath and open dwarf scrub heath. Also included area of habitat boundary, taken as a proxy of hedgerow length in agricultural areas. Calculated from Land Cover Map 2000 (LCM2000).
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. The coarse resolution of the data (1:50,000) was transformed into a 25m raster and averaged over a radius of 500m to ensure avoid problems associated with hard categorical boundaries.
Proximate variables within a) 100m, b) 300m and c) 500m of the main sett		
Arable	Area	Number of 25 raster cells classed as arable agriculture. Calculated from Land Cover Map 2000 (LCM2000) 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 (LCM2000) within buffers of differing radii.
Improved grassland	Area	Number of 25 raster cells classed as improved grassland. Calculated from Land Cover Map 2000 (LCM2000) within buffers of differing radii.

sett. Proximate landscape variables at different spatial scales (100, 300 and 500m) were likely to be correlated. Collinearity was calculated using variance inflation factors (VIF) with all variables with values <5 included as they were unlikely to influence regression coefficients (Montgomery & Peck 1982).

A variety of methods are available for the modelling of landscape favourability using presence only data (Pearce & Boyce 2006). Here we used a logistic regression based comparison of used versus available resources (Manly *et al*. 2002), assuming the form:

$$w(x) = \exp(\beta_1 x_1 + ... \beta_p x_p)$$ **Equation 5**

where β is the slope of the relationship between variable x and the response variate w. In this case w equalled sett presence or availability. It is important to note, that the resource selection value of $w(x)$ does not produce the probability that a given area is suitable for the construction of a main sett but it does provide a measure of suitability relative to other areas. A forward-backward stepwise model selection technique based on AIC was employed to select the most parsimonious model as described above.

The best model was applied on a 25m resolution and binned into 10 quantiles representing geographical classes of relative suitability for the construction of setts, hereafter referred to as 'sett suitability classes' (ranging from 1-10).

The model was tested using the independent focal sample data to ensure the model predictions were robust, especially in areas of highest badger density. The total area of each sett suitability class within the focal sample was calculated along with the number of setts observed within each sett suitability class. These data were evaluated using a presence only technique based on the area-adjusted frequencies of sett observations within each suitability class (Boyce *et al*. 2002). Hirzel *et al*. (2006) has shown this approach to be comparable to more standard presence-absence based modelling techniques. The basic premise is that as the sett suitability class increases from 1 to 10, there should be a matching increase in area-adjusted frequencies of sett observations. This was tested using a Spearman's Rank (r_s) correlation.

All statistical analysis was conducted using GenStat v6 or R©

Results

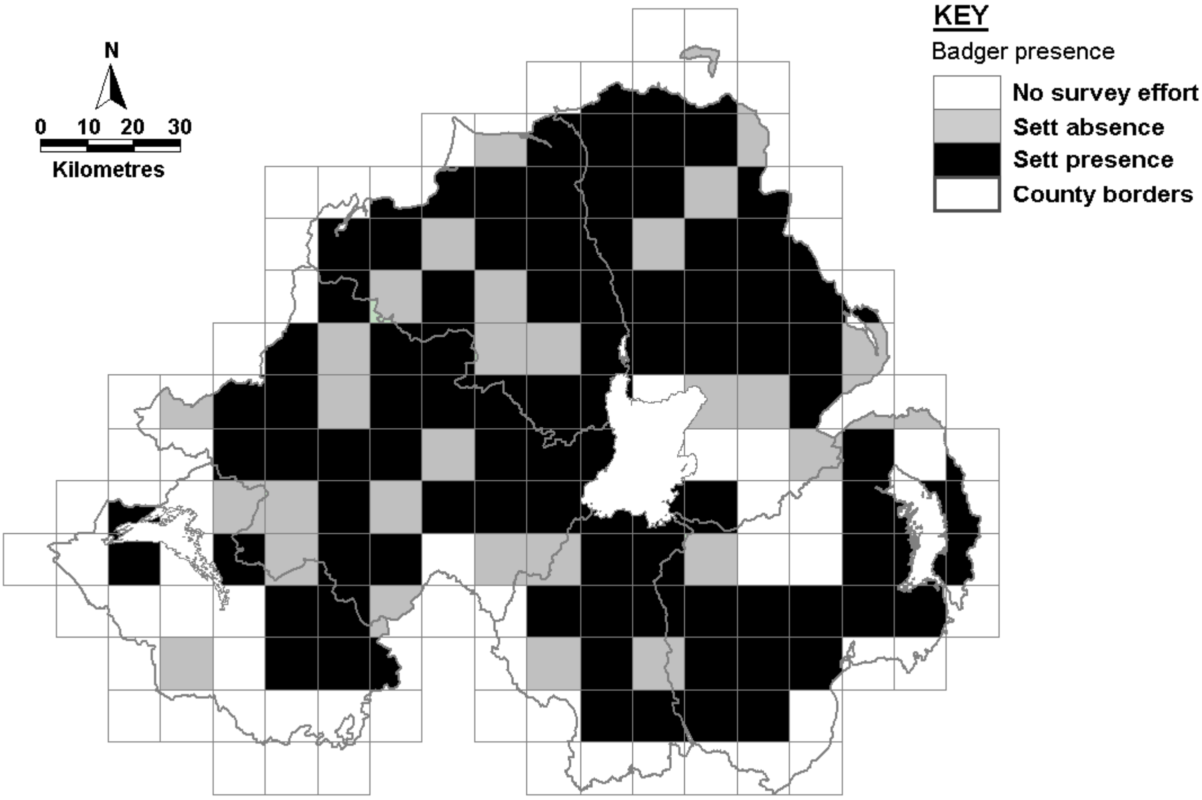
A total of 212 of 222 1km^2 squares were surveyed (140 systematic sample squares and 72 focal sample squares). Ten squares could not be surveyed; 5 squares fell within large bodies of water (Loughs Erne, Neagh and Strangford), 1 square was unsurveyed due to the terrain and access was denied by landowners to the remaining 4 squares. Surveys were conducted by 25 fieldworkers over 561 person days.

75% of survey squares contained at least one badger sett and badgers remain widely distributed in Northern Ireland (Fig. 3).

A total of 653 setts were recorded within 212 squares surveyed; 154 main setts (24%), 28 annex setts (4%), 156 subsidiary setts (24%) and 315 outlier setts (48%). The size of setts classified as main, annex, subsidiary or outlier setts did not differ between the 1990/93 and 2007/08 surveys suggesting that data were comparable (Fig. 4). Also, the level of sett use as determined by the number of well-used, partially-used and disused entrances did not differ between the two studies (Table 4). During 2007/08, main setts were generally characterised by 7 entrances; 4 well-used, 1 partially-used and 2 disused. The number of setts within any 1 survey square varied from 0 to 14 with 83% of setts in active use during 2007/08. This compared to a range of 0 to 24 setts per square with 66% of setts active during 1990/93. Sett size varied between 1-28 entrances during 2007/08 compared to 1-38 during 1990/93.

Within the systematic sample the mean density of all badger setts in Northern Ireland during 2007/08 was 3.29 (95%CI 3.04-3.54) setts per km^2. The mean density of active main setts, equivalent to badger social group density was 0.56 (95%CI 0.43-0.69) active main setts per km^2. Social group density did not differ significantly between 1990/93 and 2007/08 ($F_{1,244}$ = 0.63, p=0.428). Social group density did vary significantly among landclass groups ($F_{7,244}$= 2.25, p=0.028). Landclass group 1 (Drumlin farmland) had the highest mean social group density and landclass

(a)



(b)

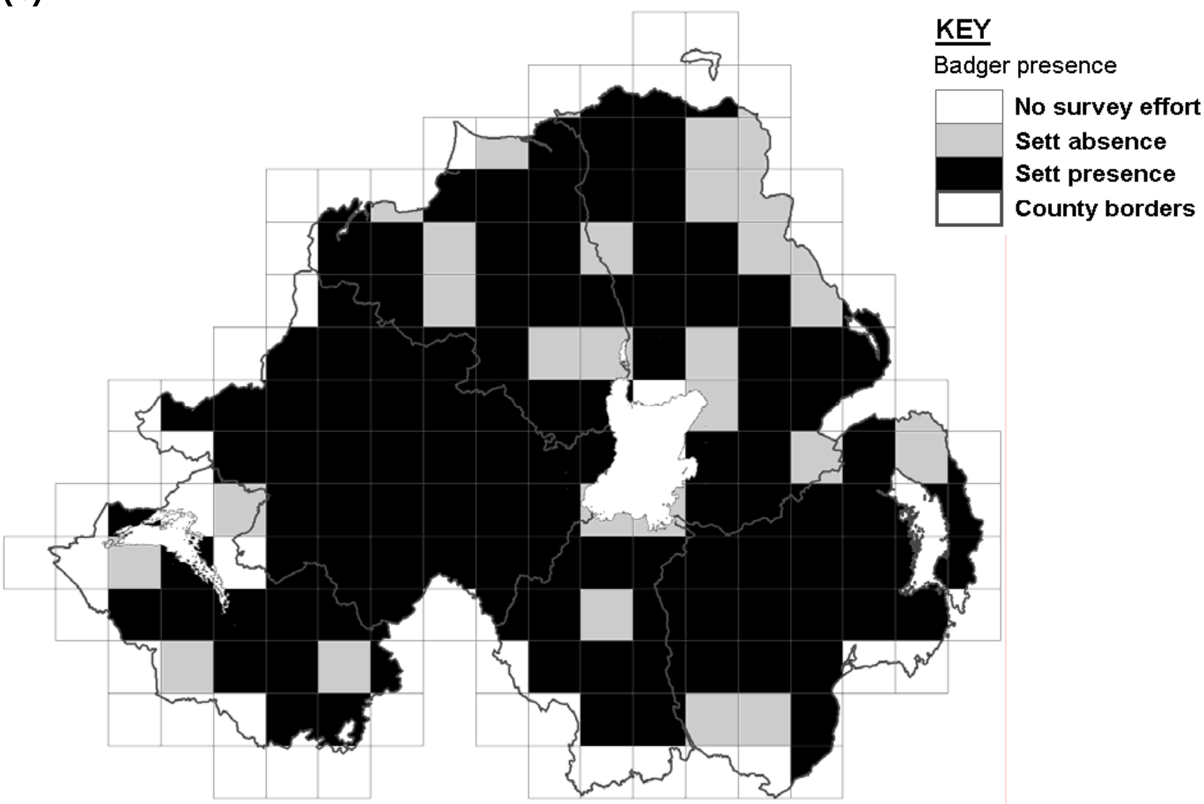


Fig. 3 *The distribution of badgers during* **(a)** *1990/93 and* **(b)** *2007/08 as defined by the presence of setts within 1km squares at the south-western corner of each 10km square.*

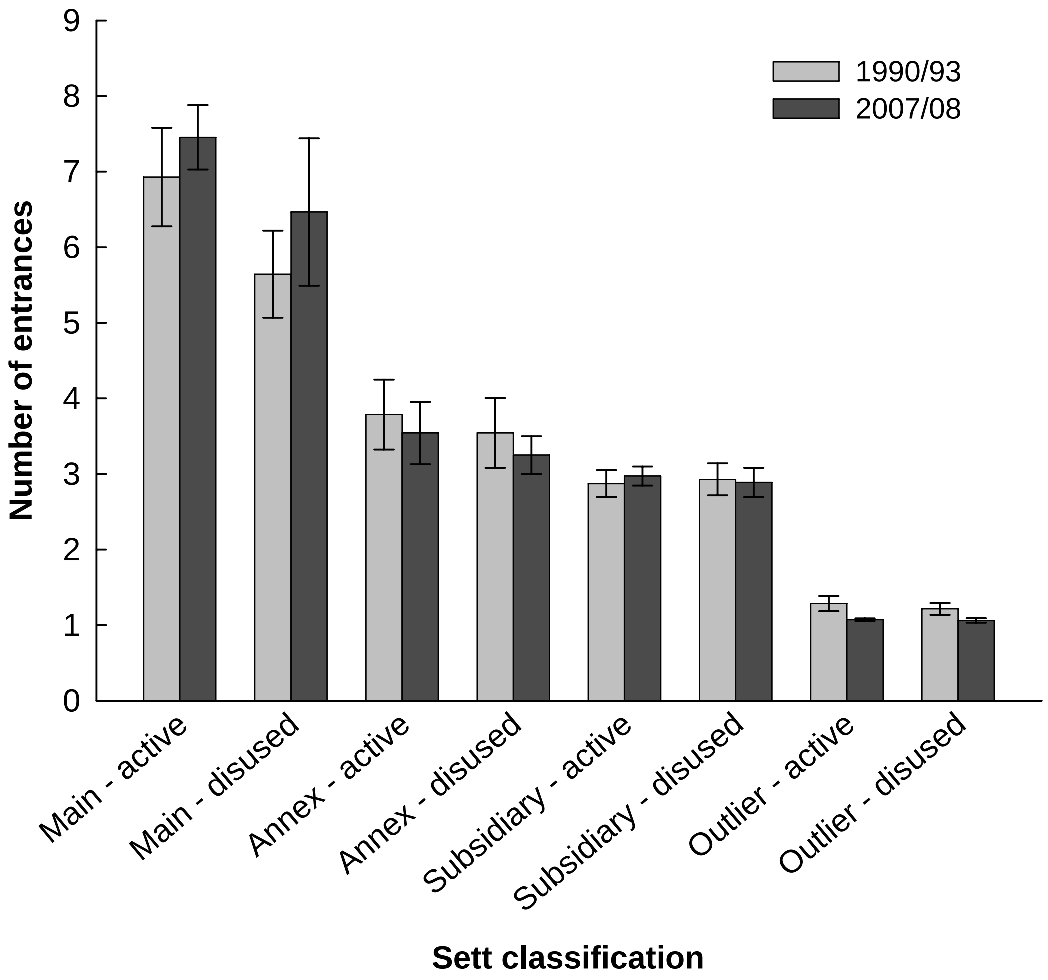


Fig. 4 *The number of entrances (mean ± standard error) for different types of badger setts during 1990/93 and 2007/08.*

Table 4 *Modal main sett activity, as defined by the number of well-used, partially-used and disused holes, compared between 1990/93 and 2007/08.*

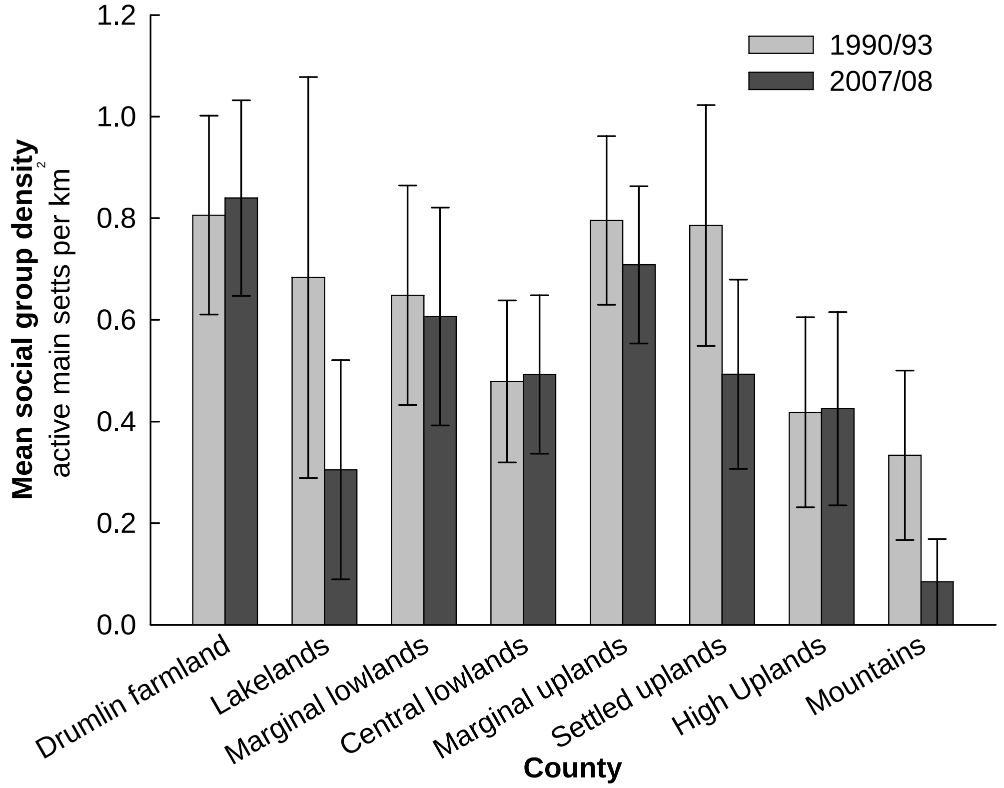
Sett classification	Number of entrances							
	1990/93 (Feore, 1994)				**2007/08** (current study)			
	Well-used	Partially-used	Disused	**Total**	Well-used	Partially-used	Disused	**Total**
Main	4	1	2	**7**	4	2	1	**7**
Annex	2	1	1	**4**	2	1	1	**4**
Subsidiary	1	1	1	**3**	1	1	1	**3**
Outlier	0	1	0	**1**	0	1	0	**1**

group 8 (Mountains) the lowest (Fig. 5a). Social group density also varied significantly among counties ($F_{5,244}$= 2.30, p=0.042). Down had the highest mean social group density and Londonderry the lowest (Fig. 5b). Neither the interaction between Survey*Landclass group or Survey*County contributed significantly to variance in badger density, indicating that patterns of variation among landclass groups and county had not changed between the surveys.

Employing a multiplicative model directly comparable to that used by Feore (1994), the total number of badger social groups in Northern Ireland during 2007/08 was estimated at 7,500 (95%CI 5,900-9,300). The 95% confidence limits for the estimated number of badger social groups during 1990/93 and 2007/08 overlapped substantially indicating that there had been no significant change since 1990/93 (Table 5). Estimates of social group abundance were similar when derived from landclass groups or counties, however, because the survey was designed according to landscape, the precision of estimates derived from landclass groups were better (compare Tables 5 & 6).

In the absence of primary data, which were outside the scope of this project and could not have been collected within the prescribed time period, the number of badgers per social group (social group size) was assumed to be the same as that determined by Feore (1994) for areas sharing similar habitat types; landclass group 1 (Drumlin farmland) = 6.05 badgers per km^2 (95%CI 5.10-7.00), landclass group 2-5 (Lakelands to Marginal uplands) = 4.27 (95%CI 3.65-4.89) and landclass group 6-8 (Settled uplands to Mountains) = 3.00 (95%CI 2.20-3.80) badgers per social group (Table 1). Not withstanding probable sources of error, the highest density of badgers during 2007/08 was estimated for landclass group 1 (Drumlin farmland) at 5.08 (95%CI 2.36-8.52) badgers per km^2 compared to the lowest for landclass group 8 (Mountain) at 0.25 (95%CI 0.00-0.95) badgers per km^2 (Table 5). During 2007/08, the highest density of badgers was estimated for County Down at 3.79 (95%CI 1.83-5.75) badgers per km^2 and the lowest for county Antrim at 1.97 (95%CI 1.52-2.42) badgers per km^2 (Table 6).

(a)



(b)

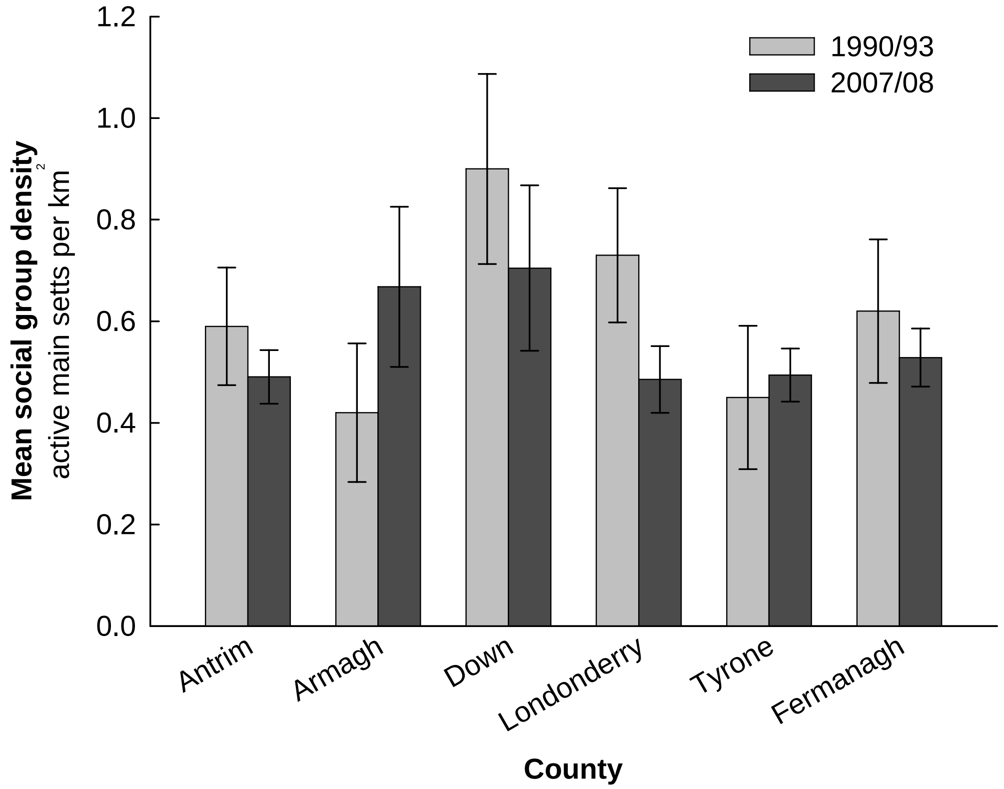


Fig. 5 *Mean social group density, taken as the number of active main setts per km ± standard errors for* **(a)** *each landclass group and* **(b)** *each county within Northern Ireland during 1990/93and 2007/08.*

Table 5 *Estimated density and abundance of badgers within each landclass group in Northern Ireland during 1990/93 and 2007/08. Mean social group size was estimated within each landclass group (see Table 1). Numbers of social groups and badgers are given to the nearest hundred.*

Landclass group	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)
1990/93 survey *(Extracted from Feore, 1994)*							
1. Drumlin farmland	2,350 (17%)	22 (17%)	0.81 (0.42 - 1.20)	1,900 (1,000 - 2,800)	6.05 (5.10 - 7.00)	4.88 (2.51 - 7.24)	11,500 (5,900 - 17,000)
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)	1,700 (0 - 3,700)
3. Marginal lowlands	1,591 (12%)	14 (11%)	0.65 (0.22 - 1.08)	1,000 (300 - 1,700)	4.27 (3.65 - 4.89)	2.77 (0.92 - 4.62)	4,400 (1,500 - 7,300)
4. Central lowlands	2,080 (15%)	19 (15%)	0.48 (0.16 - 0.80)	1,000 (300 - 1,700)	4.27 (3.65 - 4.89)	2.04 (0.68 - 3.41)	4,300 (1,400 - 7,100)
5. Marginal uplands	2,462 (18%)	30 (23%)	0.80 (0.46 - 1.13)	2,000 (1,100 - 2,800)	4.27 (3.65 - 4.89)	3.40 (1.98 - 4.82)	8,400 (4,900 - 11,900)
6. Settled uplands	1,891 (14%)	14 (11%)	0.79 (0.31 - 1.26)	1,500 (600 - 2,400)	3.00 (2.20 - 3.80)	2.36 (0.94 - 3.78)	4,500 (1,800 - 7,100)
7. High Uplands	1,454 (11%)	12 (9%)	0.42 (0.04 - 0.79)	600 (100 - 1,200)	3.00 (2.20 - 3.80)	1.25 (0.13 - 2.38)	1,800 (200 - 3,500)
8. Mountains	1,127 (8%)	12 (9%)	0.33 (0.00 - 0.67)	400 (0 - 800)	3.00 (2.20 - 3.80)	1.00 (0.00 - 2.00)	1,100 (0 - 2,300)
TOTAL/MEAN	13,544 (100%)	129 (100%)	**0.64 (0.52 - 0.76)**	**8,800 (6,800 - 10,700)**	**4.16 (3.42 - 4.90)**	**2.78 (2.14 - 3.42)**	**37,600 (29,000 - 46,300)**
2007/08 survey – *140 samples (systematic only)*							
1. Drumlin farmland	2,350 (17%)	25 (18%)	0.84 (0.46 - 1.22)	2,000 (1,100 - 2,900)	6.05 (5.10 - 7.00)	5.08 (2.36 - 8.52)	11,900 (5,500 - 20,000)
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 - 2,100)
3. Marginal lowlands	1,591 (12%)	14 (10%)	0.61 (0.19 - 1.03)	1,000 (300 - 1,600)	4.27 (3.65 - 4.89)	2.59 (0.68 - 5.02)	4,100 (1,100 - 8,000)
4. Central lowlands	2,080 (15%)	21 (15%)	0.49 (0.19 - 0.80)	1,000 (400 - 1,700)	4.27 (3.65 - 4.89)	2.10 (0.68 - 3.90)	4,400 (1,400 - 8,100)
5. Marginal uplands	2,462 (18%)	33 (24%)	0.71 (0.41 - 1.01)	1,700 (1,000 - 2,500)	4.27 (3.65 - 4.89)	3.02 (1.48 - 4.94)	7,400 (3,600 - 12,200)
6. Settled uplands	1,891 (14%)	15 (11%)	0.49 (0.13 - 0.86)	900 (200 - 1,600)	3.00 (2.20 - 3.80)	1.48 (0.28 - 3.26)	2,800 (500 - 6,200)
7. High Uplands	1,454 (11%)	13 (9%)	0.43 (0.05 - 0.80)	600 (100 - 1,200)	3.00 (2.20 - 3.80)	1.28 (0.12 - 3.03)	1,900 (200 - 4,400)
8. Mountains	1,127 (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 - 1,100)
TOTAL/MEAN	13,544 (100%)	140 (100%)	**0.56 (0.43 - 0.69)**	**7,500 (5,900 – 9,300)**	**4.16 (3.42 - 4.90)**	**2.48 (1.92 - 3.04)**	**33,500 (26,000 - 41,200)**
2007/08 survey – *212 samples (140 systematic plus 72 focal)*							
1. Drumlin farmland	2,350 (17%)	49 (23%)	0.85 (0.59 - 1.12)	2,000 (1,400 - 2,600)	6.05 (5.10 - 7.00)	5.17 (2.99 - 7.86)	12,100 (7,000 - 18,500)
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 - 2,100)
3. Marginal lowlands	1,591 (12%)	14 (7%)	0.61 (0.19 - 1.03)	1,000 (300 - 1,600)	4.27 (3.65 - 4.89)	2.59 (0.68 - 5.02)	4,100 (1,100 - 8,000)
4. Central lowlands	2,080 (15%)	21 (10%)	0.49 (0.19 - 0.80)	1,000 (400 - 1,700)	4.27 (3.65 - 4.89)	2.10 (0.68 - 3.90)	4,400 (1,400 - 8,100)
5. Marginal uplands	2,462 (18%)	63 (30%)	0.76 (0.54 - 0.98)	1,900 (1,300 - 2,400)	4.27 (3.65 - 4.89)	3.24 (1.95 - 4.81)	8,000 (4,800 - 11,800)
6. Settled uplands	1,891 (14%)	33 (16%)	0.45 (0.21 - 0.68)	800 (400 - 1,300)	3.00 (2.20 - 3.80)	1.34 (0.47 - 2.59)	2,500 (900 - 4,900)
7. High Uplands	1,454 (11%)	13 (6%)	0.43 (0.05 - 0.80)	600 (100 - 1,200)	3.00 (2.20 - 3.80)	1.28 (0.12 - 3.03)	1,900 (200 - 4,400)
8. Mountains	1,127 (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 - 1,100)
TOTAL/MEAN	13,544 (100%)	212 (100%)	**0.56 (0.46 - 0.67)**	**7,600 (6,200 - 9,000)**	**4.16 (3.42 - 4.90)**	**2.51 (1.93 - 3.11)**	**34,100 (26,200 - 42,000)**

Table 6 *Estimated density and abundance of badgers within each county in Northern Ireland during 1990/93 (Feore,1994) and 2007/08. Mean social group size was estimated within each landclass group (see Table 1) before summarising for each county separately. Numbers of social groups and badgers are given to the nearest hundred.*

Landclass group	**Area in NI** Km² (%)	**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)
1990/93 survey *(Extracted from Feore, 1994)*							
Antrim	2,922 (22%)	20 (16%)	0.59 (0.36 - 0.82)	1,700 (1,400 - 2,000)	3.92 (3.83 - 3.98)	2.27 (1.83 - 2.71)	6,600 (5,400 - 7,900)
Armagh	1,253 (9%)	15 (12%)	0.42 (0.15 - 0.69)	900 (500 - 1,300)	5.03 (4.39 - 5.30)	3.65 (1.86 - 5.44)	4,600 (2,300 - 6,800)
Londonderry	2,052 (15%)	14 (11%)	0.73 (0.47 - 0.99)	1,200 (904 - 1,400)	3.90 (3.76 - 3.99)	2.22 (1.66 - 2.78)	4.600 (3.300 - 5,700)
Down	2,430 (18%)	29 (22%)	0.90 (0.53 - 1.27)	1,800 (1,000 - 2,600)	5.19 (4.53 - 5.47)	3.88 (2.01 - 5.74)	9,400 (4,900 - 14,000)
Fermanagh	1,777 (13%)	29 (22%)	0.45 (0.17 - 0.73)	1,200 (900 - 1,400)	4.14 (4.08 - 4.18)	2.68 (2.08 - 3.29)	4,800 (3,700 - 5,800)
Tyrone	3,104 (23%)	22 (17%)	0.62 (0.34 - 0.90)	2,000 (1,600 - 2,500)	3.82 (3.84 - 3.80)	2.48 (1.97 - 3.00)	7,700 (6,100 - 9,300)
TOTAL/MEAN	13,544 (100%)	129 (100%)	**0.64 (0.52 - 0.76)**	**8,800 (6,400 - 11,100)**	**4.30 (4.02 - 4.46)**	**2.78 (1.90 - 3.66)**	**37,700 (25,800 - 49,600)**
2007/08 survey – *140 samples (systematic only)*							
Antrim	2,922 (22%)	30 (21%)	0.49 (0.39 - 0.59)	1,400 (1,100 - 1,700)	4.02 (3.94 - 4.08)	1.97 (1.52 - 2.42)	5,800 (4,500 - 7,100)
Armagh	1,253 (9%)	15 (11%)	0.67 (0.36 - 0.98)	800 (500 - 1,200)	5.28 (4.61 - 5.53)	3.53 (1.66 - 5.40)	4,400 (2,100 - 6,800)
Londonderry	2,052 (15%)	23 (16%)	0.49 (0.36 - 0.61)	1,000 (700 - 1,300)	3.96 (3.84 - 4.04)	1.93 (1.37 - 2.48)	4,000 (2,800 - 5,100)
Down	2,430 (18%)	24 (17%)	0.70 (0.39 - 1.02)	1,700 (900 - 2,500)	5.38 (4.75 - 5.62)	3.79 (1.83 - 5.75)	9,200 (4,400 - 14,000)
Fermanagh	1,777 (13%)	19 (14%)	0.49 (0.39 - 0.60)	900 (700 - 1,100)	4.17 (4.13 - 4.20)	2.06 (1.62 - 2.50)	3,700 (2,900 - 4,500)
Tyrone	3,104 (23%)	29 (21%)	0.53 (0.42 - 0.64)	1,600 (1,300 - 2,000)	3.93 (3.90 - 3.95)	2.08 (1.63 - 2.53)	6,400 (5,000 - 7,800)
TOTAL/MEAN	13,544 (100%)	140 (100%)	**0.55 (0.39 - 0.72)**	**7,500 (5,200 - 9,800)**	**4.46 (4.14 - 4.63)**	**2.47 (1.60 - 3.34)**	**33,700 (21,500 - 45,500)**
2007/08 survey – *212 samples (140 systematic plus 72 focal)*							
Antrim	2,922 (22%)	39 (18%)	0.50 (0.39 - 0.60)	1,400 (1,100 - 1,800)	4.04 (3.95 - 4.09)	2.00 (1.53 - 2.47)	5,800 (4,500 - 7,200)
Armagh	1,253 (9%)	25 (12%)	0.67 (0.35 - 0.98)	800 (400 - 1,200)	5.33 (4.66 - 5.66)	3.55 (1.64 - 5.45)	4,500 (2,000 - 6,900)
Londonderry	2,052 (15%)	32 (15%)	0.50 (0.36 - 0.63)	1,000 (700 - 1,300)	3.98 (3.85 - 4.05)	1.97 (1.39 - 2.55)	4,000 (2,800 - 5,200)
Down	2,430 (18%)	47 (22%)	0.71 (0.39 - 1.04)	1,700 (900 - 2,500)	5.39 (4.77 - 5.63)	3.85 (1.85 - 5.84)	9,400 (4,500 - 14,200)
Fermanagh	1,777 (13%)	25 (12%)	0.50 (0.39 - 0.61)	900 (700 - 1,100)	4.18 (4.14 - 4.21)	2.11 (1.64 - 2.59)	3,800 (2,900 - 4,600)
Tyrone	3,104 (23%)	44 (21%)	0.53 (0.41 - 0.64)	1,600 (1,300 - 2,000)	3.96 (3.92 - 3.99)	2.09 (1.62 - 2.56)	6,500 (5,000 - 8,000)
TOTAL/MEAN	13,544 (100%)	212 (100%)	**0.56 (0.39 - 0.73)**	**7,600 (5,200 - 10,000)**	**4.48 (4.16 - 4.65)**	**2.51 (1.61 - 3.40)**	**34,000 (21,800 - 46,100)**

During 2007/08 the total abundance of badgers in Northern Ireland was estimated to be 33,500 (95%CI 26,000-41,200). The 95% confidence limits for the estimated total abundance of badgers during 1990/93 and 2007/08 overlapped substantially indicating that, notwithstanding variation in social group size, there had been no significant overall change in badger abundance since 1990/93 (Table 5).

The 95% confidence intervals for the estimated density and abundance of social groups in landclass groups 1, 5 and 6 were improved substantially (by between 26-33%) with additional focal sampling (Table 5). Consequently, the accuracy of the overall estimate of the mean density and total number of social groups in Northern Ireland during 2007/08 was substantially increased due to a reduction in the width of the 95% confidence interval by 22% (Fig. 6). However, due to uncertainty in the estimates of social group size this improvement in accuracy was lost when estimating the mean density or total abundance of badgers (Fig. 6).

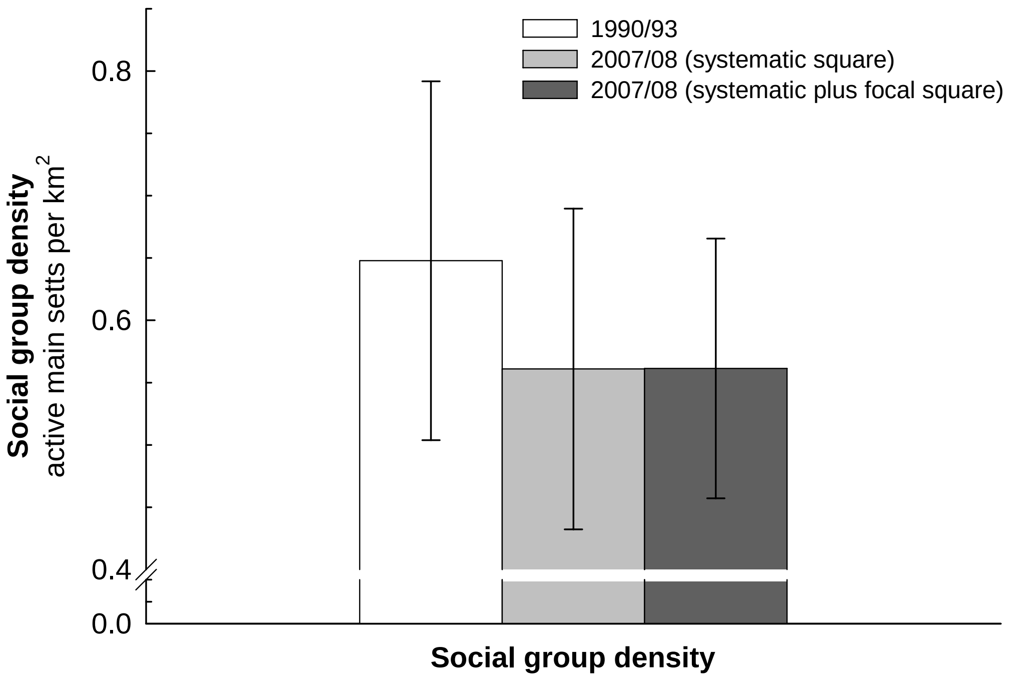
Spatial autocorrelation

Accounting for similarity in habitat, the distance between paired focal squares (1-5km) did not influence either badger sett incidence or social group density significantly during 2007/08 (Table 7). Only variation in the area of potential forage, taken as the area of improved grassland affected the similarity or difference of badger incidence between paired squares (Table 7). During 2007/08, badger social group density in landclass group 6 (Settled uplands) was substantially lower than that in landclass groups 1 (Drumlin farmland) and 5 (Marginal uplands). Therefore, paired sample squares within landclass group 6 were excluded from spatial autocorrelation analysis.

Biogeographical population model

A large number of landscape variables were associated with badger sett occurrence, some at varying spatial scales (Table 8). Setts were negatively associated with elevation and positively associated with slope, aspect (northness and eastness), soil sand content, the area of cover and the area of improved grassland and arable agriculture within 300m. Whilst not significant at $p<0.05$ the area of arable agriculture within 100m of the sett was retained in the top model suggesting it may account for a limited amount of variation.

(a)



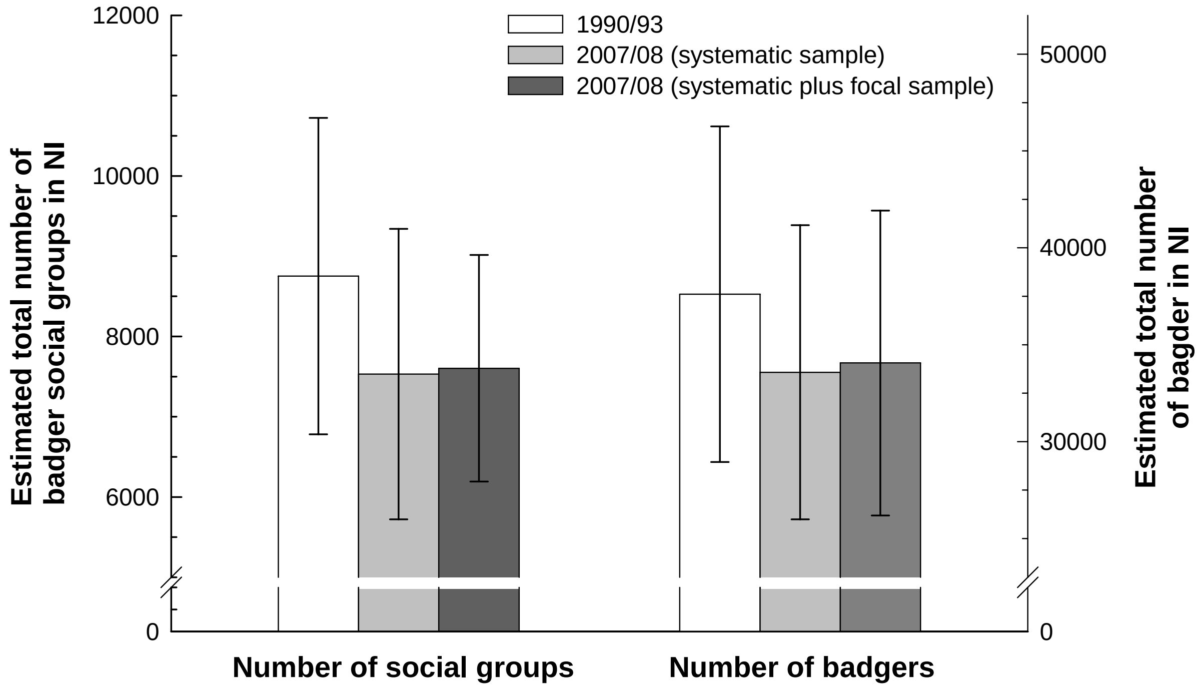


Fig. 6 *Estimates of* **(a)** *badger social group density and* **(b)** *total abundance of socials groups and badgers ± 95% confidence limits during 1990/93 and 2007/08 (using the systematic sample only i.e. 140 squares and systematic and focal samples combined i.e. 212 squares). Note the reduction in the 95% confidence interval for the estimate of social group density and abundance during 2007/08 with additional focal sampling.*

Table 7 *Variables associated with similarity in badger incidence and social group density between paired sample squares that were matched within landclass groups 1 and 5 (Drumlin farmland and Marginal uplands), n=49. Note that distance between paired squares was not retained in either model.*

Inclusion in model	Explanatory variables	Variable fit		Model fit		
		$F_{d.f.}$	p	$F_{d.f.}$	p	Pseudo-R^2 / R^2
Differenced badger sett presence (binomial logit GLM)						
+	Improved grassland	$4.63_{1,43}$	0.031	$3.75_{2,43}$	0.023	0.34
+	Open dwarf scrub heath	$2.87_{1,43}$	0.090			
-	Hilliness Index	$0.98_{1,31}$	0.323			
-	Distance between squares	$0.95_{4,31}$	0.434			
-	Mean altitude	$0.85_{1,31}$	0.356			
-	Arable	$0.52_{1,31}$	0.469			
-	Broad-leaved woodland	$0.42_{1,31}$	0.518			
-	Dense dwarf scrub heath	$0.35_{1,31}$	0.552			
-	Hedgerow density	$0.32_{1,31}$	0.569			
-	Coniferous woodland	$0.15_{1,31}$	0.700			
-	Soil sand content	$0.02_{1,31}$	0.882			
Differenced badger social group density (normal identity GLM)						
+	Soil sand content	$3.06_{1,42}$	0.088	$2.19_{3,42}$	0.103	0.07
+	Dense dwarf scrub heath	$1.95_{1,42}$	0.170			
+	Open dwarf scrub heath	$1.57_{1,42}$	0.218			
-	Distance between squares	$0.51_{4,31}$	0.729			
-	Hedgerow density	$0.36_{1,31}$	0.551			
-	Arable	$0.29_{1,31}$	0.594			
-	Broad-leaved woodland	$0.10_{1,31}$	0.754			
-	Hilliness Index	$0.07_{1,31}$	0.789			
-	Coniferous woodland	$0.02_{1,31}$	0.881			
-	Mean altitude	$0.02_{1,31}$	0.881			
-	Improved grassland	$<0.01_{1,31}$	0.982			

Table 8 *Landscape variables associated with badger main sett presence at varying spatial scales as determined by logistic regression analysis.*

Landscape variable	$\beta \pm$ SE	t	p
Slope	0.147 ± 0.027	5.37	<0.001
Improved grassland within 300m	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 within 300m	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 within 100m	-0.368 ± 0.299	-1.61	0.108

The regression coefficients shown in Table 8 were incorporated into the resource selection function formula shown in Equation 5 to obtain a relative measure of landscape suitability for badger setts. Suitability was categorised into 10 quantiles of equal width representing an ordinal scale of increasing suitability from 1 to 10. Suitability derived from the systematic sample exhibited a strong positive relationship with observations from the independent focal sample (r_s= 0.81, p<0.01, Fig. 7) suggesting that the biogeographical model was a good representation of landscape favourability for badgers. The resolution of spatial modelling was substantially increased from the landclass group scale using the multiplicative model, to a 25m scale using the biogeographical model (Fig. 8).

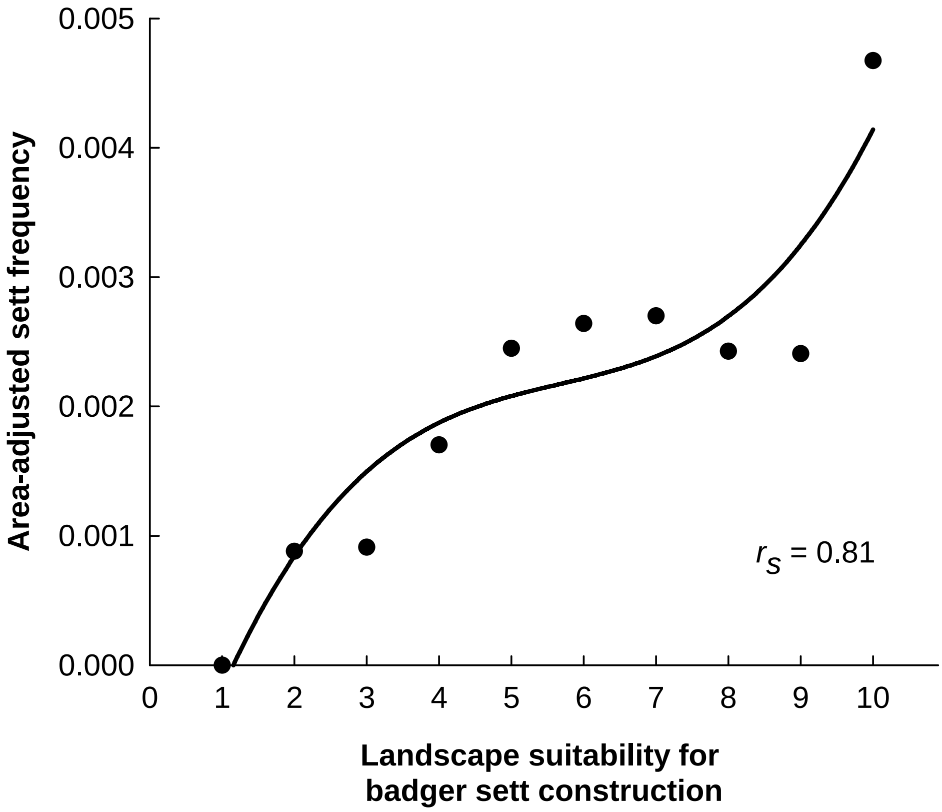
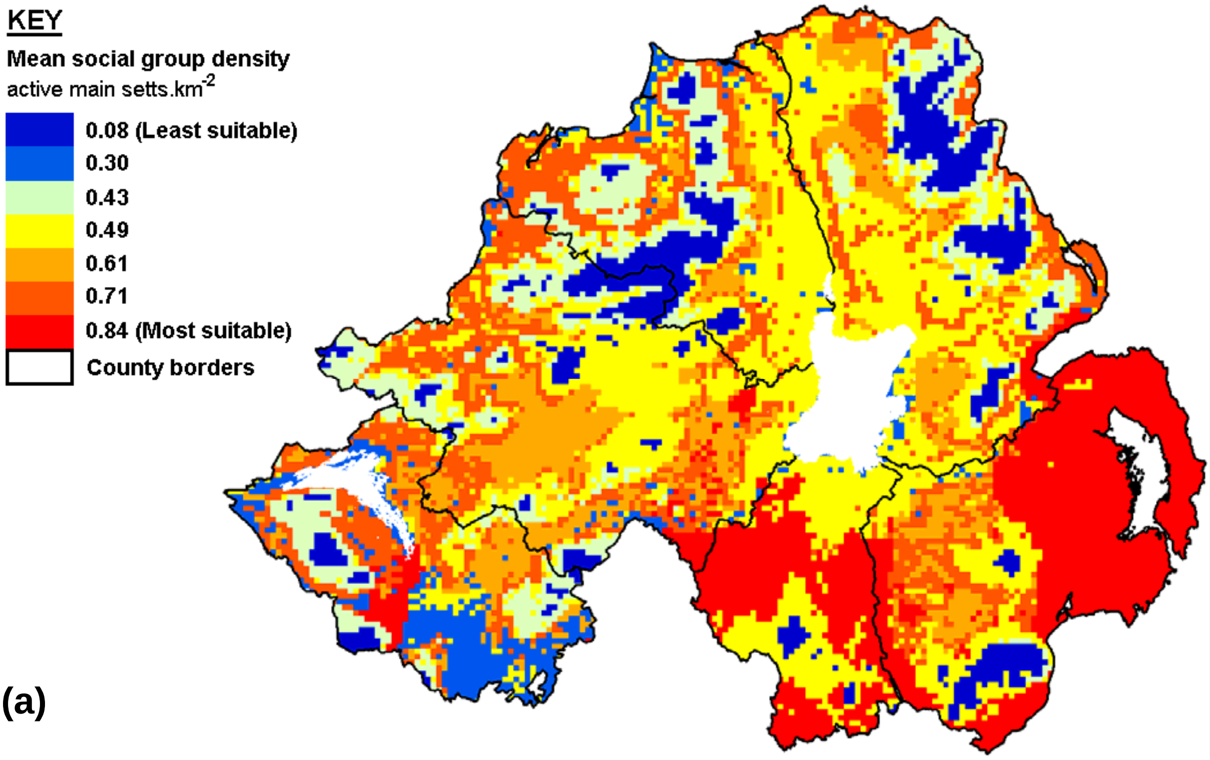
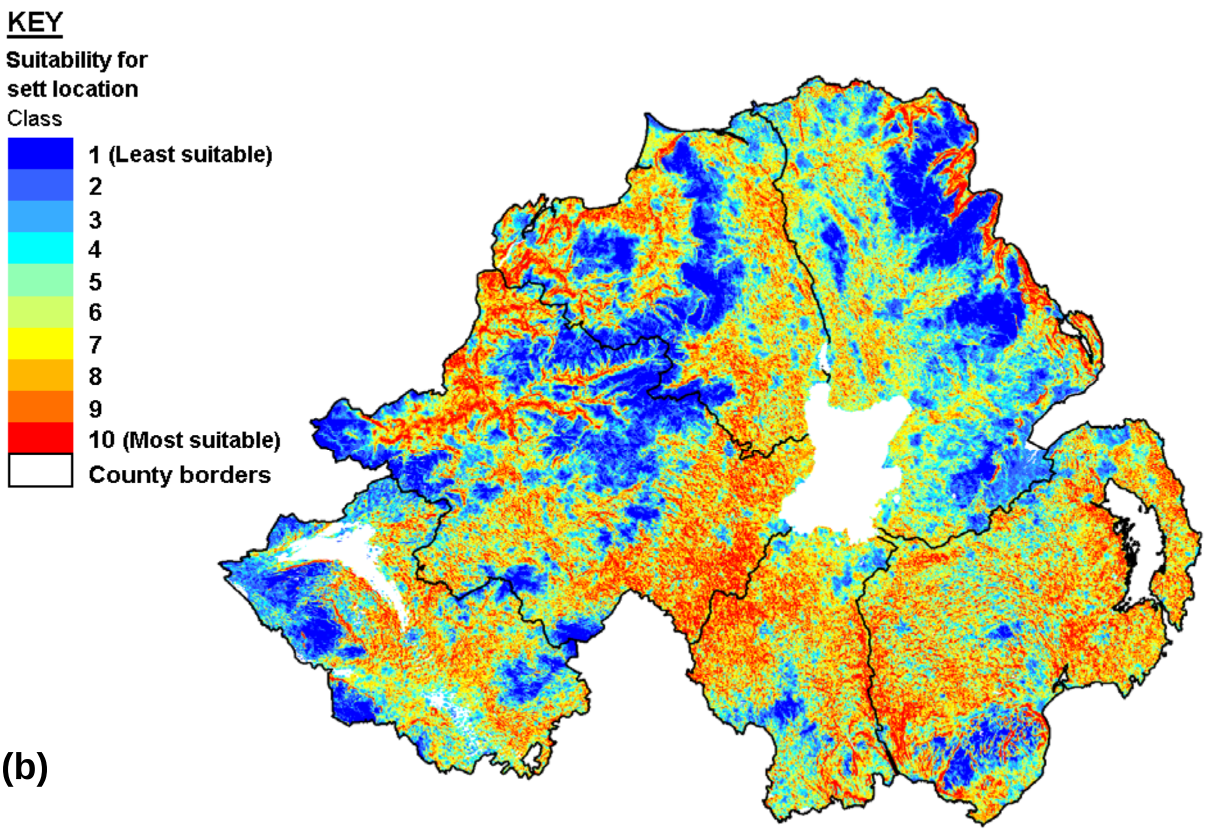


Fig. 7 *Relationship between landscape suitability for badger set presence, derived from the systematic sample, and sett frequency observed in the focal sample.*



(a)



(b)

Fig. 8 **(a)** *Spatial model of mean badger social group density across Northern Ireland on the landclass group scale (from the multiplicative model) compared to* **(b)** *Landscape favourability for badger presence on a 25m scale (from the biogeographical model).*

Discussion

Sett surveys and simple multiplicative models of factors affecting population size are well-established approaches to estimating badger populations (Cresswell, Harris & Jefferies, 1990; Feore, 1994, Smal, 1994; Wilson, Harris & McLaren, 1997). Deployment of standardised survey and analytical techniques provides an effective means by which to assess temporal changes in population size. Relatively recent advances in computing power, geographical information systems (GIS) and statistical software make it possible to build biologically realistic models that were unavailable just a few years ago. The current study has successfully combined both approaches; we provide an assessment of the current status of badgers in Northern Ireland relative to their status in 1990/93, an increased confidence in contemporary estimates by reduction of confidence intervals for population estimates in those areas where badgers were most prevalent and a spatial model of landscape favourability for badgers at a finer scale than previously available.

The observation that the badger population of Northern Ireland, defined by the estimated number of social groups and abundance of individual badgers, has not changed significantly since 1990/93 is consistent with that made by Sadlier & Montgomery (2004) who found that locally numbers of badger setts and social groups did not change between 1990/93 and 1997/98.

One major difficulty in attempting to estimate badger population size based on sett surveys is that the abundance of individuals can change independent of the number of social groups. Estimation of badger social group size was not part of this project, and could not have been undertaken within the time frame identified in the project specification. Nevertheless, most conservation and management options for badgers will be 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 25 years (Rogers *et al*. 1997). During that time the number of social groups within the park boundaries has remained more or less constant at around 22 groups.

However, the total population of badgers increased 3 fold from 1982 to 1999 followed by a 44% decrease from 1999 to 2006 (Fig. 9). Only 25% of the variation in the abundance of badgers within the park is attributable to changes in the number of social groups. 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. This is because estimation of social group abundance makes only one major assumption; that the sample taken is representative of the landscape in terms of habitat (landclass group) and geographic region.

We are therefore, confident that the number of badger social groups and their distribution and patterns of habitat association have not changed significantly in Northern Ireland between 1990/93 and 2007/08.

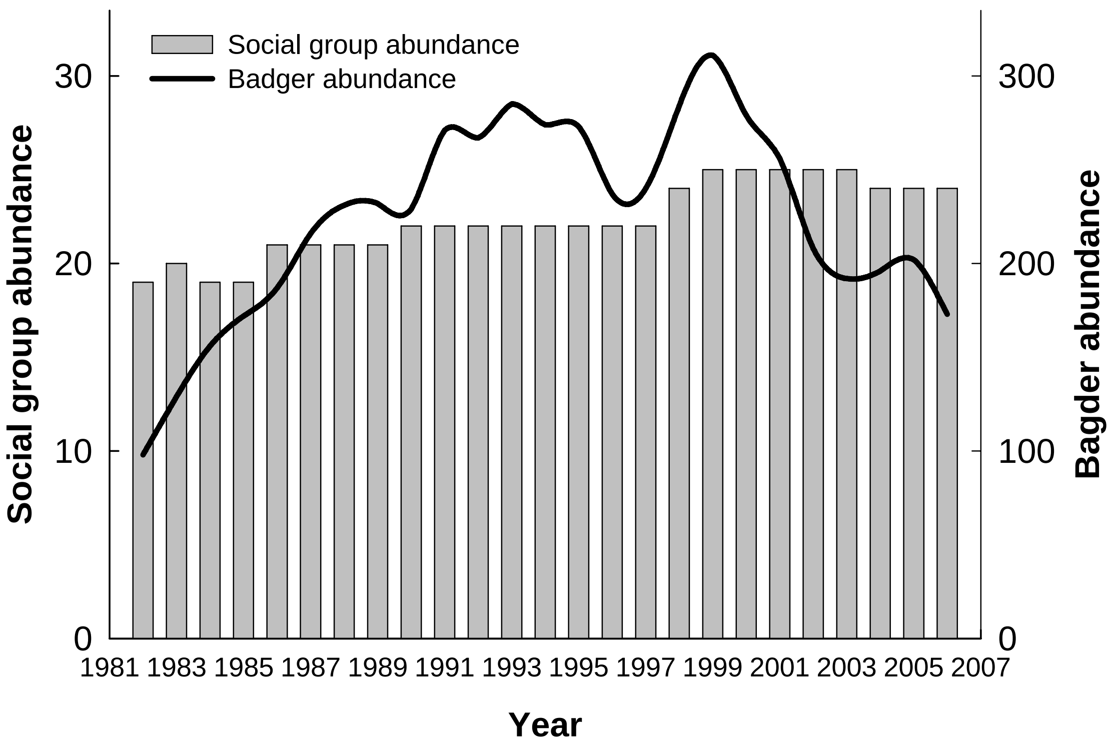


Fig. 9 *Changes in the numbers badger social groups relative to the total population of badgers at Woodchester Park, England from 1982 to 2006.*

There was no evidence that spatial autocorrelation influenced badger incidence or social group density at the spatial scales examined. It may be that potential spatial autocorrelation driven by sociality at the individual level is negated by exclusion of individuals from suitable habitat space because of intra- and inter-social group competition, specifically for territorial space. The area of improved grassland was the only variable to significantly affect similarity in badger incidence between paired focal squares. Badgers forage primarily for earthworms (Harris & Yalden, 2008) and the abundance of badgers and earthworms have been shown to be positively correlated (Muldowney *et al*. 2004). Earthworms are generally more abundant and larger in areas of high productivity grassland (Edwards & Lofty, 1982; Hansen & Engelstad, 1999: Muldowney *et al*. 2004) and it, therefore, seems likely that the area of improved grassland may be important in determining badger incidence.

Within the immediate vicinity of sett locations there was strong preference for sites at low elevation with high slope and a high proportion of sand in the soil. These were largely expected from the published literature (Thornton 1988; Skinner, Skinner & Harris 1991; Roper 1992; Reason, Harris & Cresswell 1993; Macdonald, Mitchelmore & Bacon 1996; Neal & Cheeseman 1996; Wilson, Harris & McLaren 1997; Feore & Montgomery 1999; Wright, Fielding & Wheater 2000; Hammond, McGrath & Martin 2001; Macdonald *et al*. 2004; Jepsen *et al*. 2005; Newton-Cross, White & Harris 2007). High uplands are generally characterised by wet or boggy conditions which make them unsuitable for living underground. Furthermore, it also seems likely that earthworms are less abundant in upland soils due to lower primary productivity and acid conditions. Slopes and sandy soils provide good drainage and increase soil friability (i.e. ease of digging) facilitating sett construction.

Less than 6% of Northern Ireland is wooded (Anon, 2007). Setts are, therefore, almost universally located within field boundary hedgerows, and we suspect that the weak relationship observed between sett presence and the area of available cover was more to do with the difficulty in producing an accurate measure of cover than the ecological response to cover by badgers. Habitat boundaries in the Land Cover Map 2000 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 northerly and 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. 300m. Again, it seems likely that earthworm abundance may be the main driving factor. Setts presence was negatively associated with the area of arable agriculture within 100m perhaps suggesting that location of a sett within an arable field itself may increase the risk of sett disturbance or destruction by land management practices such as ploughing.

Drumlin farmland and Marginal uplands may be associated with slopes, freely draining soils and high productivity agriculture and thus the highest density of badger social groups was recorded within these landclass groups. Counties Armagh and Down had the highest estimated abundance of badger social groups most probably due to the prevalence of suitable landscapes such as Drumlin farmland and Marginal uplands.

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

Future monitoring of the status of the badger population in Northern Ireland would benefit from assessment of the most cost-effective survey design to maximise the likelihood of detecting significant change in the number of social groups, potentially focusing effort on areas of particular management concern. This would comprise an assessment of optimum sample size in each landclass group given various possible effect sizes (i.e. differing expected magnitudes of natural or anthropogenic change). However, given the small changes in social group densities observed here over a 15 year interval, sample sizes for sett surveys that would be required to detect genuine change over the short-term are likely to be very large. If knowledge of badger abundance *per se*, rather than social group abundance, becomes relatively important, or information on shorter-term population change is required, then a range of direct survey techniques, potentially including trapping and/or genotyping badgers, could be employed to derive simultaneous assessments of social group size and social group abundance. However, this is likely to be a labour-intensive venture and outcomes are likely only to be applicable over short time periods.

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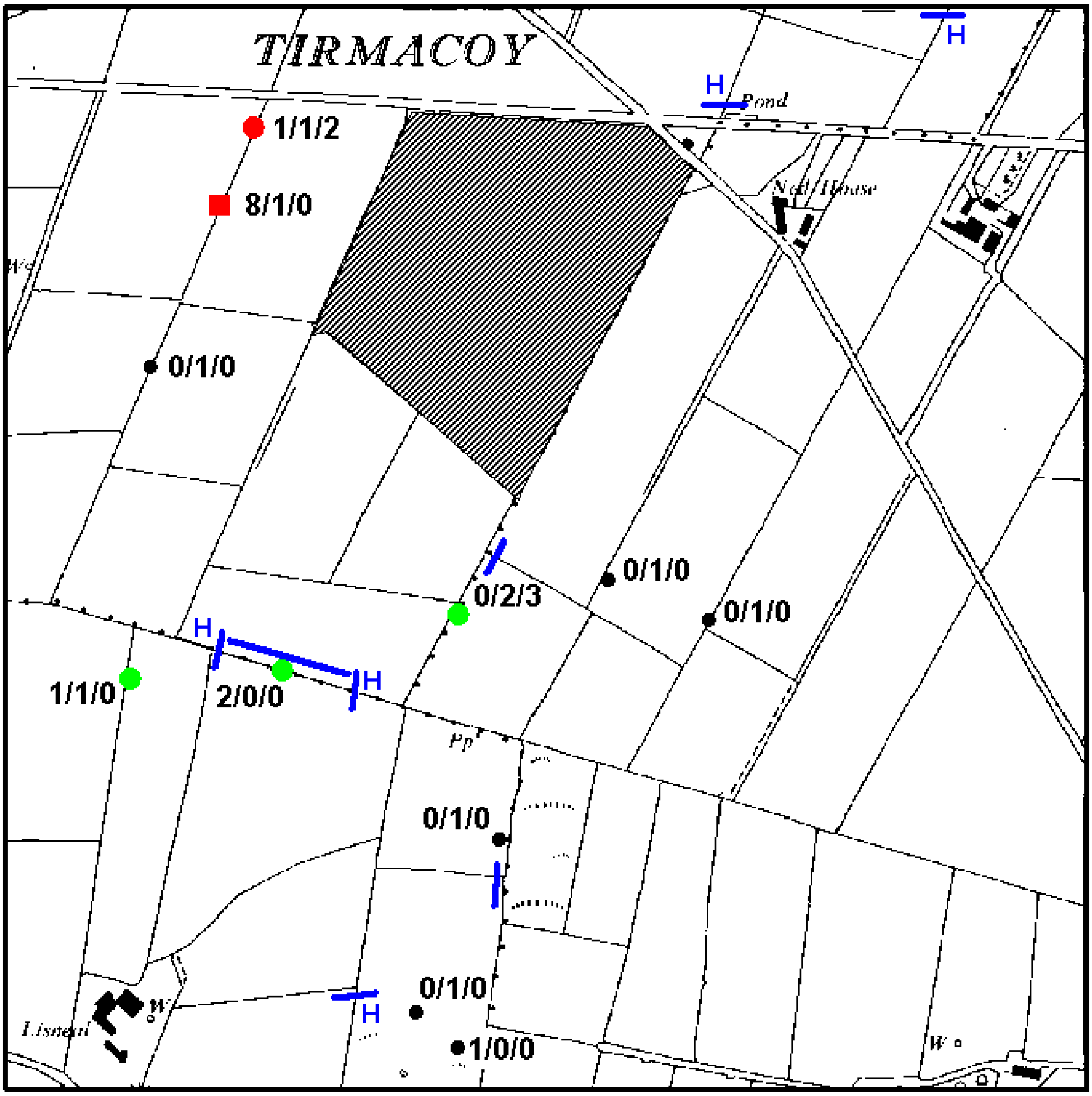
Appendix 1

An example of a survey square (C6020) showing sett classification, activity and distribution. Activity is indicated by the number of well-used/partially-used/disused holes. For example 8/1/0 equals 8 well-used/1 partially-used and 0 disused holes.



KEY

Sett classification

- Main sett
- Annex sett
- Subsidiary sett
- Outlying sett
- Badger runs
- H Hair caught on wire
- Restricted access