Badger, *Meles meles*

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Brief description of the species/group of species: basic ecology and its relevance from an epidemiological perspective

The European badger (*Meles meles*) is a member of the Family Mustelidae. It is a medium-sized omnivorous species that exhibits both crepuscular and nocturnal habits (Neal and Cheeseman 1996). Formerly, the species´ distribution ranges from Western Europe, across Eurasia (as far south as Iran) to Japan. However, recent molecular studies suggest that *Meles* contain separate species, with *Meles meles* occurring predominately in Europe, and as far east as the Ural mountains (Del Cerro et al. 2010). From an epidemiological perspective, badgers are reservoirs for *Mycobacterium tuberculosis* complex (mainly *M. bovis* and *M. caprae*, the mycobacteria with more sanitary implications) bacteria in United Kingdom and Republic of Ireland (Bourne et al. 2007; Murphy et al. 2010), and they are recently increasing their importance in different countries of continental Europe, e.g. Spain and France (Balseiro et al. 2013; Payne et al. 2013).

Recommended method(s) for most accurate population estimation

The gold standard method to estimate the population density of badgers is the capture-mark–recapture method mainly using live trapping but also genetic (non-invasive) profiles (Rogers et al. 1997; Tuyttens et al. 1999a; Delahay et al. 2000; Tuyttens 2000; Frantz et al. 2003). Capture-recapture methods based on genetic profiles were used recently in the UK during free-shooting badger culling trials (two sites; ~150km^2 each) to assess population sizes prior to intervention (AVHLA 2014). Capture-recapture is reliable if the underlying assumptions are valid, if variations in capture probability are adequately controlled, and if an adequate proportion of the badgers is trapped over a sufficient number of trapping occasions. However, it is expensive and labour-intensive, potentially disturbing to the badger population. Thus, this method is impracticable at large spatial scales and it is mainly used on intensively studied populations for research interests.

Mini-review of methods applied in Europe

3.1- General reviews

Several direct and indirect methods have been used in different environments. Mostly studies on badgers monitoring have been carried out in United Kingdom and the Republic of Ireland. For a revision on methods for monitoring badger populations see Sadlier et al. (2004); see also Byrne et al. (2012) for a complete revision on the species.

3.2- Direct methods (i.e. based on the direct observation of animals)

3.2.1. Total count of badgers

Total counts of badgers are impractical on a large scale because of the animal’s nocturnal and elusive lifestyle and because of the difficulty of visually identifying individuals within a population. Counting the number of badgers as they emerge from their setts significantly underestimates population size, and the degree of this error is likely to differ according to season, the field skills of the observer and the shyness of the badger population concerned (Macdonald et al. 1998).

3.2.2. Live-trapping

Live-trapping of badgers is useful to determine the mean size of the social groups in a given population. Mean social group in a population could be used itself as a badger abundance index but has still to be calibrated. This index will produce precise estimations of badger abundance if variations in capture probability (e.g. season) are adequately controlled, and an adequate proportion of the badgers are trapped over a sufficient number of trapping occasions. However, live trapping of badgers is expensive, labour-intensive, potentially disturbing to the badger population, and is illegal in many countries without a special permit. Thus, its applicability at large spatial scales is scarce considering the time-budget cost in relation to information provided, but this can be combined with a indirect measure (e.g. counting setts) to expand its possibilities to work at large spatial scale (e.g. Byrne et al. 2014).

3.2.3. Line transects and distance sampling

Distance sampling is a common and increasingly used method for estimating badger density (Hounsome et al. 2005; Parrot et al. 2012). Spotlight line transects and distance sampling were used to estimate regional population densities in south-west England and Wales (Parrot et al. 2012). Owing to the impractical/inefficient nature of spotlighting in closed habitats, this method on badgers is usually conducted in open habitat (stratified), almost exclusively pasturelands. Spotlight counts have, therefore, a strong limitation for monitoring badgers occurring in closed habitats (e.g. woodlands). Distance sampling produces precise estimates of badger density in open areas of medium to high density, being not recommended for low density populations due to method requirements on the number of observations.

3.2.4. Kilometric abundance indices

From a similar sampling design than distance sampling requires, kilometric abundance indices (number of badger seen per km) can be used to estimate badger population abundance (Sobrino et al. 2009). This method is easier than distance sampling since no data of the distance from the animal to the transect should be registered, and processing field data to estimate the abundance index do not demand on strong knowledge in statistics. Thus, kilometric abundance indices were one of the principal choices for monitoring wildlife, in general, at large spatial scales, especially mammals. However, working with kilometric indices the habitat detectability is not taken into account and, therefore, comparisons among values obtained for (environmental) different populations should be cautiously considered.

3.3- Indirect methods (i.e. based on the detection of presence signs, but not animals)

3.3.1- Transects for setts detection

Walked transects have been used in different studies to estimate the abundance of badgers based on the detection of setts (Harris et al. 1989; Rainey et al. 2009; Acevedo et al. 2014). Setts, and other signs of badger activity, can be detected more easily than badger's themselves. In addition, badger setts may be considered "active" or "inactive" depending on whether there is evidence of badgers frequenting the sett. Typically the following field signs are used in combination to assess activity: worn badger paths ("runs"), claw marks on trees, dung pits (fresh latrines), mounds of earth outside the entrances to setts (fresh spoil), remains of bedding material, and coarse, wiry badger hair. Estimations of badger population abundance in the United Kingdom (UK) and the Republic of Ireland (ROI) are usually based on surveys determining numbers of setts (Smal 1995; Judge et al. 2014; Byrne et al. 2014), especially enumerating "main" setts (main setts are large burrow systems which are in most active use and often the location of breeding within a social group; e.g. Byrne et al. 2012a). Therefore, sett surveys often rely on the differentiation of main setts from the other types of setts (annexe, subsidiary and outlier; *sensu* Wilson et al. 1997), and allow to determine the density of sett types in a target locality. Density of setts (total sett, i.e. considering all types of setts) can also be directly used as a badger abundance index (Lara-Romero et al. 2012), but for comparisons between populations social group size is needed. In addition, badger density can be derived as the density of main setts multiplied by the average size of badger social groups which should be estimated from different ways: trapping (or camera trapping) or appropriate genetic sampling studies (Frantz et al. 2004). For the estimation of badger density from the density of main setts, an assumption is that there is one main sett per social group, and surveyors should be able to find, and classify correctly, all main setts in an area (Tuyttens et al. 2000), that is not a trivial task but a limitation of this method. Methods based on setts are useful for monitoring badger populations at large spatial scales with adequate sampling effort. In low density populations, where the main setts are scarce and trapping badgers is very costly, the use of the total number of setts is advantageous over the estimation of badger density. In contrast, in medium-high density badger populations, the density of main setts can be determined and transformed into badger density provided that estimation of social group size can be estimated or data are available in literature for proximal badger populations.

3.3.2- Faecal counts-latrines

As badgers defecate in characteristic ‘latrines’, or clusters of dung pits, their excreta are not only easily distinguished from other species but are also relatively easy to found mainly those close to setts and in high density populations. In south-west England simple indices as latrines/km^{-1} on transects following linear features (habitat boundaries, roads, tracks, fences, hedges and so on) were strongly correlated with badger density (Tuyttens et al. 2001), providing evidence about the usefulness of this method to monitoring badger population abundance. Other researchers have also found associations between latrine presence and metrics of badger relative abundance (Wilson et al. 2003; Woodroffe et al. 2008; Byrne et al. 2013), with varying strengths, and consistency, of association. However, further research would be needed in order to explore the relationships between the latrine-use measures and the badger density on a broader set of habitats and badger populations (especially outside of ROI and UK). The use of latrines has a great promise to be use for estimating badger population abundance, and it is potentially useful for large-scale monitoring and on a wide range of badger population densities.

3.4- Others (i.e. include other relevant method – direct or indirect – applied or susceptible to be applied on the target species)

Statistical modelling is another way to estimate badger population abundance for a given territory from a number of sample localities (Reid et al. 2012; Byrne et al. 2014; Acevedo et al. 2014). By inductive and deductive procedures, the key environmental factors regulating badger population abundance can be determined, and accordingly predictions of badger abundance on unsurveyed localities can be produced. After modelling, predictions should be validated with independent datasets since there are several factors modulating badger population abundance at local scale that can be not accounted from the sample localities (Byrne et al., 2014). In the context of epidemiological studies of bovine tuberculosis, the distribution of badger abundance in Northern Ireland (Reid et al. 2012), Republic of Ireland (Byrne et al. 2014) and England and Wales (Etherington et al. 2009) were modelled. Recently, some UK spatial models (NI, England and Wales) were generalized in order to predict badger abundance in Atlantic Spain (Acevedo et al. 2014). Finally, using data on observations along roads, a model was recently developed to estimate the relative density of badgers in France (Calenge et al., in press).

APHAEA protocol (for harmonization at large scale)

Ranking methods in terms of their meaningful contribution (only my opinion), while pragmatism in terms of effort and cost, at a regional (subnational) level for monitoring:

1. Stratified sampling of area wide surveys (perhaps 1km^2) with a random subset of genetic samples to estimate an index of group size, with surveys undertaken periodically to assess change (perhaps every 5 years)

2. A defined transect measuring multiple indices of relative abundance (latrines, setts, active setts, main setts, non-main setts, signs) – but indices calibrated against a subset of locations where direct estimations of population size are undertaken using a standard method (i.e. either live trapping or non-invasive sampling).

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Tables

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Table 1. Peculiarities of the species that modulate the methods to be used.

Characteristic	Observations
Distribution	Wide distribution in Europe, present in almost all countries (Del Cerro et al. 2010).
Population trends	It is increasing in most European countries (Sobrino et al. 2009; Byrne et al. 2012).
Density range	Badger densities vary widely across habitats, finding large differences in the estimated badger population densities, for example between Britain and Ireland, with reported mean densities of 3.2 badgers/km2 and 1.9 badgers/km2, respectively (Bourne et al. 2007; Sleeman et al. 2009). Local mean densities up to 8.8 animals/km2 occur in Britain (Rogers et al. 1997). In Atlantic Spain density was estimated at 3.8 animals/km2 (Acevedo et al. 2014) In Mediterranean areas badger densities are substantially lower 0.23-0.67 badgers/km2 (Revilla et al. 1999). In central Europe and Scandinavia badger densities are lower, 0.09 animals/km2 in Belarus (Sidorovich et al. 2011), 0.5-1.5 animals/km2 in Denmark (Aaris-Sørensen 1995) and 0.01-0.25 (North) and 2.0-3.0 (South) in Sweden (Seiler et al. 2003)
Main habitat	Generally regarded as lowland animals, preferably living in habitats consisted mainly of deciduous and mixed woodlands, pastoral and agricultural lands, on well-drained soils (Reid et al. 2012).
Introduction-Releases	Reintroduction attempts have occurred in the Netherlands in the 1990s (see Mulder 1996)
Activity rhythms	Badgers are nocturnal, foraging at night and spending light hours hidden in their setts (complex burrow systems; Neal and Cheeseman 1996). On average, badgers emerge from setts at 19:00 hours and return to them at 4:00 hours. They present seasonal and interanual variation in their activity patterns (Noonan et al. 2014). In southern regions they are active year round and do not undergo strong seasonal change of body mass (Revilla et al. 1999). In contrast, in the north with severe winters badgers increase their body mass two fold from Spring and Autumn, and stayed inactive for as long as 6 months per year (Kowalczyk et al. 2003).
Detectability	High detectability, except in winter (Kowalczyk et al. 2003). Signs of badger activity can be seen more easily than the animal itself.
Gregarism	They live in underground burrows, called setts, in social groups usually of 4 to 6 badgers; however there is considerable variation in group sizes (up to ~25 badgers) depending on a number of factors (Byrne et al. 2012; Acevedo et al. 2014). Badgers that form social groups maintain territories which vary in size from <30 hectares where resources are plentiful to >300 hectares in marginal habitats.

Table 2. Classification of the different methods (all cited in this species' review, incl. the recommended method(s) for most accurate results) based on desirable characteristics for monitoring populations from an epidemiological perspective (1- very low, 5-very high).

Method	**Capture-mark–recapture**	**Total counts**	**Distance sampling**	**Kilometric abundance index**	**Sett density – badger density**	**Total setts**	**Faecal counts**	**Statistical modelling**
Abundance / **D**ensity	A/D	A/D	D	A	A/D	A	A	A
Temporal / Spatial trends	T/S	T/S	T/S	T	T/S	T/S	T	S
Info on population structure (**Y/N**)	Y	N	N	N	Y	N	N	N
Precision	5	2	4	3	4	3	3	3
Seasonal independence	3	2	3	3	4	5	4	NA
Visibility independence	5	2	3	2	5	5	5	NA
Effort effectiveness	2	3	2	5	3	5	5	5
Budget effectiveness	2	3	3	5	2	5	5	5
Ease of learning	1	3	2	5	2	5	5	2
Applicable at large scales	2	3	4	4	3	4	4	5
Useful at very low density	3	2	3	4	3	4	3	5
Useful at very high density	5	5	5	5	5	5	5	5