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Developing methods for the field survey and monitoring of breeding Short-eared Owls (*Asio flammeus*) in the UK: an interim report from pilot fieldwork in 2006.

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EXECUTIVE SUMMARY

1. The Short-eared Owl (*Asio flammeus*) is listed on Annex 1 of the EU Wild Birds Directive as a species considered vulnerable in Europe and is a qualifying species for six classified Special Protection Areas (SPA) in the United Kingdom. There is a need to determine accurate and precise population estimates for the species within designated SPAs in the UK, and for national surveys of the Scottish, and other UK populations. A previous review commissioned by SNH (Calladine *et al.* 2005) concluded that there was inadequate information with which to assess reliably the conservation status and requirements of breeding Short-eared Owls, or from which to make recommendations for suitable survey techniques. The species has been little studied previously, mainly due to its apparent nomadic nature (apparent large interannual population fluctuations, which may not be synchronised spatially) and the remoteness of much of its breeding habitat.

2. This interim report documents the findings of fieldwork carried out during the 2006 breeding season to test approaches for surveying breeding Short-eared Owls. A final report with fuller recommendations will follow after the 2007 breeding season. The main objectives in 2006 were:
   - to assemble any outstanding information on Short-eared Owl breeding behaviour and population survey data that might inform the design of pilot survey work and future full surveys;
   - to identify the most appropriate times of day and dates of season for surveying breeding Short-eared Owls and to translate the findings into feasible survey protocols;
   - to carry out observations to assist in the differentiation of separate breeding territories and to translate these findings into feasible survey and analytical protocols; and
   - to evaluate the feasibility of, and encounter rates resulting from, more extensive field surveys suitable for volunteers, as a means of monitoring interannual variation in population size for Short-eared Owl (and which might contribute monitoring data for a range of other bird species in upland and marginal upland habitats).

3. Both intensive observations (vantage point watches) and extensive surveys (point counts from road transects) were made in three areas of Scotland in 2006: the Borders, Perthshire and Ayrshire. In each study area, watches, each of two hours duration, were made from four vantage points at least once in each of four survey periods through the breeding season, and within these in each of four times of day (two sampling periods in the first five hours after first light, and two sampling periods in the last five hours before dark). All observations of Short-eared Owls were recorded, together with details of their behaviour and their flight lines. These observations were analysed to assess: (a) whether the durations for which owls were visible (and those in which they displayed key behaviours indicative of territory holding) varied with time of day or stage of the breeding season; (ii) the distances at which owls could be detected from observers; and (iii) minimum ranging distances of the owls during the breeding season. Within, or close to, each of the three study areas, two 'transects' were selected, each a series of roads or tracks that crossed habitat potentially suitable for breeding Short-eared Owls. Along each transect, between 14 and 21 suitable count points were identified, with a minimum distance of 1-km between count points. Each transect was surveyed once in each of the four stages of the breeding season, within the last three hours before dark. Timed counts (five minutes at each point) were made, to record all bird species seen or heard (which were recorded in one of five distance bands from points).

4. Overall, 186 individual observations of Short-eared Owls were made; these indicated that the proportion of time for which owls were visible during the hours of the day that were sampled was low: a median of only 2 minutes per hour of observation (9-95% percentiles = 1-13 minutes per hour). For all observations of Short-eared Owl activity combined, there were no statistically significant effects of either time of day or stage of breeding on the duration of time for owls were visible. There was some suggestion of lower Short-eared Owl activity early in the season (first 3 weeks of March) and slightly higher activity in the second two-hour period of the first five hours after first light.

5. Key behaviours indicative of territoriality were observed very rarely: there were only 43 discrete observations of Short-eared Owls that included such activities (median duration of observations including key behaviours per hour of observation was zero; 95% percentile=12 minutes). Because of the rarity of these territorial activities, the influence of time of day and season on the duration of these behaviours could not be analysed formally. A visual assessment provided some suggestion that territorial activity may be more evident in the morning than in the evening, and in the second and fourth periods of the breeding season (18 April-15 May and 1-28 July).

6. Across all 10 vantage points from which owls were seen, the mean distance from an observer at which Short-eared Owls were first detected was 522 m (95% confidence limits: 473 – 570 m; range: 172 – 825 m across vantage points), and did not vary significantly with period of the breeding season or time of day. The mean closest approach distance of Short-eared Owls to observers was 399 m (range 103-713 m across vantage points) and the mean maximum distance at which they were observed was 656 m (range 268-886 m across vantage points).

7. The flight lines of Short-eared Owls observed at each site were grouped into ranges (using territorial interactions to differentiate ranges when available). The numbers of ranges visible from each vantage point were consistent with the views of local independent raptor workers when these were available. At all but one vantage point, the observations made during the 2006 breeding season were thought to refer to a single territory. The mean minimum ranging distance, estimated as the maximum arc of the minimum convex polygons drawn around the plotted flight lines, was 1368 m (SE = 128 m). No significant influence of stage of the breeding season on the minimum ranging distance was detected.

8. Fourteen registrations of Short-eared Owls were made during the 12 evening point count surveys from the extensive transects (four each during the first and second survey periods, six during the third survey period and none during the fourth period). A further 67 bird species were recorded during the surveys (Table 7). The encounter rates from the small sample of transects covered suggested that the method could produce useful information for breeding population indexing purposes for a range of species, including a number of breeding waders (e.g. Curlew, Lapwing, Redshank, Snipe and Oystercatcher), two widespread raptors (Buzzard and Kestrel), some gamebirds (e.g. Pheasant, possibly Black and Red Grouse) and a range of passerines (e.g. Meadow Pipit, Pied Wagtail, Reed Bunting, Skylark). Five species were encountered sufficiently frequently to allow formal estimation of population densities from the data collected in 2006: Curlew, Lapwing, Oystercatcher, Meadow Pipit and Skylark. For the majority of species, including Short-eared Owl, the second two survey periods (mid-April to mid-May and 1-22 June) are likely to provide the most appropriate choice for carrying out such extensive survey work: encounter rates in these periods were generally high, and surveying in this middle part of the breeding season would reduce the complications associated with flocking birds (most of which were unlikely to be on territory).

9. We discuss in some detail, bringing in the views of the Project Partners and other local experts, whether the 2006 breeding season was representative in terms of the timing of breeding (given the cold and snowy conditions in early spring). We also discuss whether the owls in the three study areas sampled in 2006 can be taken to be broadly representative of Short-eared Owls across Britain in the context of the parameters that we set out to measure in the current study.

10. A number of recommendations are made concerning further development of the work in the 2007 breeding season, which will be required before field protocols for a full survey can be finalised:
    - a further breeding season of intensive observations at the same study sites to assess seasonal and diurnal variation in the activity patterns of Short-eared Owls (and the occurrence of key behaviours indicative of territoriality/breeding), to give support to the patterns found in 2006 and reassure that 2006 was not an aberrant year due to the cold weather in early spring;
    - additional watches from vantage points in the middle part of the day, to assess whether the survey window could be extended without lowering detection rates;

- a further breeding season of point counts from road transects, covering the transects in the three study areas used in 2007, and others across the range of the species in Britain, to assess: (i) whether the conclusions drawn from the 2006 observations are robust; (ii) whether the methods are attractive to volunteers (by attempting to get volunteers to cover a sample of transects); and (iii) whether these surveys could be carried out in the early morning in addition to the evening;
- extension of the intensive surveys from vantage points over a larger geographical area at one of the study sites (resources permitting), using the conclusions drawn from the 2006 pilot fieldwork to define a suitable survey approach (number of visits, timing of visits, diurnal sampling period(s), spacing of vantage points etc), to produce a population estimate and associated confidence limits for the selected area. This should reveal any further difficulties when interpreting the information collected using the field protocols and improve the guidance that will be produced for use for a full survey of any given area; and
- additional analyses (initially on the 2006 data set but also on the data collected in 2007) to simulate the proportion of apparent Short-eared Owl territories that would have been detected under certain scenarios of a practical number and timing of survey visits. Perhaps also further quantitative work to improve estimates of range sizes.

1. BACKGROUND AND AIMS

The Short-eared Owl is listed on Annex 1 of the EU Wild Birds Directive as a species considered vulnerable in Europe and is a qualifying species for six classified Special Protection Areas (SPA) in the United Kingdom: the Caithness and Sutherland Peatlands; Forest of Clunie; Muirkirk and North Lowther Uplands; Orkney Mainland Moors; Skomer and Skokholm; and the South Pennine Moors (Stroud *et al.* 2001). Recent estimates of the breeding population for Britain (1,000 – 3,500 breeding pairs in 1988-91: Gibbons *et al.* 1993) and for Scotland (780 – 2,700 breeding pairs in 1988-91: Greenwood *et al.* 2003) are considered unreliable and trends over time are unknown (Greenwood *et al.* 2003, Park *et al.* 2005). There is a need to determine accurate and precise population estimates for the species within designated SPAs in the UK, and for national surveys of the Scottish, and other UK populations.

1.1 Previous review of current knowledge

Given inadequate information with which to assess reliably the conservation status and requirements of Short-eared Owls, Scottish Natural Heritage (SNH) commissioned a review of literature and other available information, in order to make recommendations for developing and refining survey techniques for breeding Short-eared Owls. In addition to summarising published and 'grey' literature, the review (Calladine *et al.* 2005) included new analyses of data collected for the BTO atlases of breeding bird distribution (Sharrock 1976, Gibbons *et al.* 1993), data from the Breeding Bird Survey (BBS; e.g. Raven *et al.* 2004) and observations of Short-eared Owls recorded during fieldwork for a national survey of Hen Harriers in 2004 organised by the RSPB. The main findings of that review were (taken from Calladine *et al.* 2005):

- Habitats used by breeding Short-eared Owls include heather moorland, white grass moorland (where not too heavily grazed), young conifer plantations (where coup size > 50 ha) and some other rough grassland and marsh (particularly coastal areas). The distribution of the species is extensive in the 'uplands' but very localised in the 'lowlands'. Any national survey to estimate population size should sample the contiguous upland areas that are occupied but in the lowlands, specific targeting of sites is likely to be appropriate.

- The timing of breeding of Short-eared Owls in Britain can vary, probably in relation to vole abundance, and in some years birds may not breed even if holding a territory. Fieldwork for intensive censuses (for example of SPAs) is likely to require inclusion of the earliest potential period of territory occupancy (early March) and it was recommended that pilot work should be carried out to investigate the proportion of territories that may only be detected once young have hatched.

- Population densities in any given geographical area can vary substantially between years and these variations may not be spatially synchronous; they probably occur as a result of variations in local vole abundance and conditions influencing immigration from Scandinavia. The British breeding population is not necessarily closed but the degree of integration with populations in mainland Europe is not clear and requires further study.

- Evidence from some local surveys and the national Breeding Bird Survey suggests a degree of synchronicity in population variations across Britain, however, that is counter to the expectation if population changes were driven solely by variations in vole abundance, which in turn are at least partly determined by local land management practices. Study of the relationships between vole and Short-eared Owl abundances across Britain could help to identify the relative importance of local, national and international determinants of owl abundance within Britain.

- Further analyses of data held by individuals and other sources (e.g. the Nest Record Scheme) might provide further information on the timing of breeding and population fluctuations.

- Data on Short-eared Owls collected during the national Hen Harrier survey in 2004 (using field protocols designed for detecting harriers rather than the owls) may have underestimated their absolute population size for a number of reasons: late start of surveying; visits made during the middle of the day; and some areas of potentially suitable habitat omitted (e.g. areas within 500 m of occupied human dwellings and bracken-dominated areas).

The review concluded that a pilot study was essential to test potential field survey techniques for Short-eared Owls in advance of any national survey or intensive census of, for example, designated sites. It was recommended that such a survey should sample the range of densities of Short-eared Owls that are likely to be encountered across the UK, and that it should include both intensive fieldwork at a number of sites (to assess methods for obtaining absolute population size) and extensive but low-intensity surveys (for monitoring purposes). The latter would aim to determine resource-efficient methods for monitoring population trends, which would then allow local intensive fieldwork at a smaller number of sites (e.g. sampled areas as part of a national survey or designated sites) in any given year to be placed in the context of any overall interannual fluctuations in population size. Because of the magnitude of potential population fluctuations by this species, without long-term monitoring data collected over a broad study area, censuses from discrete study areas in any given year might sample a very high or low stage of any population 'cycle', potentially providing a biased estimate of the overall importance of the study area for Short-eared Owls.

1.2 Aims of this pilot study

Following from the principal findings of the earlier review, a pilot field study described in this report was undertaken during the 2006 breeding season. The main objectives were:

1. To assemble any outstanding information on Short-eared Owl breeding behaviour and population survey data that might inform the design of pilot survey work and future full surveys, including discussions with those with experience of research on the species.

2. To identify the most appropriate times of day and dates of season for surveying breeding Short-eared Owls (by quantifying how encounter rates and the chances of detecting breeding attempts vary with time of date and stage of breeding, and any spatial variation in these relationships) and to translate the findings into feasible survey protocols.

3. To carry out observations to assist in the differentiation of separate breeding territories: (i) by assessing the frequency and timing of breeding behaviours that would inform the categorisation of breeding attempts (as e.g. 'definite', 'probable' and 'possible'), such as territorial disputes, carriage of prey and display flights; and (ii) by assessing the distances moved by focal birds of known breeding status that would provide further information on minimum foraging ranges during the breeding season. To translate these findings into feasible survey and analytical protocols.

4. To evaluate the feasibility of, and encounter rates resulting from, more extensive field surveys and how these relate to numbers of breeding Short-eared Owls estimated from intensive observations in key study areas. The majority of the monitoring of widespread bird species in the UK is undertaken by volunteer birdwatchers, notably the Breeding Bird Survey (BBS; e.g. Raven *et al.* 2004). Upland areas have tended to be under-sampled by such volunteer-based surveys to date, largely because they are remote from areas of dense human population (sources of volunteers) and the terrain requires birdwatchers with a certain level of fitness and motivation. The trial of extensive methods to produce abundance indices for Short-eared Owls also aimed to trial alternative methods for monitoring a broader suite of upland bird species, using a method that might attract a larger number of volunteers into the uplands.

5. To make recommendations for: (i) field protocols for use in producing a population estimate of Short-eared Owls in any given area in any given year; (ii) extensive methods for producing indices of abundance to monitor population changes and allow the results of a full survey in any given year to be placed in context; and (iii) survey design for a national survey of Short-eared Owls.

Here we present an interim report on the results of fieldwork during the 2006 breeding season. A final report with full recommendations on survey design will follow after the 2007 breeding season.

2. METHODS

2.1 Study areas and seasonality of fieldwork

Fieldwork was undertaken in three broad study areas of Scotland: Perthshire, Ayrshire and the Borders (Figure 1a). The selection of these areas was based on: (i) a known history of occupancy by breeding Short-eared Owls; (ii) the established presence of volunteer raptor workers who were able to give an independent assessment of the numbers and success of breeding Short-eared Owls; (iii) an adequate network of roads and tracks to allow relative ease of access between parts of the study areas; and (iv) correspondence with local raptor workers prior to, and during the early part of, the 2006 field season to assess Short-eared Owl occupancy levels in 2006. Using criteria (i) to (iii), six possible study areas were chosen (the three above, plus Mull, Glen App in Dumfries and Galloway, and the Pentland Hills in Lothian) and contact made with the local raptor worker with an interest in Short-eared Owls. It was necessary to consider a suite of potential study areas that was larger than the three that the project resources would allow us to cover because of the uncertainty that surrounds the number of breeding Short-eared Owls that will settle to breed in an area in any give year. Based on local information early in the breeding season (iv above), a sample of three study areas was selected from the six areas under consideration.

Based on existing knowledge of the breeding cycle of the Short-eared Owl, the 2006 fieldwork was undertaken in four study periods:

Period 1	6 March – 31 March (to check for territory occupancy);
Period 2	18 April – 15 May (to check for territory occupancy in the event of a late season and to check for males attending incubating females);
Period 3	1 June – 22 June (to check for adults feeding young);
Period 4	1 July – 28 July (to check for late or replacement broods).

These timings were based on published information on breeding behaviour and the timing of breeding of Short-eared Owls (Goddard 1935, Cramp 1985, Roberts & Bowman 1986, Shaw 1995, Reynolds & Gorman 1999), data held by the BTO's Nest Record Scheme and the British and Irish ringing scheme (Moss *et al.* 2005); they are consistent with the survey recommendations of Hardey *et al.* (2006).

2.2 Fixed point observations

2.2.1 Data collection

Detailed behavioural observations of Short-eared Owls were made from 12 vantage points, four in each of the three study areas (Table 1). Vantage points were chosen as areas with an open aspect providing a good field of view over apparently suitable habitat for breeding Short-eared Owls (after Calladine *et al.* 2005), with advice from raptor workers with local knowledge. The selection aimed to maximise the likelihood that owls would settle within view of the vantage points. Observations were made from the vantage points within a maximum arc of 180°. Once selected, the vantage points, and the search arc from them, remained constant through the study. The proportions of broad habitat types within the areas monitored from the vantage points were estimated by eye. For all vantage points combined, the proportions of habitats viewed were: heath and bog (*ca.* 60%), semi-natural grassland (*ca.* 32%), mature conifer plantation (*ca.* 3%), improved grassland (*ca.* 3%) and young pre-thicket plantation (*ca.* 2%; see Table 1). The vantage points ranged in altitude between 180 and 500 m above sea level (Table 1).

Fixed point observations were made in sampling periods of two hours in length within the first and last five hours of daylight. This gave four sampling windows within each day (termed 'early morning', 'late morning', 'early evening' and 'late evening'). Each vantage point was sampled at least once during each of these sampling windows within each of the four survey periods (Table 2). Every

Short-eared Owl seen was recorded, together with details of its behaviour; the latter was used as evidence to determine the probability of breeding. The following categories of behaviour, in generally ascending order of evidence for a breeding attempt or holding territory (modified after Shaw 1995), were used:

a) Owls(s) seen in flight in transit (not hunting); ONLY POSSIBLE BREEDING
b) Owl(s) seen perched;
c) Owl(s) seen using an area for hunting;
d) Owl(s) carrying prey; PROBABLE BREEDING
e) Courtship display (wing clapping);
f) Owl(s) giving alarm calls or mobbing potential predators;
g) Owl(s) repeatedly carrying prey to an area (feeding an incubating female or young);
h) Recently fledged young owl(s) seen. CONFIRMED BREEDING

For each record of a Short-eared Owl, the start and end times of the observation were recorded, and the flight lines were plotted onto large scale maps. The flight-lines were transferred to GIS (Geographic Information System; ArcView 3.3) and cross-referenced with the behavioural data and any other notable observations. The distance from the observer at which each Short-eared Owl was first detected, the closest to which it approached, and the greatest distance to which it could be followed were estimated in the field and the estimates were checked against the flight-lines plotted in the GIS.

2.2.2 *Analyses of variability in detection*

The duration of all observations of Short-eared Owls, and those of some ‘key behaviours’, were analysed to assess the influences of stage of the breeding season, time of day and study area on the detection of Short-eared Owls. ‘Key behaviours’ were those considered to be most indicative of territory holding by Short-eared Owls: courtship display; alarming or mobbing potential predators; carriage of prey to likely nest sites; and the presence of recently fledged young (i.e. e to h in the list in 2.2.1). Generalised linear models were used to test the influence on the length of time for which Short-eared Owls were observed within a 2-hour watch of: Season (n = 4 survey periods); Time of Day (4 classes: the two two-hour periods after first light and the two two-hour periods before dusk); and Site (n = 10 vantage points and fitted as a repeated measure; two vantage points from which Short-eared Owls were never seen - Perthshire D and Ayrshire A - were excluded from the analyses under the assumption that there were no owls at those sites during the season). The interaction between Season and Time of Day was not included because of insufficient degrees of freedom (lack of model convergence). The models assumed a negative binomial error distribution (appropriate for zero-inflated data) and a log-link function. A second set of models was also fitted, identical to the first with the exception that morning and evening observations were treated separately and, in each case, were divided into five hourly periods after first light (morning model) or five hourly periods before dark (evening model).

The ‘Sites’ (individual vantage points) were entered as a repeated measure in the models, because each was re-visited several times through the season (such that the sample of owls observed was not likely to be independent on each repeated visit to any given vantage point). It was assumed that an influence of ‘Site’ in the models could have arisen from a number of factors. First, there were likely to be differences in the proximity of vantage points to nesting owls, such that some were better placed to oversee the activities of a territorial owl or pair than others. The vantage points were necessarily selected prior to the owls setting up territory, and each was selected because it gave a clear field of view over an area of habitat suitable for breeding Short-eared Owls and also using the prior knowledge of the local raptor worker (when available) as to where nesting had occurred in previous years.

Second, there were some differences in topography/chances of owls being visible between the individual sites, particularly as the three study areas were selected to provide topographic and habitat variation. Although the vantage points were selected to give a wide field of view, there were inevitably some areas within the viewing arc from each point that constituted 'dead ground', where owls would not have been seen. This would have included areas completely obscured from view due to physical topography but also areas in which visibility was affected in a more subtle way (e.g. because of habitat/background coloration/aspect). Because of the complexity of these effects, we did not attempt to quantify the between-site variation in 'dead ground' and control for it directly in the modelling process.

Third, there could have been differences in the activity patterns of the individual owls/pairs that were observed from each vantage point. Finally, differences in the number of territorial owls/pairs visible from each vantage point could have had a direct effect on the amount of time for which any one owl was visible, and also potentially influence activity patterns, for example resulting in a greater need for territorial interaction at higher owl densities.

As a nest site was found in only one case (Table 3), it generally was not possible to assess with certainty how the visibility of local territories varied between vantage points, although this was considered by field staff to be the major source of between-site variation. When the observations of field staff were considered together with those of independent raptor workers at some of the sites (Table 3), concentrations of flight lines and observations of behavioural interaction (Figure 2), it was concluded that most of the activity at each vantage point was attributable to a single territory/pair of owls, with the exception of one site with two territories (Borders 'C'; see Figure 2). No weighting to control for the number of territories under observation was felt to be required in the models, however, as: (i) we could not state with certainty how many territories were being observed at each site; and (ii) the study was in any case designed to sample a range of owl densities if possible.

When more than one owl was visible at the same time, the durations of observations were taken as additive for modelling purposes, on the assumption that periods when more than one individual was visible could increase overall detectability (by creating more opportunity for conspicuous behaviours) and therefore should be given greater weighting in the data set. For the key behaviours indicative of territoriality, the length of observation used in the modelling was that for which an owl was visible to the observer at a vantage point during which time it performed at least one of the key behaviours.

2.2.3 *Analyses of detection distances*

The distances at which Short-eared Owls were detected were analysed to provide an indication of the density of an array of vantage points that would be required to survey a given study area reliably. If the vantage points used for a survey were placed too far apart, then there would be a risk of missing birds and territories. The influences of Season and Time of Day (n=4 classes in each case; see 2.2.2) on the distances at which Short-eared Owls were first detected were examined using a generalised linear model. A normal error distribution was assumed (with identity link function) and site (vantage point) was included as a repeated measure (see 2.2.2).

2.2.4 Analyses of ranging distances

To give an indication of the distances ranged by Short-eared Owls during the breeding season, minimum convex polygons (MCPs) were drawn around the flight lines plotted within the GIS. When behavioural observations indicated that simultaneous observations of owls were of birds from different territories (e.g. an aggressive encounter between individuals, or birds seen hunting independently where one individual carried prey to a suspected nest site with an incubating female), these were taken as boundaries for the polygons. In the absence of such distinguishing behaviours, clusters of flight lines were assumed to be made by bird(s) within the same territory. Using this approach, the derived MCPs are at least partly a function of visibility from each individual vantage point (Section 2.2.2) and, therefore, the maximum arc of each MCP (i.e. that most distant from the vantage point) was taken to be the most representative measure of the *minimum* distances ranged by breeding Short-eared Owls.

The influence of Season (n=4 classes; see 2.2.2) on the maximum arc distance (a measure of ranging distance) was examined using a generalised linear model. A normal error distribution was assumed (with identity link function) and site (vantage point) was included as a repeated measure (see 2.2.2). The dependent variable (distance) was weighted by the number of flight lines that contributed towards the MCP to give a greater emphasis to measures that were the result of a greater number of field observations.

2.3 Point counts

2.3.1 *Data collection*

Within, or close to, each of the three broad study areas, two 'transects' were selected (Figure 1b). Each transect was a series of roads or tracks that crossed habitat potentially suitable for breeding Short-eared Owls (moorland and moorland fringe; e.g Goddard 1935, Roberts & Bowman 1986, McGarry 1998, Raw 2000, Stott 2002). Along each transect, suitable count points were identified that offered a relatively unobscured view, where a vehicle could be parked safely, and with a minimum distance of 1-km between count points (to ensure a high degree of independence of data collected from different points); there were between 14 and 21 suitable count points on each of the six transects.

Each transect was surveyed once in each of the four stages of the breeding season (section 2.1), within the last three hours before dark. Timed counts, five minutes at each point, were used to measure the abundance of all bird species encountered (seen or heard). Surveyors used vehicles to drive between count points. From each count point, each registration of a bird was assigned to one of five distance bands from the count point (0-25 m, 25-100m, 100-500m, 500-1000m and 1000m+); the first distance at which each individual bird was seen was recorded, regardless of any subsequent movements. Birds seen or heard only in flight were also recorded separately, with the exception of displaying birds (e.g. Skylark, Meadow Pipit and Curlew) that were recorded within the respective distance bands above which they were flying. Care was taken in the field to try to avoid recording individuals more than once, either at neighbouring count points or anywhere along the transect (i.e. when individuals could be seen from multiple count points). Only birds in open habitats were recorded (those in any woodland present were excluded).

2.3.2 *Analyses of point count data*

Two indices of abundance are presented in this report:

a) *Occurrence rates* - the number of count points at which each species was recorded; and
b) *Species abundance* –the number of registrations for each species.

For the more abundant species, population densities of individual birds were estimated using standard distance sampling approaches (Buckland *et al.* 2001) and the program Distance 5.0 (Thomas *et al.* 2005). This was undertaken for those species for which there were more than 40 registrations across all sites in any one of the survey visits, the minimum number recommended for reliable estimation of population density (Buckland *et al.* 2001). In addition to setting a minimum number of records, to reduce complications from clustering of data (i.e. flocking birds), we also only considered those species that were widespread enough to have been recorded from at least 25% of the count points in any one of the survey visits. For each species, we used the data from the single survey period with the greatest number of registrations and that also satisfied our requirement for dispersal (i.e recorded from 25% or more of the count points). Distance sampling works on the principal that randomly distributed objects (in this instance, birds) become more difficult to detect with increasing distance (in this instance, from the count points). As a result, an increasing proportion of the birds become more difficult to detect in the more distant recording bands. The program Distance 5.0 models this decline in detectability with distance (the detection function) in order to include an estimate of undetected individuals in its calculation of density. In our analyses, we assigned the distance of the mid-point of the relevant distance band (i.e. 12.5 m, 62.5 m, 300 m and 750 m) that the birds were first recorded in. Records within the final distance band (> 1000 m) were excluded from the analyses, as counts within an unbounded category are difficult to interpret. Truncation of this kind is routinely recommended for accurately estimating density using the distance sampling technique (Buckland *et al.* 2001). The assumed detection function was a half-normal cosine distribution. When a low density of a given species was apparent in the nearest distant band (i.e. within 25 m of the count point), this was assumed to be real rather than an artefact of the presence of the observer with the general recommendation for regrouping of data (Buckland *et al.* 2001). This was because the count points were on roads or tracks which could feasibly have had a real effect on the most proximate bird population densities. The calculated estimates of bird density, and their precision, were used to assess to what extent the population densities found in the study areas were typical of the Scottish habitats sampled, and were also produced to make them available as reference data for other, similar studies.

3. RESULTS

3.1 Seasonal and diurnal variation in the detection of Short-eared Owls

Overall across the 2006 breeding season, 186 individual observations of Short-eared Owls were observed (Appendix 1). These showed that the proportion of time for which owls were visible during the hours of the day that were sampled was low: overall, a median of only 2 minutes per hour of observation (3.3% of the time; 9-95% percentiles = 1-13 minutes per hour, equivalent to 1.7-21.7% of the time). For all observations of Short-eared Owl activity combined, there were no statistically significant effects of either time of day (4 classes: first and second two-hour periods in the five hours after first light and the five hours before dark) or Season (4 periods through the breeding season) (Table 4 and Figure 3 a & b). Interpreting these results in the light of the relatively small sample of data collected in 2006 (and hence the low statistical power), there was some suggestion of lower Short-eared Owl activity early in the season (Period 1, first 3 weeks of March, Figure 3a) and slightly higher activity in the second two-hour period of the first five hours after first light (Figure 3b). When separate models were run splitting the morning and evening observational data, there were still no significant effects of either time of day or season in either case (Table 4). Visual assessment of the back-transformed estimates from these models (Figure 4 a & b) also provided little support for variation in activity patterns with time of day.

Key behaviours indicative of territoriality were observed very rarely: there were only 43 discrete observations of Short-eared Owls that included activities defined as key territorial behaviours, such that the median duration of observations including key behaviours per hour of observation was zero (95% percentile=12 minutes; Appendix 1). Because of the rarity of these territorial activities, the influence of time of day and season on the duration of these behaviours could not be analysed formally (the models failed to converge). A visual assessment of the frequency of observations in which these behaviours were recorded, and the 95% percentiles, with respect to time of day and season (Appendix 1) provided some suggestion that territorial activity may be more evident in the morning than in the evening, and particularly in Periods B and D of the breeding season.

3.2 Detection distances

The mean distance from an observer at which Short-eared Owls were first detected was 522 m (95% confidence limits: 473 – 570 m; range: 172 – 825 m across vantage points; Table 5). This mean detection distance did not vary significantly with period of the breeding season (n=4 periods; χ^2=1.21; *P*=0.75) or time of day (n=4; χ^2 =4.24; *P*=0.24). Across all 10 vantage points, the mean closest approach distance of Short-eared Owls to observers was 399 m (range 103-713 m across vantage points) and the mean maximum distance at which they were observed was 656 m (range 268-886 m across vantage points; Table 5).

3.3 Number of territories observed and foraging ranges

When the flight lines of Short-eared Owls observed at each site were grouped into ranges (using territorial interactions to differentiate ranges when available), the numbers of ranges visible from each vantage point largely supported the views of the local independent raptor workers (Figure 2 and Table 3). At all but one vantage point (Borders C; Figure 2), the observations made during the 2006 breeding season were thought to refer to a single territory. In a few cases, it was thought that birds from a neighbouring territory were seen occasionally but these comprised only a very small proportion of the total observations.

The mean minimum ranging distance, estimated as the maximum arc of the MCPs drawn around the plotted flight lines, was 1368 m (SE = 128 m) (Table 6). No significant influence of stage of the breeding season on the minimum ranging distance was detected (GLM including site as a repeated measure and the observations of range size weighted by the number of flight lines from which each was derived: χ^2=3.01, P=0.39).

3.4 Point counts

A total of 68 species were recorded during the 24 evening point count surveys (Table 7). Amongst these were 14 registrations of Short-eared Owls, four each during the first and second survey periods, six during the third survey period and none during the fourth (Table 7).

Forty or more registrations within any one survey period were achieved for 12 species (Table 7). Of these, Carrion Crow, Fieldfare, Black-headed Gull, Lesser Black-backed Gull, Swallow, Sand Martin and Starling were recorded from less than 27 count points (25% of the total) within those periods and so were not considered sufficiently dispersed for estimation of their abundance using distance sampling. Furthermore, most of those 12 species achieved 40 registrations in either the first or fourth survey periods and the recorded flocks were likely to be either pre- or post-breeding and therefore not representative of breeding population densities.

Five species were recorded sufficiently frequently and were sufficiently dispersed to permit estimation of their population densities using the program Distance. Combined across all sites, the most abundant was Meadow Pipit with 97 individuals per km^2 (95% confidence interval 66 – 142), followed by Lapwing (94 km^{-2}; 35 – 253), Skylark (20 km^{-2}; 12 – 33), Oystercatcher (9 km^{-2}; 5 – 17) and Curlew (8 km^{-2}; 3 – 19) (Table 8).

4. DISCUSSION

4.1 Count units, timing and duration of survey visits for a full area census

The intensive fieldwork carried out from vantage points in 2006 showed that across the breeding season Short-eared Owl activity during the daylight hours was generally low. On average owls were only visible for 3.3% of the observation time, despite there being good evidence that territorial birds were present in close proximity to most of the vantage points. This low level of activity will itself make surveying the species a real challenge, probably necessitating one or more watches of several hours duration at appropriate stage(s) of breeding. Of the 186 discrete observations of owls made during the 2006 breeding season, only 43 (23%) involved the owls carrying out activities that were indicative of holding a territory: the majority of observations simply involved foraging birds. The rarity of such territorial activities increases the need to: (i) survey at times when there is the greatest chance of observing these activities; (ii) survey at a stage of the breeding season when the majority of birds seen can be assumed to be territory holders (as opposed to e.g. passage birds early in the breeding season); and (iii) find alternative methods for differentiating between birds from neighbouring territories (e.g. using knowledge of usual foraging ranges during the breeding season; see 4.3).

The observations made during the 2006 breeding season did not show any statistically significant differences in the duration of Short-eared Owl activity (or observations involving key territorial behaviours) either with stage of the breeding season (starting in the second week of March) or between the morning and evening periods during which observations were made. The resource-intensive nature of the fieldwork unfortunately meant that sample sizes (of vantage points, and of visits to each vantage point in each time of day and stage of season sampling period) were small, reducing the statistical power to detect differences, particularly with such a low incidence of activity overall. Visual assessment of the results (together with the marginally non-significant effect of season in the modelling) provided some suggestion that Short-eared Owl activity was lower in March than later in the year, and this was noted by the field staff involved in the project. We had expected that territorial behaviours might be more evident: (a) during territory establishment and the period immediately before eggs were laid; and (b) once young had hatched and the carriage of prey increased. In 2006 there was suggestion that territorial behaviours were more frequent during periods B (18 April – 15 May) and D (1 July – 28 July). Those raptor workers with an interest in the species who were consulted prior to the pilot fieldwork had indicated that they believed the owls to arrive back on their breeding areas as early as early March; they also noted that they rarely saw the owls until breeding was established later in the season (when they observed carriage of prey and saw or heard fledged young) however. The suggestion from the one year of pilot work carried out to date is that it might be preferable to made first survey visits during April. There might be a risk of missing some early birds that either do not attempt to breed or fail early but, if the first visit was made in March, there could equally be a risk of (double) counting passage birds that subsequently go on to breed elsewhere.

Given the low incidence of behaviours that might be used to confirm breeding status, it is likely that any comprehensive census of Short-eared Owls will produce an estimate with a larger proportion of birds of unknown breeding status than is the case for other upland raptors (e.g. Hen Harrier, Peregrine). Based on the observations made in 2006, such censuses are likely only to be able to record accurately those breeding attempts in which eggs are laid (as the detection rates in March were very low at territories that went on to show breeding activity later in the season, whereas some areas held birds in March but none later in the breeding season). It is likely that it will not be possible to differentiate those birds that fail to lay, or fail soon after laying, from birds that are still travelling to breeding areas. Similar problems occur when attempting to census other species (e.g. Hen Harrier, I. Sim, pers. comm.), such that estimates of absolute population size are never likely to be complete.

Given that the above results and suggested approaches are based on one year of pilot work only, there is also a need to consider whether 2006 was a representative breeding season (see 4.4).

There was suggestion of a higher incidence of Short-eared Owl activity (and key behaviours) in the mornings (first five hours after first light) compared to the evenings (last five hours before dark) but differences were not marked and they were certainly not statistically significant. Given that the fieldwork required to carry out a comprehensive census of Short-eared Owls is likely to be time-intensive (in terms of the duration of watches that will be required, above), each volunteer would be able to cover a larger survey area if the diurnal sampling window could be extended further into the middle part of the day without reducing the detectability of the owls (and hence potentially biasing counts). The diurnal sampling window selected for the pilot work in 2006 was based on the assumption that the species was largely crepuscular, and we had expected that the duration of owl activity would lessen in late morning and early evening compared with early morning and late evening. As no such reduction in activity was detected in 2006, it would be prudent to trial some watches through the middle part of the day to assess to what extent the diurnal sampling window could be extended in a full census (such as a national survey involving volunteer birdwatchers).

Given the rarity of Short-eared Owl activity (and particularly that involving behaviour indicative of territory holding/breeding), this single year of fieldwork suggested that watches from vantage points need to be of at least two hours duration, perhaps longer (see section 5).

4.2 Detection distances and survey design

For any species, if the field protocols for a full census of a study area are to be based on watches from vantage points, then it is important to have some indication of the range at which individuals can be detected. An array of vantage points can then be selected to ensure that any ground with suitable habitat for the species is within range of one of the vantage points. Some guidance on the maximum distance between adjacent vantage points that should be adopted when observing the activities of breeding large- to medium-sized raptors has been provided with regard to the survey work required to underpin terrestrial wind farm planning proposals (SNH 2005), where a maximum spacing of 4 km (such that no area of observation is more than 2 km from a vantage point) has been suggested.

The fieldwork carried out in the 2006 breeding season was not designed specifically for assessing the detection distances for Short-eared Owls from vantage points. This was because the observation points needed to be selected before the location of individual owl territories was established but then maintained in the same positions so as to ensure that the observed durations of owl activity recorded in the first period of the breeding season were directly comparable with those in subsequent periods. The individual vantage points thus differed in terms of their proximity to an owl territory and a number of other environmental factors that could influence detection rates (topography, habitat, aspect etc). However, the design was considered representative of the situation when selecting vantage points for a census of breeding owls in any given study area.

We considered the distances at which Short-eared Owls were first detected by fieldworkers to be of relevance when considering how to space vantage points in a full census. This mean first detection distance was just over half a kilometre (95% confidence limits 473 – 570 m) across the 10 vantage points at which owls were observed. Whilst field staff were able to follow owls visually to around twice that distance from vantage points once they had first detected them (maximum sighting distance around 1.2 km), they might not have detected them (at least not in every case) had they first appeared much further away. These observations from a single breeding season initially suggest that an array of vantage points no further than 1 km distant from one another (such that all areas to be viewed are within 500 m of the vantage point) might be appropriate when surveying an area of contiguous habitat suitable for Short-eared Owls. The findings that first detection distances were around half a kilometre, and that owls rarely came within 100 m of the observer, could suggest some deterrence effects of observers on the activity patterns of the owls. If this were the case, then there could be a need to overlap the areas to be surveyed from individual vantage points in an array, such that areas close to the observer at one vantage point could also be surveyed independently from a different point.

However, in some cases owls did approach field staff very closely (see Figure 2), and the apparent deterrence effects could simply be a result of the actual location of territory centres, or areas of suitable habitat, in relation to the positions of observers. A further field season of data collection (when vantage points would once again effectively be placed randomly in relation to territory centres because the locations of the latter would be unknown until later in the season) might provide further evidence or otherwise for deterrence effects.

Despite the relatively small sample of points from which owls were observed in 2006, study areas were selected to contain a range of topography and habitat. Hence we believe that the maximum detection distances recorded in 2006 were fairly representative of those that might prevail across much of the Short-eared Owl's habitat in the UK (but see also 4.5 below).

4.3 Foraging ranges and interpretation of observations during a full area census

The intensity of observations carried out in 2006 provided important information on the possible home range sizes of Short-eared Owls in Scotland during the breeding season. We have referred to these as *minimum* range sizes, and only quoted the maximum arc of each minimum convex polygon drawn around groups of flight lines, rather than quoting potential range areas. This is because the study design (watches from single vantage points at each site) will have placed artificial boundaries on the ranges (e.g. due to spatial variation in visibility, maximum distances at which owls could be seen, and/or potential biases due to disturbance from observers; 4.2 above).

Knowledge of home range size during the breeding season is likely to be very important when interpreting the results of a comprehensive survey of any given area because there will be a need to differentiate separate territories from discrete observations of individual birds. It is unlikely that enough volunteer birdwatchers could be persuaded to carry out the very long or large number of watches that we have shown would be likely to be required to differentiate individual territories directly, or to search for nests (and indeed the latter might cause unnecessary disturbance). We have also shown that a high proportion of the observations made are likely to be of foraging birds (even at key stages of the breeding cycle), and that observations of specific behaviours that would confirm territory occupancy, and importantly territory boundaries, are likely to be extremely rare. For these reasons, it is likely to be necessary to set some minimum threshold distance when interpreting individual sightings during a full survey of an area, based on the known spacing of territories and spatial extent of territorial behaviour in representative study areas.

In a previous analysis of Short-eared Owl observations collected during the 2004 Hen Harrier Survey, arbitrary separation distances between individual owl territories of 500 m, 1000 m and 2000 m (based on the published range of breeding densities recorded in Britain) were used to calculate the potential number of occupied territories in (the majority of) cases for which no specific owl activities that could be used to discriminate between separate territories had been recorded (Calladine *et al*. 2005). The observations during the 2006 breeding season suggested that the individual home ranges of Scottish owls during the breeding season are often well over 100 ha in extent (see text and Table 1 in Calladine *et al.* 2005 for comparison with published estimates of apparent territory size). Hence, in many cases, the use of a minimum separation distance of 1000 m between these apparent territories would have resulted in an overestimate of population size. Assuming that the apparent ranges recorded in 2006 were not unduly biased by topography or limits to the detection distance of observers, a threshold minimum separation distance of 2000 m might be more appropriate for interpreting observations made during a full census of an area in the absence of observations of key behaviours or evidence of breeding to separate individual territories. However, whether these results from the pilot work in 2006 could be used across all Short-eared Owl breeding areas in Britain depends to what extent the densities of owls sampled in 2006 were representative (4.5 below).

4.4 How representative was the 2006 breeding season?

Because of the large resources required to carry out the pilot work in 2006, it has been critical to attempt to assess whether 2006 was a representative breeding season across Scotland; this was discussed at length by the Project Partners at the end of the field season and, in addition, the views of a number of other local raptor workers with an interest in Short-eared Owls were sought. Two major environmental influences were considered in this context: (i) weather (and its effects on the timing and success of breeding); and (ii) the densities at which Short-eared Owls settled to breed (thought to be highly variable both geographically but also within any given breeding area between years; literature reviewed in Calladine *et al.* 2005). Settling densities in Britain are thought to be determined by a combination of variation in local prey abundance (e.g. voles) between years (which may or may not be spatially synchronous across the UK (see evidence discussed in Calladine *et al*. 2005), and also variation in the numbers of immigrant owls from mainland Europe that remain to breed (which is likely to be at least partly a function of variation in the main prey species abroad; Calladine *et al.* 2005).

The early part of the breeding season in 2006 (March, Period A, when the first observations were made) was characterised by heavy and persistent snow cover across the study areas; such weather conditions have not been infrequent in recent years (pers. obs.) but were perhaps less typical in earlier decades (including those to which some of the previous published studies refer; Calladine *et al.* 2005). It would be risky to assume that the lower level of owl activity that was certainly apparent in the first half of March in 2006 was normal, and there may have been resultant delays in settling and breeding that would influence how the results should be interpreted to suggest the best times of the breeding season to make visit(s) when carrying out a comprehensive census of any given area. Given that Short-eared Owls are thought to be at least partly nomadic in Britain, the unusually cold and snowy weather in early spring in 2006 may have led to some birds moving breeding areas. Others with an interest in Short-eared Owls in other study areas of Scotland noted that it was an "exceptionally poor" year for the species (and for Hen Harriers) on Mull, and numbers of owls were also lower than in 2005 in the Uists, although they were still plentiful there (the wet and windy weather may have reduced sightings on the Uists; P. Haworth, pers. comm.). Conversely, Short-eared Owls were noted as breeding on Colonsay (preying on rats and Meadow Pipits *Anthus pratensis*, as there are no voles) for the first time in 2006 (following only a few sightings previously of single, presumed passage birds from Islay, Jura or Mull; D. Jardine, pers. comm.). A correspondent from Angus saw his first Short-eared Owl of the year on 1 April in 2006, which he said was "pretty early" compared to his previous records; but he then noted that despite a further 10 days spent in the field, he did not see another owl until 6 May (M. Groves, pers. comm.). He reported that the 2006 breeding season had the most sightings since 2003 but also that some sites that had been frequently occupied previously did not have owls in 2006. In Angus, Mike Groves reports most sightings of Short-eared Owls in May and June (although, as is the case with most of those with an interest in the species in Scotland, sightings are made incidentally when focussing fieldwork on other species, in this case Hen Harriers and Merlin).

Other existing data sets from which further information on potential variation in the timing of breeding of Short-eared Owls in recent years can be gleaned are sparse and they do not allow an analysis of whether breeding has become earlier in recent years (see 4.6).

As well as potentially influencing the breeding phenology of Short-eared Owls, the combination of cold and snow in the spring of 2006 could have influenced the timing of prey availability and prey abundance, which could themselves have had a knock-on influence on foraging effort, and hence on the activity patterns and foraging ranges of the owls.

For the reasons above, we (and the Project Partners) felt strongly that a further year of pilot fieldwork was essential before drawing conclusions about the most suitable times of the breeding season or times of day in which survey visits should be made, or about the potential size of foraging ranges.

Whilst two breeding seasons of fieldwork could not hope to cover all possible variation in these parameters, it should at least show whether 2006 was a completely aberrant year. If undertaking a further breeding season of pilot fieldwork, it will be important to carry this out at the same study sites as those used in 2006 (assuming owls are present in the following year), so that any differences between the results in 2006 and 2007 are not confounded with possible geographical variation in the parameters under consideration (timing of breeding, diurnal activity patterns and ranging behaviour).

Previous sets of observations that would allow us to assess quantitatively the extent to which the density of Short-eared Owls in our three study areas in 2006 varied from the densities in those areas in previous years did not exist (see 4.6). The possible implications of varying Short-eared Owl densities for the parameters considered in the pilot fieldwork in 2006 are discussed in 4.5 below.

4.5 How representative were the study areas used in 2006?

The resources available in 2006 only allowed intensive observational work to be carried out at 12 sites in three broad study areas: the Borders, Perthshire and Ayrshire. Whilst these areas were selected to cover as broad a range of topography and suitable Short-eared Owl habitat as possible, for the purposes of logistics they were all located on the Scottish mainland and in a relatively restricted area of southern and central Scotland. For this reason, it is essential to assess the extent to which the study areas sampled were representative of Short-eared Owl habitats in the UK as a whole.

After discussion with the Project Partners, we considered whether the 2006 study areas were representative in terms of three potentially influencing parameters.

4.5.1 Variation in densities of breeding Short-eared Owls

First, we considered the densities of breeding Short-eared Owls in the study areas used in 2006 and, specifically, any implications that areas with higher or lower densities would have when applying our findings to date to design field protocols for a full national survey of the species. Based on information supplied by local experts, and the abundance map in the last BTO bird atlas (Gibbons *et al.* 1993), we would suggest that the breeding densities of owls observed in 2006 in our study areas were average rather than high. There are certainly other areas of Britain where breeding densities are generally thought to be much higher (e.g. Orkney, the Uists) and populations in our three study areas are certainly thought to have been higher in some previous years. After discussion with the Project Partners, we agreed that our degree of concern over the application to areas of higher owl density of survey methods based on the fieldwork carried out in 2006 was lower than for some other aspects of the work (and that those latter areas of work should be given priority with the limited resources available for 2007). We would predict that in areas of higher breeding densities, owls will need to engage in more territorial activity per individual than in low density areas, hopefully making them more detectable and providing more direct observations suitable for differentiating between individual territories. Hence, even if a higher density of territories would invalidate our estimates of range sizes (as range sizes are likely to be smaller at higher density; see studies reviewed in Calladine *et al.* 2005), the greater degree of territorial activity shown by birds breeding at higher density should make the owls easier to detect and territories easier to separate. However, it is also possible that in areas of higher owl density (with higher prey levels), owls will need to search less to find prey, such that the duration of foraging activity will be reduced.

The Project Partners were more concerned about whether we had sampled low density areas sufficiently because owls would be likely to be harder to detect when densities were low. However, we noted that: (i) we thought we had been sampling at the medium to lower end of Short-eared Owl densities recorded in Britain (above); (ii) we had sampled at least two sites where we detected no breeding owls; and (iii) from a pragmatic point of view, attempting to carry out a further year of pilot fieldwork in an area with even lower density would result in so few observations that we would gain little or nothing towards development of the survey method. We conclude that any further pilot fieldwork in 2007 should be carried out in the same study areas (rather than areas that might have lower owl densities), to ensure that the results are directly comparable with those for 2006. We might address the problem of surveying areas of lower owl density to some extent by attempting to survey one larger study area in 2007 and evaluating the success of that attempt (see section 5). However, such problems with surveying areas of low population density arise when designing survey protocols for many other species, including some raptors (e.g. Hen Harrier). In any such survey, it is a reasonable assumption that under-recording in the low density areas will not have a large influence on an overall national or regional population estimate. If this assumption does not hold true (e.g. because the area potentially holding the species at low density is very large), then a different but complementary survey approach could be used in the low density area (e.g. seeking incidental sightings or local expert knowledge to fill any gaps).

4.5.2 Variation in prey and predators

During the planning for the field work in 2006, it was noted that some Scottish offshore islands hold high (e.g. the Uists, Orkney, Arran, Islay) or medium (e.g. Mull) densities of Short-eared Owls, such the precise surveying of their populations will be important for the precision of any overall national or UK population estimate. However, none of these island study areas was eventually selected for trial field work in 2006 because the availability of mainland areas with sufficient numbers of owls present meant that work on the mainland was most straightforward logistically, and unusually low numbers of owls settled to breed on Mull (P. Haworth, pers. comm.), which was one of the six study areas considered in 2006. As well as the potential implications of these higher densities of owls on islands for the field protocols (covered above), we also felt it important to consider whether any differing prey or predator base on the individual islands could cause Short-eared Owl activity patterns to differ from those on the mainland. If this were the case, for example if owls were more active at night and less so during the day, then survey methods developed on the mainland might not result in satisfactory detection of owls on islands. However, resources for further pilot work in 2007 will again necessarily be limited, and we have already concluded that further observations should be made at least in some of the study areas used in 2006 (4.4 above). For these reasons, we needed to agree whether some pilot work away from the mainland was essential for development of survey methods.

Of the Scottish islands that have held regular breeding populations of Short-eared Owls (Arran, Islay, Mull, Orkney, Skye and the Uists; Sharrock 1976; Gibbons *et al.* 1993), only on Orkney is the main prey species (the Field Vole *Microtus agrestis*) not present (replaced by the Orkney Vole *M. arvalis orcadensis*). Hence, with the exception of Orkney, breeding Short-eared Owl activity patterns on the above Scottish islands are not likely to differ from those on the mainland due to variation in the main prey that they exploit. On Orkney, intensive observational work on Short-eared Owl activity patterns during breeding has been carried out on a small sample of territories (one male radio-tracked, and four territories watched from 04:00-22:00 from 29 May to 22 June in 1990; Reynolds & Gorman 1999). This, plus some extensive counts of owls made on car journeys across Orkney, showed that the owls there were active during the day from March to July (but much less do during other months of the year), and that the daily activity patterns of the owls appeared to be highly synchronised to those of their vole prey. This meant that there were peaks (four) and troughs (three) in owl activity throughout the daylight hours. Activity was high from *ca* 05:30-07:30 and from 18:00-21:00 but there was also some activity between 09:00 and 14:30, with the major diurnal trough in activity occurring between *ca* 14:30 and 18:00. These observations from Orkney, albeit referring to a small sample of birds, suggest that survey protocols based on our pilot work carried out on the mainland should still be relevant to the activity patterns of owls on Orkney.

It is also possible that the activity patterns of Short-eared Owls could be influenced by those of other predatory species, which may or may not be present on some of the offshore islands. For example, Orkney, the Uists and Mull do not have any of the major ground mammalian predators (e.g. Red Fox *Vulpes vulpes*, Stoat *Mustela ermine*, Badger *Meles meles*), while other of the islands have one or more, such as Arran (Badger present), Islay (Stoat present) and Skye (Fox and Stoat present; see http://www.abdn.ac.uk/~clu008/BIO_SOIL/distribution). It is possible that Short-eared Owls might forage more during the day where there is a need to protect eggs or young from nocturnal ground predators, or even that they might forage more at night if there was a need to avoid larger avian predators (e.g. eagles; but see Fielding *et al.* 2003). None of these possible hypotheses has been tested empirically, however, and, on balance, based on the information provided from local raptor experts, we suggest that diurnal activity is likely to be at least as high on the islands (particularly those with higher breeding densities of owls, above) as on the mainland. On balance, pilot fieldwork on an offshore island should not be a priority with the limited resources available in 2007.

4.5.3 Variation in habitat

Assuming that similar prey was being exploited, there is little reason to suspect that Short-eared Owl activity patterns would vary greatly across the range of habitats utilised in Britain (reviewed in Calladine *et al.* 2005). However, habitat could certainly influence the detectability of the species during vantage point watches, such that some habitats might require modifications of the basic field protocols that were piloted in 2006.

Of the three principle habitats in which the species has been found breeding in the uplands of Britain, moorland (heath and bog) and rough grassland (including marginal hill ground or 'white moor') were felt to be very adequately sampled within the three study areas used in 2006 (see Table 1). Two habitats that were potentially undersampled in 2006 were noted by the Project Partners: unkeepered moorland (which is thought to be increasing in Scotland, with less muirburn and predator control being undertaken) and newly planted forestry. Of these, only the undersampling of forestry areas was thought to be a potential limitation on the objectives of the 2006 study, particularly on the assessment of owl detectability.

Although Short-eared Owls are known to nest in young plantations (literature reviewed by Calladine *et al.* 2005), only one published study (from Glentrool Forest, Dumfries and Galloway, in 1991) gives detailed information on the age of trees and coup (patch) size occupied by owls (Shaw 1995). That study indicated that both first and second rotation plantings were used by the owls but also indicated that 1991 was a year of high vole abundance in the area, so to what extent the findings were representative more widely of the use of forestry by breeding Short-eared Owls is debatable. Overall, of the habitats visible from the study sites used in 2006, pre-thicket forestry comprised only 2% (range 0-4% across the 12 vantage points; Table 1). However, whether this constitutes a problem when developing survey methods based on the 2006 findings depends on: (i) how much appropriate new forestry planting is now occurring in Britain; and (ii) whether there is existing evidence for the use of second rotation forestry by the owls. We consulted a number of individuals with relevant experience of Short-eared Owls and forestry to attain their opinions on these issues. The general consensus was that the area of new young conifer plantations suitable for Short-eared Owls now is very small in an historic context (D. Anderson, D. Jardine & G. Shaw pers. comm.); few new schemes are thought to be sufficiently large to hold owls, some are at lower elevations and produce a more vigorous field layer less favoured by voles (G. Shaw, pers. comm.), and the larger planting schemes now tend to involve native woodland (Caledonian pine), so that the understorey tends to be more heather-dominated with less voles and therefore less attractive to Short-eared Owls (D. Jardine, pers. comm.). Currently many second rotation schemes are being designed with relatively small clear-fell/restock areas, which are probably less likely to attract the owls based on their requirements from Shaw's (1995) study. In the Borders, owls still breed on the largest restocked sites (some as large as 100 ha) but they do not seem to occupy the sites every year and there are few such sites (G. Shaw pers. comm.). Second rotation forestry may have been more important for the owls in the past, and it is possible that was because larger raptors were then at artificially low densities; prey items collected in the 1980s and 1990s from Goshawk and Buzzard nest have confirmed Short-eared Owls in the diet (D. Anderson, pers. comm.) and provision of nestboxes have increased the numbers of Barn Owls and Tawny Owls that compete for voles (G. Shaw, pers. comm.). It is possible that second rotation forests are becoming too crowded with competitors for a species that is adapted to exploit temporary gluts of prey in situations where other resident vole-eaters are scarce (G. Shaw, pers. comm.). Those re-stock forestry areas that might be suitable for owls in future (based on the scale of felling and new planting) could possibly be identified via a desk-based GIS study (D. Jardine, pers. comm.).

In conclusion, the above suggests that new and second rotation forestry plantings might be less important habitats for Short-eared Owls in Britain than they were previously. A previous review (Calladine *et al.* 2005) suggested that some other localised areas of Short-eared Owl habitat in Britain might demand modified or completely different protocols compared to the principle habitats. For example, by using local knowledge as a guide to known breeding areas in coastal marshes and checking these individually, rather than the formal sampling of contiguous areas of suitable upland habitat that would advocated. For a full survey, surveyors can be supplied with some guidance with regard to the age of forestry areas that would need to be checked during a full survey (e.g. on the maximum age of trees and minimum areas of forest that will be used by the owls; as in Calladine *et al.* 2005) but it is also likely that recommendations for the selection of vantage points will need to be modified when areas of forestry do need checking, and in some cases foot searching rather than watches from vantage points could be recommended. Given the advice provided by local experts above, we do not feel that these habitat considerations warrant further pilot work involving vantage point watches over forestry (where there would be likely to be few owls and therefore few resulting data).

4.6 Other information sources on Short-eared Owl breeding biology

As part of this project, a number of local raptor workers and others with experience of working on the species were consulted regarding suitable data sets from which to estimate the laying dates of Short-eared Owls in recent years (e.g. from dates that they ringed young Short-eared Owls) or for any other new information on breeding biology or phenology that might usefully inform the design of surveys of breeding owls. However, many observers do not appear to hold the detailed observations of individual breeding attempts that we had hoped to find, and none has been able to provide any such data within the timescales of this project to date. Some datasets have been promised to arrive in 2007 but until they do we are unable to comment with confidence on their utility.

Short-eared Owls have been reported as laying as early as mid-March in Britain (Goddard 1935; BTO Nest Record Scheme data) but peak laying periods have typically been stated as April and early May in published studies (Mikkola 1983, Cramp 1985, Roberts & Bowman 1986). Since 1966, only 19 record cards for Short-eared Owls from which the timing of laying can be estimated by back-calculation have been submitted to the BTO Nest Record Scheme. Of these, 10 were from England, eight from Scotland and one from Wales. Overall in only 5% of these had laying taken place by 5 April (16 April for Scottish birds), 50% had laid by 2 May (6 May in Scotland) and the latest laying date recorded was 29 May (and that latest record was for a Scottish territory; Moss *et al.* 2005). This small number of records does not allow changes in the timing of breeding to be investigated. Moss *et al.* (2005) also analysed the ringing dates of Short-eared Owl young and back-calculated from these to estimate the laying dates (see Figure 2 in Calladine *et al.* 2005 for a graphical comparison of these data against those from nest record card data). A sample of 124 independent (from separate broods) ringed young was available, of which 76 were from Scotland. Of these, 5% came from clutches laid on or before 27 March (29 March in Scotland), 50% from clutches laid on or before 26 April (22 April in Scotland) and the latest from a clutch laid on 30 June (which was a Scottish clutch). Moss *et al.* (2005) did not find any significant effect of year (temporal change) on the timing of laying as estimated from ringing dates but the statistical power would have been low due to the small sample of ringed nestlings available.

4.7 Utility of the extensive monitoring technique

The extensive point counts along road transects produced a satisfactory rate of encounter with Short-eared Owls during the first three periods of the breeding season, with the highest number of encounters in the penultimate period (1-22 June); there were no records of owls during the last period (1-28 July). As well as recording Short-eared Owls, these surveys provided encounter rates that would be likely to provide satisfactory information for monitoring trends (or for use in combination with data from other sources, e.g. the BTO/JNCC/RSPB Breeding Bird Survey) for a suite of other upland

and marginal upland bird species, including a number of breeding waders (e.g. Curlew, Lapwing, Redshank, Snipe and Oystercatcher), two widespread raptors (Buzzard and Kestrel), some gamebirds (e.g. Pheasant, possibly Black and Red Grouse) and a range of passerines (e.g. Meadow Pipit, Pied Wagtail, Reed Bunting, Skylark). For the majority of species, including Short-eared Owl, the second two survey periods (mid-April to mid-May and 1-22 June) might provide the most appropriate choice for carrying out such extensive survey work; across the range of species encounter rates in these periods were generally high and confining the survey work to the middle part of the breeding season would reduce the complications associated with flocking birds (most of which were unlikely to be on territory), most of which were recorded in the first and last survey periods. However, a further breeding season of data collection (as in 4.4 above) would help to confirm whether 2006 was a representative or aberrant year.

We suggest that a further stage of pilot work is also required to assess whether this survey method would be attractive to volunteer birdwatchers, as the success of the technique for monitoring the interannual population trends of Short-eared Owls will depend on a larger sample of transects being driven across the breeding range of the species in Britain. Given that, to date, we have found little evidence for any difference in Short-eared Owl activity rates between the morning and evening sampling periods (4.1 above), it could also be useful to give volunteer birdwatchers more potential survey time, by allowing them to carry out car transects in the early morning as well as the evening. Any differences in the activity patterns of the other species between morning and evening could be tested and accounted for during indexing analyses if required.

5 RECOMMENDATIONS

Based on the findings of the 2006 field surveys, and discussions with the Project Partners, we make the following recommendations with respect to the original objectives of the study:

a. Intensive observations to assess seasonal and diurnal variation in the activity patterns of Short-eared Owls (and the occurrence of key behaviours indicative of territoriality/breeding) should be repeated in the same three study areas during the 2007 breeding season, to give support to the patterns found in 2006 and reassure that 2006 was not an aberrant year due to the cold weather in early spring (see 4.1);

b. Additional watches from vantage points should be carried out in the middle of the day, to assess whether the survey period could be extended without lowering detection rates (see 4.1);

c. The extensive monitoring method utilising point counts from road transects should be repeated in the 2007 breeding season, covering the transects in the three study areas used in 2007 but also further areas across the range of the species in Britain. This work should be designed to assess: (i) whether the conclusions drawn from the 2006 observations are robust; (ii) whether the methods are attractive to volunteers (by attempting to get volunteers to cover a sample of transects); and (iii) whether these surveys could be made in the early morning in addition to the evening (see 4.7);

d. As the next step towards devising protocols for a full census of breeding Short-eared Owls, the intensive surveys using vantage point watches should be extended over a larger geographical area at one of the study sites (resources permitting). Given the conclusions drawn from the 2006 pilot fieldwork, a suitable survey approach (number of visits, timing of visits, diurnal sampling period(s), spacing of vantage points etc) should be selected, and steps taken to produce a population estimate and associated confidence limits for the selected area. Such an approach would help to reveal any further difficulties when interpreting the information collected using these field protocols (e.g. when using territorial behaviours and ranging distances to separate potential breeding territories), and improve the guidance that will be produced for use for a full survey of any given area; and

e. Once the additional data from the 2007 breeding season are available, it will be possible to carry out analyses to simulate the proportion of apparent Short-eared Owl territories that would have been detected under certain scenarios of number and timing (seasonal and diurnal) of survey visits (that would be feasible to ask volunteers to undertake in a full survey). Preliminary analyses of this type with the 2006 data suggested that most combinations of two two-hour visits in periods B and C or the breeding season would have detected the majority of the territories that were detected in total. A slightly more complex simulation should be designed and run after the 2007 data collection, to select the most satisfactory combination of visits for use when carrying out a full survey of any given geographical area. It is possible that further quantitative work could also be carried out to improve estimates of range sizes, by controlling (to some degree at least) for variation in the amount of ground visible to observers from vantage points.

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TABLES

Table 1. Habitats visible from the vantage points from which fixed point observations of Short-eared Owls were made during the 2006 breeding season.

Study area	Vantage Point	Altitude (m asl)	Habitats visible (approx. % cover)				
			Heath & bog	Semi-natural grassland	Mature conifers	Young plantations	Improved grassland
Perthshire	A	240	70	28	2	0	0
	B	300	50	46	0	2	2
	C	320	70	10	10	4	6
	D	500	95	0	5	0	0
Ayrshire	A	330	80	15	5	0	0
	B	320	55	40	5	0	0
	C	280	30	70	0	0	0
	D	180	70	20	0	4	6
Borders	A	400	25	70	5	0	0
	B	300	60	30	0	0	10
	C	480	80	20	0	0	0
	D	300	40	40	5	0	15

Table 2. The number of two-hour watches completed from the fixed vantage points during each of the four study periods of the breeding season, and each of the four diurnal sampling times (two two-hour watches in the first five hours after first light and two two-hour watches in the last five hours before dusk) during the 2006 breeding season.

Vantage point	**6 – 31 March**				**18 April – 15 May**				**1 – 22 June**				**1 – 28 July**			
	Early am	Late am	Early pm	Late pm	Early am	Late am	Early pm	Late pm	Early am	Late am	Early pm	Late pm	Early am	Late am	Early pm	Late pm
Perthshire																
A	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1
B	1	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1
C	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
D	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Ayrshire																
A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
C	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Borders																
A	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
B	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
C	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3. Summary of conclusions regarding the number of territories of Short-eared Owls, and the outcomes of each breeding attempt, for each study area and vantage point used in the 2006 study. These conclusions are based on a combination of observations from the intensive fieldwork, local raptor workers and local land managers.

Study area	Vantage point	Apparent territory	Assumed outcome*
Borders	A	(i)	A food pass to an apparent nest site suggested that young hatched but no fledged young were seen. A fledged young was seen in the south of this range however late in the season by TD.
	B	(ii)	3+ fledged young. Nest site was found by TD. TD also thought there may be another territory adjacent to the south-west but the area was largely obscured from view (TD's suspicion was based only on observations of a post-fledged young that could have originated from our territory (ii) however).
	C	(iii)	Site occupied but relatively few observations as largely obscured from view from the vantage point. TD suspected nest site to west of road.
	C	(iv)	2+ fledged young. This territory was differentiated from '(iii) by the intensive fieldwork but not by TD's casual observations.
	D	(v)	Breeding unlikely: only 2 observations of owls. Not seen by TD.
Ayrshire	A		No owls seen.
	B	(i)	Occasional observations of owls but none indicative of breeding. Similarly reported by GC and local shepherds.
	C	(ii)	Young hatched (repeatedly carrying food to one location) but no fledged young seen. No independent observations for this site.
	C	(iii)	Few observations: owls were distant and only seen when stimulated by a bird from territory (ii).
	D	(iv)	Few observations and no suggestion of breeding. BS had a series of observations here in March but not later in season, although he “didn't get there much”.
Perthshire	A	(i)	Food carrying seen, suggesting that young hatched, but no fledged young seen. NM thinks there may have been 2 pairs here but his view was based on a single observation of birds seen at opposite ends of the single range identified by the intensive fieldwork.
	B	(ii)	Food carrying seen, suggesting that young hatched. No fledged young seen. NM thinks breeding attempt here was unsuccessful (includes reports from the local keeper).
	B	(iii)	NM considered there was another territory in the area of site B but the area he described was mostly out of range of the vantage point. NM thought it did not fledge young (includes reports from local keeper).
	C	(iv)	Few observations: unlikely to have bred. NM thought similarly (including reports from local keeper).
	D		No owls seen.

Note * Observers: TD=Tom Dougall; GC=Graeme Clelland; BS=Bob Stakim; NM=Neil Morrison

Table 4. The influence of Season and Time of Day on the duration of all observations of Short-eared Owls and of behaviours indicative of territory holding, from generalised linear models assuming a negative binomial error distribution and using a log link function. Site (vantage point) was included as a repeated measure.

Model	Season[a]		Time of Day[b]	
	χ^2	*P*	χ^2	*P*
All observations[c] (4 time of day classes)	6.68	0.08	1.49	0.69
All observations (Morning only, 5 classes)	5.23	0.16	5.92	0.21
All observations (Evening only, 5 classes)	3.70	0.30	6.18	0.19
Key observations[d]	Models would not converge – insufficient observations			

Notes: a) Season refers to the four periods of the breeding season: 6-31 March; 18 April – 15 May; 1- 22 June; 1-28 July.

b) Time of Day refers to either the four time of day classes (two two-hour periods within the first five hours after first light and two two-hour periods within the last five hours before dusk) or, for models in which morning and evening observations were treated separately, the five time of day classes (five one-hour periods after first light or five one-hour periods before dusk).

c) The dependent variable is the length of time for which owls were seen (all activity codes combined). Durations of simultaneous observations were treated as additive.

d) The dependent variable is the length of time for which owls were seen in which behaviour indicative of holding territory (courtship display, alarming or mobbing potential predators, carrying prey to likely nest sites and the presence of recently fledged young) was observed. Durations of simultaneous observations were treated as additive.

Table 5. The mean distances at which Short-eared Owls were detected from each vantage point.

SITE	Mean (m)	95% confidence limits	N observations
Perthshire A			
First distance	693	499 – 887	
Min. distance	626	434 – 818	25
Max. distance	771	580 - 962	
Perthshire B			
First distance	609	428 - 790	
Min. distance	445	267 – 623	21
Max. distance	884	659 – 1108	
Perthshire C			
First distance	172	97 - 247	
Min. distance	103	12 – 195	6
Max. distance	268	184 – 353	
Ayrshire B			
First distance	639	450 - 828	
Min. distance	536	331 – 741	8
Max. distance	886	668 – 1104	
Ayrshire C			
First distance	562	437 - 686	
Min. distance	444	318 – 570	31
Max. distance	666	546 – 787	
Ayrshire D			
First distance	825	497 - 1153	
Min. distance	713	392 – 1033	4
Max. distance	838	523 – 1152	
Borders A			
First distance	378	312 - 443	
Min. distance	232	172 – 291	33
Max. distance	512	444 – 581	
Borders B			
First distance	446	350 - 542	
Min. distance	315	218 – 411	30
Max. distance	587	475 – 699	
Borders C			
First distance	504	369 - 639	
Min. distance	383	246 – 521	25
Max. distance	611	468 – 755	
Borders D			
First distance	533	16 - 1050	
Min. distance	367	8 – 725	3
Max. distance	567	187 – 946	
ALL SITES			
First distance	522	473 - 570	
Min. distance	399	350 – 449	186
Max. distance	656	603 – 709	

Table 6. Minimum ranging distances of Short-eared Owls estimated from observations from fixed vantage points.

SITE	RANGE[a] (m)	N[b]	SITE	RANGE[a] (m)	N[b]
Perthshire A			**Borders A**		
Period B	1430	14	Period B	1150	3
Period C	2425	10	Period C	1680	18
Period D	330	1	Period D	1110	12
All	2510	25	All	1680	33
Perthshire B			**Borders B**		
Period B	1995	11	Period B	2160	4
Period C	1450	6	Period C	1470	15
Period D	2990	4	Period D	1080	11
All	3860	21	All	2160	30
Perthshire C			**Borders C (range i)**		
Period A	170	1	Period A	670	2
Period B	620	2	Period B	1940	7
Period C	420	3	Period C	630	6
All	790	6	Period D	1390	10
			All	1940	25
Ayrshire B					
Period C	1990	5	**Borders C (range ii)**		
Period D	1250	3	Period A	163	1
All	1990	8	Period B	1170	4
			Period C		0
			Period D	552	2
			All	1170	7
Ayrshire C			**Borders D**		
Period B	1490	7	Period D	1000	3
Period C	1880	18	All	1000	3
All	1880	31			
Ayrshire D			**ALL SITES**	**Mean**	**SE**
Period B	430	1	Period A	1010	340
Period C	1230	3	Period B	1357	204
All	2050	4	Period C	1463	213
			Period D	1358	359
			ALL	1368	128

Notes: a) Estimated minimum ranging distances are the maximum arcs of the minimum convex polygons drawn around the plotted flight lines of Short-eared Owls observed from fixed vantage points (see text for details).
b) The sample size of flight lines around which the minimum convex polygons were drawn.

Table 7. Registrations of species recorded during point count surveys during the 2006 breeding season.
* = Species with 40 or more registrations in at least one period;
+=Species not sufficiently dispersed for estimation of densities using distance sampling (recorded from less than 25% of count points in the period of the season in question);
++=Species only achieving 40 registrations in the first or last period (when they may not have been on breeding territories);
**=Species for which formal estimation of breeding population density was carried out.
See text (sections 2.3 and 3.4 for further explanation).

Species	**Period A (6-31 March)**		**Period B (18 April – 15 May)**		**Period C (1 June – 22 June)**		**Period D (1 July – 28 July)**	
	No. of points	No. of regs.	No. of points	No. of regs.	No. of points	No. of regs.	No. of points	No. of regs.
Barn Owl	1	1	1	1	0	0	0	0
Black Grouse	5	17	5	37	2	5	5	7
Blackbird	0	0	1	1	0	0	0	0
Black-headed Gull*/+	0	0	7	104	13	134	5	6
Buzzard	16	25	17	24	12	14	8	9
Canada Goose	0	0	3	5	0	0	0	0
Carrion Crow*/+	31	67	17	32	20	80	20	44
Common Gull	1	2	4	22	0	0	1	1
Common Sandpiper	0	0	4	4	7	7	5	7
Cuckoo	0	0	3	3	2	2	0	0
Curlew*/**	36	155	42	107	55	143	16	28
Dipper	4	4	0	0	0	0	1	1
Fieldfare*/+/++	1	75	0	0	0	0	0	0
Golden Plover	0	0	1	1	0	0	0	0
Goldfinch	0	0	0	0	0	0	1	2
Goosander	2	4	0	0	0	0	0	0
Grasshopper Warbler	0	0	1	1	3	3	1	1
Grey Heron	1	1	1	1	5	7	2	2
Grey Partridge	0	0	0	0	0	0	1	2
Grey Wagtail	1	1	1	1	1	1	0	0
Grey-lag Goose	0	0	0	0	2	5	0	0
Hen Harrier	0	0	1	1	0	0	0	0
Herring Gull	0	0	2	2	1	1	0	0
House Martin	0	0	0	0	4	17	4	9
Jackdaw	2	14	4	14	2	13	3	25
Kestrel	10	10	9	9	8	9	10	12
Lapwing*/**	31	117	29	77	26	66	16	31
Lesser Black-backed Gull*/+	1	2	4	41	2	2	2	2
Lesser Redpoll	0	0	0	0	0	0	3	7
Linnet	0	0	1	2	1	1	0	0
Mallard	3	7	12	23	2	4	5	16
Meadow Pipit*/**	39	133	40	86	77	150	46	82
Mistle Thrush	0	0	4	7	0	0	0	0
Osprey	0	0	0	0	0	0	3	4
Oystercatcher*/**	14	38	20	55	31	68	20	68
Peregrine	0	0	0	0	0	0	1	1

Species	Period A (6-31 March)		Period B (18 April – 15 May)		Period C (1 June – 22 June)		Period D (1 July – 28 July)	
	No. of points	No. of regs.	No. of points	No. of regs.	No. of points	No. of regs.	No. of points	No. of regs.
Pied Wagtail	5	14	11	12	10	15	9	19
Raven	5	6	0	0	0	0	0	0
Red Grouse	12	14	8	12	1	1	3	12
Red Kite	0	0	0	0	0	0	1	1
Red-legged Partridge	1	2	2	2	2	3	1	1
Redshank	2	3	4	7	6	13	2	2
Reed Bunting	2	2	6	8	7	7	3	4
Ring Ouzel	0	0	1	1	2	2	0	0
Ringed Plover	0	0	0	0	1	1	0	0
Robin	0	0	0	0	0	0	1	1
Rook	1	1	4	35	2	26	4	39
Sand Martin*/+	0	0	9	18	9	61	13	45
Sedge Warbler	0	0	1	1	2	2	0	0
Short-eared Owl	4	4	3	4	6	6	0	0
Siskin	0	0	2	2	0	0	0	0
Skylark*/**	10	14	17	25	35	63	6	6
Snipe	4	4	8	12	16	17	4	5
Song Thrush	0	0	1	1	0	0	0	0
Sparrowhawk	1	1	0	0	0	0	0	0
Starling*/+/++	1	1	4	8	4	19	5	78
Stonechat	7	7	3	3	4	5	7	9
Swallow*/+	0	0	19	42	11	44	20	68
Swift	0	0	0	0	1	1	1	3
Teal	0	0	0	0	1	2	0	0
Tufted Duck	0	0	1	2	0	0	0	0
Wheatear	1	1	8	10	5	6	2	2
Whinchat	0	0	2	2	1	1	1	1
Wigeon	0	0	1	2	0	0	0	0
Wood Pigeon*/+	0	0	7	54	1	5	3	11
Wren	6	6	5	6	11	13	12	15
Yellowhammer	0	0	0	0	0	0	1	1

Table 8. Population density estimates for the most abundant and widespread species recorded during the point count surveys using distance sampling and the program DISTANCE.

SPECIES	Transect	DENSITY (km^{-2})	95% confidence interval
Meadow Pipit	Ayrshire 1	106	65 – 176
	Ayrshire 2	316*	166 – 604
	Borders 1	21*	9 – 47
	Borders 2	46*	23 – 91
	Perthshire 1	64*	31 – 130
	Perthshire 2	28*	11 – 72
	ALL COMBINED	97	66 – 142
Oystercatcher	Ayrshire 1	6*	1 – 22
	Ayrshire 2	21	9 – 47
	Borders 1	1*	0 – 25
	Borders 2	2*	1 – 25
	Perthshire 1	16*	4 – 11
	Perthshire 2	8*	2 – 39
	ALL COMBINED	9	5 – 17
Lapwing	Ayrshire 1	35*	11 – 117
	Ayrshire 2	1*	0 – 3
	Borders 1	10*	2 – 59
	Borders 2	10*	5 – 22
	Perthshire 1	194*	52 – 722
	Perthshire 2	316*	72 – 1390
	ALL COMBINED	94	35 – 253
Curlew	Ayrshire 1	24	10 – 58
	Ayrshire 2	10*	1 – 111
	Borders 1	1*	1 – 3
	Borders 2	3*	1 – 7
	Perthshire 1	2*	1 – 13
	Perthshire 2	8*	2 – 30
	ALL COMBINED	8	3 – 19
Skylark	Ayrshire 1	30*	13 – 70
	Ayrshire 2	78*	39 – 157
	Borders 1	2*	1 – 7
	Borders 2	9*	3 – 26
	Perthshire 1	0*	
	Perthshire 2	0*	
	ALL COMBINED	20	12 – 33

* Note: These estimates are derived from sample sizes of less than 40 registrations and should therefore be considered unreliable.

FIGURES

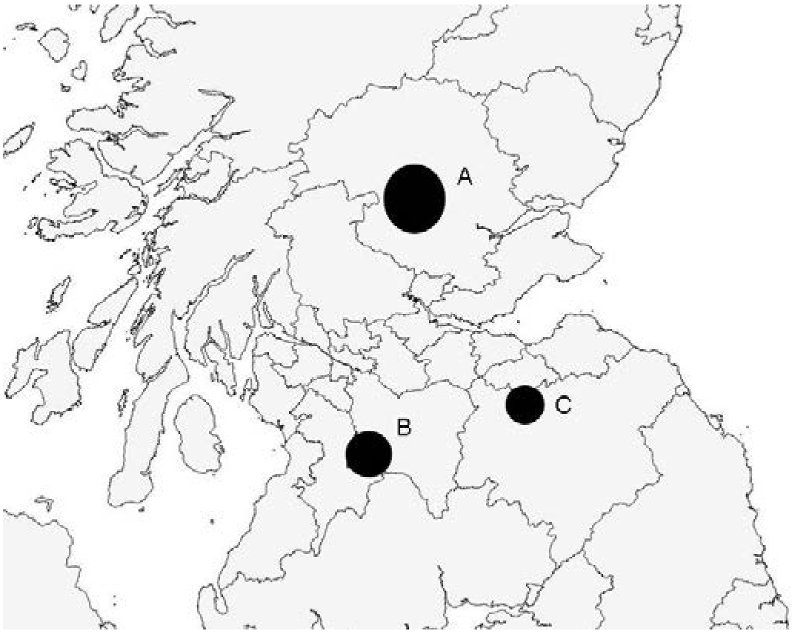


Figure 1a. Location of the three study areas used in 2006: A – Perthshire; B – Ayrshire; C – Borders.

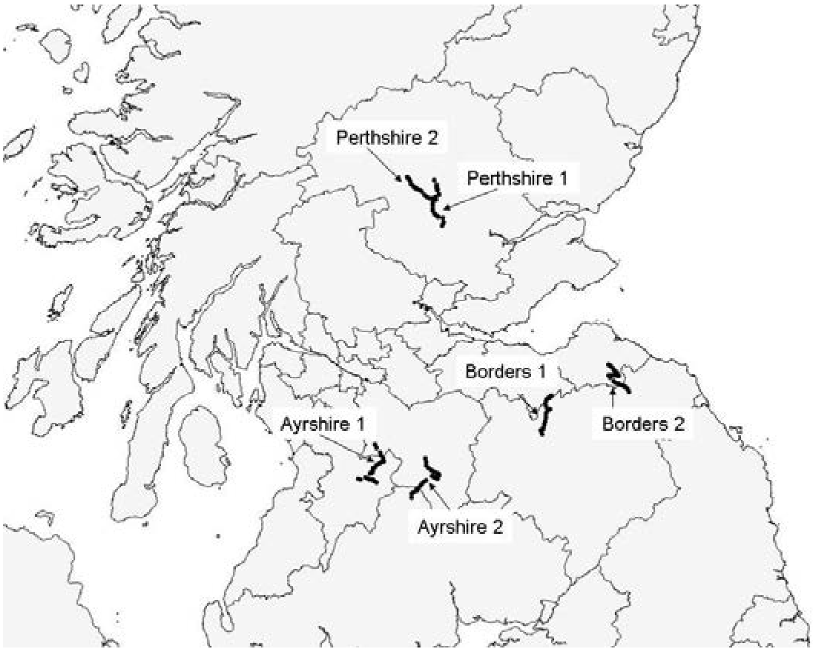
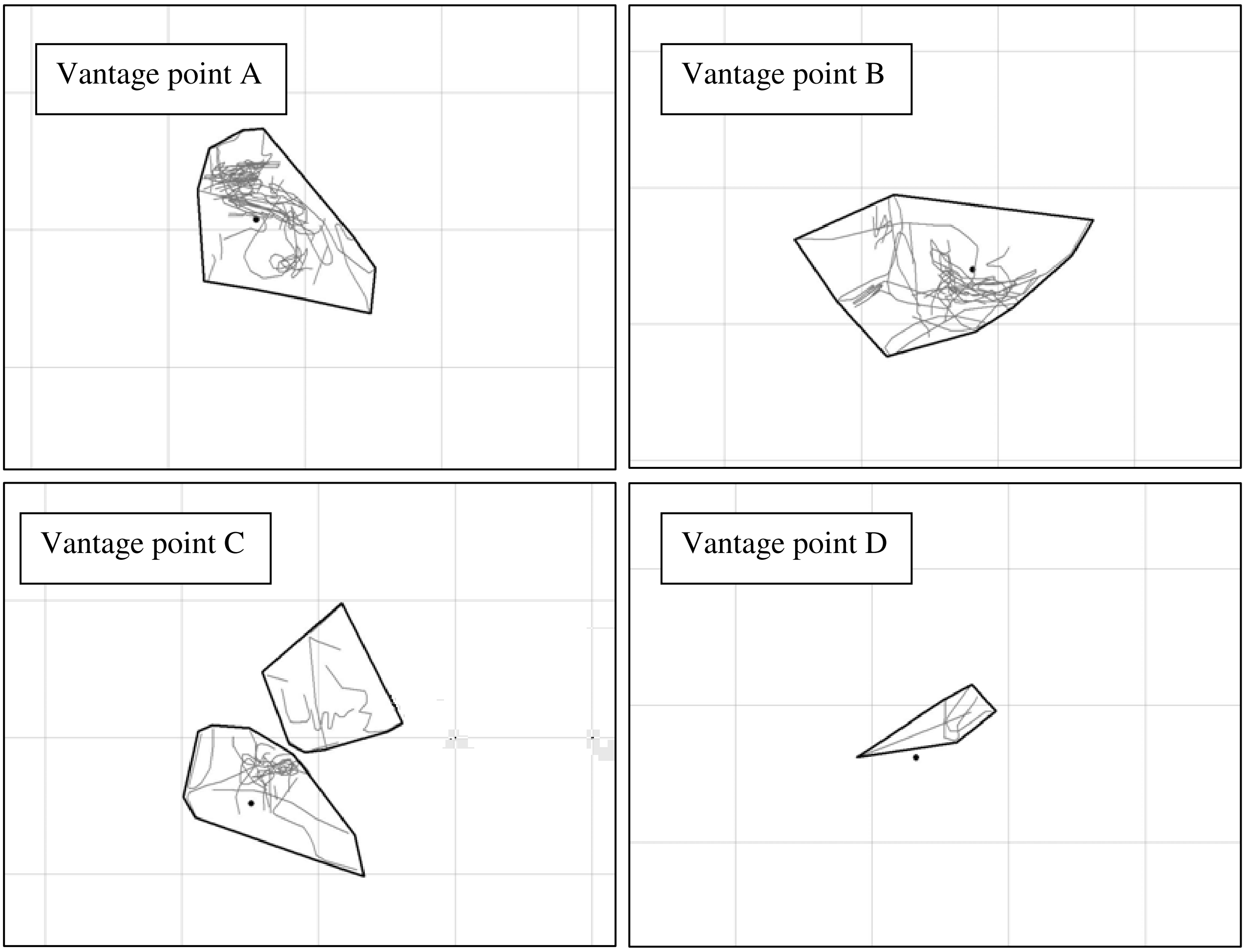


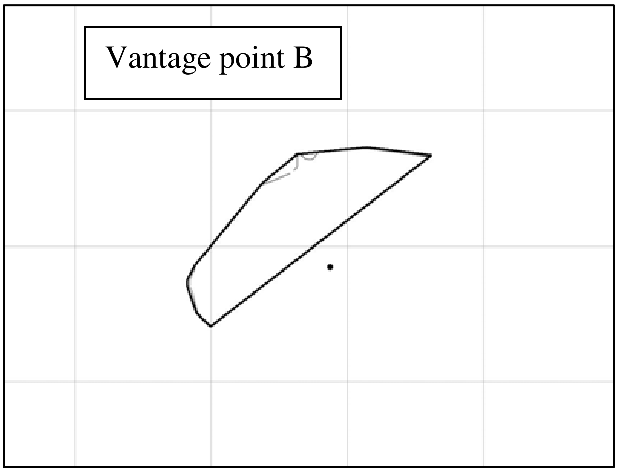
Figure 1b. Locations of the point count transects used in 2006.

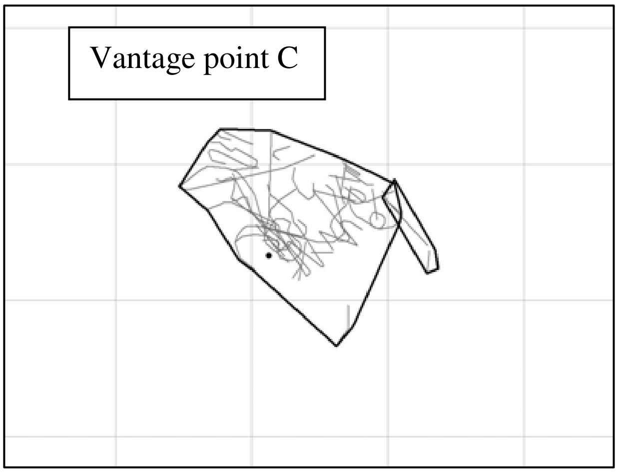
Figure 2. Minimum convex polygons drawn around the outer limits of the flight lines of Short-eared Owls during the 2006 breeding season at 10 sites within three study areas: (a) the Borders; (b) Ayrshire; and (c) Perthshire. Observations in which behaviours indicative of territorial interaction were noted (when available) were used to establish boundaries between adjacent ranges (see text for further details). The position of the vantage point is shown by the black point on each map. The grid shows 1-km squares of the National Grid.

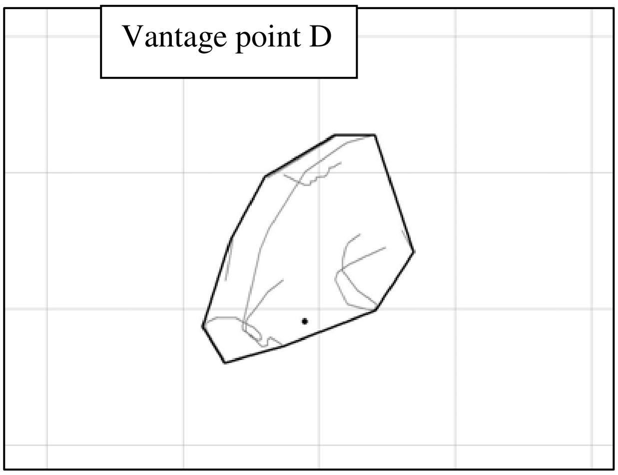
(a) Borders



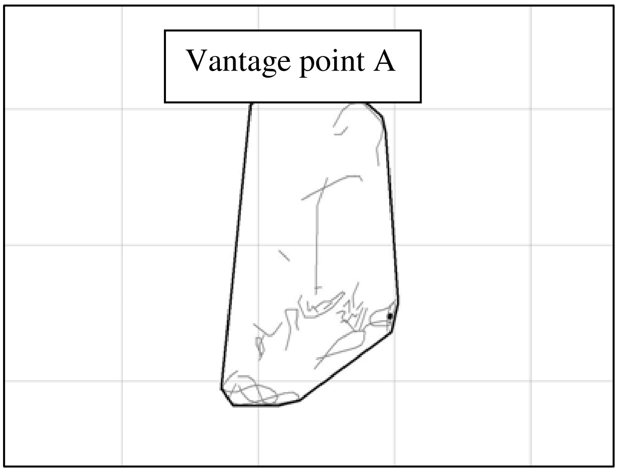
(b) Ayrshire

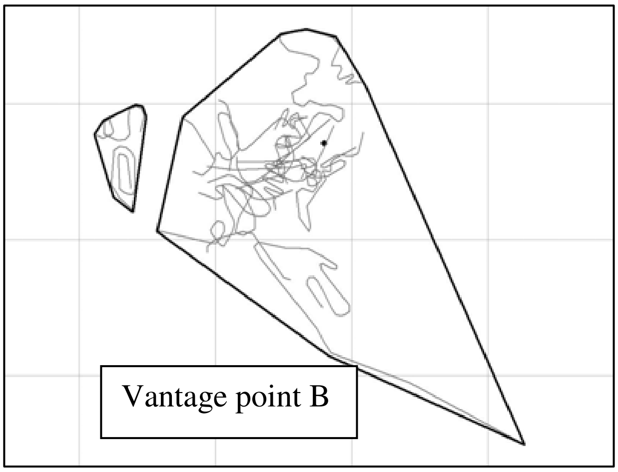


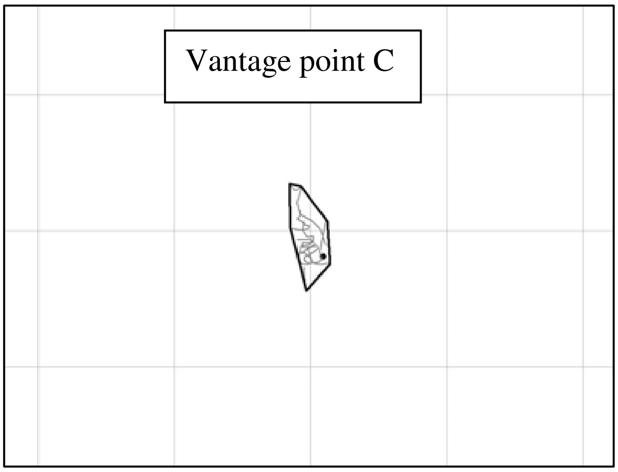




(c) Perthshire







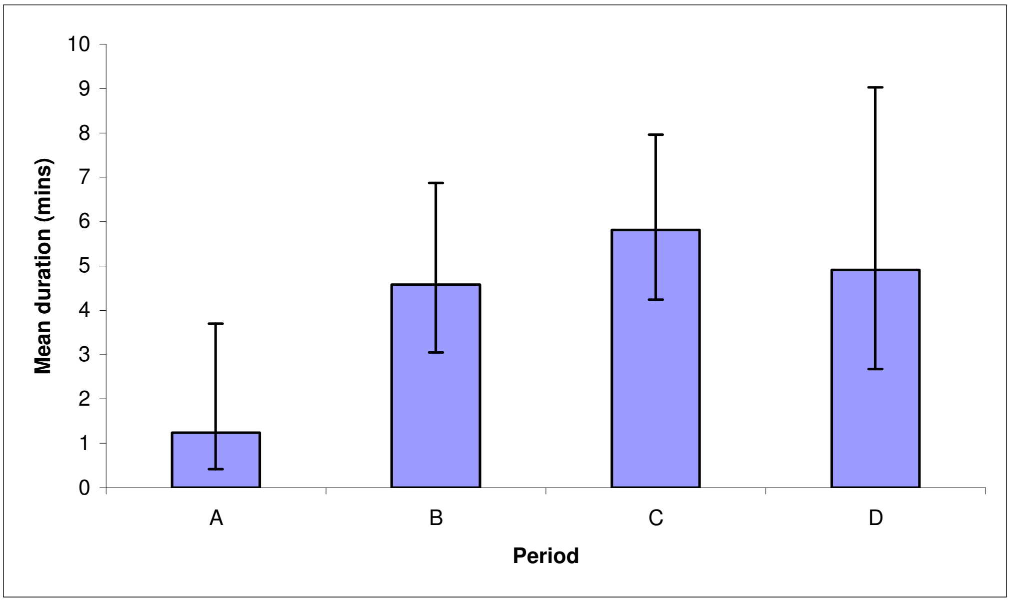


Figure 3a. The duration of time for which Short-eared Owls were visible during two-hour watches during four survey periods (A: 6-31 March, B: 18 April – 15 May, C: 1-22 June, D: 1-28 July) in the 2006 breeding season. Means and 95% confidence limits (back-transformed from estimates from the generalised linear model in Table 4) are shown.

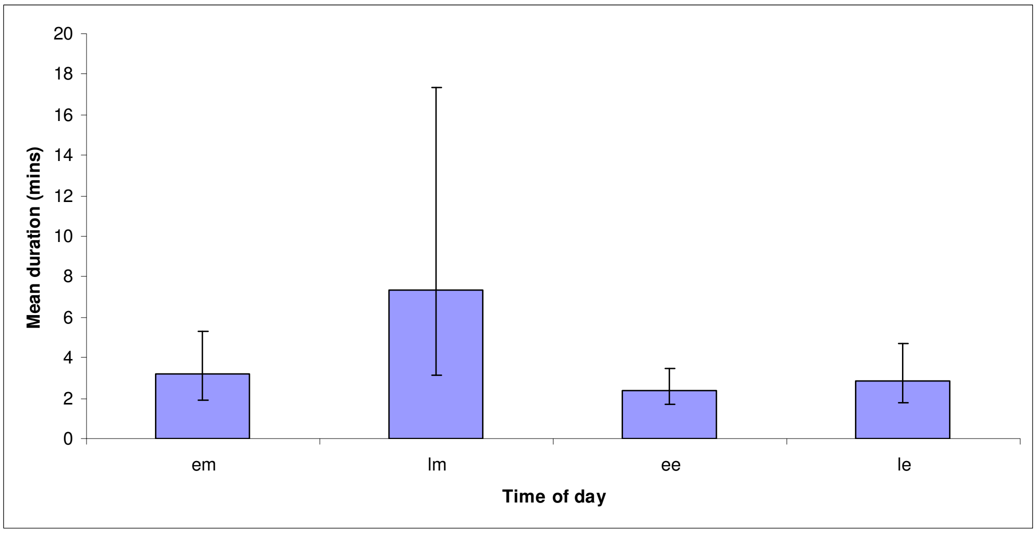


Figure 3b. The duration of time for which Short-eared Owls were visible during two-hour watches during four times of day (em=early morning; lm=late morning; ee=early evening; le=late evening) during the 2006 breeding season. The time of day classes refer to the two two-hour watches within the first five hours after first light and the two two-hour watches in the last five hours before dusk. Means and 95% confidence limits (back-transformed from estimates from the generalised linear model in Table 4) are shown.

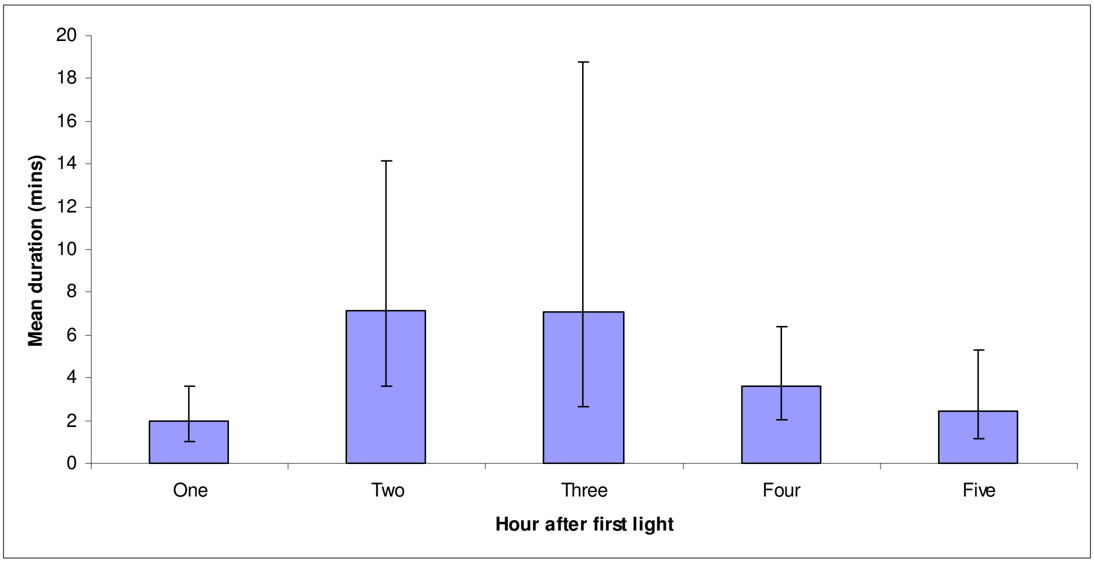


Figure 4a. The duration of time for which Short-eared Owls were visible in the first five hours after first light during the 2006 breeding season. Means and 95% confidence limits (back-transformed from estimates from the generalised linear model in Table 4) are shown.

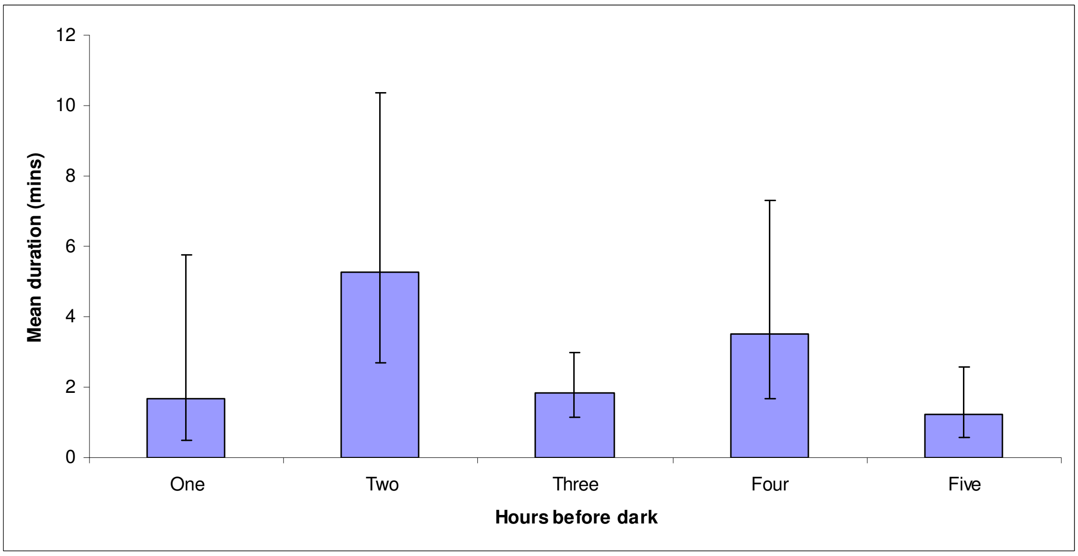


Figure 4b. The duration of time for which Short-eared Owls were visible in the last five hours before dark during the 2006 breeding season. Means and 95% confidence limits (back-transformed from estimates from the generalised linear model in Table 4) are shown.

Appendix 1

(1a) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (all activities) within the four time of day periods (em=early morning; lm=late morning; ee=early evening; le=late evening) and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	Time	N	Median	P5	P95	UNIT
A	em	0	0	0	0	per hour
A	lm	7	0	0	3	per hour
A	ee	1	0	0	0	per hour
A	le	1	3	0	7	per hour
B	em	12	1	0	13	per hour
B	lm	12	1	0	4	per hour
B	ee	10	1	0	9	per hour
B	le	18	2	1	13	per hour
C	em	23	1	0	17	per hour
C	lm	11	1	0	13	per hour
C	ee	21	2	1	8	per hour
C	le	31	1	0	8	per hour
D	em	9	1	0	16	per hour
D	lm	20	3	0	47	per hour
D	ee	3	2	1	4	per hour
D	le	9	0	0	5	per hour

Summary of all observations by period:

Period	N	Median	p5	p95
A	9	2	1	40
B	52	2	1	9
C	84	2	1	16
D	41	2	1	16
ALL	186	2	1	13

Summary of all observations by time of day:

Em	42	2	1	9
Lm	50	0	1	40
Ee	35	2	1	9
Le	59	2	1	8

(1b) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (all activities) in the MORNING within the first five hours after first light and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	HrAfLt	N	Median	P5	P95	UNIT
A	1	0	0	0	0	per hour
A	2	1	4	4	4	per hour
A	3	0	0	0	6	per hour
A	4	0	0	0	0	per hour
A	5	0	0	0	0	per hour
B	1	8	1	0	9	per hour
B	2	11	3	1	26	per hour
B	3	2	0	0	8	per hour
B	4	3	4	2	6	per hour
B	5	0	0	0	0	per hour
C	1	7	4	0	25	per hour
C	2	8	2.5	1	36	per hour
C	3	10	1	0	34	per hour
C	4	7	2	1	7	per hour
C	5	0	0	0	0	per hour
D	1	5	0	0	29	per hour
D	2	4	14	1	31	per hour
D	3	6	2	0	93	per hour
D	4	6	13	1	17	per hour
D	5	8	2.5	1	14	per hour

Summary of all observations in MORNING by period and hour after first light:

Period	n	Median p5	p95	
A	7	1	1	80
B	24	2	1	9
C	32	2	1	34
D	29	6	1	93
ALL	92	2.5	1	34

HrAfLt	N	Median P5	P95	
1	20	2.5	1	27
2	24	3	1	31
3	24	1.5	1	93
4	16	3.5	1	17
5	8	2.5	1	14

(1c) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (all activities) in the EVENING within the last five hours before dark and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	HrBeDk	N	Median	P5	P95	UNIT
A	1	1	6.5	0	13	per hour
A	2	1	4	4	4	per hour
A	3	0	0	0	0	per hour
A	4	0	0	0	0	per hour
A	5	0	0	0	0	per hour
B	1	7	3	1	16	per hour
B	2	12	7.5	1	25	per hour
B	3	6	2	0	7	per hour
B	4	3	1	1	1	per hour
B	5	0	0	0	0	per hour
C	1	9	1	0	7	per hour
C	2	10	3.5	1	20	per hour
C	3	11	2	1	9	per hour
C	4	16	4	1	29	per hour
C	5	6	1	1	4	per hour
D	1	4	0	0	5	per hour
D	3	6	5	1	11	per hour
D	4	2	4.5	2	7	per hour
D	5	0	0	0	0	per hour

Summary of all observations in the EVENING by period and hour before dark:

Period	n	Median p5	p95	
A	2	8.5	4	13
B	28	3.5	1	18
C	52	3	1	16
D	12	3.5	1	11
ALL	94	3	1	16

HrBeDk	N	Median P5	P95	
1	21	3	1	13
2	23	4	1	20
3	23	3	1	9
4	21	3	1	15
5	6	1	1	4

(1d) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (key activities indicative of territory holding) within the four time of day periods (em=early morning; lm=late morning; ee=early evening; le=late evening) and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	Time	N	Median	P5	P95	UNIT
A	em	0	0	0	0	per hour
A	lm	0	0	0	0	per hour
A	ee	0	0	0	0	per hour
A	le	0	0	0	0	per hour
B	em	3	0	0	13	per hour
B	lm	4	0	0	3	per hour
B	ee	5	0	0	9	per hour
B	le	7	0	0	13	per hour
C	em	6	0	0	11	per hour
C	lm	2	0	0	4	per hour
C	ee	1	0	0	0	per hour
C	le	0	0	0	0	per hour
D	em	2	0	0	6	per hour
D	lm	12	1	0	47	per hour
D	ee	0	0	0	0	per hour
D	le	1	0	0	0	per hour

Summary of Key observations by Period:

Period	N	Median p5	p95	
A	0	0	0	0
B	19	0	0	16
C	9	0	0	5
D	15	0	0	24
ALL	43	0	0	12

Summary of Key observations by time of day:

Em	11	0	0	12
Lm	18	0	0	24
Ee	6	0	0	4
Le	8	0	0	5

(1e) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (key activities indicative of territory holding) in the MORNING within the first five hours after first light and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	HrAfLt	N	Median	P5	P95	UNIT
A	1	0	0	0	0	per hour
A	2	0	0	0	0	per hour
A	3	0	0	0	0	per hour
A	4	0	0	0	0	per hour
A	5	0	0	0	0	per hour
B	1	2	0	0	2	per hour
B	2	3	0	0	26	per hour
B	3	1	0	0	8	per hour
B	4	1	0	0	6	per hour
B	5	0	0	0	0	per hour
C	1	2	0	0	25	per hour
C	2	3	0	0	22	per hour
C	3	2	0	0	1	per hour
C	4	1	0	0	7	per hour
C	5	0	0	0	0	per hour
D	1	2	0	0	29	per hour
D	2	0	0	0	0	per hour
D	3	4	0	0	93	per hour
D	4	1	0	0	14	per hour
D	5	7	1	0	14	per hour

Morning Key observations by Period:

Period	N	Median	P5	P95
ALL	29	0	0	14
A	0	0	0	0
B	7	0	0	8
C	8	0	0	22
D	14	0	0	29

Morning Key observations by Hour after Light:

HrAfLt	N	Median	P5	P95
1	6	0	0	12
2	6	0	0	22
3	7	0	0	24
4	3	0	0	14
5	7	1	0	14

(1f) Frequency, median, 5 and 95% percentiles for the duration of Short-eared Owl observations (key activities indicative of territory holding) in the EVENING within the last five hours before dark and four periods of season (A= 6-31 March; B=18 April-15 May; C=1 June-22 June; D=1 July-28 July).

Period	HrBeDk	N	Median	P5	P95	Unit
A	1	0	0	0	0	per hour
A	2	0	0	0	0	per hour
A	3	0	0	0	0	per hour
A	4	0	0	0	0	per hour
A	5	0	0	0	0	per hour
B	1	3	0	0	16	per hour
B	2	5	0	0	25	per hour
B	3	4	0	0	7	per hour
B	4	0	0	0	0	per hour
B	5	0	0	0	0	per hour
C	1	0	0	0	0	per hour
C	2	0	0	0	0	per hour
C	3	0	0	0	0	per hour
C	4	0	0	0	0	per hour
C	5	1	0	0	1	per hour
D	1	0	0	0	0	per hour
D	2	0	0	0	0	per hour
D	3	1	0	0	6	per hour
D	4	0	0	0	0	per hour
D	5	0	0	0	0	per hour

Evening Key observations by Period:

Period	N	Median	P5	P95
ALL	14	1	0	15
A	0	0	0	0
B	12	0	11	18
C	1	0	0	0
D	1	0	0	0

Evening Key observations by Hour before Dark:

HrBeDk	N	Median	P5	P95
1	3	0	0	3
2	5	0	0	18
3	5	0	0	4
4	0	0	0	0
5	1	0	0	1