Mammal Rev. 2004, Volume 34, No. 1, 75–98. *Printed in Great Britain*.

Methods of monitoring red foxes *Vulpes vulpes* and badgers *Meles meles*: are field signs the answer?

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ABSTRACT

1. A national monitoring scheme for recording the abundance of foxes and badgers in Britain would have to utilize a technique or techniques that could detect a wide range of animal densities in structurally different habitats. Furthermore, the likely reliance on volunteers for data collection means that these techniques must be easily applied by people with different levles of field expertise.

2. Direct methods that rely on counts of the animals themselves (e.g. capture-mark-recapture, radio-tracking, spotlight counts) are generally unsuitable because of cost, manpower and licensing requirements, are not readily applied to all habitats and cannot easily be used by volunteers. However, density estimates derived from capture-mark-recapture and radio-tracking methods are likely to represent the benchmark against which other estimates of abundance are measured.

3. The number of foxes killed per unit area is currently collated by non-governmental organisations for some patterns of land use, e.g. game estates. No such data are available for badgers, as this species is legally protected in Britain. However, the applicability of hunting statistics for monitoring fox abundance is limited by differences in culling effort, the non-independence of different culling practices applied in the same region, possible future changes in the legal status of different culling methods and changes in the ratio of land where foxes are and are not culled.

4. Indirect methods that rely on counts of the signs of the animals (e.g. droppings, breeding refugia) are less expensive than direct methods, can be applied to the range of habitats found in Britain and can easily be used by volunteers. To date, indirect methods have been utilised to derive estimates of relative animal density or the density of social groups. However, the major factor currently limiting the use of indirect methods is that their relationship with absolute animal density has not been validated. The preliminary results of two projects quantifying the use of field signs as a measure of absolute fox and badger abundance suggest that indirect methods could be applicable for monitoring changes in fox and badger numbers at a national scale.

Keywords: badger, fox, monitoring, sign surveys

INTRODUCTION

Monitoring changes in the number of red foxes *Vulpes vulpes* and badgers *Meles meles* is problematic. Both species are nocturnal and elusive, so that direct observation is often difficult; and both are widely distributed throughout Britain (Arnold, 1993), occur in a wide

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variety of different habitats, and can be found at densities that vary from locally very high to very rare or absent (see summaries in Harris *et al.*, 1995). Therefore, a national monitoring scheme in Britain has to utilize a technique (or techniques) that is able to detect a wide range of animal densities in structurally different habitats and, as data collection is likely to be reliant on unpaid volunteers, these techniques must be easily applied by persons with different levels of field expertise.

Mammalian carnivores have been censused using techniques based either on direct observations of the animal itself or on indirect observations of the animal's activities, such as scats, tracks and breeding dens (overviews in Beltrán, Delibes & Rau, 1991; Wilson & Delahay, 2001). However, each of these techniques has its associated advantages and disadvantages, particularly in terms of their applicability to different habitats, their use by volunteers and cost. In this paper, we review the methods that have been used to census populations of foxes and badgers and consider their suitability for a national scheme in Britain to monitor changes in population size (Macdonald, Mace & Rushton, 1998; Toms, Siriwardena & Greenwood, 1999; see Table 1). In addition, we outline our own experiences with the use of field signs in two projects to quantify fox and badger density. In conclusion, we consider which methods are most applicable for a volunteer-based monitoring programme, and outline further research that is required before such methods can be applied nationally.

DIRECT METHODS OF MONITORING FOXES AND BADGERS

Capture-mark-recapture/resight

Capture-mark-recapture/resight (CMR) methods rely upon the capture and conspicuous marking of individuals that are subsequently recaptured or observed either directly or indirectly. In Britain, foxes can legally be captured by anyone without a licence; badgers can only be captured under licence from the Countryside Council for Wales, English Nature or Scottish Natural Heritage. Approved methods for capturing foxes include free-running snares and cage traps: all spring traps are illegal. Badgers are typically captured using cage traps. However, both species have low to moderate capture rates (Rogers, Cheeseman & Mallinson, 1997; Tuyttens *et al.*, 1999a; Baker *et al.*, 2001), so that CMR methods are very labour intensive and have generally only been utilized in small study sites.

Individual marking can be achieved using coloured ear-tags or collars, tattoos, or by using fur-clips (Stewart & Macdonald, 1997). Resampling may be achieved by retrapping, by observation in the field, or by the use of infrared video cameras (Stewart, Ellwood & Macdonald, 1997) or remote camera traps to photograph individuals (see Cutler & Swann, 1999): financial constraints would limit the widespread use of remote surveillance at a national scale. Because capture and recapture rates are low, trapping often takes place over an extended time period such that most statistical CMR models are not applicable, although Tuyttens *et al*. (1999b) proposed a closed-subpopulation model that may be suitable for badgers. Lastly, anaesthetizing either species for scientific purposes is regulated by the Home Office, although foxes can be handled without anaesthesia. Therefore, CMR methods are not suitable for a national monitoring programme, although estimates of abundance derived by CMR techniques typically represent the yardstick against which other abundance estimates are compared.

Radio-tracking

Radio-tracking can be used to delimit individual home ranges, and these in turn can be used to derive estimates of group territorial boundaries, thereby indicating the density of social

Table 1. A summary of the applicability of census techniques to a proposed national monitoring programme for Britain

Method	Suitability of technique to a range of habitats	Ease of use by volunteers	Cost for inclusion in a national monitoring scheme	Other comments	Applicability for the proposed national monitoring scheme in Britain
Direct methods					
Capture-mark-recapture (CMR)	Moderate: animals are trappable in any habitat, but some populations known to be very difficult to trap because, e.g. of current levels of persecution or low densities	Low: requires licence from regulatory authorities and animal handling skills	High: equipment is moderately expensive and substantial effort is required to obtain sufficient data for analyses	–	Low: too labour intensive and costly at national scale
Radio-tracking	Moderate: practical application of radio-tracking can be limited by habitat structure, and by ability to trap animals to fit collars (see 'CMR' above)	Low: data collection requires extensive hours in the field, and moderate levels of practical skill	High: equipment is very expensive and substantial effort is required to obtain sufficient data for analyses	–	Low: too labour intensive and costly at a national scale
Spotlight counts	Low: unsuitable for habitats where visibility is low (e.g. woodlands, forests) or where access is limited	Moderate: spotlight counts could be recorded by culling practitioners (see 'Hunting statistics' below), but other areas would need to be surveyed specifically	High: substantial parts of Britain would not be covered by existing recorders, e.g. gamekeepers. Equipment is moderately expensive and substantial effort is required to obtain sufficient data for analyses	–	Moderate: cannot be applied to all habitats, but could be useful in some regions as volunteer base already exists

Table 1. (*Continued*)

Method	Suitability of technique to a range of habitats	Ease of use by volunteers	Cost for inclusion in a national monitoring scheme	Other comments	Applicability for the proposed national monitoring scheme in Britain
Hunting statistics	Low: foxes extensively culled throughout Britain, with exception of urban areas, but methods are not directly comparable: regional differences in culling practices limits comparability. Badgers not culled	Moderate: culling is currently undertaken by many persons as part of their normal activities, and some information is already collated by, e.g. Game Conservancy Trust. However, only a limited number of volunteers could use the technique	Moderate: gamekeepers already record the number of foxes killed, but not hunting effort. Farmers are not currently included, and would have to be surveyed specifically for a national monitoring scheme. Data collection would have to standardize hunting effort	It is not legal to cull badgers in Britain except under licence	Foxes, low: confounded by non-independence of different culling methods within and between regions, but data likely to be collected regardless by existing volunteer base. Badgers, not applicable
Counts of road traffic accidents	Moderate: road density varies with habitat and it is unclear how this may affect sampling	High: volunteers are likely to include counts as part of their daily activities	Low: volunteers are likely to include counts as part of their daily activities, but some areas may need to be surveyed specifically	–	Currently low: data could be collected straightforwardly but relationship to animal density is unclear and requires validation
Poisoning indices	Not applicable	Not applicable	Not applicable	Poisoning foxes and badgers is illegal in Britain	Not applicable

Table 1. (*Continued*)

Method	Suitability of technique to a range of habitats	Ease of use by volunteers	Cost for inclusion in a national monitoring scheme	Other comments	Applicability for the proposed national monitoring scheme in Britain
Driven counts	Low: in practical terms, impossible to implement in a range of habitats	Low: would require extensive coordination between volunteers	High: would require extensive coordination between volunteers	Only suitable for foxes as badgers underground during day. Success dependent on factors affecting likelihood of foxes being above ground, e.g. weather and season	Foxes, low: degree of coordination required is prohibitive and only cost-effective at high densities. Badgers, not applicable
Questionnaire/ sighting surveys	Low: generally applicable only to urban areas where direct observation is relatively frequent	High: general public can easily be questioned in urban areas; technique less easily applied in rural areas	Moderate: may involve substantial printing costs, but this would be reduced using, e.g. website to record observations	–	Low: in practical terms are only really applicable to urban areas
Aural surveys	Not applicable	Not applicable	Not applicable	Neither foxes nor badgers utilize calls in such a way that could be used to derive estimates of group density	Not applicable
Indirect methods					
Counts of breeding dens/refugia	High: stratified approach can be used to sample across a range of densities in all habitats; urban areas may require questionnaire surveys	Moderate: some expertise needed to identify whether a fox den is occupied or not, and may require training. Expertise already exists for badgers	Low: no equipment required	–	Moderate: random stratified sample can be used across habitats with high volunteer time in the field required; moderate expertise required

Table 1. (*Continued*)

Method	Suitability of technique to a range of habitats	Ease of use by volunteers	Cost for inclusion in a national monitoring scheme	Other comments	Applicability for the proposed national monitoring scheme in Britain
Track counts	Moderate: use of artificial substrates would allow the technique to be applied in all habitats	Moderate: artificial substrates needed would increase workload; moderate level of expertise needed to distinguish tracks of different species	Moderate: artificial substrate would elevate costs	–	Moderate: random stratified sample can be used across habitats but with high volunteer time in the field required to run artificial stations; moderate expertise required
Bait recovery	As for 'Track counts'	As for 'Track counts'	As for 'Track counts'	–	As for 'Track counts'
Faecal counts	High: stratified approach can be used to sample across a range of densities in all habitats, excluding urban areas	High: moderate level of expertise needed to distinguish scats of sympatric predators	Low: no equipment required	–	High: random stratified sample can be used across habitats with moderate volunteer time in the field required; moderate expertise required
Molecular approaches	Low: requirement of very fresh scats may limit this technique more than scat counts alone, especially in areas of low density	High: moderate level of expertise needed to distinguish scats of sympatric predators. Experts needed to process samples collected	High: molecular analysis of scats is expensive	–	Low: cost is prohibitive on a national scale

Applicability was assessed using three criteria: (i) the suitability of the technique for the range of habitats found in Britain; (ii) the ease with which the technique could be used by volunteers; and (iii) the likely cost for involving the technique in the national monitoring scheme. Each criterion was scored as high, moderate or low, with an explanation given for each score awarded. On the basis of these criteria, the general applicability of the technique was determined.

groups. However, group size can be highly variable even where territories are consistent in size and/or location (Rogers *et al*., 1999; Baker *et al*., 2000; Macdonald & Newman, 2002), so it is not possible to derive estimates of animal density without ancillary data. In addition, the interpretation of group territorial boundaries can be complicated by the presence of itinerant animals (Dekker, Stein & Heitkönig, 2001) and changes in the location of territorial boundaries (Doncaster & Macdonald, 1991), which can vary with group density. The technique is very labour intensive and requires the capture and handling of individuals to fit radio-transmitters, so its applicability to a national monitoring programme is limited by those factors affecting the use of CMR methods.

Spotlight counts

Nocturnal transect counts of animals from a vehicle using a spotlight have been used to estimate both the relative (Stahl, 1990a; Stahl & Migot, 1990; Weber *et al*., 1991; Greentree *et al*., 2000; Kay *et al*., 2000; Sharp *et al*., 2001) and absolute density of foxes and badgers (Heydon, Reynolds & Short, 2000) using the distance-sampling method (Buckland *et al*., 2001). Von Schantz & Liberg (1982) and Stahl (1990a) have also used this technique in conjunction with marked individuals to estimate fox density. One major advantage of the distance-sampling method is the associated array of mathematical techniques for the statistical quantification of animal density (Buckland *et al*., 2001); such techniques are lacking for most other census methods.

However, spotlight counts have their limitations. Most importantly, where animal density is low, they may fail to detect a species' presence (Mahon, Banks & Dickman, 1998; see also Read & Bowen, 2001), and as they are generally conducted from a car, vehicular access may be a constraining factor. Furthermore, one key assumption of the distance-sampling method is that all animals on the transect, or some equivalent, line are detected (Buckland *et al*., 2001). This assumption may be violated by vegetation structure adjacent to the road limiting visibility, avoidance or preference of road habitats by foxes (Mahon *et al.*, 1998) and persecution pressure, e.g. where foxes are culled using spotlights and rifles (see 'Hunting statistics' below), this may lead to avoidance behaviours. In most cases, this would lead to reduced sightings of foxes immediately adjacent to the transect line (see Ruette, Stahl & Albaret, 2003; but see Heydon *et al.*, 2000), and fox density would be underestimated (Buckland *et al*., 2001); such problems may be overcome by excluding data from a strip adjacent to the transect line (left-truncating) and/or by increasing the size of the first interval (Ruette *et al*., 2003).

Specifically, spotlight surveys relate to density estimates of active foxes in open habitats (Ruette *et al*., 2003) and these may be affected by changes in the utilization of open and closed habitats, both in space and time. Changes in habitat utilization may occur in response to changes in, e.g. food availability (Halpin & Bissonette, 1988; Lovari, Lucherini & Crema, 1996) and weather patterns (but see Stahl, 1990a). From a monitoring perspective, this may be particularly problematic where changes in large blocks of habitat are likely to occur; in Britain, planned major habitat changes comprise the construction of community forests (http://www.communityforest.org.uk) and new urban areas (Bibby & Shepherd, 1996).

Hunting statistics

The number of foxes culled annually (hunting bags: e.g. Hewson & Kolb, 1973; Hewson, 1984; Tapper, 1992) or the number 'moved' or taken by hunts (Wilson, 1982; Macdonald & Johnson, 1996) represent potential methods for monitoring changes in fox abundance in

Britain. Furthermore, as these practices are already being undertaken, there is an existing volunteer base that could be utilized in a national monitoring scheme. However, these methods are not applicable to badgers, which are protected under the Protection of Badgers Act 1992.

Hunting bags have also been used in other countries as a means of assessing or indexing fox abundance (Chiasson, 1953; Wood, 1959; Artois & Andral, 1980; Lindström, 1989; Lindström *et al*., 1994; Vos, 1995; Gortázar *et al*., 1998; Lewis, Sallee & Golightly, 1999; Forchhammer & Asferg, 2000; Nyenhuis, 2000). However, such techniques are heavily dependent on standardizing the amount of effort expended to obtain reliable data (see McDonald & Harris, 1999). If hunting effort is standardized, hunting indices could potentially be used to monitor changes in fox density. For example, Heydon *et al.* (2000) found that the number of foxes *observed* each hour by gamekeepers culling foxes by shooting at night with a rifle and spotlight on hunting estates agreed closely with estimates of fox density derived from systematic spotlight and breeding den counts in nearby regions. However, it must be noted that the number of foxes *killed* on these estates did not indicate fox density, as in several instances the cumulative number of foxes shot failed to reach an asymptote due to the immigration of juveniles from neighbouring farms and estates (Reynolds, 1995). Consequently, the number of foxes culled over winter was very dependent on the pattern of productivity and availability of dispersing juveniles from neighbouring areas, rather than the pre-breeding density of foxes in spring. This latter measure is arguably more useful for monitoring interannual changes in animal numbers as the productivity of a population can vary markedly despite little underlying change in the pre-breeding density (Hewson & Kolb, 1973). Furthermore, the relationship between the number of foxes killed and the number that remain can be equivocal, such that the number removed from a population does not necessarily represent the number that survive.

In addition, surveys of the number of foxes killed by farmers, hunters and/or wildlife management personnel can be problematic due, e.g. to reporting error (see Heydon & Reynolds, 2000). Different culling practices applied in the same area are not independent, the number taken by one method being heavily reliant on the extent and timing of other practices. Thus, for example, the number killed by method A, used predominantly in winter, will be affected by the number killed by method B in the preceding summer season. Therefore, changes in the use of such methods could result in an increase or decrease in the number of animals killed even with no underlying change in fox density. Similarly, differences in the extent to which a given technique is used in different areas (overview in White *et al*., 2000) could limit comparability between regions. Methods of culling have changed significantly in the last 100 years as a consequence of legislative changes (e.g. outlawing of spring traps, self-locking snares, poisons, hunting with dogs in Scotland) and further changes in culling practices are likely. Therefore, it is unlikely that traditional culling indices represent a reliable indicator of past and future changes in fox density (see also Myrberget, 1988).

Counts of road traffic casualties

Foxes and badgers are frequently killed through collisions with vehicles (Davies, Roper & Shepherdson, 1987; Reichholf, 1997) and road kills can be used to indicate fox distribution (Marks & Bloomfield, 1999). Such deaths could easily be included in a national monitoring programme at minimal cost, with volunteers incorporating counts of casualties into their normal daily routine. However, there are a number of potential problems with using counts of road traffic casualties as a monitoring technique; these are discussed by Baker *et al.* (2004).

Poisoning indices

Algar & Kinnear (1992) have measured relative changes in fox abundance by cyanide baiting along a transect: cyanide kills foxes quickly such that their carcasses are available for counting. However, this technique is not applicable to Britain where poisoning of both foxes and badgers is illegal.

Driven counts

In dense habitats, animals can be counted by using beaters to drive animals past a line of counters (Tellería & Sáez-Royuela, 1984). Foxes are also culled by this method in some regions (Heydon & Reynolds, 2000). This method would only be applicable to foxes (outside the breeding season) as badgers rest underground during the day. In practice large numbers of people would be required, and given that foxes occur at relatively low densities, driven counts are probably not a practical census technique even on a small scale.

Sighting and questionnaire surveys

Questionnaire surveys of the general public and animal welfare organizations, local authorities operatives and police wildlife liaison officers have been widely used in urban areas to estimate fox distribution, density and changes in abundance (Harris, 1981; Marks & Bloomfield, 1999; Gloor *et al.*, 2001; Wilkinson & Smith, 2001). Questionnaire surveys of this type typically use indirect estimates of changes in fox density, e.g. number of animals treated, number of complaints received. In rural areas, questionnaire surveys typically consider the number of animals killed (see 'Hunting statistics'). Therefore, such surveys are potentially prone to problems such as reporting error, standardization of effort and, in some cases, to a non-linear or inverse relationship with fox density. For example, during an outbreak of sarcoptic mange, the number of calls received by the University of Bristol increased dramatically even though fox density was declining (S. Funk, P. Baker & S. Harris, unpublished data).

Summary of direct survey methods

Methods that rely on counts of animals are unlikely to be utilizable in a national monitoring scheme as they are too labour intensive, require trained personnel, are potentially confounded by a range of factors and/or are not applicable to all habitats. For example, estates where gamekeepers could be used to census foxes over winter comprise only 34% of the rural land in Britain (Anonymous n.d.), and fox densities on these estates may be unrepresentative of the rest of the country. However, intensive methods such as CMR and radio-tracking at small spatial scales are likely to be required to validate indirect measures of abundance.

INDIRECT METHODS OF MONITORING FOXES AND BADGERS

Indirect monitoring of foxes and badgers has typically relied on the quantification of a single parameter such as tracks, droppings or refugia, although some authors have utilized multiple signs to calculate either the proportion of transects or quadrats where one or more signs indicated that a species was present (Scott, 1940; Virgós, 2001) or to obtain a relative level of activity (Wilson, Harris & McLaren, 1997). The use of individual parameters is outlined below.

Breeding dens/refugia

Fox groups typically produce one litter of cubs annually so that counts of litters or breeding dens indicate the density of social groups (Sargeant, Pfeifer & Eberhardt, 1975; Insley, 1977; Harris, 1981; Hewson, 1986; Lindström, 1989; Goszczyński, 1999; Marks & Bloomfield, 1999; Heydon *et al.*, 2000). However, such counts are complicated by subordinates breeding and by dominant females splitting litters between dens, both of which may elevate estimates of group density. Conversely, the failure of the dominant female to reproduce will lower estimates of group density. To apply this method correctly therefore, it is necessary to determine correction factors for the occurrence of multiple litters in the same group and the loss of litters prior to emergence: both these measures would require behavioural studies using techniques such as radio-tracking and CMR (Harris, 1981). In the absence of such factors, estimates of fox density may be erroneous (Baines *et al.*, 1995).

Badger social groups utilize underground burrows, setts, as diurnal refuges. Each group may have a number of setts within their territory. These vary in size and pattern of use, and can be readily categorized (Kruuk, 1978; Cheeseman *et al.*, 1981). The main sett within the territory is typically the largest and is occupied year round, although some territories may contain more than one main sett (Tuyttens *et al.*, 2000); other sett categories include subsidiary, outlier and annexe (Thornton, 1988). Counts of main setts will generally therefore indicate group density, and to date these have been used in surveys at both local (Aaris-Sørensen, 1987; Skinner, Skinner & Harris, 1991; Macdonald, Mitchelmore & Bacon, 1996; Ostler & Roper, 1998; Kowalczyk, Bunevich & Jędrzejewska, 2000) and national levels (Cresswell, Harris & Jefferies, 1990; Wiertz, 1992; Feore, 1994; Bevanger & Lindström, 1995; Smal, 1995; Wilson *et al.*, 1997). The major limiting factor is, therefore, the ability to locate and correctly classify sett types, in order that the presence of a social group can be determined. In areas of low badger density, main setts may be very small and difficult to classify (Tuyttens *et al.*, 2000), such that additional factors (e.g. intersett interval) may be useful in determining group density. However, these problems were not apparent in the national survey conducted by Wilson *et al.* (1997).

Measures of group density may not be a good indicator of animal density where populations are locally very abundant (see Rogers *et al.*, 1999; Baker *et al.*, 2000; Macdonald & Newman, 2002). However, such pronounced variability is probably atypical, and across Britain generally, estimates of group density are likely to be realistic measures of fox and badger abundance (Kruuk & Parish, 1987).

Aural surveys

Surveys of distinctive calls have been used to census wolves *Canis lupus* (Harrington & Mech, 1982). However, for both foxes and badgers, vocalizations tend to occur between individuals in close proximity, and would not be detectable by an observer (Newton-Fisher *et al.*, 1993; Wong, Stewart & Macdonald, 1999). The possible exception is the long-range contact call made by foxes during the breeding season, although these occur at very low frequency (Newton-Fisher *et al.*, 1993) and are unlikely to be a reliable indicator of animal abundance.

Track counts

Counts of animal tracks can be used in conjunction with either natural substrates (e.g. snow) or artificial substrates (e.g. sand) and have been used by several authors to estimate fox abundance; the technique has not generally been applied to badgers (but see Wilson *et al.*, 1997). Relying on natural substrates can confine surveys either to specific habitats (Stanley & Bart, 1991; Mahon *et al.*, 1998) or seasons (Pulliainen, 1981; Lindström, 1989; Kurki *et al.*, 1998; Forsey & Baggs, 2001). Artificial substrate surveys are not limited in these ways.

Surveys can be conducted either as a continuous transect or at a number of discrete points. For artificial substrates, the latter approach is more common with a series of ‘stations’ used, with or without some form of attractant (Travaini, Laffitte & Delibes, 1996; Odell & Knight, 2001). Estimates of animal abundance can then be derived as, e.g. the number of tracks encountered per unit length surveyed, the presence or absence of tracks per unit length surveyed, the distance between sets of tracks or the number of track stations with prints. Generally, however, such estimates only indicate relative densities or predator pressure (Kurki *et al.*, 1998), and further techniques are required to determine conversion factors to estimate absolute numbers from track counts (Servin, Rau & Delibes, 1987).

The major practical problems associated with track counts are: (i) the reliance on suitable conditions and (ii) the accurate identification of tracks. In Britain, artificial substrates would be required to obtain reliable data at particular times of the year (e.g. pre- or post-breeding) across the country as snowfall is not predictable: the provision of track stations would increase the financial costs and logistical problems of a national monitoring scheme. Badger prints are very conspicuous and unlikely to be easily confused with other species. By contrast, fox prints are similar to those of domestic dogs, requiring a degree of training to ensure that volunteers could reliably identify tracks. Patterns of range utilization may also affect the validity of track counts as a measure of animal activity. For example, Stanley & Bart (1991) showed that track counts varied most in relation to the pattern of adjoining habitat rather than underlying fox density. Artificial substrate counts are also potentially prone to errors associated with changes in the behaviour of 'visit-happy' foxes that travel from one track station to another. One potential means to overcome this is to utilize lines of stations as the basic sampling unit rather than individual stations (Sargeant, Johnson & Berg, 1998).

Bait recovery

Dexter & Meek (1998) and Thompson & Fleming (1994) have used visitation rates to non-toxic food stations as a means of assessing fox abundance, although both studies also relied on the identification of tracks to identify species. Consequently, this technique is essentially analogous to track count methods at artificial substrate stations.

Molecular approaches

Shed hairs and faecal material may contain DNA that could be used to derive a genetic profile of individual animals. By collecting a number of such samples, it is possible to build up a temporal and spatial map of the presence of individuals within a given area, from which animal density can be calculated (Kohn *et al.*, 1999). General problems include obtaining fresh scat samples to minimize degradation of DNA and identifying molecular primers for the amplification of specific DNA sequences (see Kohn & Wayne, 1997). Yet, such problems are not insurmountable even for carnivores at low density (Taberlet *et al.*, 1997), and the technique could potentially be applied to a range of species. Genotyping protocols have successfully been developed for foxes (G. Smith, personal communication) and badgers (Frantz *et al.*, 2003). Furthermore, a preliminary study investigating the use of repeated sampling from latrines close to the group's main sett has indicated that this technique may be suitable for estimating badger abundance (Wilson *et al.*, 2003). However, at the present time, the cost of this approach is likely to be prohibitive for monitoring foxes and badgers at a national level, although it could be used to verify measures of abundance at small spatial scales.

Faecal counts

Badgers deposit faeces in latrines to delineate territorial boundaries, and by providing food with an indigestible marker ('bait marking'), faecal position can be used to identify territorial boundaries and hence group density (Kruuk, 1978; Delahay *et al.*, 2000). However, the technique is very labour intensive and the proportion of faeces occurring in latrines appears to vary with density (Hutchings, Service & Harris, 2001, 2002), such that it may not be easily applied across a range of badger densities. The technique does not appear to have been used successfully for foxes, possibly due to the difficulty in getting animals to eat sufficient marked bait and the highly dispersed nature of fox faeces.

Faecal counts have also been utilized to estimate animal abundance through the quantification of the total amount of faeces in a given area (the 'standing crop') or by measuring the rate at which droppings accumulate on a transect or sample plot (see Putman, 1984). Of these approaches, only the latter appears realistic for most carnivores because of habitat and temporal differences in the decomposition rates of faeces. Accumulation rates are typically measured by marking fresh or old faeces such that they can be distinguished from each other, or by first clearing the transect/plot of old faeces before sampling after a known period. The former approach would avoid any potential change in scent-marking behaviour caused by the removal of scats, although it is not clear whether such changes occur.

There are a number of factors that could confound the use of scat counts as a survey technique for foxes and badgers: (i) the number of scats produced will vary with diet; (ii) the persistence of scats will vary with weather conditions; (iii) the pattern of deposition of scats is likely to vary with season and habitat characteristics, and this may affect detectability; and (iv) the ability of surveyors to locate and correctly identify droppings (see Davison *et al*., 2002). For example, Macdonald & Halliwell (1994) conducted a stratified fox survey of the Isle of Man based upon the detection of faeces. However, their conclusion that foxes were common and widespread on the island has been hotly contested, and a recent spotlight survey failed to find a single fox (Reynolds & Short, 2003). Experimentation can be used to determine the number of scats produced for a given diet (Litvaitis & Mautz, 1976; Stahl, 1990b) and faecal decay rates. However, care must be taken in extrapolating from captive studies where, e.g. patterns of activity, and therefore defaecation rates, are likely to vary significantly from wild individuals. Standardizing the timing of surveys would control for seasonal variation in the pattern of scat deposition, but not habitat-related variation: to compare between habitats, it is necessary to determine scat detection probabilities for different environments. Therefore, the estimation of total animal density using scat counts relies on a range of conversion factors and several authors (Kolb, 1982; Beltrán *et al*., 1991) have recommended that they be used only as an index of relative abundance (see Kolb & Hewson, 1980; Rau *et al*., 1985; Cavallini, 1994; Banks, Dickman & Newsome, 1998; Bright & Smithson, 2001; Sharp *et al*., 2001). However, these problems are surmountable, and this approach has been utilized to estimate the number of foxes in Britain, and to evaluate whether there has been any change in the number of foxes in lowland Britain as a result of restrictions on hunting with hounds during an outbreak of foot-and-mouth disease (FMD; Baker, Harris & Webbon, 2002). These approaches are outlined below.

Example 1. The use of faecal counts to determine fox abundance in Britain

In Britain, the fox is widely perceived as a major predator of livestock, game and threatened wild species, as well as a quarry for sport hunting (Reynolds & Tapper, 1995, 1996; Tapper, Potts & Brockless, 1996; Heydon & Reynolds, 2000). The management of any species is dependent on a thorough understanding of its demography and behaviour, but relatively little is known about regional variation in fox density in Britain (but see Insley, 1977; Tapper, 1992; Heydon *et al.*, 2000). Therefore, a national survey was undertaken to quantify fox density throughout rural landscapes in Britain.

Transects along linear features (e.g. hedgerows, fences, rivers, woodland edges) within a random stratified sample of 444 1-km squares were surveyed across Britain between 1 February and 17 March in 1999 and 2000 by a combination of volunteers and paid surveyors. This survey period was chosen as it is a phase of relative population stability, following the main dispersal period (Harris & Trewhella, 1988) but preceding the period of peak births (Lloyd, 1980) and coincides with the end of the peak culling period. Each transect was walked twice within the 6-week period, with 2–4.5 weeks between each walk. This interval enabled faecal accumulation rate to be calculated (Putman, 1984), but was not long enough to allow faeces to disappear through decomposition.

On the first visit, all fox scats were removed; on the second visit, the position of all new scats was recorded. On both walks, scats were collected for dietary analyses and to confirm that scats counted were fox droppings. The median faecal accumulation rate for each stratum (A) is given by:

$$A = \text{median}[S_j L_j / D_j K_j],$$

where S_j is the number of fox scats counted on the second walk, L_j is the total length of linear features, D_j is the number of days between the two walks and K_j is the length of linear features walked in the jth 1-km square. Median values are preferable to means, as the data are unlikely to be normally distributed. Strata are regions under the same ecological (Bunce *et al.*, 1996) or anthropomorphic (Heydon & Reynolds, 2000) influences.

However, to calculate the total number of foxes, it is also necessary to account for (i) the difference in the total number of scats produced due to differences in diet and (ii) the proportion of scats deposited along linear features in different habitats. The calculations of these factors, and some preliminary results, are outlined below. To determine the number of scats produced daily (N) under varying diets, captive foxes were fed a known amount of a range of food types (e.g. lagomorph, rodent, bird). For a given stratum-specific diet, N was calculated as:

$$N = (Q/I)Z,$$

where Q is the daily mass of food required by a free-living fox, I is the average daily mass of food ingested during the experiment and Z is the average number of faeces produced per fox per day during the experiment. Q was calculated for a fox of mass 6.0 kg (Harris & Lloyd, 1991), based on an observed daily consumption of 0.78 kg for foxes weighing 5.3 kg (Stahl, 1990a), i.e. a mass-specific rate of 0.15 kg food/kg body wt/day. Therefore, Q is given by: $0.15 \times 5.3 \times (6.0/5.3)^{0.75} = 0.87$ kg prey/fox/day.

The proportion of scats associated with linear features was calculated using a bait-marking trial. Captive foxes were fed a known amount of an artificial food source (approximately 0.80 kg) marked with indigestible plastic chips, and the total number of marked faeces produced in the subsequent 48-h period was recorded: daily defaecation rate was 8.0 scats/fox/day. Therefore, the expected number of marked scats produced per day for a free-living fox would be: $(0.87/0.80) \times 8.0 = 8.7$ scats/day.

Bait stations in a range of habitats were then used to feed individual wild foxes the artificial food for a period of 14 days. The expected total number of marked scats produced (n) is given by: $(C/0.87) \times 8.7 \times 14$, where C is the average daily mass of artificial food consumed. Subsequent walks along the linear features in the area surrounding the bait stations indicated the total number of marked scats associated with linear features (m). The proportion of marked scats associated with linear features (P: $0 \leq P \leq 1$) was then calculated as: $P = m/n$.

From these data, it was possible to determine fox density within each stratum (Y) as:

$$Y = (A/P)/N = A/PN.$$

In addition to determining an estimate for the average density, it is also necessary to calculate confidence limits for the estimate of average fox density in each stratum. With this approach, confidence limits are likely to be large due to the additive effects of successive error distributions associated with each parameter, e.g. A is actually related as:

$$A \pm \sigma_A = (S \pm \sigma_S/L \pm \sigma_L)(D \pm \sigma_D/K \pm \sigma_K),$$

where σ is an error distribution associated with the corresponding mean values. Methodologies for combining error distributions are outlined by Pentz, Short & Aprahamian (1988).

The results of this survey clearly showed that it is possible to conduct a national survey of foxes successfully based on faecal counts using volunteers, both in terms of the quality and quantity of data collected. Information received by volunteers was scored on a scale of 1–7 using criteria relating to the quality of information supplied about both the transect route walked and associated habitat structure; only 1-km squares ranked 1–5 were used in the analyses. Overall, 518 1-km squares were surveyed: of these, 69 and 449 were surveyed by paid personnel and volunteers, respectively. Seventy-four squares were removed from the analyses (two by paid personnel, 72 by volunteers). Of those squares surveyed by volunteers, 275 (61% of volunteer squares) were assigned the highest quality score, with only 23 (5%) gaining a rank of 5. There was no significant difference in faecal accumulation rate (A) between squares with quality scores 1–5 (General Linear Model: $F_{4,372} = 0.45$, $P > 0.05$). In addition, all scats returned by volunteers were independently checked to confirm their identification: of 8263 faeces collected, only 2.9% were not fox scats.

Paid surveyors were required in only four regions (Northern Scotland, Southern Scotland, South-west England and Wales) to ensure optimal coverage; most of these comprised areas of upland or marginal upland where human density was low. There was no significant difference in the relative abundance of foxes in 1-km squares surveyed by volunteers vs. those surveyed by paid staff in Northern Scotland ($F_{1,54} = 1.14$, $P > 0.05$), Southern Scotland ($F_{1,48} = 1.67$, $P > 0.05$) or Wales ($F_{1,43} = 1.11$, $P > 0.29$); in South-west England, faecal density recorded by paid surveyors was marginally higher than that recorded by volunteers ($F_{1,48} = 4.51$, $P < 0.05$). Therefore, the quality of data collected by volunteers was generally comparable to that collected by paid surveyors, with the latter required only in a minority of areas where the available volunteer base was limited. This small dependence on paid surveyors is likely to be a component of any volunteer-based national monitoring scheme to ensure sufficient sample sizes in a small number of regions.

Example 2. Using scat counts to monitor changes in fox density

However, for the purposes of a national monitoring programme, it is only necessary to quantify relative rather than absolute changes in density, and we have recently used a scat survey to monitor changes in fox density following the outbreak of FMD in Britain in February 2001 (Baker *et al.*, 2002). One hundred and sixty of the 1-km squares outlined above were randomly selected from lowland areas and resurveyed in February–March 2002, following a complete 10-month and a partial 2-month ban on hunting with hounds; surveyors were asked to walk the exact transect route that had been surveyed before the outbreak of FMD. Faecal density for each transect in each period (F) was calculated as:

$$F = S/KD,$$

Table 2. The effect of initial scat density on the final value (R') for the relative change in scat density before and after the outbreak of foot-and-mouth disease (FMD)

		Square A	Square B
Pre-FMD	Transect length (K)	7.0	7.0
	Elapsed time (D)	19.1	19.1
	Number of scats found (S)	5.0	100.0
	F	0.03740	0.74794
Post-FMD	Transect length (K)	6.8	6.8
	Elapsed time (D)	18.7	18.7
	Number of scats found (S)	7.5	150.0
	F	0.05898	1.17962
R		0.45527	0.56954
R'		0.16294	0.19577

For a 20-fold difference in scat density in the pre-FMD period, an increase of 25% results in 1.2-fold difference in R'. Faecal density for each transect in each period (F) was calculated as: $F = S/KD$, the change in faecal density (R) was calculated as: $R = (F_{\text{post-FMD}} - F_{\text{pre-FMD}})/(F_{\text{pre-FMD}} + 0.01)$, and $R' = \log(R + 1)$.

where S is the number of fresh faeces found on the second walk, K is the transect length (km) and D is the number of days between the first and second walk. The change in faecal density (R) was calculated as:

$$R = (F_{\text{post-FMD}} - F_{\text{pre-FMD}})/(F_{\text{pre-FMD}} + 0.01).$$

To obtain a normalized distribution, the data were transformed as $R' = \log(R + 1)$. For analyses, nine regions were utilized. There was a significant difference in the relative change in scat density between regions (ANOVA: $F_{8,145} = 2.69$, $P < 0.05$), with scat density increasing in Eastern England (one sample t-test against mean change of zero: $t_{22} = 2.52$, $P < 0.05$) and declining in Southern England ($t_{37} = -2.65$, $P < 0.05$; Fig. 1); in the remaining regions, change in mean scat density did not differ significantly from zero.

However, it is possible that the statistical transformation utilized may have masked differences between squares with an initial low scat density vs. those with an initial high scat density; for a given percentage increase, R' increases with increasing initial density (Table 2). This would be problematical if hunted squares typically had lower scat counts than squares where hunting with hounds was not restricted. Yet there was no consistent tendency for hunted squares to have a lower initial scat density than not-hunted squares (Fig. 2), nor for hunted and not-hunted squares to differ in the direction or magnitude of change in scat density (Fig. 3). Furthermore, considering only absolute changes in scat density in the absence of any statistical transformation (i.e. $F_{\text{pre-FMD}}$ vs. $F_{\text{post-FMD}}$), the only significant increase was observed in Eastern England (Table 3). Overall, the results of this survey indicated that the restrictions on hunting with hounds had had no detectable effect on fox abundance.

Validation of indirect census methods

Indirect sampling techniques offer a range of advantages over direct censusing methods in the context of a national monitoring scheme: (i) signs can be found in a wide variety of habitats, (ii) with practice, they are readily identifiable, and (iii) they are not labour intensive relative to direct methods of quantifying animal abundance. Another major advantage is that a random stratified approach can be adopted. By comparison, approaches based on, e.g.

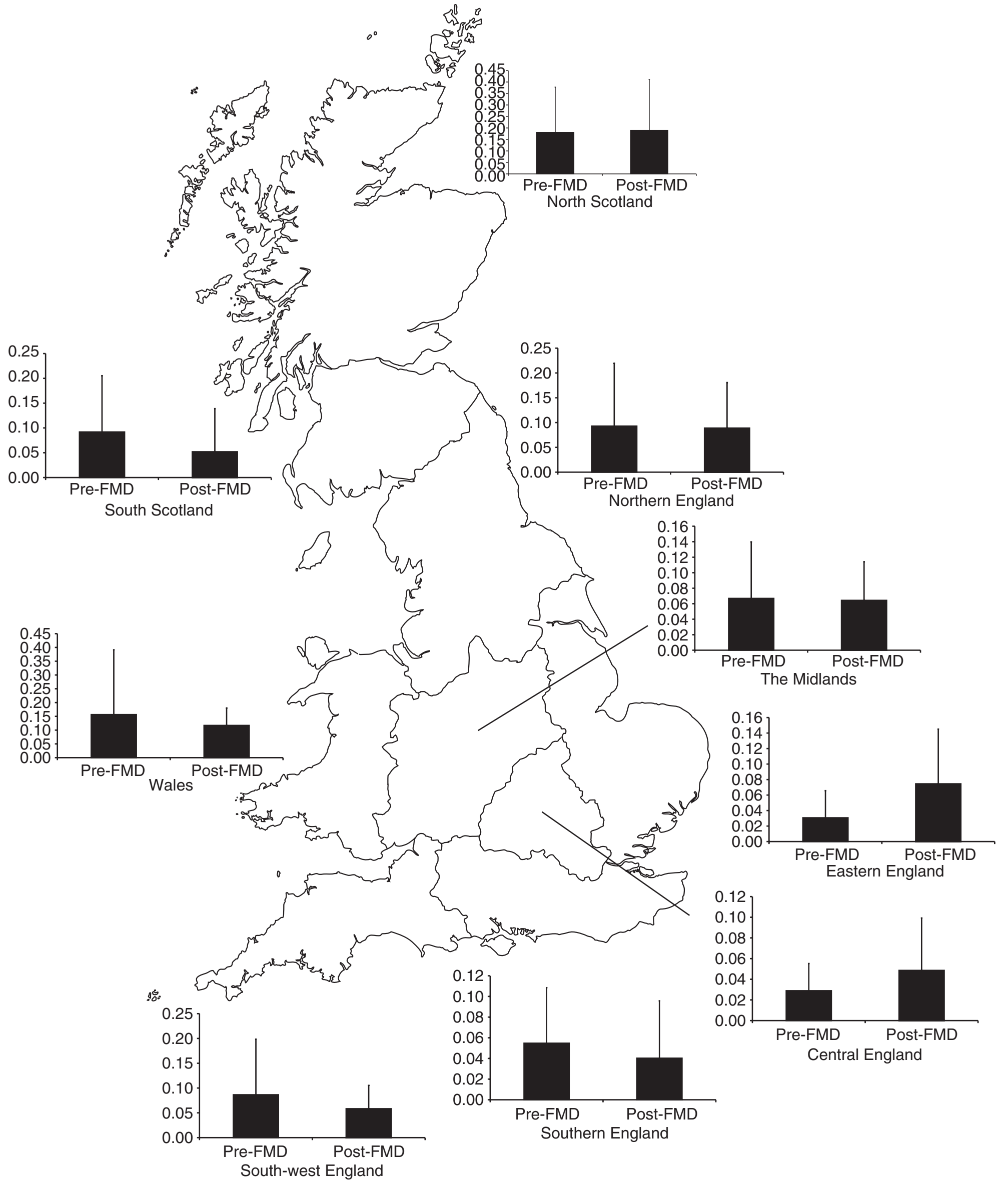


Fig. 1. Regional changes in fox scat density in Britain before and after an outbreak of foot-and-mouth disease (pre-FMD and post-FMD, respectively). Figures are the number of scats per day per kilometre of linear feature surveyed.

hunting statistics may not be a random sample of the British countryside. By adopting an appropriate sampling scale as well, sign surveys can also be designed to limit the time in the field, thereby increasing the likelihood of volunteer participation.

However, at the present time, there are very few quantified data on the relationship between sign abundance and animal density (but see Stahl & Migot, 1990; Sharp *et al.*, 2001; Tuyttens *et al.*, 2001). Consequently, indirect (and a number of direct) methods require validation within a range of habitats to determine their precision and sensitivity, and such studies must rely on direct methods to determine known animal abundance. Below we outline some

Fig. 2. The mean (±SD) scat density in hunted and not-hunted squares prior to a ban on hunting during FMD. NS, Northern Scotland; SS, Southern Scotland; NE, Northern England; EE, Eastern England; M, the Midlands; CE, Central England; SWE, South-west England; SE, Southern England; W, Wales.

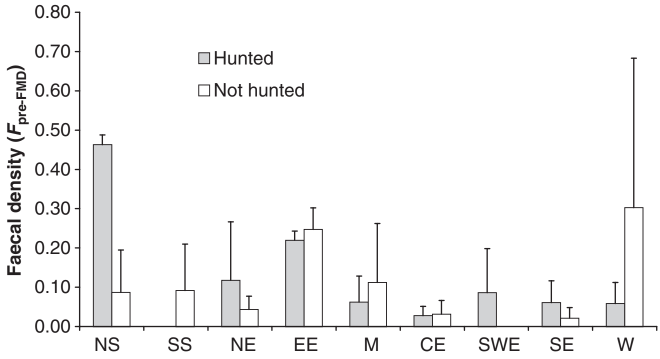


Fig. 3. The mean (±SD) absolute change in scat density in hunted and not-hunted squares following a ban on hunting during FMD. NS, Northern Scotland; SS, Southern Scotland; NE, Northern England; EE, Eastern England; M, the Midlands; CE, Central England; SWE, South-west England; SE, Southern England; W, Wales.

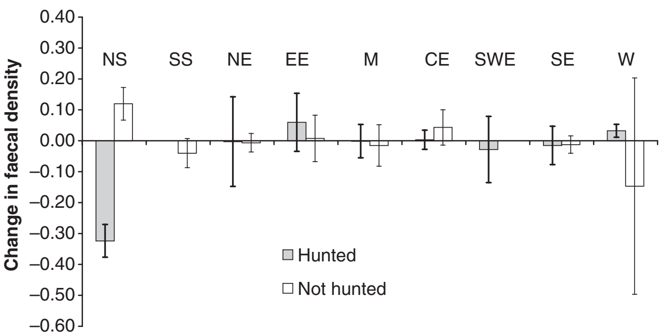


Table 3. Region-by-region comparison of absolute changes in faecal density following a ban on hunting during FMD, including five additional 1-km squares not available to Baker *et al.* (2002)

Region	*N*	*Z*	*P*	Comment
Northern Scotland	8	–0.42	0.67	
Southern Scotland	9	–2.07	0.04	Significant decline
Northern England	16	–0.63	0.53	
Eastern England	23	–2.42	0.02	Significant increase
The Midlands	21	–0.16	0.88	
Central England	20	–1.42	0.16	
South-west England	25	–0.24	0.81	
Southern England	38	–1.74	0.08	(Decrease)
Wales	5	–0.67	0.50	

Data have been analysed using a series of Wilcoxon matched-pairs tests of faecal density before and after the outbreak of foot-and-mouth disease. *N*, the number of 1-km squares surveyed; *Z*, value of test statistic; *P*, probability level associated with test statistic.

preliminary results from an ongoing study examining the relationship between badger abundance and a range of field signs.

Example 3. Quantifying the relationship between badger density and field signs

During the 1990s, badger numbers increased throughout much of Britain (Rogers *et al.*, 1997, 1999; Wilson *et al.*, 1997; Macdonald & Newman, 2002), but may have declined in some areas due to persecution (Wilson *et al.*, 1997) and possibly increased traffic casualties (Clarke, White & Harris, 1998). Since the 1970s, there has been considerable interest in the role of badgers in the epidemiology of bovine tuberculosis, and badger density is widely believed to play a key role in the incidence of tuberculosis in cattle, with herds in areas of high badger density being worst affected (Krebs *et al.*, 1997). Therefore, developing a technique for quantifying badger density is of considerable applied importance (Tuyttens *et al.*, 1999b, 2001; Wilson *et al.*, 2003).

As outlined above, many studies have used surveys of badger setts to determine group density. However, this approach relies on the assumption of an average group size to estimate total badger density, yet group size is known to vary widely within and between habitats (Feore & Montgomery, 1999), such that this assumption may not be valid at small spatial scales. Conventional methods of determining badger density have relied on CMR methods, but these are not suitable for large-scale studies, and differences in trappability further confound comparisons between sites (Tuyttens *et al.*, 1999b). Therefore, there is the need to develop an indirect method for estimating badger density in large-scale studies, and which could use volunteers to collect field data (see also Tuyttens *et al.*, 2001). Such an approach would be amenable to the proposed national monitoring scheme.

Data on a range of easily identifiable field signs and habitat data have been collected from badger social groups around Britain in conjunction with estimates of group size. Bait-marking (Kruuk, 1978; Delahay *et al.*, 2000) was used to delineate the territorial boundary of each study group so that only field signs belonging to that group were recorded subsequently. Two categories of field sign have been used: those related to latrines (e.g. the number of pits and faeces) and those related to setts (e.g. size, level of activity, density). Detailed habitat data have been collected from each territory, as habitat richness is known to be related to badger density (Wilson *et al.*, 1997), and habitat, soil type and slope may also affect the abundance of various badger signs (Wilson *et al.*, 2003). Where volunteers were not able to undertake bait-marking, only those data in the vicinity of the main sett were recorded.

Group size was determined either through CMR techniques or by counting badgers as they emerged from a sett. Badgers were trapped and marked using both ear tags and fur clips (Stewart & Macdonald, 1997), and remotely operated camera units were placed around the sett, allowing both marked and unmarked individuals to be sighted: total group size was then calculated using estimators applicable to mark-resight data (*sensu* Tuyttens *et al.*, 1999b). At social groups where trapping was not practicable and those studied by volunteers, group size was determined by recording numbers of individuals directly. Observers were asked to watch the main sett for a minimum of five nights, and to simultaneously watch other setts within the territory where possible. The results for each social group were then assessed and scored for quality according to criteria such as the number of evenings the sett was observed, whether other setts within the group's territory were observed simultaneously and ease of visibility of the sett. Data were scored on a scale of 1–3, with only data scoring 1 (highest quality) utilized in the analyses.

Preliminary data collected during 1998–2000 have been analysed to examine the potential of a range of field signs for predicting badger abundance, such as the number of well-used holes present at the main sett (termed sett activity). To eliminate between-landscape variation, data were stratified according to landscape type (arable, pastoral, marginal upland or upland; Bunce *et al.*, 1996); at present, there are insufficient data from marginal upland and upland regions for statistical analyses.

There was a very strong relationship between sett activity and the number of adult badgers in the arable landscape (linear regression: $r^2 = 0.96$, $P < 0.001$; Fig. 4), with 96% of variance in the data being explained by this single variable. This level of precision would be sufficient to estimate badger density in a national monitoring scheme. However, there was no significant relationship between sett activity and the number of adult badgers in pastoral landscapes ($r^2 = 0.18$, $P > 0.05$; Fig. 5).

Fig. 4. Relationship between sett activity (the number of well-used holes present at the main sett) and badger social group size (number of adult badgers) in arable landscapes (linear regression: $r^2 = 0.96$, $P < 0.001$).

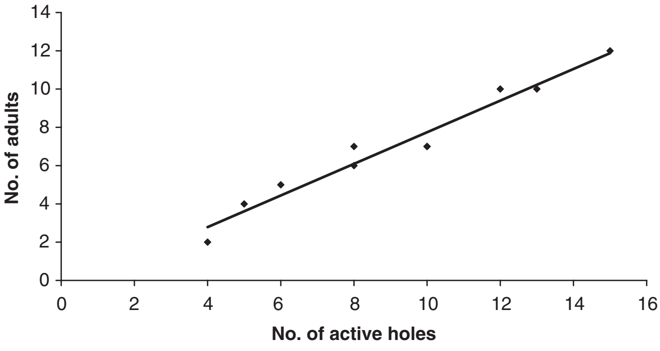
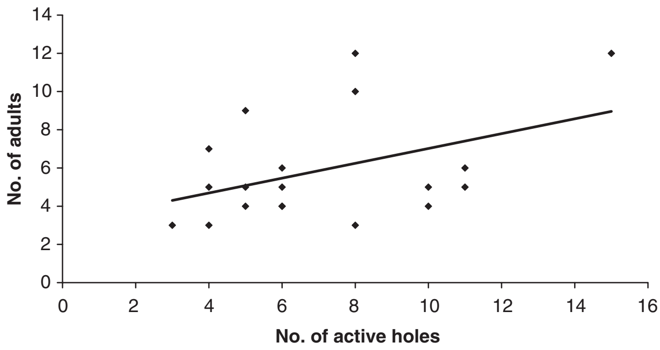


Fig. 5. Relationship between sett activity (the number of well-used holes present at the main sett) and badger social group size (number of adult badgers) in pastoral landscapes (linear regression: $r^2 = 0.18$, $P > 0.05$).



Other similar studies have also demonstrated variability in the relationship between field signs and badger numbers. For example, in the two populations studied by Tuyttens *et al.* (2001), measures of latrine activity were frequently significantly related to badger density in one population but not the other, although with some variables (e.g. latrine density) the relationship appeared stable between the two populations. Similarly, Wilson *et al.* (2003) observed seasonal differences in the relationship between badger numbers and measures of sett activity. As a whole, these studies clearly illustrate a complex relationship between sign density and badger abundance. This is likely to be due to differences in, e.g. environmental conditions and badger behaviour. Consequently, there is the need for wide-scale validation of indirect census techniques, and extrapolating from a small number of study sites is likely to be problematic.

DISCUSSION

At present, there is no single proven reliable method for monitoring changes in the absolute density of either foxes or badgers on a national scale, although badger group density is quantifiable using counts of setts. Indirect census techniques clearly offer a greater potential within the framework of the proposed national monitoring scheme for Britain, as they can be utilized within a random stratified sample from all (or nearly all) habitats, and can be readily applied by volunteers with a minimum of training. However, at present, these indirect methods can only be used to measure relative changes in animal density in the same region over time. There are few data to indicate that they can be used to compare between regions or to obtain quantifiable estimates of animal density. Therefore, further studies on populations of known size are required to qualify and quantify relationships with field sign abundance. Results of such studies conducted so far indicate that field signs may represent a means of quantifying fox and badger density, although it remains to be seen whether there is sufficient precision within field sign surveys for a national monitoring scheme, or whether a range of direct and indirect techniques will be required.

ACKNOWLEDGEMENTS

We would like to thank the Department for Environment Food and Rural Affairs (LMJS), International Fund for Animal Welfare (CCW & PJB) and The Dulverton Trust (SH) for financial support. We gratefully acknowledge the help given by members of the general public in the fox and badger surveys. The National Fox Survey was conducted by The Mammal Society: Malcolm Burgess and Lucia Galvez Bravo helped with data collection. The manuscript was improved by the comments of an anonymous referee.

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Submitted 15 August 2002; returned for revision 17 February 2003; revision accepted 26 April 2003
Editor: DY