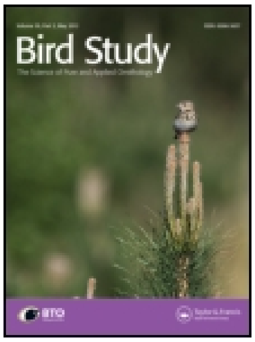

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The status of breeding Barn Owls *Tyto alba* in the United Kingdom 1995–97†

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A national survey of breeding Barn Owls was undertaken between 1995 and 1997 using intensive fieldwork methods within a stratified sample of 1100 2 × 2-km survey squares selected at random from those available. Each year, fieldwork was divided into two sessions: one to locate potential nest-sites (winter session) and one to determine occupancy of these sites (summer session). Fieldworkers spent an average of 30 hours on fieldwork within each survey square. The survey produced national population estimates of 2830 (95% confidence intervals: 1952–3761) breeding pairs for 1995, 3967 (95% CI: 2785–5252) for 1996 and 3951 (95% CI: 2769–5214) for 1997. Analysis taking account of the poor coverage in certain regions of high Barn Owl density in 1995 suggests that a population estimate of 3480 would be more accurate for that year. Regional and temporal variations in estimates were examined and interpreted in relation to Barn Owl productivity and ecology. Validation of fieldwork efficiency was carried out within a random selection of the available survey tetrads, demonstrating that fieldworkers achieved a high degree of survey reliability. This paper provides a baseline population estimate and standardized, repeatable methods, allowing future population changes to be monitored effectively.

The Barn Owl *Tyto alba* is one of the most widely distributed terrestrial bird species, occurring on all the continents except Antarctica (Taylor 1994). Despite this, the species has been in documented decline across much of its range (Colvin 1985, Shawyer 1987, van de Hut *et al.* 1992). Within Europe this decline has prompted its placement in SPEC Category 3 and listing in the UK's Red Data Book (Batten *et al.* 1990, Tucker & Heath 1994).

Barn Owls have had a long history in the UK and throughout the 18th and early 19th centuries the species was regarded as being the most common owl over much of the country (Latham 1781, Riviere 1830, Magillvray 1840). However, the Barn Owl population is believed to have begun to decline from the middle of the 19th century (Holloway 1996) prompting an ambitious survey of the breeding population to be undertaken during the 1930s (Blaker 1933, 1934). This survey was based upon a circulated request for information on breeding pairs throughout England and Wales, the results of which suggested that the breeding population consisted of around 12 000 pairs (Blaker 1933).

The decline documented by Blaker seems to have continued, becoming more general from about 1955 onwards (Prestt 1965, Parslow 1973). At the time of the British Trust for Ornithology's (BTO's) first breeding atlas (Sharrock 1976), covering 1968–72, there were estimated to be 4500–9000 breeding pairs in Britain and Ireland, although this estimate was based on an untested assumption of 2–4 pairs per occupied 10-km square (Marchant *et al.* 1990). A four-year national survey of breeding Barn Owls, initiated in 1982 by the Hawk Trust (now the Hawk and Owl Trust), estimated a breeding population of 3778 pairs in England

†A report to the British Trust for Ornithology and The Hawk and Owl Trust.

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and Wales, with a further 640 pairs in Scotland and 33 pairs in the Channel Islands (Shawyer 1987).

When this estimate is compared with that produced by Blaker, a decline of 70% over the period 1932–85 is apparent. Although the Barn Owl population has certainly suffered a major decline over this period, the precision of the measured decline is unknown because of differences in the methods used by the two surveys. Both surveys were based on requests for information from casual observers and were consequently subject to unknown regional biases in observer response. Neither survey is strictly repeatable, making it difficult to provide statistical estimates of population change over time. Despite these limitations, it is thought that the Barn Owl population within the UK has declined dramatically during the last 100 years and that this decline may be continuing (Percival 1990, Gibbons *et al*. 1993, Tucker & Heath 1994).

Various aspects of a changing agricultural landscape have been implicated in the decline including both the loss of nest-sites (van der Hut *et al.* 1992, Ramsden 1998) and suitable hunting habitat (Bright 1993, De Bruijn 1994, Toms 1994). Changing weather patterns and a major expansion of the road network have also been put forward as possible factors involved in bringing about the documented changes in abundance and range of this species (Shawyer 1987, Illner 1991, Martinez & Lopez 1995, Panks 1997). A large number of British Barn Owls are killed annually through collision with road traffic. Some 44.7% of the 1101 carcasses examined by Newton *et al*. (1997) came from road casualties, although it should be noted that the reporting rate for this type of mortality is likely to be higher than for other mortality causes (Newton *et al*. 1991). Data from the BTO's second breeding atlas demonstrated a decline in the number of 10-km squares with evidence of breeding pairs of 43% between 1968–72 and 1988–91 (Gibbons *et al*. 1993), but this estimate also suffers from uncertainty in differences in observer coverage between the two atlases.

Conservation efforts, in the form of nestbox provision, habitat protection and re-establishment have been increasingly targeted to stabilize and to increase the Barn Owl population within the UK (Shaw & Dowell 1990, Taylor 1993). Attempts have also been made to introduce captive-bred Barn Owls into areas where wild pairs have disappeared (Ramsden & Ramsden 1989). Such schemes have achieved varying levels of success, prompting an evaluation of the process of breeding and release and its subsequent control through legislative means (Andrews Ward Associates 1995).

Collectively, uncertainty over the causes of the decline, the number of breeding pairs remaining and the success of conservation efforts, meant that a new national survey was needed, both to provide a statistically precise estimate of national population size using a strictly repeatable methodology and to act as a baseline for future monitoring work. For these reasons, and because of the recommendation in 1987 by the Hawk Trust that repeat surveys be conducted every ten years, Project Barn Owl was initiated, with discussions between conservation organizations and experts in the field of Barn Owl ecology leading to the establishment of a number of specific aims. The central aim forms the basis of this paper: to carry out a repeatable survey of breeding Barn Owls in the UK, producing a baseline survey that includes a description of regional variations in population density.

METHODS

Practicalities of surveying Barn Owls

The Barn Owl is acknowledged as being a difficult species to survey accurately, mainly because it is thinly distributed over a wide geographical area and is largely nocturnal (Sharrock 1976, Bibby *et al.* 1992, Taylor 1994). Compared with other owl species, the Barn Owl is not particularly vocal, nor does it defend a clearly defined territory (Bunn *et al*. 1982). It also nests in tree cavities or buildings to which access may be difficult. During the breeding season only the area immediate to the nest-site appears to be actively defended and many nesting pairs go unnoticed, even by people living close by (Taylor 1994). This means that locating breeding pairs is difficult without intensive fieldwork.

Some Barn Owl populations, like other owls and raptors, show pronounced short-term fluctuations in abundance, driven by variations in the density of the small mammal species upon which they prey and by climatic extremes (Dobinson & Richards 1964, Madge & Tyson 1987, Hagen 1965, Hörnfeldt 1978, Village 1990, Petty & Fawkes 1997). Within Britain, the influence of small mammal fluctuations on Barn Owl populations appears to be more pronounced in areas of homogenous early-successional vegetation, for example areas of unimproved grassland or young conifer plantation (Taylor 1994, Sherratt *et al.* 2000). Such areas typically contain a species-poor small mammal community dominated by the Field Vole *Microtus agrestis* (Hansson & Henttonen 1985, Taylor 1994). These fluctuations may introduce a bias in producing an accurate and meaningful population estimate, for survey design and, in particular, survey timing. To overcome any possible bias arising from these short-term fluctuations, the survey needed to be carried out over a 3–4 year period (the length of a vole cycle).

Development of a sampling strategy and simulation studies

There are generally insufficient resources to mount a single-species survey involving complete coverage of the UK. Thus the survey design involved a random sample of survey squares, stratified to increase efficiency and precision. A range of potential sampling strategies were evaluated using a combination of computer simulation and fieldwork trials. This work was carried out during a pilot year (1994) which preceded the main survey and investigated how the number, size and distribution of sample plots could best be manipulated to maximize survey efficiency and the precision of the final estimate (Crick *et al*. 1994). Simulations were carried out using a subset of the data gathered during the Hawk Trust's 1982–85 national survey (Shawyer 1987). This subset was taken from the 100-km square SE (SE00–SE99) located in Yorkshire, northeast England, and was considered to be representative of a moderately populated area. Ten of the 100 10-km squares were excluded from the data set because they represented areas that had been intensively studied during the 1982–85 survey and within which intensive nestbox studies were being carried out. Full details of the simulation process are presented elsewhere (Crick *et al*. 1994).

A bootstrapping technique (Efron & Gong 1983, Efron & Tibshirani 1986) was employed to establish which size of sample plot provided the smallest confidence intervals around the calculated estimate. The bootstrapping approach was used to overcome the heavily skewed (non-normally distributed) nature of the sample data set. The confidence intervals obtained using randomly selected 5-km squares, tetrads (2 × 2-km squares) and 1-km squares were similar, given the same total area covered. These results suggested that the choice of an appropriate size of sample square could be based purely on the practicalities of what could be surveyed by observers in the field, i.e. that the size of the sample square is immaterial. Further simulations demonstrated that grouping subsamples of 1-km squares or tetrads within random 10-km squares provided larger confidence intervals than those obtained by sampling 1-km squares or tetrads completely randomly without grouping them within 10-km squares.

Evaluation of potential stratification methods was carried out using computer simulation and the data set for England and Wales from the 1982–85 survey (Shawyer 1987). This work showed that a stratification based on Barn Owl data from the two BTO breeding atlases maximized sampling efficiency and survey precision through the application of three strata. The greatest survey effort would be directed to squares where Barn Owls had been found in both atlas surveys and the least effort to squares where they had not been found for either atlas. The simulations using tetrads (the chosen size of survey square) showed that *c*.1100 tetrads would be needed to achieve confidence intervals of 20–25% around the population estimate. Such confidence levels would be similar to those obtained for a range of other single-species surveys (Bibby & Etheridge 1993, Donald & Evans 1995, Hancock *et al*. 1997). The confidence intervals from an estimate of change in numbers in future years would be substantially narrower than those for a one-off estimate of numbers, given that the same survey areas were used in both surveys.

The distribution of the 1100 survey tetrads is shown in Fig. 1 according to stratum, and in Table 1 according to stratum and country. Some tetrads fell in areas that were totally unsuitable

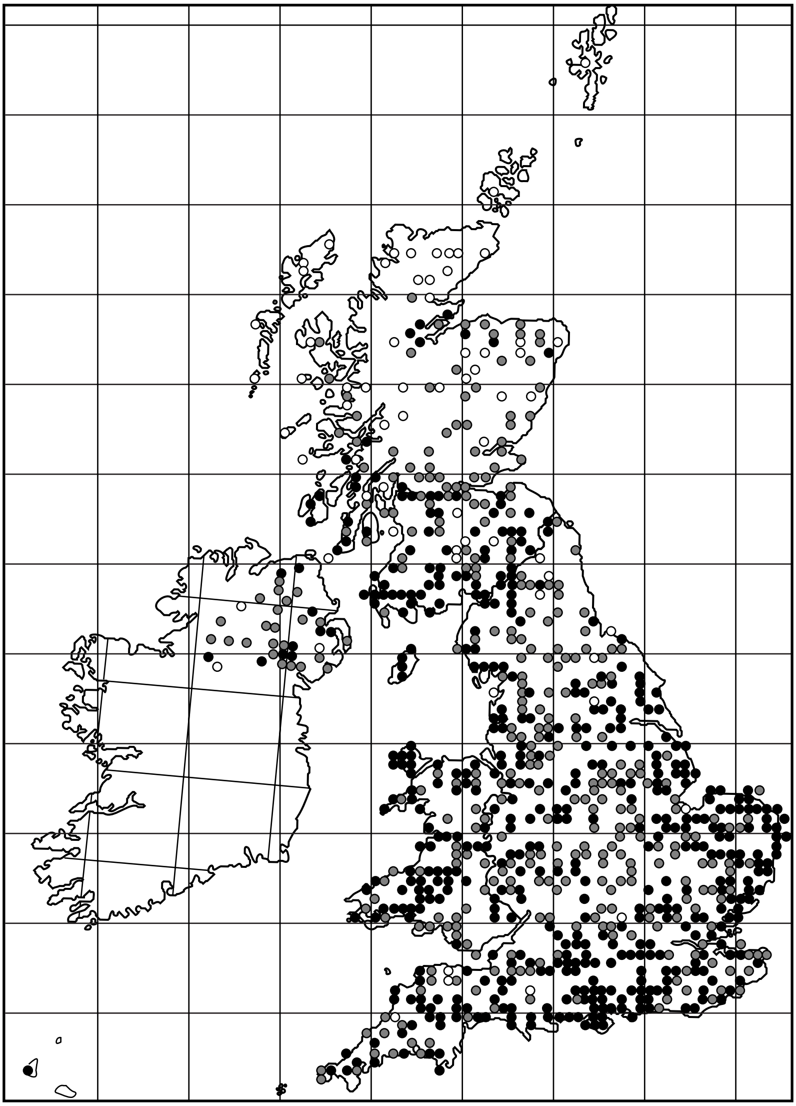

Figure 1. Distribution of the 1100 survey tetrads shown at the 10-km square level according to stratum. Each 10-km square may contain one or more survey tetrads. White dots, stratum 0; tinted dots, stratum 1; black dots, stratum 2. Stratum 0, no breeding Barn Owls found in either Breeding Bird Atlas survey; stratum 1, breeding Barn Owls found in one or other of the two Breeding Bird Atlas surveys; stratum 2, breeding Barn Owls found in both Breeding Bird Atlas surveys.

for Barn Owls, because they were positioned in wholly urban areas or at too high an altitude on open moorland. In such cases, these tetrads were placed in a 'zero class' following liaison with local co-ordinators and/or one year's fieldwork. These tetrads were not visited in subsequent seasons and were assumed to contain no breeding pairs for the purposes of population estimation.

Fieldwork methods

Fieldwork was carried out over three years (1995–97) to allow for the short-term fluctuations in Barn Owl productivity. Project fieldworkers were asked to visit their tetrads twice in the first and last years of the three-year survey period and once during the second year. During the first visit (carried out between November and January and termed 'winter

Table 1. Distribution of survey tetrads according to stratum and country. Stratum 0, no breeding Barn Owls found in either Breeding Bird Atlas survey; stratum 1, breeding Barn Owls found in one or other of the two Breeding Bird Atlas surveys; stratum 2, breeding Barn Owls found in both Breeding Bird Atlas surveys.

	Stratum			
Country	0	1	2	Total
England	14	257	427	698
Northern Ireland	3	30	17	50
Scotland	53	91	91	235
Wales	0	37	80	117
Total	70	415	615	1100

fieldwork') fieldworkers were instructed to record all potential Barn Owl nest-sites within their survey tetrads. These were sites that the fieldworkers considered potentially suitable for use by breeding Barn Owls, including farm buildings, tree cavities, bale stacks, cliff sites and nestboxes. The timing of the winter fieldwork was set to facilitate the location of tree cavities, when leaves were absent, and to reduce the risk of disturbing breeding Tawny Owls *Strix aluco*.

Detailed instructions, in the form of specially prepared information sheets, provided fieldworkers with the means to recognize and correctly record the various types of potential nest-sites they were likely to encounter. Such information was further supplemented by a series of regional training workshops aimed at providing fieldworkers with field experience of different site types. The successful application of the information sheets was evaluated annually by examining survey responses and data collected during the validation visits on the way in which observers were recording different types of sites. Fieldworkers were instructed to search the whole of their survey squares, recording all potential nest-sites. The locations of potential sites were recorded on 1:25 000 scale maps enabling fieldworkers to locate the sites when they returned during the summer to determine occupancy.

Second fieldwork visits (termed 'summer fieldwork') took place between mid-June and the end of August. Fieldworkers were instructed to determine the occupancy of all the potential nest-sites they had located during the winter component of the survey work. By June the majority of breeding Barn Owls are at the late incubation or early nesting stage (Bunn *et al*. 1982) and the length and timing of the summer fieldwork was targeted to maximize the probability of detecting breeding pairs. Early breeding attempts that failed may have been missed because of the timing of fieldwork. However, pairs that fail early in the season may fairly frequently lay a replacement clutch (Bunn *et al*. 1982). In addition to this, the running of the survey over a three-year period, with production of separate estimates for each year, will also have reduced the effects of any potential biases associated with pairs that fail early. Decisions on whether breeding attempts were replacement clutches or second broods were taken on an individual basis following discussions with the fieldworkers concerned. Any bias introduced at this stage is unlikely to be systematic and, in the event, there were only a small number of nesting attempts (1.5%) that needed to be questioned as to whether they represented second or replacement nesting attempts.

Fieldworkers were under instruction to minimize disturbance to breeding birds, and fieldwork was structured so as to ensure that potential nest-sites were only searched (under licence from the appropriate national conservation agency) if no evidence of breeding was readily apparent from a site watch. Site watches, tested during the pilot year, involved the fieldworkers watching from a vantage point at dusk to establish whether adult birds were consistently bringing food to the site or young birds were making begging calls. Both were taken as confirmation of breeding and no further searches were made at such sites. If breeding was not evident from the site watch then fieldworkers actively inspected the site, searching for evidence of breeding birds. Records received were examined to determine whether breeding had definitely taken place. Where there was any doubt about the data received, further clarification was sought from the fieldworker. Records were classified into four types. (1) Confirmed breeding: breeding was proven to have taken place, as demonstrated by the presence of young (seen or heard) or eggs, or by adults regularly seen taking food into a potential nest-site.

(2) Possible breeding: from the information supplied (initially and during follow-up correspondence) it was not possible to establish fully whether breeding had definitely taken place, but available evidence suggested that it may have done so. These records included birds seen taking food into a site on a single occasion or second-hand reports that could not be substantiated by the fieldworker. (3) Roosting: a single bird or pair of birds found to be occupying a site within which no evidence of breeding could be found. These records typically referred to single birds and came from sites near to those at which breeding had been confirmed. Males will roost close to the breeding site at various stages during the nesting period (Bunn *et al*. 1982). (4) Breeding status unknown: breeding status could not be established on the basis of the information supplied. This included a handful of records where fieldworkers stated that breeding had taken place but were unable to provide any supporting evidence. All fieldwork was carried out under licences issued subject to Schedule 1 of the Wildlife and Countryside Act 1981.

Validation of the fieldwork undertaken during the course of the project was carried out by the Project Officer (MPT) who made visits to *c*. 6% of the tetrads selected for survey. During these validation visits the Project Officer carried out intensive fieldwork within selected tetrads to locate all potential nest-sites and to determine their occupancy. These visits were made without prior knowledge of the tetrads, enabling potential biases to be examined and quantified (see Results). The purpose of the validation visits was to compare results between observers and to provide an estimate of the proportion of owls detected. This required the not unreasonable assumption that the Project Officer could find every breeding pair of owls within each of the tetrads being validated. During validation, detailed notes were made of the location of all potential nest-sites and all sites noted during validation visits were classified as follows. (a) Suitable – the site was considered by the Project Officer to be suitable for breeding Barn Owls. The presence of the site should definitely have been recorded by the fieldworker. (b) Possible – the Project Officer considered that breeding Barn Owls could have used the site, but it was not ideal. Fieldworkers should have recorded the presence of these sites. (c) Unlikely – the site was not considered by the Project Officer to be suitable for nesting Barn Owls, but its presence may have been recorded by the fieldworker. This category included cavities that appeared suitable from the ground, but which on closer inspection using a ladder, proved to be too small.

Classifying potential sites in this manner enabled the Project Officer to identify whether fieldworkers were correctly recording sites of different types and to make improvements to the survey guidelines if required. Such comparisons were made on a tetrad-by-tetrad basis to determine which sites were being recorded by fieldworkers and which were being missed.

Calculation of national estimates and confidence intervals

An estimate of the number of breeding pairs in each of the three strata was calculated independently for each year of the survey. This was possible through knowledge of the sampling intensity within each stratum (in a given year) and of the number of breeding pairs found during fieldwork for that year. The estimates derived for the three strata were then summed to produce a national estimate of the number of breeding pairs. As the data were not normally distributed, a bootstrapping procedure was used to calculate the confidence intervals[a] (Efron & Tibshirani 1986, Greenwood 1991). All analyses and calculations were carried out using SAS software (SAS Institute Inc. 1996).

The effects of reduced levels of coverage in some regions on the resulting national population estimates were investigated using a Jackknife approach (Efron & Gong 1983) in which we substituted independent survey data for counties with poor coverage. A Jackknife was applied to the data sets from each of the three survey years by removing covered squares from those regions with poor coverage.

A second Jackknife was employed to examine the validity of using independent data from local surveys to support national surveys. For this we used a reduced data set, excluding from the national data set all the squares from poorly covered regions (those regions used in the initial Jackknife). The second Jackknife was then applied to the data sets from each of the three survey years by omitting surveyed squares from several regions with good coverage and matching independent local population estimates. Recalculation of the national estimate and addition of the local independent estimates produced the final Jackknife estimates.

RESULTS

Coverage and fieldwork effort

Of the 1100 survey tetrads chosen, 261 (20%) were considered unsuitable for Barn Owls and were assigned as 'zero class' tetrads. These fell disproportionately into Scotland, which contains large areas at high altitude. Eight hundred and eighty-nine tetrads (81%) were covered at least once during the survey period, with 453 tetrads (41%) visited during three summer sessions and a further 148 tetrads (14%) during two summer sessions. Differences in coverage between strata were examined by excluding 'zero class' tetrads from the data set and then looking at the number of sessions completed for a given stratum. Total coverage levels were found to be similar across strata and no significant difference could be found ($\chi^2 = 4.492$, df = 2, ns).

Levels of coverage varied significantly between the eight project areas ($\chi^2 = 52.2$, df = 7, $P < 0.01$) with more sessions completed than expected in central and southern England and fewer in southern Scotland (Table 2). These differences were mainly due to differences in the density of fieldworkers across areas, together with variations in the accessibility of individual tetrads.

Table 2. Levels of coverage achieved for Project Barn Owl tetrads according to region. Each non-zero class tetrad should have been covered in five fieldwork sessions over the course of the project (in the winters of 1995 and 1997, and the summers of 1995, 1996 and 1997).

Area	Number of sessions available	Number of sessions completed	Coverage achieved (%)
Southwest England	550	228	41.5
Southern & central England	1260	671	53.3
East Anglia	615	275	44.7
Northern England	590	244	41.4
Wales	415	178	42.9
Southern Scotland	355	133	37.5
Northern Scotland	220	106	48.2
Northern Ireland	190	74	38.9
Total	4195	1909	45.5

The survey results could be biased if coverage had not been consistent over the course of the survey. In order to test for such bias we investigated whether fieldworkers were more likely to drop out of the survey if they failed to locate Barn Owls. We compared the continuation rates between sessions for fieldworkers with breeding Barn Owls with those who did not find owls. This analysis revealed continuation rates for 1995 to 1996 of 61% for fieldworkers with owls and 66% for those without owls. Rates for 1996 to 1997 were 64% and 71% respectively. None of the differences were found to be significant ($\chi^2 = 0.232$, df = 1, ns for 1995–96; $\chi^2 = 1.023$, df = 1, ns for 1996–97), suggesting that the presence of breeding Barn Owls did not influence the likelihood of a fieldworker continuing with the project in a subsequent season.

Fieldwork effort is also a potential source of bias and needed to be investigated. Each fieldworker spent, on average, 30 hours carrying out fieldwork during the course of the project (Fig. 2). Median times spent on fieldwork differed among the six fieldwork sessions (Kruskal–Wallis test $\chi^2 = 51.79$, df = 5, $P = 0.0001$), although there were no significant differences between the summer sessions (Kruskal–Wallis test $\chi^2 = 2.56$, df = 2, ns). This consistency in fieldwork effort across the summer sessions strongly suggests that the likelihood of breeding owls being found did not change as the project progressed. Within individual years, fieldworkers spent more time on winter fieldwork than on summer fieldwork during 1995 and 1996, when they were familiarizing themselves with their survey squares, but in 1997 this was reversed. There were no significant differences in the time spent on fieldwork for tetrads with or without a pair of Barn Owls, suggesting that those who found owls did not work 'harder' than those who did not (Table 3).

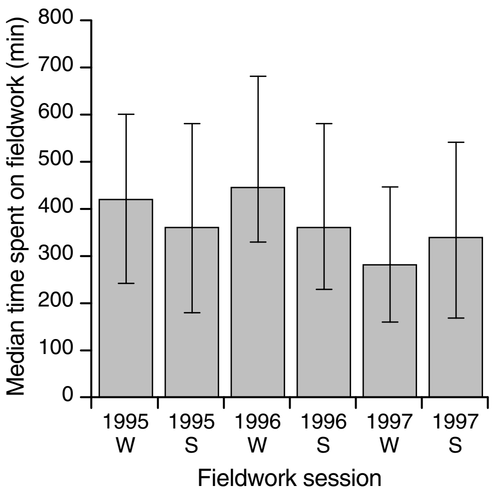

Figure 2. Median time spent on fieldwork by project field-workers with respect to session (W, winter; S, summer). Bars show interquartile ranges.

Validation work

Sixty-one of the 1100 survey tetrads received validation visits by the Project Officer during the project. The validation work showed that fieldworkers were able to identify 92% of 'suitable' sites and 84% of 'possible' sites. The figure for 'unlikely' sites was 46%, reflecting the value judgements made by the Project Officer during validation about which sites a fieldworker might record. No breeding Barn Owls were missed by fieldworkers whose tetrads were validated. Overall, the results supported a high level of confidence in fieldworker ability and demonstrated the value of providing fieldworkers with detailed instructions and practical training.

Population estimates

A total of 133 Barn Owl breeding attempts were recorded from 82 tetrads during the three years over which the fieldwork took place. Two squares were found to hold three pairs in at least one session and five squares held two pairs. Of the 133 confirmed breeding attempts, 105 (79%) were in England, 16 (12%) in Scotland and 12 (9%) in Wales. No breeding pairs were recorded within survey squares in Northern Ireland or on the Channel Islands. One hundred and one (76%) of the attempts were from stratum 2 and 32 (24%) were from stratum 1. Importantly, no breeding attempts were recorded in stratum 0 tetrads.

National population estimates based on records of confirmed breeding attempts are shown in Table 4. Second broods or replacement clutches by pairs (which can often take place at different sites to the first) were excluded from the calculations. The confidence intervals produced, at around ±30%, were wider than those predicted from the pre-survey simulation work, but were consistent with the level of coverage achieved. In addition, only data for England and Wales were available for the simulation process and wider confidence intervals may be due to the increased variance within the data set from the inclusion of data from Scotland, Northern Ireland and the Channel Islands.

The difference between the estimate produced for 1995 and those for 1996 and 1997 probably results from poor coverage during the early stages of the project within a number of regions known to be important for Barn Owls. A Jackknife approach allowed the recalculation of national estimates that did not include

Table 3. Time spent on summer fieldwork in tetrads where breeding Barn Owls were found and in tetrads where they were not.

Year	Breeding Barn Owls found	*n*	Time spent (min): Median	Time spent (min): Interquartile range	Mann–Whitney test results
1995	No	308	352	198–565	$U = 0.021$, $P = 0.88$
	Yes	30	375	180-–570	
1996	No	271	360	210–570	$U = 0.51$, $P = 0.47$
	Yes	36	325	158–592	
1997	No	237	330	180–525	$U = 0.96$, $P = 0.33$
	Yes	37	360	210–615	

Table 4. Barn Owl population estimates derived from Project Barn Owl survey work, 1995–97. Stratum 0, no breeding Barn Owls found in either Breeding Bird Atlas survey; stratum 1, breeding Barn Owls found in one or other of the two Breeding Bird Atlas surveys; stratum 2; breeding Barn Owls found in both Breeding Bird Atlas surveys.

Year	Stratum	Number of confirmed breeding pairs	Number of squares surveyed	Total number of squares available	National estimate of breeding pairs	Confidence limit	
						Lower	Upper
	0	0	58	18 119			
1995	1	8	243	23 617	2830	1951	3761
	2	30	346	23 669			
	0	0	58	18 119			
1996	1	11	219	23 617	3967	2785	5252
	2	39	332	23 669			
	0	0	52	18 119			
1997	1	13	208	23 617	3951	2769	5214
	2	32	306	23 669			

Table 5. The effects of coverage on the national population estimate as revealed by a Jackknife approach (see text for details). Run number 1 used Devon, Cornwall, Cumbria, Shropshire, Somerset, Dumfries; the ratio of squares from these regions within strata 0:1:2 = 4%:35%:61%. Run number 2 used Hampshire, Oxfordshire, Sussex; the ratio of squares from these regions within strata 0:1:2 = 1%:33%:66%.

	1995	1996	1997
Jackknife run number 1			
Estimate from Jackknife	3480	4522	4175
National estimate	2830	3967	3951
Difference (%)	+23%	+14%	+5%
Jackknife run number 2			
Estimate from Jackknife	2550	3576	3332
National estimate	2490	3832	3485
Difference (%)	+2%	–7%	–4%

regions with poor coverage (Cornwall, Cumbria, Devon, Dumfries, Shropshire and Somerset). To each estimate were added recent, independent county-specific estimates from the corresponding regions: recent estimates for Dumfries and Somerset were not available and data from the 1982–85 survey had to be used instead (Table 5).

Confidence intervals for the recalculated estimates (prior to the addition of local figures) were only slightly larger than those obtained from the full data sets. The final Jackknife estimates were all higher than those derived from the full data set (1995: +23%; 1996: +14%; 1997: +5%), suggesting that poor coverage in these key areas during the initial years of the project may have led to an underestimation of the true population size. All Jackknife estimates were within the confidence limits of the original national estimates. The national estimate for 1995 would perhaps be nearer to 3500 pairs if high-density areas in Devon, Cornwall, Dumfries and Somerset had been adequately surveyed.

The results of the second Jackknife, used to examine the validity of using independent data from local surveys to support national surveys, produced similar national population estimates to those derived from the full data set (1995: +2%; 1996: –7%; 1997: –4%). This demonstrates that data from independent surveys, if available, could be used to support the calculation of national estimates where some areas suffer from poor coverage.

Both temporal and spatial differences in the national estimates were apparent (Table 6), with the former supporting anecdotal observations from local Barn Owl fieldworkers. These suggestions that Barn Owl populations in the south and east of England had a good

Table 6. Regional densities calculated for Barn Owl breeding pairs derived from Project Barn Owl survey data, 1995–97. Density is shown as the number of breeding pairs per 10-km square, calculated from regional population estimates using the same procedure as for the calculation of national estimates.

Region	Breeding densities recorded during Project Barn Owl 1995	1996	1997	Density estimate derived from Shawyer (1987)	Density estimates derived from recent local survey work including region and source
Southwest England	3.06	3.37	4.50	4.34	4.40 Devon (Grant *et al.* 1994a) 4.00 Cornwall (Grant *et al.* 1994b)
Southern & central England	1.42	3.15	2.30	2.65	3.84 Sussex (Sandison 1981, James 1996) 4.47 Hampshire (Clarke & Eyre 1993) 0.72 Hertfordshire (Smith *et al.* 1993) 1.15 Bedfordshire (Trodd & Kramer 1991)
East Anglia	4.05	5.60	4.55	3.08	–
Northern England	0.72	0.53	0.95	1.48	0.54 Northumberland (Day *et al.* 1995)
Wales	0.74	2.24	1.82	2.68	–
Southern Scotland	2.40	0.79	1.62	–	–
Northern Scotland	–	0.26	0.30	0.68	–
Northern Ireland	–	–	–	–	–

breeding season in 1996 but a poor one in 1997, and that the reverse was true in Scotland and northern England were consistent with our findings (Fig. 3). Analysis of BTO Nest Record Scheme data provided additional evidence of regional differences in productivity (Table 7): 1996 was a good year in England, with large clutch and brood sizes and high nest success, although Scotland suffered from low brood sizes; while 1997 was a good year for Scottish birds, but a relatively poor one in England and Wales.

The regional density estimates shown in Table 6 are expressed as the number of breed-

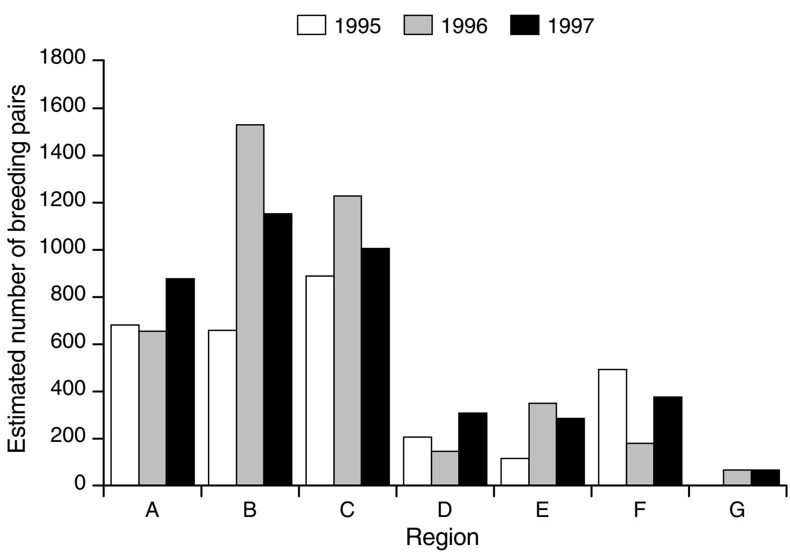

Figure 3. Regional estimates of numbers of pairs of breeding Barn Owls for the three survey years. The regions marked A–G are: A, southwest England; B, southeast & central England; C, East Anglia; D, northern England including the Isle of Man; E, Wales; F, southern Scotland; G, northern Scotland.

Table 7. Comparison of mean brood sizes in four regions of the UK derived from an analysis of Nest Record Scheme data. Sample sizes are shown in brackets.

Region		1995	1996	1997
Southwest England		3.42 (38)	4.18 (65)	4.00 (1)
Southern & central England and East Anglia		3.80 (26)	4.07 (42)	3.04 (53)
Northern England & Wales		2.83 (24)	3.33 (12)	3.14 (35)
Scotland		2.69 (65)	2.88 (24)	4.05 (81)
Kruskal–Wallis	χ^2_3	16.80	22.83	24.65
	P	0.0001	0.0001	0.0003

ing pairs per 10-km square, calculated over the area surveyed within each region (for the purposes of the regional analysis the UK was divided into eight regions: southwest England, south & central England, East Anglia, northern England, Wales, southern Scotland, northern Scotland and Northern Ireland). Regional population estimates were calculated using the same approach as that adopted for calculation of the national estimates and it was these estimates upon which the density estimates are based. The results show the relative importance of southwest England, southern England and East Anglia. However, these regional estimates hide much of the local variation within regions: for example, much of southern Scotland is unsuitable for Barn Owls, so the densities in occupied squares are likely to be much higher than suggested by the regional means given in Table 6.

DISCUSSION

Survey design

The current study demonstrates that it is possible to undertake a national survey of a species perceived to be difficult to study, and to produce statistically precise estimates in a repeatable manner. It has proven possible to cover a large number of survey squares and to involve volunteer fieldworkers in demanding fieldwork across a wide range of landscapes, while maintaining statistical precision. The reliability of the method was also tested through the validation of work carried out during the course of the study, with fieldworkers seemingly able successfully to identify and to record potential Barn Owl nest-sites and to determine their occupancy. Rigorous evaluation of the survey methods during the pilot year, using field trials and computer simulation, has further ensured that the methods employed have been reliable and appropriate. The novel approach adopted, involving the use of training workshops for volunteers, detailed documentation and supporting validation visits, has been one of the strengths of this study. Consideration should be given for more widespread use of training workshops for studies of this type: fieldworkers are likely to increase their proficiency having attended workshops and there is the additional benefit of increased feedback to survey organizers and improved commitment to the study.

Population estimates

Allowing for the temporal fluctuations in the number of breeding pairs detected, the results from the three survey sessions suggest a Barn Owl population in the order of 4000 pairs (±1000). This estimate is slightly lower than that of 4457 pairs produced by the Hawk Trust during their 1982–85 survey (Shawyer 1987), although the latter estimate is within the confidence intervals produced by the current work. This might suggest that the population is now stable and that the decline witnessed this century has been halted. However, the Hawk Trust survey involved the amalgamation of breeding records over a three-year survey period. The results of the current survey, together with the findings of other recent studies (Taylor 1994), demonstrate that local Barn Owl populations fluctuate out of synchrony and that in any one year, the total breeding population will be less than the sum of the sites occupied over three years. It would, therefore, be inappropriate to make comparisons between the two surveys because of the different methods employed, particularly given the way in which the national estimates were calculated.

Because of this, there are no national data from which it is currently possible to quantify recent population changes. The species is not monitored effectively by any of the long-term schemes recording population trends in UK bird species. Some unpublished local studies point towards a continued decline in recent years, while others suggest a population increase following the application of various conservation measures. The design of the current survey, with its emphasis on statistical precision and repeatability, provides the baseline estimate required to allow future changes in Barn Owl populations to be determined.

Barn Owl populations across much of Europe have been in decline during recent decades, with declines of over 50% reported in seven countries and of 20–50% in a further 13 (Tucker & Heath 1994). The bulk of the European population is now found in Spain (50 000–90 000 pairs), France (20 000–50 000 pairs), Germany (5000–15 000 pairs) and Italy (6000–12 000 pairs) (Tucker & Heath 1994). The UK population is important, representing 1.9–4% of the wider European population and more than 5% of the race *alba*. However, this could underestimate the importance of the UK population because no other European country has been surveyed as rigorously as the UK. The estimates from other European countries are largely based on expert opinion, often from previous decades and with unknown accuracy. Given large-scale changes to agricultural systems in southern Europe in recent years (Pain & Pienkowski 1997) substantial declines in Barn Owl populations are possible, but could have largely gone unnoticed. Similar surveys to the 1995–97 UK survey are urgently needed elsewhere in Europe.

The interannual variations in the number of breeding pairs recorded by the current survey support the decision to carry out fieldwork over a three-year period rather than during a single field season. Annual changes in the number of breeding pairs have been shown to be related to the abundance of prey, rather than directly to any weather variables (Taylor 1994). Taylor found very few non-breeding owls in his southern Scotland study area during years of high prey abundance, whereas in years of low prey abundance substantial numbers were found (Taylor 1994). Interannual fluctuations in the regional estimates generated by the current study match those from Nest Record Scheme data (Table 7) further highlighting the potential influence of short-term fluctuations in the number of breeding pairs on national estimates based on a single year of studies.

Of the regional density estimates produced by the current study only that for East Anglia is consistently higher than that derived from the Hawk Trust data (Table 6). Major conservation efforts have been directed in this region over the last 12 years and noticeable increases in populations have recently been reported in Norfolk and Lincolnshire (Johnson 1990, Shawyer 1998). Organochlorine pesticides are thought to have been an important cause of mortality in eastern England during previous decades and a ban on their use may have contributed to the recent population increases (Newton *et al*. 1991). The main populations in East Anglia are centred on the Norfolk Broads, Breckland, the Fens and the north Norfolk coast (Seago 1977, Johnson 1989, Taylor *et al*. 1999).

The design of the current survey prevents the production of regional estimates for the smaller regions (Northern Ireland, Jersey and Guernsey). A significant number of additional survey squares would have been needed in these regions to allow regional estimates to be produced. Although there are currently no data available for Northern Ireland, there are population estimates for the Channel Islands (Malcolm Smith pers. comm.). These are shown in Table 8 along with the corresponding figures from the Hawk Trust survey.

The results of the current work provide a baseline population estimate and a standard methodology by which future changes in the Barn Owl population might be monitored. A baseline estimate is extremely important, providing a yardstick against which the effectiveness of current and future conservation measures can be assessed, and enabling realistic targets to be set as part of conservation action plans for this species (e.g. the RSPB Species Action Plan for Barn Owl that provides a target for an increase in population size of 50% by 2010).

The development of this standardized sur-

Table 8. Number of breeding pairs reported during the Hawk Trust survey (1982–85) and Project Barn Owl (1995–97) from the Channel Islands.

Island	Hawk Trust data	Project Barn Owl Malcolm Smith
Jersey	9	55
Guernsey	13	20
Alderney	6	3
Herm	–	1
Sark	4	0
Total	39	79

vey methodology will enable a repeat survey to be carried out in ten or 15 years' time (or whenever appropriate), using the same techniques and study sites. While such regular, systematic surveys are necessary for monitoring purposes they do not, by themselves, reveal the processes governing the population changes or which section of the population is being affected. A co-ordinated annual monitoring programme gathering data on demographic parameters may provide some indication of the ultimate environmental causes driving population change (the development of such a programme was examined as a secondary aim of the current project) (Toms 1997). However, specific studies are required if we are to determine exactly how environmental factors such as food or nest-site availability influence population change, alongside which the additional influences of density dependence may act.

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ENDNOTES

a. Because the data used to calculate the population estimates did not fit a normal distribution, a bootstrapping procedure was employed to generate the confidence intervals (Efron & Gong 1983, Efron & Tibshirani 1986). This is a technique that has been widely used in the calculation of confidence intervals for population estimates of birds since it makes no *a priori* assumptions about the underlying distribution of the samples. The technique is particularly useful in overcoming the effects of having a large number of 'zero' values within the data, representing survey squares within which no breeding owls had been found.

The bootstrapping procedure involved the random selection with replacement of n survey squares from stratum x, where n is the number of survey squares within stratum x actually covered during the session for which the estimate is being calculated. A stratum-based population estimate was then derived for the n-selected survey squares using the same method as employed for the actual survey data. This process was repeated for each of the three strata defined for this survey and the resulting stratum-based estimates were combined to produce a simulated national population estimate. In total, this process was repeated 9999 times to produce a sample of 9999 simulated national estimates based on the original data. Once these had been ranked by size it was possible to produce the 95% confidence intervals for the actual population estimated, calculated as the 2.5 and 97.5 percentiles of the distribution of the simulated values.

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