

**Woodlark and Nightjar Recreational
Disturbance and Nest Predator
Study 2008 and 2009**

**Final Report
to Breckland District Council**

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Executive summary

This report presents results from work conducted by the University of East Anglia and British Trust for Ornithology, under contract to Breckland District Council and with the support of the Forestry Commission.

The breeding success of nightjar and woodlark, the abundance and distribution of fox and carrion crow, and the levels of recreational activity, were studied in 2008 and 2009 within the Breckland Forest SSSI, part of the Breckland SPA. A large and robust sample size was achieved for woodlark nests, visitor survey points and crow and fox counts. A smaller but informative sample size was achieved for nightjar nests.

There was no relationship between levels of fox or crow activity, and levels of recreational activity, or proximity to carpark, or amount of urban settlement in surrounding buffers. Thus recreational activity and development are unlikely to increase the activity of these potential predator species.

Monitoring of nests by miniature digital nest cameras showed that woodlark are exposed to a wide range of nest predators, including fox, kestrel, adder, hedgehog and stoat, and minor contributions from an additional seven species that included domestic cat and domestic dog. Analysis of a large sample of nests (147 nests providing 781 egg days and 1144 chick days) provided strong evidence that neither woodlark nests success, nor the productivity of successful nests, were affected by the levels of recreational activity observed within this study. Analysis of broods from 54 successful nests gave no evidence that recreational activity affected post-fledging survival.

Nightjar nests were only predated by mammalian predators, primarily fox and badger, with no predation by crow or any other diurnal avian predator over the 13 predation events where the predator was identified. There was no evidence that rates of flushing of incubating female nightjar were higher close to paths, nightjar did not nest further from paths in patches with greater levels of recreational activity, and no instances of flushing by dogs were observed in over 2000 hours of diurnal footage from 22 nests. Thus overall, no support was found for the hypothesis that recreational disturbance exposes nightjar nests to predation by crows when females are flushed by dogs, at least in this landscape at the current rates of recreational activity. Analysis of a useful sample of nests (44 nests, providing 297 egg days, 430 chick days and a total of 522 nest days) produced no evidence for any effect of recreational activity on nightjar nest success; conversely strong evidence for a nil effect is presented.

Overall, there was no evidence that current levels of recreational activity are having any detrimental impacts on the breeding success or productivity of those woodlark and nightjar that establish territories and attempt to breed. Conversely there is very strong evidence of a nil effect for woodlark, and good evidence for a nil effect on nightjar, at least at current levels of recreational activity.

However, if levels of recreational activity were to increase beyond those encountered during this study, that may result in detrimental effects on breeding productivity of nightjar and or woodlark. Recommendations for future monitoring are therefore provided.

This study was not designed to examine whether woodlark or nightjar fail to occupy, or have lower abundance in, patches experiencing higher levels of recreational disturbance. Recommendations for such study are made.

If no effect on either territory displacement or breeding productivity is detected or likely now or in the future, then mitigation is not required. In case mitigation were required in the future, available techniques are reviewed.

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Acknowledgements

Fieldwork was carried out by a team employed by the BTO, under subcontract to UEA, with training and support from Dr Paul Dolman (UEA). Additional BTO volunteers assisted with predator and visitor surveys. Ian Henderson and Greg Conway supervised and managed the BTO fieldworker team in both years and without the dedicated effort and skill of Chas Holt, Mark Hulme, Simon Pickett, Sabine Schäfer and Kerry Skelhorn the study would not have been possible.

Nest cameras were hired from RSPB, and Nigel Butcher provided valuable technical support and advice regarding nest cameras throughout the study. We are grateful to Rowena Langston of the RSPB for discussions of study design prior to this study, and Rowena also conducted some surveys of nightjar in support of nest searches during 2008.

The Forestry Commission, particularly Neal Armour-Chelu, Trevor Banham and Richard Brooke provided logistical support, allowed access to areas of the forest usually closed to the public, and permitted fieldworkers to liaise with wildlife rangers in accessing areas subject to deer control. The Forestry Commission prepared and provided sub-compartment maps coded by forest growth stage for the fieldwork team. Ron Hoblyn and additional woodlark surveyors that he coordinated particularly John Secker, Bernard Pleasance and John Dries, liaised with the nest predation team and provided additional nest locations for monitoring by cameras.

Numerous volunteers from the RSPB, BirdLife International, BTO, UEA, Breckland District Council and a number of Forestry Commission personnel assisted with nightjar nest search days and evening surveys for nightjar.

In 2009, a PhD study conducted by Katrina Evans and jointly supervised by UEA and BTO, began using radio-telemetry to track nightjar movements and foraging locations. This radio-telemetry study located additional nightjar nests, that were subsequently monitored by nest cameras within the nest predation and recreational disturbance study.

Diurnal nightjar camera footage was analysed at UEA as part of an M.Sc. conducted by Lucy Wilshaw (Wilshaw, 2010).

1. Background to the study

An estimated 40% of UK woodlarks *Lullula arborea* breed in forestry re-stocks (Gillings and Wotton 1997), with the Breckland SPA holding approximately 25% of the UK population during the last national survey in 2006 (G. Conway pers, comm).

In 2004, 57% of UK nightjar *Caprimulgus caprimulgus* were associated with conifer plantations, at which time Thetford Forest comprised 7.6% of the UK population (Conway *et al.* 2007) and the largest single local population.

The 39,433 hectare Breckland Special Protection Area (SPA), was designated under the European Birds Directive (79/409/EEC) and confirmed on the 21st September 2006, with the objective to provide protection of habitat for the benefit of Woodlark, Nightjar and Stone Curlew, which are annex 1 protected species. The Stone Curlew are predominantly found on open farmland and are protected by the Breckland Farmland SSSI.

Within the Breckland SPA Nightjar and Woodlark are mainly found in the 18,126 hectare Breckland Forest SSSI. Of the Breckland Forest SSSI, 17,517 ha comprises land managed by the Forestry Commission. Of this, 13,159ha is freehold land and has public access, the FC has also dedicated most (10,112ha) of its freehold land within the Breckland Forest SSSI under the CROW Act to ensure continued public access.

Future increases in recreational activity as a result of increased urban populations within the recreational catchment area, or resulting from changes in visitor management policy, are subject to provisions of Habitats Regulation Assessments in and around the Breckland SPA. This study concerns potential impacts of recreation on breeding productivity of woodlark and nightjar within the Breckland Forest SSSI.

1.1 Previous evidence indicating concern that recreational activity may influence levels of nest predation of woodlark and nightjar within the Breckland SPA.

A recent study of woodlark *Lullula arborea* in Breckland (Wright *et al.* 2009), showed that the rate of predation of nests had increased substantially over the last three decades, and the magnitude and temporal trend in increasing nest failure rates was sufficient to predict the observed post-1999 decline in this regional population. Increased numbers of corvids and other predators due to changes in surrounding land use were suggested as potential factors in this demographic change.

A UEA study of the intensity of nest predator activity within woodlark habitats on heathland in Dorset (Taylor, 2002), found that predation of artificial nests was largely due to carrion crow and fox. Furthermore, numbers of potential nest predators (fox and crow) and predation rates on artificial nests, were both higher in sites with greater numbers of recreational visitors.

For woodlark, chick losses in the period immediately after leaving the nest may limit breeding productivity (Mallord *et al.* 2007b). It is possible that flushing of weakly flying chicks by recreational disturbance during this vulnerable period, may increase their exposure to visual searching predators, such as carrion crow or kestrel *Falco tinnunculus*.

UK trends in nightjar breeding productivity over the last four decades suggest a substantial rise in daily nest failure rates at both egg, and particularly at chick, stages (BTO, 2008).

An RSPB study of nightjar in Dorset showed that nest predation was the main cause of nest failure and that breeding success was significantly lower close to paths (Langston *et al.* 2007a,b). Nightjar eggs were exposed to an increased risk of predation when the incubating bird was flushed from the nest during daylight as a result of disturbance (Langston *et al.* 2007a). The predator involved was often thought to be carrion crow (Murison 2002). Nightjar nests on Dorset heathland were more likely to be predated if they were located in areas of short vegetation and had significantly lower vegetation cover (Langston *et al.* 2007b). These findings led to the suggestion of a hypothesis: that nightjar nests located in areas with higher levels of recreational activity may be subject to greater disturbance, particularly by domestic dogs, resulting in increased rates of nest predation, possibly by carrion crows.

1.2 Limitations of previously available evidence and what further evidence is required.

For woodlark, the study by Wright *et al.* (2009) indicated an increase in nest failure rates, largely attributable to nest predation. However, this study did not separately analyse failure rates at clutch and chick stages, limiting inferences of the extent to which nest predation has contributed to a reduction in overall numbers. However, current high nest predation rates remain an important aspect of population demography and numbers within the Breckland SPA.

The identity and relative impact of different predator species, and any relationship between predation rates and levels of recreational disturbance, are not understood. Although it is often assumed that fox *Vulpes vulpes* and carrion crow *Corvus corone* must be major predators of nests of woodlark and other ground nesting birds in Thetford Forest, there is a lack of reliable empirical evidence to identify the relative importance of different predator species.

Although the artificial nest study in woodlark habitat in Dorset (Taylor, 2002) found greater rates of predation of plasticine eggs in sites with greater numbers of recreational visitors, extreme caution is required when interpreting results of artificial nest studies. Both overall predation rates and the relative impact of different predator species may differ profoundly

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between artificial and real nests (see Willebrand & Marcström 1988; Storaas 1988; Roper 1992; Haskell 1995; King et al 1999; Thompson & Burhans 2004). Artificial nests may particularly attract visually searching predators (Storaas 1988). Thus evidence from artificial nest studies must be treated with extreme caution as it may not reflect the activity or spatial patterns of those predators actually responsible for predation of real nests..

In a study of woodlark breeding in Dorset, Mallord (2005) did not find any relationship between visitor numbers and nest predation rates of active nests. However, woodlark breeding in Dorset differ in a number of aspects from those breeding in Thetford Forest. In Dorset food limitation and starvation were important causes of nest failure, while in Thetford Forest nest predation is the overwhelming cause of nest failure (Wright et al. 2009). Nesting habitats, vegetation and potential for concealment differ, being largely heather heathland in Dorset and grass dominated forestry restocks in Thetford Forest. The relative importance of different predators may also differ between habitats and regions (Thompson et al. 2002).

Although neonatal survival is an important aspect of woodlark breeding productivity and therefore has potential to influence population size (Mallord *et al.* 2007b), no study has evaluated the relationship between levels of recreational disturbance and survival of woodlark chicks in the immediate post-fledging period.

The hypothesis suggesting that nightjar nests experience elevated nest predation by crows as a result of disturbance by recreational dog-walkers, currently lacks sufficient evidence for robust evaluation. In a nest camera study conducted in Dorset, only one predation event was captured on camera (Langston *et al.* 2007a).

Furthermore, predator species responsible for nest failure and any effects of recreational disturbance on nest failure rates, may differ for nightjar nests located within forestry restocks compared to those nesting within Dorset heathland. Nightjar nesting in extensive forest plantation landscapes experience different local path density, while vegetation structure differs greatly between heather dominated heathland and Thetford Forest plantations (particularly thickets), both of these may have consequences for the accessibility of nests to dogs, and their visibility to potential avian predators.

Clarifying the relationship between recreational disturbance, activity of potential nest predators and the consequences for the breeding productivity of woodlark and nightjar attempting to nest within managed forestry environments, is necessary in order to assess any possible impacts of increased numbers of recreational visitors on interest features of the Breckland Forest SSSI.

1.3 The need for a robust sample size in view of the precautionary principle and burden of evidence.

Nest predation is essentially a stochastic, chance process and is therefore subject to variation and 'noise'. To detect any underlying relationship with factors such as recreational disturbance requires a large sample size of nests, with good spatial replication. As nest failure rates may vary within and among years, it is preferable to conduct studies across multiple breeding seasons. A failure to detect an effect in a study that is not sufficiently robust, does not provide strong evidence of a lack of an effect. In view of the precautionary principle a weak or poorly designed study that showed no effect (or failed to detect an effect) would not provide sufficient justification for disregarding potential concern. In light of responsibilities under the Habitat Regulations, it is therefore important to undertake work of sufficient scope.

Most studies addressing the issue of recreational impacts on bird species primarily focus fieldwork effort on the birds. However, it is notoriously difficult to obtain large sample sizes of

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spatially replicated nest observations for cryptic well camouflaged ground nesting species. This study therefore took a different approach. In addition to directly focusing on the nest success rates of the two birds species of concern (woodlark and nightjar), in order to obtain a sample of nest observations and test whether there is evidence of a relationship or association between recreational frequency and nest success rates, the study also addressed to further key questions.

- 1) It identified the predator species responsible for degradation of nests using nest cameras
- 2) And by sampling across a very well replicated spread of locations, it independently examined whether there is any evidence for an association between the abundance of these predators, and levels of recreational activity.

This last approach can conclusively address the hypothesis that urban, car parks, and recreational activity influence the abundance of predators.

It cannot address the separate question as to whether recreational disturbance influences the behaviour of the nesting bird species, in such a way that they experience increased rates of nest predation or failure despite little or no change in the abundance of predators. For this, it is still necessary to directly relate failure rates to measures of recreational activity, which this study was also designed to do.

2. Study Aims

This study aimed to improve understanding of the predator-base and its impact on productivity rates on nesting woodlarks and nightjars in the context of potential increases in human recreation activity.

Specifically the study aimed to:

- 1) Quantify species-specific relationship between levels of recreational activity and the local abundance of different potential nest predator species.
- 2) For woodlarks, quantify overall rates of nest predation and estimate the species-specific impacts of different nest predator species on breeding success.
- 3) For woodlarks, monitor broods after fledging to assess chick survival and relate this to predator and visitor abundance.
- 4) For nightjars, quantify overall rates of nest success and nest predation (these are currently not known), monitor female incubating behaviour in territories with differing levels of recreational activity, obtain sufficient records of predation and nest disturbance to distinguish between a) background levels of generalist nest predators such as fox *Vulpes vulpes*, stoat *Mustela erminea*, corvids, and kestrel, *versus* b) the hypothesis that dogs disturb nesting females exposing eggs to predation by corvids.
- 5) For nightjars, monitor chick survival prior to fledging and analyse this relative to levels of recreational activity among territories. For nightjar, it is not possible to monitor subsequent neo-natal survival of fledged chicks.

3. Methodology

3.1 Study Design

Fieldwork was carried out a broad spread of locations across Thetford Forest (see **Map 1**), from late February through to August, in both 2008 and 2009. A two-year study was required to reduce the influence of chance year to year variation, such as extended periods of wet and cold weather during the breeding season which can directly affect nesting success and potentially the activity of different predator species (Stephens et al. 2003).

Digital infrared nest cameras with motion sensor technology (see Bolton *et al.* 2007 for detailed specification), were installed at each woodlark and nightjar nest found. Digital images were then used to confirm fledging of apparently successful nests (rather than depending on field signs), to confirm or reveal predation events and, whenever possible, identify the predator species responsible for nest failure.

Nest finding effort and camera study were intended to provide an adequate sample to quantify the relative contribution of differing predator species to failure rates of woodlark and nightjar respectively.

Predator and visitor surveys were conducted in the vicinity of nesting areas monitored for woodlark and nightjar nesting, but importantly they were also conducted across a much wider sample of locations throughout Thetford Forest than could be included in the intensive ornithological fieldwork (see **Map 2**). Survey points were widely distributed across the entirety of the Thetford Forest part of the Breckland Forest SPA, including core forest and outlying blocks (see **Table 1**) but with proportionately more blocks within the core forest areas as these contribute the majority of the forest area.

At each survey location, independent measures of avian predators, foxes, and human recreational activity (including dogs) were obtained. The extensive coverage and high degree of replication provides the statistical power required to conclusively examine any potential relationships between the frequency of recreation events and abundance of nest predators.

A general rule of thumb in ecological analysis of multivariate data is that a minimum of 15, and preferably 30 or more, samples are required for each independent factor considered in multiple tests. Visitor, recreation frequency, dog, fox and avian predator information were obtained from more than 180 independent points. This provides a powerful data set with which to analyse 1) relationships among visitors and predator abundance and 2) relationships between visitor frequency and nest success, though the power of the latter will primarily be limited by nest sample size.

3.2 Field methods and sampling protocols.

3.2.1 Woodlark nest finding and monitoring

All fieldworkers operated under Schedule 1 licence as woodlark is protected from disturbance under the Wildlife and Countryside Act, 1981.

Fieldwork was conducted across a large sample of the Forest Estate, in order to provide nest camera data from a range of independent locations. Thetford Forest comprises a large central core area (particularly Lynford, High Lodge and Elveden) that is dominated by acidic soils, with limited access to farmland or external habitats, and other outlying fragmented blocks with a much greater proximity to forest edge, farmland and external habitats. As it is possible that these may differ in predator assemblage, blocks for surveying, nest searching and nest monitoring were chosen from both core (e.g. Lynford including West Tofts, Croxton, and parts of Mundford) and outlying (e.g. Diddlington, Roudham, Hockham) forest blocks, guided by stock maps produced from the FC GIS sub-compartment database. Additional core areas of Feltwell, High Lodge and Elveden were not available to the nest predation team for woodlark survey, as these are monitored by core members of the FC team (RH, JS). However, additional woodlark nests located in these areas were provided to the study by these surveyors.

Within each area allocated to them, surveyors surveyed and monitored woodlark in all areas of potential nesting habitats, defined as plantations aged 0-7 years, felled unplanted areas and permanent open areas, including wide ride margins where these support suitable vegetation structure. In addition, surveyors placed and monitored nest cameras on additional nests located by other field observers, including nests located in the core blocks of Feltwell, Elveden and High Lodge, outlying blocks Harling, Hockham, and in the large southern Kings Forest block.

Woodlarks breed between early to mid March and early July and typically have two or three nesting attempts in one season (Mallord *et al.* 2008; Wright *et al.* 2009). Pairs were located during late February or early March, prior to their first nesting attempt, and a concerted attempt was made to monitor the first and subsequent nesting attempts. Nests are primarily found by watching the behaviour of territorial adults, to accurately identify nest location before conducting any nest search. This is both more efficient than cold searching and minimises disturbance.

For each monitored woodlark territory or patch of potentially suitable habitat, at least two visits were made per month from March to July. At each visit, surveyors located and observed adult woodlark to confirm status (defined as an apparently unpaired male, pair, female exhibiting pre-nesting behaviour, female incubating, adults provisioning young, etc.). If a male Woodlark was observed without a female, repeated focal watches were conducted for a minimum of 1-hour at intervals through the breeding season to confirm paired / unpaired status, following Mallord *et al.* (2007a, 2007b). When paired, surveyors proceeded to locate and monitor nesting attempts. For each nest found, surveyors monitored and reported the estimated first egg date, uncertainty in this estimate, clutch size, hatch date and nest outcome. Attempts were made to locate sequential nesting attempts within each monitored territory.

It was important to minimise disturbance due to the study, and thus avoid confounding any affects of recreational disturbance, while locating and monitoring nests.

When a pair was suspected to have an active nest, a period of unobtrusive observation followed in order to define and narrow down the nest location, at all times avoiding 'cold' searching and prolonged disturbance. When incubating eggs, female woodlark periodically leave their nest to feed, generally for a period of 20-40 minutes and at some distance from

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the nest. Adults feeding chicks make brief provisioning visits to the nest, interspersed by longer periods of foraging when they gather food, though the female may also incubate the brood for periods of time. Nest areas were located by observing adult behaviour, often using a car as a hide, and were then pinpointed by watching the incubating female coming off and/or going back on to the nest, or by watching provisioning adults taking food into the nest site, often from a considerable distance away. Only after the nest location was known or suspected with reasonable accuracy, did the fieldworker enter the habitat to search for and find the nest. Whenever practicable, nests at incubation stage were located after the female had left to forage, thus avoiding disturbance. Alternatively, some nests were found by carefully approaching the incubating bird without flushing it, reducing disturbance. When adults were observed carrying food into a suspected nest site, a period of careful observation again followed to pinpoint the nest location and a search was conducted only after a provisioning visit when the adults had left the area to forage, again minimising disturbance.

Woodlark nests found were subsequently monitored using nest cameras, as described below.

3.2.2 Woodlark post-fledging survival checks

After successful fledging, surveyors were instructed to attempt to locate adults on territory as follows:

- at 7 days to confirm whether any chicks survive, by observation of adults to see if they are provisioning hidden chicks, or whether female will be initiating a re-nest. During this visit chicks were not flushed, to avoid disturbance.
- Two subsequent visits at between 2-3 weeks after fledging to confirm the numbers of chicks surviving, attempt to read colour rings and observe the female behaviour in order to locate a subsequent nesting attempt. During this visit the juveniles were sometimes flushed to confirm the numbers in the family party and allow an opportunity to confirm colour rings (as juveniles sometimes perch after being disturbed).

Post fledgling survival checks were not conducted for all fledged woodlark broods following successful fledging in 2008, due to necessity to concentrate on nightjar nest finding once the nightjar nesting season began. In 2008 of 41 woodlark nest attempts that fledged chicks, 20 received at least one follow up visit and 13 received two or more visits, remaining fledged broods were not checked. This reduced the sample size available for analysis of post-fledging survival. In 2009 a great effort was made to monitor fledged chick survival despite demands of the nightjar fieldwork in the latter part of the woodlark breeding season. In 2009, out of 49 successfully fledged broods, 45 received one or more follow up visits, and 43 received two or more visits.

On numerous occasions neither a family party nor the adults could be located. Pairs may forage elsewhere following fledging, even though the adults may subsequently return to re-nest in the original nest territory, and on other occasions (including the final nesting attempt of the season) adults may leave the forest entirely. If not located on two visits separated by 1-2 weeks, it becomes likely that a pair would have terminated their breeding season. However, it cannot be assumed that failure to locate adults on their nesting territory indicates failure of chicks to survive. Adults may have left the territory following loss of chicks. However, although more often remaining on territory, pairs with surviving juveniles have been observed to move to another area, either before making a subsequent breeding attempt (either back on the original territory or more unusually in the new location), or having terminated breeding attempts that season (e.g. if it is late in the season, or if adults have already successfully fledged two broods that year).

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Therefore, visits where no adults or chicks are located must be treated as missing data, despite the effort of having made the search. Adults were located in a total of 52 first visits (15 of 20 first visits made in 2008, 37 of 45 first visits made in 2009), 48 second visits (9 of 13 second visits made in 2008, 39 of 43 second visits made in 2009) and 14 third visits (3 in 2008, 11 in 2009). The lower proportion of adults located during visits made to territories following successful fledging in 2008 than in 2009, may reflect poor weather conditions and greater frequency of adults giving up, alternatively it may reflect a difference in chick outcomes and subsequent response of the adults.

When analysing post-fledging survival, checks on chicks within the first few days of leaving a nest were not considered as these are weakly flying and differ little from nestlings, remain extremely vulnerable to ground predators and have not been exposed to predation for sufficiently long. Territory visits after nine days were considered, as these show whether the fledglings have survived the critical initial vulnerable period. Although juveniles were still observed with adults or on their natal territories at ages of 27, 28, 32, and 33 days post-fledging, chicks beyond three-four weeks of age are free flying juveniles and become increasingly independent of their parents and it is not possible to reliably detect their survival through territory visits, particularly if the territorial adults have re-nested by this time. Therefore, territory visits conducted more than 24 days post-fledging were not considered.

Consequently, for analysis, any monitoring visit made 10-24 days post fledging, and during which the adults were successfully located on territory, was considered when examining post-fledging survival. The number of days that had elapsed since fledging was included as a control variable in analysis. Across the two years, 54 fledged broods were monitored at least once during the period 10-24 days after fledging with the adults successfully located, providing a reasonable sample size to examine recreation effects on post-fledging survival.

3.2.3 Nightjar nest finding and monitoring

Efforts were made to locate nightjar nests in the same forest blocks allocated for monitoring of woodlark nests (e.g. Didlington, Lynford, Croxton, Hockham). In addition, surveys and nest searches were conducted in additional core areas that had not been available to the nest predation team when working on woodlark (e.g. High Lodge, Elveden).

Nightjars breed from late-May to mid-August and typically have one or two nesting attempts in a season. Nests were found by watching the behaviour of territorial individuals and by individual fieldworkers or teams of workers and volunteers walking across targeted areas to 'flush' the incubating female. For nightjar, surveyors were asked to:

- Survey potentially suitable habitat patches to identify the location of churring males and observe any females,
- Conduct some pre-dawn visits to watch females back to the nest,
- Conduct opportunistic nest searching on the basis of observational evidence,
- Organise and coordinate team nest searches focusing on areas identified through survey work,
- Note GPS locations for any roosting adults flushed during nest searches, as these may include pre-nesting females or males roosting in the vicinity of an incubating female
- Install and monitor nest cameras on nests (see 3.2.4 below),
- Monitor nest outcome and ring chicks,
- Monitor the survival of fledged juveniles,
- Ensure focal watches of visitors were conducted on monitored territories.

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Nightjar are nocturnal and extremely cryptic nesters. The only practicable way of locating nightjar nests is to flush the sitting female during the day, after identifying potential areas to search by observation of adult behaviour in the late evening and very early morning. However, this inevitably results in some disturbance to the breeding birds. To reduce this disturbance as much as possible, after flushing a female from a nest during a nest search all but one of the nest searchers withdrew from the area, while this person remained at the nest until the nest camera was installed (to prevent the female returning only to be flushed again shortly afterwards).

In 2009, as part of an ongoing UEA-BTO-FC PhD study, a total of 13 male and 7 female Nightjars were fitted with radio tags. Radio-tracking resulted in the location of six nests; increasing the total number of nests available for nest camera monitoring and providing nest locations that were unbiased in respect of habitat and search patterns of nest finding teams.

3.2.4 Nest camera methodology and protocols

Fieldworkers installed and maintained cameras on woodlark and nightjar nests. Nest camera protocols for woodlark were refined following a UEA pilot nest camera study funded by FC, conducted in 2007 (Dolman 2008), and for nightjar in consultation with RSPB personnel with experience of nest camera work on this species.

Eighteen cameras were obtained for use during 2008, increasing to 25 cameras in 2009. The number of cameras available to the fieldwork team only occasionally limited the number of woodlark nests that could be simultaneously monitored, while the numbers of nightjar nests that could be monitored was solely limited by difficulties in locating nests.

For nest camera monitoring, the following were recorded:

- Time elapsed after installation before return of incubating females (where clearly visible)
- the duration of monitoring (in days)
- date of hatching (if applicable)
- date of fledging or failure
- the nest outcome (provisionally determined from standard field signs, validated by watching camera footage to confirm fledging or detect predation)
- the identity of predators (from camera footage) and any uncertainty in this identification

Miniature digital infrared nest cameras were positioned at nests. Cameras comprise a 3.6mm lens surrounded by six infrared LEDs to provide passive lighting, housed in a rainguard, mounted on a short peg <1cm diameter, inserted into the ground (see Bolton *et al.* 2007 for detailed specification). Cameras were linked by waterproofed cables to a box containing digital recording unit, timer unit (to control infrared lighting) and 12-V battery, buried together 5 m - 10 m from the nest. For nightjar, the battery and recording units were buried further from the nest site (up to 10 m) to reduce disturbance during subsequent maintenance, battery and card changes.

Woodlark nests are constructed from grass, roots and moss and lined with finer material. Although the total nest may be relatively bulky, the base and cup are built into an initial scrape or hollow in the sandy soil, so that generally only the immediate rim and lining of the completed nest are visible. As these are made of local dry vegetation they blend well with surrounding vegetation. Nests may be built in an open and relatively exposed position or may be extremely well concealed within vegetation (e.g. underneath bracken, bramble, broom or brash). However even when well concealed, they generally have at least one direction from

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which the nest cup is visible (the direction in which the female walks into the nest, and faces out when incubating) (Mallord *et al.* 2007c). Cameras were therefore positioned to provide as good a view of the nest cup as practicable, and were positioned between 0.75 m - 1.0 m from the nest.

In contrast, nightjar nests (or 'scrapes') consist of nothing more than areas of flat litter or soil, in which the incubating female sits concealing the otherwise obvious pale eggs, or broods the chicks (which are well camouflaged). As the female may change her orientation and can shuffle around within the scrape, cameras were installed at nightjar nests to obtain a good general view of the nest site.

The video motion sensor of the recording unit was configured on the SD data card prior to installation. Therefore, at first installation, nest camera recording units were left with the video motion sensor (VMS) configured on a broad area in the central third of the image, to ensure the actual location of the nest when the camera was installed fell within the area covered by the video motion sensor. Although the area covered should be sufficient for any intruding predator to trigger an image, in addition to images being triggered by adults arriving at or leaving the nest, in anything other than dead calm weather the broad VMS results in frequent triggering of unnecessary images by moving vegetation. This can risk missing a predation event that may occur during the subsequent 'sleep period' following image capture. Therefore, during camera installation, an image of the nest as it appeared from the final camera location was triggered on a second SD data card, before swapping cards leaving the broadly configured VMS card in place and removing the card containing an image for subsequent configuration. The VMS of the retained card was later configured on the limited area immediately around the nest cup (in the case of woodlark) or around the perimeter of the nest scrape (in the case of nightjar). Cards were then exchanged and the more focused VMS installed, to reduce the frequency of false images being triggered. For woodlark, the second visit to exchange data cards was made one to two days after the initial installation. For nightjar, as finding the nest and initially installing the camera invariably involved disturbing and flushing the incubating female, nest sites were left undisturbed for at least two or three days after camera installation before returning to exchange cards.

For subsequent maintenance, surveyors replaced the battery every four days and simultaneously checked the status of the nest (either by direct observation in the case of woodlark, or by subsequent examination of card images for nightjar where the direct nest site had not been approached).

Disturbance to the breeding adults during camera installation

At woodlark nests, fieldworkers were able to install cameras in approximately 20 minutes (2008, mean = 19 mins, n = 61, 2009, mean = 18 mins, n = 86). The time elapsed before females returned to the nest, as subsequently determined from camera footage, was less in 2009 (mean 15 minutes, n = 63) than 2008 (mean 22 minutes, n = 41), perhaps reflecting better foraging conditions in the second year rather than any difference attributable to the study. Combined, the total female absence during camera installation and subsequent return, was similar to the usual duration of female absence from a nest during foraging at the incubation stage (which ranges from 25 - 40 minutes, P D. pers obs).

For nightjar nests, the time required for camera installation was similar in (2008, mean = 20 minutes, n = 14; 2009, mean = 19 minutes, n = 29). Females returned to resume incubating / sheltering eggs or young approximately forty minutes after nest installation was completed (2008: mean 37 minutes, n = 11; 2009, mean = 44 minutes, n = 20). This emphasises the potential risk of exposure following flushing by recreational activity.

All monitoring visits were conducted in a way that minimised disturbance. For woodlark, some batteries could be replaced without flushing the incubating female but if necessary

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fieldworkers waited a considerable time until the female came off the nest to forage, so that the nest could then be visited without causing disturbance. For nightjar, batteries could be changed at distance from the nest, usually without disturbance.

Batteries were replaced at least three days before chicks were expected to fledge. This allowed nest cameras to function beyond the expected fledging date, as undisturbed woodlark chicks in a well concealed nest sometimes remain in the nest for a further one to three days. As it takes c 5-10 minutes to expose replace and re-bury a battery, this protocol also avoided disturbance at nests containing chicks that were on the verge of fledging. Disturbance at that time can encourage premature leaving of the nest shortly after the nest visit has been made, therefore only brief monitoring visits were made at two and one days before the expected date of fledging, to confirm predation or nest success.

Determining nest outcome

Standard nest monitoring protocols indicated the likely outcome of nests. Where dead chicks or cold dead eggs were found in the nest this was attributed to desertion; this was validated by watching nest camera footage to determine last adult visit time and date. Where chicks had reached expected fledging age, and the nest was subsequently found empty and trampled with droppings in and around the nest, this was provisionally considered to indicate success, however this was confirmed where-ever possible by checking camera footage (for woodlark, it is usually possible to see chicks leaving the nest). On some occasions, nests that appeared successful solely from field signs were subsequently found to have been predated (or partially predated) close to fledging once camera footage was checked. When nests were found empty prior to the expected fledging date predation was assumed, and camera footage was carefully checked to confirm the fate of chicks or eggs and the identity of the predator (or predators in the case of multiple events).

In addition, for nightjar, 2126 hours of diurnal female incubation behaviour were examined, from 22 nests that provided a good view of the incubating female by a UEA M.Sc. student as part of a research dissertation (Wilshaw, 2010). Flushing frequency of incubating females was recorded and when visible the cause of the flushing event was noted.

3.2.5 Surveys of visitor frequency and abundance of avian predators

Simultaneous surveys of recreational visitors and of potential avian nest predators (crows, jays, magpies and kestrels) were conducted across a large number (n=184) of independent locations throughout Thetford Forest.

In each of 2008 and 2009, survey points were each visited on three occasions, that together spanned the breeding seasons of both woodlark (first visit matched peak nesting periods, the second visit occurred during late attempts) and nightjar (settlement occurs during May, second and third visits span the nesting and chick rearing season). Survey methods were developed following a pilot study of recreation and predators conducted in spring 2007 (Wilson 2007) and a survey of recreational visitors in August-October 2007 (Dolman, Lake & Bertoncelj 2008).

A total of 184 visitor and predator count points within the forest were initially selected for survey in 2008. Points were situated in patches of plantation less than seven years old, in felled unplanted coupes, or open areas of heathland re-creation. These included the 144 points used by the 2007 UEA Visitor Survey study (Dolman, Lake & Bertoncelj 2008); although where these were situated within unsuitable age classes of habitat they were moved to the closest suitable patch. Survey points were also located in patches targeted for fieldwork in the forest blocks allocated to the nest predator fieldwork team. A further 40 points

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were added to provide further coverage of additional areas of suitable woodlark habitat within Thetford Forest. The distribution of points is shown in (**Map 2**) and their frequency in core and outlying blocks is tabulated in (**Table 1**).

In 2009, the same set of count points were surveyed as in 2008, to permit data for predator and visitor numbers to be analysed together, across years. For visitors, the repeat measures from visits conducted across both years, provide a more robust estimate of the relative level of recreational activity at each location (once time of day and day of week are controlled for) than would be achieved using just half the number of visits. Therefore, areas of newly created habitat, resulting from felling operations after autumn 2008, were not sampled in 2009.

Three of the 184 points surveyed in 2008 (#108, 110 and 165) were subsequently removed and not surveyed in 2009, as they were considered unsuitable for access. Of the 181 points targeted for survey in 2009, one point could not be accessed during any survey period, due to forestry operations. Thus 180 survey points were visited in both 2008 and 2009. Three points (# 84, 131 and 166) were slightly relocated, but remaining within their respective territory survey patch. In GIS analysis of these points, data have been extracted from the mean of the 2008 and 2009 locations for points #131 (distance between successive years was 207m) and #166 (distance between successive years, 74m) as these both surveyed the same visible part of the compartment; point #84 has been treated as a separate location for the two years as the relocated survey point (distance between successive years 506m) was not visible from the initial location.

Most survey points were surveyed during all three periods (2008, 161 of 184 points; 2009, 174 of 181 points). However, due to access restrictions (mostly forest operations, plus some instances of rare breeding birds limiting access) a small number of points received fewer visits (two visits only were made to 23 points in 2008 and 5 points in 2009; a single visit made to one point in 2009; one point was completely inaccessible and received no visits in 2009).

Visitor and avian predator surveys were conducted between 0600-2000 hrs on weekdays and also at weekends (comprising one out of the overall six visits to each survey point). In 2008 one third of sample points were visited between 0600-0900 and the remaining two thirds visited between 0900-2000 hrs, however overall the majority of counts occurred in the morning period, prior to 1300 hours. In 2009, survey times were more evenly distributed among three periods: 0600-0900 hrs, 0900-1400 hrs and 1400-2000 hrs (see **Table 2**).

First visits were made during late March or mid April, to the end of May (2008: 15 April – 3 June; 2009: 27 March – 27 May), second visits from early June to mid of late July (2008: 6 June – 17 July; 2009: 2 June – 28 July) and the third visit during July and August, into early-mid September (2008: 2 July – 17 September; 2009: 16 July – 5 September).

For human visitors, surveyors were asked to record the following:

- each individual group as a separate event,
- numbers within each group,
- visitor activity (cycling, jogging, walking, horse riding, dog walking),
- the number of dogs,
- dog behaviour (whether on or off the lead, whether keeping to the track, the verge or their estimated distance of movement into the tree crop, in meters).

At each sample location surveyors conducted one hour focal watches of corvids (carrion crow *Corvus corone*, magpie *Pica pica*, jay *Garrulus glandarius*), kestrel *Falco tinnunculus*, stoats *Mustela erminea*, simultaneous to a survey of human visitors.

For predator counts, the visit hour was divided into twelve separate 5-minute recording periods. In each 5-minute period the maximum number of individuals of a species engaged in

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a particular activity was recorded. If the same individual or group was involved in more than one activity in the same sample period they were recorded again under each of the relevant activities. For carrion crows, three classes of activity were considered: flying over the sample site, perched (on a tree) within or on the margin of the sample site, or located (walking, foraging) on the ground within the compartment. For jay two activity classes were used, either perched (on the margin) or foraging on the ground.

3.2.6 Surveys of fox and dog abundance at survey locations using faecal transect methodology

Measures of fox abundance were obtained from the same survey points monitored by the visitor and avian predator survey.

Mammalian predators are difficult to survey by visual census techniques, and faecal count methods are frequently used. Surveys of fox scat abundance and of domestic dog (*Canis familiaris*) scats were conducted on transects around each of the visitor / avian predator survey location, using faecal transect methodology (Webbon et al. 2004), on two occasions in each year.

Transects routes included the track/ride immediately within each monitored stand, plus a 50m extension into adjoining forest. The resulting transects of variable length, were plotted using a handheld GPS and their length subsequently measured in GIS to control for sampling effort during analysis.

In 2008, transects were established around 181 of the 184 visitor and predator count points; however, at three points (#108, #146, #165) there were no suitable rides for transects to be deployed.

Scat transects were first visited in spring to early summer (2008: 15 April – 9 May; 2009: 21 April – 2 June) and were repeated late summer (2008: 16 July – 13 September, exceptionally 3 October for n= 6 transects; 2009: 15 July – 27 August). Most transects received both spring and late summer visits (175 of 181 transects in 2008, and 169 of 177 transects in 2009), with small numbers receiving only one visit due to access restrictions (2008 six, 2009 eight).

For each transect at each visit, two parallel strips of 1m width were walked, with one 1m wide transect walked on one side of a trackway during the outward journey and a second 1m wide transect walked on the opposite side of the same trackway when returning. Thus each 1m strip transect encompassed a track wheeling, and part of the adjacent verge. All domestic dog *Canus familiaris*, fox, hedgehog and stoat scats encountered, were counted and removed.

Mean length of scat transects was 643 m \pm 284 m SD (minimum 164 m, maximum 1364 m). Thus for sites receiving both spring and summer visits, an average of 1286 m² per site were searched for fox scats in each of the two years, a very high search intensity.

All faecal transects were conducted by a small number of trained fieldworkers, to ensure standardisation and consistency of coverage and recording. In addition to fox, stoat and hedgehog, domestic dog scats were recorded, as cross-validation between scat counts and measures of dog activity obtained from visitor surveys has the potential to corroborate both the survey methodology and scat count methodology (i.e. as used for foxes for which independent corroboration was not possible).

Fox scats were recorded at between 39%-58%, and dog scats in 31%-67%, of transects within each season of each year, providing a large volume of abundance / activity data to relate to visitor numbers.

In contrast, a low frequency of hedgehog scats (first visit 13% & 18% of transects, second visit 0% & 6%, in 2008 and 2009 respectively) and few stoat scats (first visit 2% and 7% of transects in 2008 and 2009 respectively, second visit 1% both years) were recorded. These measures are unlikely to provide a useful indication of the activity of these predators and are therefore not analysed further. Thus any potential effect of recreational levels on the abundance of stoat and hedgehog cannot be tested. However, no plausible hypothesis or mechanism has been suggested as to why there might be an affect of recreation on the abundance of these predator species, so the lack of such a test is not considered to pose an issue.

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Visual counts of mammalian predators

Attempts were made to use visual sightings of mammalian predators to supplement other distributional information. However, during 2008 and 2009 only four and three sightings of stoat were made during combined avian predator / visitor surveys, totalling 529 hours and 533 hours respectively. A single sighting of weasel *Mustela nivalis* was made in 2008 only. In addition only five and eleven sightings of fox were obtained during visitor counts, reinforcing the importance of faecal transect data as a method to index abundance / activity of this species. Fieldworkers were also asked to record incidental observations of predators during other fieldwork (non-standardised by effort), as it was hoped that this may provide an additional measure of stoat activity, too few additional sightings were obtained to provide a useful index of abundance.

Due to the low frequency of hedgehogs detected in scat transects, the potential of nocturnal transects as a methodology to survey hedgehogs was investigated. A total of 22 visual nocturnal transects were completed, between 14 June and 11 August 2008. Transects (marked on maps) were begun at least half an hour after sunset, and were walked or driven very slowly along the route (a trackway or ride). However, as no hedgehogs were detected by this method, nocturnal transects were discontinued.

3.3 Data Analysis

3.3.1 Statistical models based on surveys of visitors, dogs and potential avian nest predators

The objective of this part of the study is to obtain an unbiased and robust measure of the relative level of recreational activity (people, walkers, dogs, other recreational events) at each of the surveyed localities. This can then be related to

- 1) the number of predators seen (crows, magpies, jays and kestrels),
- 2) the index of fox abundance (calculated from the scat surveys,)
- 3) the survival and outcome of woodlark and nightjar nest attempts, and
- 4) the subsequent rates of survival of fledged woodlark chicks.

The number of dogs, walkers and other recreational visitors observed at a particular survey location on a particular visit, will be affected both whether it is a popular and well used locality versus a quiet or remote part of the forest, but also by the date (season), day of the week and time of day at which the count was made. As each location received multiple survey visits, one approach would be to average counts across these visits to obtain a mean abundance of visitors at each survey locality, with the assumption that biases due to weekends and lunchtimes etc. would tend to cancel out.

However, a more robust approach is to develop statistical models controlling for these effects by simultaneously examining how the overall pattern of recreation (examined using all visits to all localities) varies with date (season effects), day of week, time of day and then, controlling for and accounting for these effects, produce an estimate of the underlying popularity of each location. The deliberate sampling stratification of visits by seasonal period, time of day and day of the week allows these to be controlled for when estimating the mean prevalence of visitor activity at each survey point. This can be done using generalised linear models that control for multiple effects, and fitting survey point as a categorical variable: the model controls for the noise from the other effects and estimates values of a parameter for each location.

The same approach was adopted in analysing the abundance of avian predators and foxes (from scat survey) at each survey point locality.

Therefore, models of predator, fox scat, and visitor abundance at survey points were examined, in relation to the effects of year, season (date), time of day and, for visitors, the day of the week.

Alternative generalised linear models (using Type III analyses, i.e. without specifying any *a priori* assumptions for ordering effects in the models) were fitted to compare the fit of Normal (identity link), Poisson and negative binomial (log link) error distributions, assessed by AICc (Aikike's Information Criterion, corrected for finite sample size). AICc is a measure of how much of the variance in the data is explained by the model, in a way that takes account of the number of parameters (variables) fitted in that particular model. This allows the relative performance (explanatory power or 'fit') of alternative models to be directly compared. Models with lower AICc provide a better fit to data.

In addition, the ratio of deviance to the model degrees of freedom (Dev/DF : the scale parameter) as also examined. For count data models with Dev/DF values closer to one are preferable, and values of Dev/DF that are much greater than one represent 'over-dispersal' of data – so that the pattern of counts (the frequency of different count values) is not well captured by the assumed error structure of the model, reducing its power.

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The basic approach was to first fit full models, compare alternative error structures to determine the best model structure and also to explore the distributional properties of variables using P-P and Q-Q plots to determine appropriate error structure or transformations.

Subsequently, models were simplified by removal of non-significant terms (effects) as judged by Wald tests, with improvement in model fit examined by the change in AICc. As a rule of thumb, the lower the value of AICc the better the performance of the statistical model in explaining the data. If adding or removing a variable to a model results in an increase in the AICc, then the model has deteriorated and offers a poorer explanation of the data. If adding or removing a variable results in a decrease in AICc, this is regarded as a better model. Generally, a reduction in AICc by one unit or less tends to be regarded as a substantial improvement; however change in AICc values does not have hard and fast 'cut-off' by which 'significance' can be estimated. Where AICc is very similar between alternative models, both offer plausible alternative explanations of the data. In such cases, a model averaging approach was adopted following Burnham and Anderson (2002). This involves calculating Aikike weights, that give a weighting to each model depending on its relative performance (the relative size of the AICc's) and then using these to calculate a weighted-average value of the model parameters for the 'averaged' model.

A guiding principle in construction of statistical models, is that of parsimony. A simpler model, with fewer variables and parameters, is always preferable if it offers an adequate explanation of the variation in the data. Therefore, for complex categorical variables with many levels (particularly day of week, which initially has seven parameters (levels within the one variable) that are coded 1-7; and hour of day which initially has 15 parameters (levels within the time variable), coded 05.00 through to 19.00). Therefore, parameter estimates were examined to judge whether some were having very similar effects allowing them to be combined and merged in order to simplify the structure of the model. For example, this approach was taken to ask whether there similar numbers of people on both Saturday and on Sunday, relative to weekdays, so that these could be merged to a single 'weekend' parameter, or whether the effects of Saturday and Sunday are distinct and different. In attempting to simplify parameters, the outcome of simplified variables was again judged by the change in AICc – if model fit improved substantially then the simpler model was used.

All statistical analyses were conducted in the Generalised Linear Model module of SPSS v16. This module was used consistently for all models, irrespective of their error structure. Fit of all models is therefore based on a Maximum-Likelihood approach and judged by AICc, irrespective of error structure. This was considered preferable to the alternative, of using different approaches for different types of models [i.e. using Maximum Likelihood generalised linear models solely for those models with complex error structure such as Poisson, Binomial or Negative binomial errors; but for basic models with normal ('Gaussian') errors and linear link model structures adopting the historic least-square approach, that fits parameters by minimising the sums of squares of residuals and judges significance of terms by F tests of variance partitioning]. One advantage of this is that the performance of normal to non-normal error structures can be directly compared for a particular data set, but contrasting the AICc values.

3.3.2 Extraction of spatial variables in GIS.

Nests were associated with the nearest visitor and predator survey point in GIS. Information from the survey point (abundance of predators, visitors, dogs and landscape variables extracted in GIS, see below) was then used to analyse outcomes of nests.

Subsequent analyses were conducted to establish whether there is any relationship between corvid abundance, activity, and numbers of recreational visitors, but also with other factors such as proximity to urban settlement, proximity to farmland, or distance to car-park.

Therefore GIS layers were created and manipulated using Arc GIS v9. Urban areas, car parks, and main roads (A and B roads, excluding minor roads) were extracted from OS Meridian 2 (1:50,000). Carparks that do not provide immediate access to the forest (e.g. to enclosed recreational amenities such as Grimes Graves English Heritage site, the USAF Lakenheath plan watchers vantage point, and Weeting Heath NWT reserve) were excluded when considering distance of survey points to nearest carpark. Human population in buffers around survey points were extracted from the postcode headcount survey (Office for National Statistics, 2001) contains counts of all people, males, and females, and the number of households with one or more residents from the 2001 Census. This is based upon the number of people present on census day (29 April 2001) for unit postcodes in England and Wales. The postcode centroids grid references are the mean delivery grid reference of around 15 households (i.e. each postcode). As polygons created from these therefore cover larger areas much of which will be empty space in rural areas (i.e. the population is not evenly distributed across the polygon), we extracted population data from those postcode centroids intersected by buffers, and not from the proportion of postcode polygons intersected by buffers.

In calculating the distance to 'farmland edge', the external perimeter of the forest abutting farmland, or semi-natural grassland was defined after exclusion of forest lands, urban areas, and other major landuses (e.g. Golf course).

The full list of variables extracted and considered for analysis, and their codes, are given in **(Table 3)**.

The distance to the nearest track or path ('ride' or road if closer) was also calculated for each nest, using readings taken with a hand held GPS unit at each nest location (accurate to c5 m), overlain on a ride layer created and developed by UEA, validated by forest wildlife rangers and various surveyors with detailed knowledge of different parts of the forest, and also by reference to Google Earth where necessary to clarify ambiguities.

3.3.3 Analysis of behavioural responses to disturbance: nest placement (both species) and flushing of incubating nightjar

Whether woodlark or nightjar show a behavioural response to recreational disturbance by locating nests further from trackways (rides) in those patches with higher levels of recreational disturbance, was examined by linear regression examining the relationship between distance of the nest to the closest ride (in meters, square root transformed) and predicted levels of recreational disturbance (walker events, dog events).

For incubating nightjar, diurnal flushing rates were compared to flushing frequencies recorded for nightjar in Dorset heathland (Langston et al. 2007a). Whether mean flushing rate per nest was related to the proximity of the nest to the closest ride, was examined using linear regression.

3.3.4 Analysis of disturbance effects on woodlark and nightjar nest success at egg and chick stages

Nest data were used to examine success, separately at egg and chick stages. For nightjar only one desertion event was observed, all other failure was due to predation. Given the limited number of nests, models of overall success/failure were considered.

For woodlark, separate models were constructed considering overall success (0 failure, for any cause; 1 success). It was again considered that too few observations of desertion were obtained to allow separate analysis of this as a cause of failure. This is not a problem; the test conducted examines whether or not overall nest success is related to levels of recreation.

Many nests are only found part way through incubation or even after hatching, when they have already survived a period of exposure to predator risk. Thus, nest success rates reported as a proportion of the nests found, will over-estimate the underlying success rate which is lower. Events (0/1) were therefore modelled as a binary response, with exposure days (egg days or chick days) as the number of binomial trials.

Base models were constructed, examining potential effects of year (ordinal, categorical) and season (indexed by estimated first egg date). Where first egg date was non-significant and removed from the model, sample sizes tended to increase slightly as the first egg date was not already known and inclusion of this term in models excluded some missing cases.

The best base models were then used to examine evidence for any effects of recreational disturbance. Three variables were tested that were considered the most meaningful:

- Number of walker events
- Number of dog events
- Total number of recreational events

Insufficient observations of predation by individual predators were available to allow meaningful modelling of predator-specific impacts.

3.3.5 Analysis of any potential effects of disturbance on woodlark fledgling survival after leaving the nest

Where large numbers of individuals are followed using mark-resighting methods, sophisticated analysis of survival probabilities is possible using the MARK programme, incorporating multiple covariates or effects within statistical models. However, this approach was not possible due to a) the limited number of broods from fledged nests that were available for analysis, and b) problems in confirming the identity of individual fledglings – as for recently fledged and juvenile woodlark it is generally difficult to read their colour rings as they respond to disturbance by crouching or skulking and then eventually flying it is generally not possible to read colour ring combinations of young juveniles. Instead analysis considered the total number of individuals surviving (while controlling for numbers fledged) and, separately, the probability of one or more individuals from a brood surviving (overall brood survival as 0/1).

Apparent rates of entire brood mortality, based on checks when adults were relocated but no surviving chicks were seen, were:

- period 1, 4-9 days from fledging (11.4%, n=35 adults checked),
- period 2, 10-18 days from fledging (31.1%, n=45),
- period 3, 19-28 days from fledging (40%, n=30).

This suggest a progressive attrition. However, it was possible for fieldworkers to visit a territory and locate the adults but fail to locate surviving fledglings, inflating apparent mortality. Of three visits during the first period where fledglings were not found (suggesting mortality) and a subsequent follow up visit was made that also located the adults, one or more fledglings were subsequently found to have survived in 2 of these 3 instances. Therefore, there is a high degree of error in attributing mortality during the first period and data from this period were therefore excluded from further analyses.

For the second period, a territory visit located adults without locating any surviving fledglings (suggesting mortality of the entire brood) in 14 territories following fledging. Of these 14, 8 received a subsequent check at a later date where one or more adults were successfully located. Surviving fledglings were located in 3 of these 8 instances (indicating error in the second visit), while in the remaining 5 cases the subsequent visit appeared to confirm the brood mortality. Therefore, where possible information on survival was corroborated or corrected according to any later visits. However, for the remaining 6 cases of apparent brood mortality during the second visit period, no correction could be made as no subsequent visit occurred, and it is therefore likely that a handful of cases will have been erroneously classified. However, the amount of error (unlikely to exceed 2-3 cases out of the 45 observations available) was considered sufficiently limited to allow basic analysis of mortality probability.

Alternative models were constructed to consider

- 1) numbers of fledglings surviving, modelled as a count variable with negative binomial or Poisson error structure), with the numbers originally fledging considered as a covariate in the model. As no fledglings will be observed when none fledge, this passes through the origin; hence no intercept term was fitted.
- 2) probability of brood survival, considering entire brood loss (0) versus one or more fledglings surviving (1) to that date.

Models of the proportion of the brood surviving were initially considered also, but were discounted due to the stepped nature of the response variable (essentially a transformation of 0, 0.25, 0.33, 0.5, 0.67, 0.75, 0.8, 1.0, etc.).

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As survival may be non-linear in relation to age, analysis was restricted to fledged broods visited within a broadly defined period of 10-24 days post fledging (wider than the Period 2 considered above to maximise sample size for analysis). To control for progressive exposure to risk through time, the numbers of days that had elapsed since fledging was included, either as a covariate (models 1), or as the number of binomial trials in models of brood survival (model 2). Few of these territories received multiple visits within the period considered, and for these the survival to the earlier visit date was used in analysis.

This provided a sample size available for analysis of $n = 54$ fledged broods (mean visit date 15.5 days post fledging 4.0 SD) from 29 different forest patches (each associated with one visitor / predator survey point). Of these, 15 patches contributed one monitored brood and in the remaining 14 patches two or more broods were monitored. Results from multiple broods were not pooled or averaged within each of these 14 patches, as it was important to consider each brood separately in order to control for the days elapsed since fledging. A sample size of 15-30 is generally considered sufficient to test a single effect; thus testing for an effect of recreational disturbance on fledging success across 29 patches provides a reasonable test.

Basic models were first examined, controlling for day of observation (as a covariate or as the number of binomial trials), and the numbers initially fledged (for analysis of numbers surviving, not for analysis of brood survival as a 0/1 binomial response), and testing year as a random factor. The resulting core model was then used to individually test terms for predator abundance at the closest survey point, visitor abundance and number of dog events at the closest survey point.

3.4 Assessment of study and methodological limitations

3.4.1 Lack of independence of multiple events within territories

The study design involved monitoring of particular selected patches throughout the breeding season. This design was necessary to make it possible to collect spatially matched information on nest predation, frequency of recreational activity and abundance of potential nest predators all from the same locations. The objective was to maximise the number of spatially independent locations from which information on nest success could be obtained. As subsequent nesting and re-nesting attempts within a territory may be located, the design of the study potentially provides information on multiple predation events within individual nesting territories. Following the fate of successive breeding attempts in this way is actually a much more efficient way of locating second and later nesting attempts, than freshly encountering pairs later in the season at a stage when their nesting history and expected activity is completely unknown. This approach was successful in maximising the total number of nests found and available for analysis, making the study more powerful and better capable of detecting any effects of recreational disturbance.

However, as the relative prevalence of different predators may vary spatially, multiple observations within one territory cannot be considered truly independent – for example they may involve the same individual predator who includes that patch or territory in its home range or foraging area. However, we often found that within a single woodlark territory, predation of initial and subsequent nest attempts, were due to completely different predator species. Therefore, the technical issue of independence is not considered to have posed a problem.

3.4.2 Potential camera effects and biases

If potential nest predators respond to the presence of nest cameras, either avoiding the nest, or investigating and locating it, then predation rates and attribution to different predator species may be biased. An intuitive concern is that cameras might make nests more obvious, so that inquisitive generalist predators investigating the camera are more likely to find and depredate the nest. Alternatively, it has been suggested that wary predators, particularly corvids, may be deterred from approaching because the camera is an unfamiliar object. However, it is considered very unlikely that the miniature unobtrusive cameras used in the current study resulted in any camera effect or bias. The evidence for and against camera effects in previous studies, and the basis for concluding it is unlikely to be a concern in this study, are discussed in detail below.

A recent review of nest camera effects has been carried out by Richardson, Gardali & Jenkins (2009). Unfortunately, they include numerous early nest camera studies that used large and relatively obtrusive cameras, very different to the highly miniaturised equipment currently used in this and other similar studies – this must be kept in mind when considering their findings (see below).

Richardson et al. (2009) found that effects of cameras on nest predation rates have been inconsistent. The majority of studies did not find any significant effect of nest cameras on daily survival rates (e.g. Brown et al. 1998; Staller et al. 2005). Although this may sometimes be due to small sample size and lack of statistical power rather than the lack of any effect, some robust studies sizes have found no difference in survival between nests with and without cameras (e.g. Small 2005 for spotted towhee *Pipilo maculatus* nests; Thompson et al. 1999 for indigo bunting *Passerina cyanea*).

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In other cases either positive or negative effects have been found. The one study reviewed by Richardson et al., that found cameras increased predation rates, had pooled nests of different ground-nesting bird species (mostly savannah sparrow *Passerculus sandwichensis* and meadowlarks *Sturnella* spp.) which is unsatisfactory, and placed cameras very close (12 – 25 cm) to nests (Renfrew & Ribic 2003). This is much closer than cameras were placed in the current study.

By carrying out quantitative meta-analysis, that averaged findings and effect sizes across 19 studies (of real not artificial nests), Richardson et al. (2009) showed that, on average, cameras reduced nest predation rates. More studies found predation rates were lower at nests with cameras (e.g. Thompson et al. 1999; Herranz Yanes & Suárez 2002; Small 2005), than found the opposite effect. However, Richardson et al. (2009) found camera effects were less in studies of birds nesting in open habitat (such as ground nesting woodlark) compared to forest. Furthermore, in some studies where differences in survival have been found for nests with and without cameras, this was largely due to greater rates of nest desertion (e.g. Thompson, Dijak and Burhams, 1999, for field sparrow *Spizella pusilla* nests). In contrast, in the current study of woodlark and nightjar, rates of abandonment were low.

Despite this, the suggestion has been made that reduced predation rates at nests with cameras emerging from the meta-analysis and from some individual studies, may be due to the wariness of visual predators. For example, Richardson et al. (2009) comment that the failure of Thompson et al. (1999) to detect predation by scrub jays or crows, despite their expectations, may be due to the wariness of these corvids. One study, did show that magpies *Pica pica* predation of artificial woodpigeon *Columba palumbus* nests was reduced when large conspicuous cameras were placed at the nest, while in contrast a small mammalian predator (garden dormice *Elyomys quercinus*) were not affected by the cameras. This suggests intelligent corvids may be wary of obvious cameras. However, despite the large size of the cameras used in this study (a compact 28mm camera with artificial flash, autowind motor, trigger mechanism and counterweight - much much larger and more obvious than the miniature digital infrared video cameras used in the Thetford Forest study) magpie predation was not affected (relative to controls without cameras) once cameras were camouflaged (Herranz et al. 2002). This suggests that magpie would not be deterred by miniature camouflaged cameras.

The cameras used in the current study are much smaller (only 2 cm x 2 cm x 3 cm: with volume 12 cm³: Bolton et al. 2007) than the miniature video cameras used in previous studies in which significant or marginal camera effects were found (e.g. 61 cm³ and 175 cm³ Small 2002; 61 cm³ Thompson et al. 1999; 64 cm³ Renfrew & Ribic 2003). No effect of these smaller RSPB camera systems was found for nest survival rates in a well-replicated study of spotted flycatcher *Muscicapa striata*, with cameras placed between 0.5 m and 4 m from the nests, where the main predator detected on camera was actually a corvid (Eurasian jay), with additional predation by domestic cat, great spotted woodpecker *Dendrocopus major*, raptors and another corvid, the jackdaw *Corvus monedula* (Stevens et al. 2008). In addition, two European studies using miniature infrared video nest cameras in woodland habitats found Eurasian jay to be the most frequently detected predator (Schaeffer 2004; Stevens et al. 2008), with no effect of nest cameras on nest survival rates in one of these studies. Thus among corvids, jay does not appear to be deterred by these cameras. In a smaller sample of lapwing nests monitored by the RSPB miniature cameras, the predators where mainly fox, but badger and carrion crow were also recorded (Bolton et al. 2007). Carrion crow have been recorded by these miniature cameras on woodlark nests in Breckland in the pilot study in 2007, and carrion crow and magpies were recorded by similar miniature cameras at artificial nests baited with plasticine eggs in Dorset (Taylor 2002). The success of gamekeepers using Larsen traps (large wire mesh cage traps with a decoy) strongly suggests that carrion crows and magpies do not appear to be deterred by human artifacts within Thetford Forest; although this does not fully exclude the possibility that predators may be deterred by newly placed objects (Richardson et al. 2009). However it is hard to believe that carrion crow would be

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inquisitive enough to examine and handle plasticine eggs in artificial nests shortly after their placement (crow and fox were the two main predators detected in the Dorset artificial nest study by Taylor 2002) but would still be deterred by a drab camouflaged nest camera.

In conclusion, although there is evidence that in at least some studies nest cameras may reduce predation rates, and that this could selectively bias against detection of wary visual hunting predators, particularly small mammals and corvids (Richardson et al. 2009), the camera design used in the current study make such effects unlikely.

Nevertheless, all possible precautions were taken to further minimise visibility of cameras as described below.

Precautions taken to avoid any potential camera bias

Camera mounts were painted in drab camouflaged colours to reduce their visibility and break up their outline. Wherever possible, cameras were installed directly against vegetation such as a frond of bracken or bramble or a young pine, in order to conceal their appearance both from the adult birds and also from any potential predators. Where a nest was in a particularly exposed location, particularly for some woodlark nests located in young recently replanted coupes, cameras were mounted on shorter stands to reduce their visibility.

Even the youngest forestry plantations in which some woodlark nests were located contain frequent brash, broken branches, lengths of root and other forestry debris as well as occasional discarded items including occasional pieces of metal, broken machinery and other debris. The nest cameras did not stand out in such a situation; in fact it was often difficult for fieldworkers to relocate a camera that had been installed by someone else. Plantations used by nightjar often contained trees up to 2-3 meters high and dense bracken, providing good concealment for cameras.

Fieldworkers crouched but did not kneel at nests, to minimise trampling or scent cues that could bias predation by visual or olfactory predators respectively. However, unlike some previous studies, surgical gloves were not worn to minimise scent.

So that visibility of nests were to predators was not altered, no 'gardening' or removal of obscuring vegetation was carried out at the immediate nest site, even if this meant the nest cup was partly obscured from view. However, grass growing immediately in front of the camera lens (and at some distance from the nest itself) was sometimes trimmed to ensure a continued view of the nest, for example if vegetation grew during a prolonged monitoring installation. The camera is connected by a video cable to a recording box and battery, that was located at least five meters away. Cables were concealed in a shallow slot in the ground and vegetation and recording units and batteries were buried in the ground. Soil removed in this process was scattered away from the nest site and was not unusual given the amount of bare ground created by rabbit activity and forest planting furrows. Cables and recording units were generally not visible to the eye.

Although an ideal study design would leave a sample of nests without cameras, in order to provide a control and measure any camera effects (Richardson et al. 2009), this protocol was not compatible with the study aim of maximising the number of predation events observed.

3.4.3 Potential bias due to failure to identify some predator events

Systematic bias may result, if the predator species responsible is not identified in a sizeable proportion of predation events, and if certain predator types or species are more likely to be unidentified.

Some previous miniature nest camera studies have failed to identify the predators responsible for many of the sampled predation events (e.g. 16 out of 40: Renfrew & Ribic, 2003). In contrast, in the current study we were able to identify the predator from the subsequent images in 93% to 94% of predation events for nightjar and woodlark respectively. The instances where the predator identity was not known were very few: for woodlark only three out of 48 predation events (6.3%, all at chick stage); for nightjar only one out of 14 events (7.2%).

For woodlark, the single undetermined predation event in 2008 was of 8 day old chicks. Of the two undetermined predation events in 2009, the first was nocturnal predation of two day old chicks, in this case the camera was functioning but no predator was detected; the second was predation of 1-2 day old chicks undetected as the data card was over-written (due to movement of vegetation triggering continuous images). Therefore this latter unknown event does not represent any bias in terms of which predator may have been responsible - it was just bad luck that the event was not confirmed.

Thus for woodlark, two of the undetermined events may have been particularly likely to have involved small or low predators (e.g. small mammals such as woodmouse, adder, weasel or stoat) that may be obscured by vegetation. However, adder move slowly and make repeated visits to a nest, increasing the chance of them triggering an image and at least one of these undetermined events was at night which excludes adder. In a pilot study conducted in 2007, one of two unknown predation events (where no image was obtained on the camera) was subsequently attributed to stoat on the basis of the severed legs of one of the colour ringed chicks found within c30cm of the nest cup.

Therefore predation by stoat, or by small mammals, may potentially be underestimated by up to 4.2% of all woodlark nest predation events.

For nightjar, movement of chicks and of the female often made it hard to follow the activity by the camera, necessitating re-installation on some occasions. It is unlikely that the unidentified event represents any bias to a particular type or species of predator.

3.4.4 Sample sizes

For woodlark, the number of nest predation events observed is unusually robust for a two year study. For nightjar, fewer events were detected, but this was expected given the difficulty in locating nests of this species. Nevertheless, considerably more nightjar nests were found than in any equivalent study previously.

Follow-up visits to check survival of fledged woodlark chicks are not straightforward. Low detection rates of adults (that can move away from territories following either a successful or unsuccessful nest attempt) following fledging, reduced sample sizes further, but sufficient data were obtained to allow a basic test of whether there is any relationship between post-fledging survival of woodlark chicks in their vulnerable first few weeks outside the nest, and levels of predators and recreational activity.

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A large number of independent points were surveyed for visitors, and predator abundance, this provides a robust analysis of whether recreation affects local predator abundance / activity.

Although visitor and predator surveys were conducted in locations spread throughout the forest area, and in all patches of suitable habitat selected for territory and nest surveys, some opportunistic woodlark nests reported by additional observers were not in locations selected for systematic visitor and predator survey. Thus the sample size for directly relating nest outcome to visitor rate is slightly less than the total sample of nests monitored.

Due to the large size of many clearfells monitored for woodlarks or searched for nightjar nests, nests were located at some distance from the exact visitor survey point located within the monitored patch (for woodlark nests: mean distance from nest to survey point was 190 m \pm 129 m SD in 2008; 181 \pm 124 m SD in 2009; with 62 of 66 nests <400m from survey points in 2008 and 78 of 81 nests <400m in 2009). However, the count of corvids, people, dogs made from the survey points extended across the monitored patch and relate well to the immediate locality in which the nest is exposed.

3.4.5 Lack of data on spatial abundance of stoat

It was not possible to obtain sufficient measures of abundance of either stoat or hedgehog to allow these to be analysed in relation to visitor activity. However, neither are scavengers, and hedgehog are largely nocturnal or crepuscular. No hypothesis of a casual mechanism linking abundance or predation impact of either hedgehog or stoat to levels of recreation has been presented.

3.4.6 Limitations to statistical analysis of nest survival

Due to the low number of events attributable to particular individual predator species, the decision was taken to not attempt to measure species-specific nest-predator risk.

Analysis of nest survival was undertaken simultaneously considering all causes of nest failure – and examining whether nest failure rates (separately at egg and chick stage) were higher in locations with a greater frequency of recreational activity. This approach was taken rather than separately modelling failure from predation and failure from desertion because: 1) there were many fewer deserted nests to model, 2) because there are multiple potential mechanisms being tested: disturbance may increase failure rates through desertion; through exposure to weather or chilling of chicks or eggs (if females are repeatedly flushed or if they experience disturbance during foraging); or through increased rates of nest predation (if flushing of females exposes or alerts predators to the nest, or if disturbed females have to spend more time away from the nest feeding). Thus there are multiple potential mechanisms and the question tested was whether there is an overall effect on nest success or failure.

If disturbance results in an increased rate of nest predation this should be detected. Similarly, if disturbance results in an increased rate of nest desertion, this should also be detected in analysis of overall nest success / failure if effects are strong. There is the possibility that stochastic 'noise' in the nest failure data due to desertion during poor weather, or due to predation of the female, may obscure or make it harder to detect an underlying effect of recreational disturbance on failure due to predation.

Results I: Which are the predator species depredating woodlark and nightjar nests?

4 What are the predator species depredating woodlark and nightjar nests?

4.1 Summaries of numbers of nests monitored, and numbers of predation events observed (by species and year).

Very poor weather during spring 2008, with exceptionally heavy rain, delayed the start of woodlark nesting activity, and reduced the frequency of repeat nests with many pairs delaying re-nesting or appearing to abandon their nesting territory. Despite this, a total of 66 woodlark nests were monitored with nest cameras in 2008 and a further 81 nests were monitored in 2009.

Over the two years, a total of 147 woodlark nests were monitored by cameras.

For woodlark, 47 predation events were detected, of which nine were of eggs and 38 at the chick stage, with the predator species responsible identified in all but three of these events. This provides a good sample with which to attribute the relative importance of different predators.

The successful monitoring of such a large sample of woodlark nests makes this one of the most thorough nest predation studies so far conducted on a passerine in the UK.

A small number of nests were deserted, amounting to three in each of 2008 and 2009. Of three nests deserted in 2008, two were considered to have been abandoned prior to camera installation although the third may have been disturbed by the camera installation as the pair attempted to return before the installation was complete. The three nests deserted in 2009 all occurred subsequent to camera installation, with incubating females flushed from their nest sites by unknown agents (as seen on nest cameras), and not seen to return to the nest despite the contents not being disturbed. Potentially all three females were predated. In 2009, a nest camera recorded a Sparrowhawk *Accipiter nisus*, which caught a female Woodlark incubating on a nest, resulting in the chicks starving. However, most other nests where chicks starved (**Table 4**) were associated with periods of wet and cold weather, presumably resulting in chicks becoming wet and subsequently chilled, in combination with reduced food availability.

Nightjar

Locating good numbers of Nightjar nests was a major challenge, with nest search days involving over a hundred hours of volunteer-effort producing just one or two nests.

A total of 18 Nightjar nests were monitored with nest cameras during 2008 and a further 26 nests were monitored in 2009, providing a total of 44 nests throughout the two years of study. The duration of nest camera monitoring was substantially greater in 2009 partly as a result of six nest provided through a UEA-BTO-FC radio-tracking PhD study.

Nightjar nest success was higher than expected. In 2008, two thirds of monitored nests were successful, whereas in 2009 the number of successful nests was slightly less, although the outcome of two nests in 2009 was not known with certainty (**Table 5**).

A total of fourteen nightjar nest predation events were detected, compared with just one previously recorded on camera prior to this study (Langston et al 2007a). Of these fourteen, the predator responsible could be identified in all but one event.

Results I: Which are the predator species depredating woodlark and nightjar nests?

4.2 Frequency of predation of woodlark clutches and broods attributable to different predator species

In both 2008 and 2009, a wide variety of nest predator species were identified as responsible for nest losses (**Table 6**), with no one clear dominant species.

Mammals were responsible for most of the nest predation events at the egg stage (7 out of 9 events: 78%), and for 51% of those predation events at the chick stage where the predator was identified.

Combining observations at both egg and chick stages and pooling both years, the main species of nest predator (each contributing five or more events, see **Table 6**) were, in rank order :

First:	Fox	(9 events),
Second:	Kestrel	(8)
Third:	Adder	(7)
Fourth:	Hedgehog	(5)

Only three predation events were attributed to corvids, of which only one was due to carrion crow, with two due to jay. Therefore, carrion crow was not confirmed as a major nest predator, contrary to expectation.

A single woodlark nest was predated by domestic cat, this was within 80m of a house located within the forest, and within 40m of the boundary of this isolated property (garden, caravan / outhouses etc).

A single woodlark nest was predated by a domestic dog, however a total of 13 woodlark nests were monitored that were located within 10m of ride (trackway) margins. Of the 147 woodlark nests monitored, the median level of recreational activity (as predicted from models controlling for day of week, time of day) was 0.7 recreational events per hour (allowing for an individual or group approaching and leaving the survey point to be considered as two events, each on a different ride element), while the upper 25% of the monitored nests were in patches experiencing >2.2 events per hour, when averaged across the whole day including both peak and quiet times. Thus most nests were in relatively quiet parts of the forest.

The frequency of adder *Vipera berus* predation was notably higher in 2009 (reaching 24% of observed events for which the predator was known) than 2008 (5% of identified events in that year). This may reflect a warmer spring compared to the exceptionally wet start to 2009, or a difference in the ecological characteristics of patches monitored.

The small mammal predator may be woodmouse (*Apodemus sylvaticus*) which are omnivorous and are abundant within Thetford Forest.

It should be noted that an additional three predation events occurred where the predator species could not be determined. Of these, one was due to the data card filling up and is thus a 'random'; rather than biased event. Of the remaining two, the failure to identify the predator may have been made more likely if smaller predators were involved (e.g. stoat, snake or small mammal). This is discussed above in Section 3.4.3.

Results I: Which are the predator species depredating woodlark and nightjar nests?

4.3 Frequency of predation of nightjar clutches and broods attributable to different predator species

All 13 events where the predator was identified involved mammals (**Table 7**), mostly nocturnally. No instances of diurnal (daytime) predation by crows (or other corvids, such as magpie or jay) were detected. The single occasion where an avian predator was seen to take a nightjar clutch, involved a jay that 'scavenged' a deserted nest with eggs, 11 days after the female had abandoned the nest. Furthermore, observation of extensive diurnal footage (Wilshaw 2010) showed an incubating female nightjar successfully performing a threat display to a jay; this nest was not predated.

No support was found for the hypothesis that a key agent of nest failure is recreational disturbance that allows carrion crows to predate nightjar nests.

In both 2008 and 2009, Badger and Fox were the main agents of predation (**Table 7**).

The single predation event where the predator species was not determined, involved predation of three day old chicks at 11.20am, with the chicks stomachs left in the nest site – suggesting a mammalian predator.

5 Constructing the measures of site-specific abundance of predators, people and dogs.

Firstly models are developed to measure abundance of predators at survey points.

Secondly a separate analysis of visitor count data is undertaken to estimate the frequency of recreational events at survey locations, controlling for year, time of day, day of week etc.

Finally, the two sets of data are related to each other, to explore whether there is evidence that the abundance of predators is greater in areas with higher levels of recreational activity, or in proximity to carparks or urban areas.

5.1 Modelling abundance of fox and dog scats on transects around survey points

Fox scat data were obtained from a total of survey 182 locations. The faecal data were reported as, the number of scats found on each visit, and were analysed while controlling for the total transect length walked as well as any seasonal or year effects.

Of the five species for which scats were identified, domestic dog and fox scats were most numerous, across visits and years (**Table 8**). The percentage of scats detected for all species, apart from dog, was highest on the first of the two visits. In 2009, the percentage of scats detected for all species, except hedgehog, was greater than in 2008, most likely due to higher rainfall in spring of 2008 that will have accelerated decay and disappearance of scats.

Fox scats were recorded during 341 transect visits (48.4%) while no fox scats were found on 363 transect searches (51.6%). 89% of survey transects had fox scats detected on at least one visit. The mean number of fox scats recorded per site (across all visits) ranged from 0 to 10.5 (average of site means = $1.27 \pm 1.37SD$, $n = 183$).

A logistic model of scat presence / absence per transect visit, using binomial error and logit link (AICc = 1680), controlling for transect length as an offset, was significant for survey point, survey date (Wald 6.356, $p=0.012$) and year (Wald 102.95, $p<0.001$). Removing the marginally significant survey date term resulted in reduced model fit (AICc = 1681) and this term was therefore retained.

Generalised models of the number of fox scats recorded (dependent: scat count per transect per visit), controlling for date (days since 01 February as a continuous variable, or considering visit number first/second as a nominal categorical variable), year (nominal categorical) and including transect length as an offset, failed to reach convergence.

Alternative generalised linear models of scat count, that incorporated transect length as a covariate rather than an offset, did reach convergence. However, the effect of transect length on the number of fox scats counted was not significant and this term was therefore removed. A model with significant terms for survey point, year and visit (first / second; nominal) (AICc = 2281.18) had considerably better fit to the data, than an alternative model that substituted a term for survey date (numeric, continuous) instead of visit (AICc = 2503.76) and was therefore accepted as the better model. Effects of year, and season in these models were in agreement with those detected by the logistic model that considered presence / absence of scats per visit. This model is detailed below (**Table 8**). However, it is unsatisfactory to have estimate fox scat frequency at survey sites without accounting for survey effort (i.e. transect length).

Results II: Is predator abundance related to the frequency of recreation events?

To achieve this further models were explored, analysing the number of scats counted per km of transect length. As the response variable is no longer an integer (count) a normal error term (with linear link) was adopted. This model was over-dispersed (**Table 9**), with unsatisfactory distribution of residuals. Subsequent square-root transformation of the measure of scat density per visit achieved a satisfactory error distribution (**Table 9**; Model 1).

An alternative model, with square-root of scat density (per km), also controlling for year, but substituting survey date (numeric, continuous) for visit (nominal, categorical), provided very similar goodness of fit as judged by AICc (**Table 9**, Model 2: $\Delta\text{AICc} = 0.173$). As these two alternative models have a similar change of being the best explanation of scat density, Aikike weights and model averaged parameters for each survey point were calculated from these two models, following Burnham and Anderson (2002).

The resulting variable, FoxMMI, had a similar magnitude of variation as the arithmetic mean of multiple visits per survey point (FoxMMI, range across $n=182$ survey points $-0.443 - 5.236$, mean 0.696 , SD 0.726 , CV 1.059 ; mean of untransformed scat count data per point, range across survey points $0 - 10.5$; mean 1.276 , SD 1.373 , CV 1.076) but accounts for bias arising from year and survey date. The resulting variable, FoxMMI was in subsequent analyses used as a measure of fox abundance/activity at survey points.

Similar models were explored for the abundance of dog scats, modelled as $\text{SQRT}(\text{count dogscats per km})$. The best supported model included significant effects for year, survey visit and survey point and was used to estimate the abundance of scats per point.

The number of fox scats recorded per transect on each visit (mean 1.27 ± 2.15 SD, range $0 - 15$, $n = 703$) was significantly, but weakly, positively correlated to the number of dog scats ($r = 0.107$, $p = 0.005$; for square-root transformed density per km $r = 0.122$, $p=0.001$, $n = 703$). Either there is a weak but significant tendency for foxes to be more abundant in the same parts of the forest with more dogs, or both dog and fox scats tended to be more visible in certain track margins.

5.2 Modelling abundance of avian predators at survey points

A number of different variables were available by which to measure the abundance of crows and jays. For crows, counts of crows flying or perched on a tree at the patch margin ('CrowT') had 56% and 52% zero values respectively, and were strongly correlated ($r=0.416$, $p<0.0001$, $n=1064$), while counts of crows on the ground had much greater frequency (74%) of zero values. Thus counts of crows on the ground contain less information, while crows observed perching during the time that a surveyor was present are nevertheless capable of foraging on the ground at other times. Measures of crows perching around the margin of a patch relate to resident birds, who may have potential impact. In contrast, counts of crows flying often relate to interacting individuals and territorial defence, inflating the count. For these reasons, the count of crows perching was used as a sole measure of abundance of carrion crow.

Similarly, counts of jays on the patch margin ('JayM') were strongly correlated with counts of them foraging on the ground ('JayG') ($r=0.354$, $p<0.0001$); however, although one or more jays were recorded working along the patch margin on 32% of visits, they were observed foraging on the ground much less often (90% zero count). Therefore the variable JayGround provides little information and was not considered for further analysis. Counts of magpie and kestrel during individual visits had 86% and 75% zero registrations respectively.

The distribution of count data, with large numbers of zeros but a tail of infrequent but high counts, and very large range (e.g. maximum 144 for crow flying, 111 for crow perched, 44 for magpie), was problematic in fitting generalised linear models (with either a Poisson or a negative binomial error term) to the raw count data. For all avian predator variables, when

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fitting a model with survey point as a categorical ordinal variable, warnings were received during modelling that convergence criteria were not satisfied and validity of model fit was uncertain.

Examination of P-P plots (that contrast observed to expected cumulative frequencies of observations compared to a hypothetical distribution) showed that square-root transformed variables of abundance achieved normality, compared to raw untransformed count data. Generalized Linear Models fitted to square-root transformed data (with normal error and identity link) converged without problems. Square-root transformed avian predator variables were therefore considered in subsequent models.

The mean, range and standard deviation of the resulting variables considered for modelling avian predators (N= total number of visits across 185 survey points) were:

Variable	N	Frequency of zero counts (%)	minimum	maximum	mean	SD
SQRT(CrowT)	1064	556 (52%)	0.00	10.54	0.934	1.230
SQRT(JayM)	1064	728 (68%)	0.00	4.00	0.463	0.756
SQRT(Magpie)	1064	912 (86%)	0.00	6.63	0.249	0.724
SQRT(Kestrel)	1064	802 (75%)	0.00	3.46	0.338	0.648

Mean abundance of avian predators at each survey point was examined testing models that controlled for potential effects of: year (nominal categorical), date (number of days after 01 Feb; continuous), date(squared) and hour (of day) (nominal categorical, survey start taking values 05.00-19.00), or substituting more parsimonious variables of morning(11) (survey start ≤ 11.00 ; categorical), or morning10 (survey start ≤ 10.00 ; categorical).

For carrion crow (modelled as square-root of the total count of perched birds in replicate 10 minute periods during the hour focal watch) the minimal model retained significant effects of year, date and date squared, and early morning ($<10\text{am}$). In this model (**Table 10**) the difference in crow abundance among survey point locations was highly significant. Thus the parameter values for survey point predicted by this model are considered a good measure of relative crow abundance among locations, while controlling for these other effects.

For jay, two alternative minimal models received similar support as judged by AICc. These contained significant terms for survey date and or survey date(squared) and for morning ($<10\text{am}$); i.e. they controlled for seasonal and time of day effects on jay abundance and activity. However, the term for survey point was highly non significant and was only retained by 'forcing' it in the model. Therefore the predicted measures of jay abundance from this model cannot be used to represent spatial variation in jay numbers.

For both magpie and kestrel, no effects were significant (date, time of day, year were all non significant and removed in model development). The only significant term was the intercept (overall mean), while the forced retention of a term for survey point in the models was marginally non significant for magpies, and strongly non significant for kestrel. Thus as with jay, these models cannot be used to represent spatial variation in kestrel or magpie numbers. This reflects the lower frequency of sightings of jay, magpie and kestrel compared to crow.

Therefore when subsequently examining potential relationships between recreation and these other species, for jay, magpie and kestrel, the mean of counts (square-root transformed to achieve normality based on inspection of P-P plots) across replicate survey visits was used as a measure of relative abundance among and across survey sites.

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Thus the site level variables used were:

- CrowT_GLM estimate of abundance per survey location, controlling for year, season, time of day
- SQRTJayM_Mean of visits
- SQRTMagpie_Mean of visits
- SQRTKestrel_Mean of visits

5.3 Modelling the abundance of recreational visitors at survey points

For visitor counts, as dogs were occasionally seen running without any accompanying person, or following a cyclist or car, it was not straightforward to simply distinguish 'dog walkers' from other types of recreational activity. Therefore, the following category of potential disturbance were recognised:

- Dog events – all instances when one or more dogs passed along the ride section or adjacent compartment, whether accompanied by humans (walking, cycling, driving) or not.
- Dog count – the total number of dogs passing along the ride section.
- Walk events – all human walking events, whether or not accompanied by a dog.
- Other events – cyclists, horse-riders or vehicles.
- Total potential disturbance events – all events of any kind within the hour (not the sum of the above which are not mutually exclusive).

Therefore, for recreational activity, five potential variables were considered: Dog events; Dog count; Walk events; Other events; Total events. For each hour survey hour period, the sum of events observed on the separate ride sections was calculated and considered as the response variable.

The count of dogs and number of dog events were so strongly correlated (raw count data $r=0.9$, $p<0.0001$; square root transformed data $r=0.968$ $p<0.0001$, $n=1064$) that they are redundant, both providing the same information. Therefore the number of dog events only was considered.

Similarly, the frequency of dog events and the frequency of walker events were also highly correlated (square root transformed data $r=0.884$ $p<0.0001$, $n=1064$). In contrast the frequency of 'other' types of recreational event was unrelated to either the frequency of dog events (square root transformed data $r=0.014$ $p<0.641$, $n=1064$) or of walker events (square root transformed data $r=0.057$ $p<0.064$, $n=1064$).

The total frequency of Total events was strongly positively correlated with the individual measures (square-root of Total events: $r = 0.682$, 0.764 and 0.655 with square rooted Dog events, Walk events and Other events respectively).

Although the visitor and predator activity variables have frequent zero counts (i.e. no event observed within the hour) and moderate numbers of observations with small numbers, they also have a few observations with large counts and do not fit a negative binomial distribution particularly well. In addition, as the measure of visitor and dog abundances is the sum of events occurring on individual trackway elements as counted from track junctions, there are many zeros, few ones, but a much greater number of counts of 'two' events, as people enter (approach) and depart from a patch on different track elements. This makes the distribution of count data strongly bimodal.

Again, for each of the recreational variables, when attempting to fit a model for the survey point location to count data, warnings were received that criteria for convergence were not satisfied and validity of the models were uncertain. In contrast models fitted to square root data converged without such problems.

Examination of P-P plots showed that square-root transformation of the raw count data provided a very good fit to a normal distribution. Therefore, models were again constructed using square root transformed count data.

Results II: Is predator abundance related to the frequency of recreation events?

The range, mean and standard deviation of the resulting variables considered for modelling the frequency of recreational events (N= total number of survey visits to 185 points) are shown below:

Variable	N	Frequency of zero counts (%)	minimum	maximum	mean	SD
SQRT(DogE)	1064	816 (77%)	0.00	4.36	0.41	0.80
SQRT(WalkE)	1064	763 (72%)	0.00	4.69	0.51	0.88
SQRT(OtherE)	1064	898 (84%)	0.00	8.00	0.29	0.79
SQRT(TotalE)	1064	654 (62%)	0.00	8.00	0.75	1.09

For models of visitor abundance the following alternative codings were explored to account for potential effects of different days of the week, based on a priori assumptions about relative levels of recreational activity on weekends, days immediately bracketing weekends, and midweek days.

DOW7	1 (Monday), 2 (Tuesday), 3 (Wednesday), 4 (Thursday), 5 (Friday), 6 (Saturday), 7 (Sunday)
DOW4	1 (Monday + Friday), 2 (Tuesday, Wednesday, Thursday), 6 (Saturday), 7 (Sunday)
DOW3	1 (weekdays), 6 (Saturday), 7 (Sunday)
DOW3B	1 (Monday + Friday), 2 (Tuesday, Wednesday, Thursday), 3 (Saturday + Sunday)
DOW2	0 (weekdays), 1 (Saturday + Sunday)

Bank holidays during the study period on which survey counts were conducted (05/05/2008; 25/08/2008; 04/05/2009; total of 9 survey visits) were re-coded as Sundays.

Although daylight periods changed radically through the survey and breeding season (i.e. from March-August) time periods were considered as fixed, as patterns of people's activity appear to primarily relate to daily work / lunch/ evening routines (e.g. <8am, >8am, lunchtime, late afternoon, etc.).

To allow construction of parsimonious models of recreational activity, the 15 one hour periods were simplified and combined. Survey events beginning within 05.00-06.00 am or after 19.00 pm were excluded as no recreational activity was recorded during these surveys. The pattern of visitor abundance (pooling across survey locations) versus time of day was examined separately for dog walking events, walker events and other events (see **Table 11**). After examining temporal pattern of means, the periods were grouped, to produce an initial variable with 8 levels (HOUR8Code). This was then further simplified during modelling, based on examination of fitted parameters, combining levels with similar effects. Alternative categorical time variables were created and explored during simplification of models of recreational activity frequency at survey points, testing and comparing alternative codings by examining change in AICc.

Results II: Is predator abundance related to the frequency of recreation events?

Alternative codings for period of day tested and when constructing generalised linear models of recreational activity.

HOUR8code	(06.00+07.00); (08.00+09.00); (10.00); (11.00+12.00); (13.00+14.00); (15.00+16.00); (17.00); (18.00)
HOUR7code	(06.00+07.00); (08.00+09.00); (10.00); (11.00+12.00); (13.00+14.00); (15.00+16.00); (17.00); omitting 18.00 as missing data
HOUR6code	(06.00+07.00); (08.00+09.00); (10.00); (11.00+12.00); (13.00+14.00+15.00+16.00); (17.00); omitting 18.00 as missing data
HOUR4code	(06.00+07.00); (08.00+09.00); (10.00+11.00+12.00+13.00+14.00+15.00+16.00); (17.00); omitting 18.00 as missing data
HOUR4Bcode	(06.00+07.00+10.00+13.00+14.00+15.00+16.00); (08.00+09.00); (11.00+12.00); (17.00); omitting 18.00 as missing data
HOUR3code	(06.00+07.00+08.00+09.00+10.00+13.00+14.00+15.00+16.00); (11.00+12.00); (17.00); omitting 18.00 as missing data
HOUR3Bcode	(06.00+07.00+10.00+11.00+12.00+13.00+14.00+15.00+16.00); (08.00+09.00); (17.00); omitting 18.00 as missing data

A minimal model for the frequency of dog events (square-rooted) retained significant effects of day of the week, simplified to just two categories of weekend versus weekday (DOW2), a coding for period of day, and a highly significant term for the differences in recreational activity among survey points (**Table 12**). Minimal models for the frequency of walker events had similar structure and effects, but with slightly different coding of periods of the day (**Table 12**). In both cases, year and season effects were non-significant and removed during model simplification.

The overall frequency of 'other' events (square-rooted) was lower than the frequency of dog and walker events, but similar effects of weekend versus weekday and period of day were found to be significant. Two alternative models received similar support, the best fitting model included an effect for year but the second best model that excluded year differed by only 0.639 AICc units. Model averaged parameters were calculated using Aikike weights (**Table 12**).

Finally, a model of total recreational events was constructed. Year was again significant, along with terms for weekend / weekday and period of day. The effect of survey point was highly significant, revealing very strong differences in levels of recreational activity among locations (**Table 12**).

Thus the final recreational variables available for examining effects on woodlark and nightjar breeding productivity, and any relationships with predator abundance, were:

- SQRT Walk Events_ GSLM parameters, controlling for effects of weekday / weekend and time of day
- SQRT Dog Events_ GSLM parameters, controlling for effects of weekday / weekend and time of day
- SQRT other Events_MMI of GSLM parameters, controlling for effects of weekday / weekend and time of day
- SQRT Total Events_ GSLM parameters, controlling for effects of weekday / weekend and time of day and year

6 Are there effects of recreation event frequency, urban area or proximity to carparks on the local abundance of nest predators?

The aim is to investigate potential relationships between the abundance of predators, proximity to carpark and urban area, and the abundance of recreational visitors and dogs at survey points. However, it is important to avoid 'data dredging' – the examination of very many individual tests in order to find some relationships. The indiscriminate testing of very many associations can lead to spurious relationships being identified. In contrast, rigorous controlling for the number of tests conducted for example by Bonferroni correction, can lead to genuinely significant relationships being discarded. For these reasons a carefully selected set of *a priori* hypotheses were tested. These are listed below.

6.1 Explicit hypotheses tested:

- 1) Is the density of dog scats detected on the scat transects, positively related to the frequency of dog events recorded by separate visual counts at these survey locations? If the scat methodology is a reliable measure of fox abundance then it would be expected that a positive association should also be obtained between visual counts of dogs, and counts of dog scats on transects.
- 2) Is there an association between the density of fox scats, and the frequency of dog events recorded by visual counts at survey locations? This test is conducted to further investigate the apparent positive association suggested by the initial correlation between densities of fox and dog scats.
- 3) Is there any evidence that the abundance of fox, carrion crow or magpie is greater in closer proximity to car parks, and in closer proximity to urban areas.
- 4) Is there any evidence that the abundance of crows is greater in closer proximity to main roads (it has been suggested that crows may be at higher density where road kill are available)
- 5) Is there any evidence that the abundance of crows is greater in closer proximity to forest / farmland edge (it has been suggested that crows may benefit from access to external farm and semi-natural heath or grassland habitats).
- 6) Is there any evidence that the abundance of crow or fox is positively or negatively associated with the frequency of recreational events at survey points across the forest. The hypothesis that kestrel may be deterred by recreational activity can also be tested.

No hypotheses were tested for jay as i) they were responsible for a very low frequency of predation events, ii) they have not been suggested to associate with people or car parks, iii) being frequently found in peri-urban and garden areas they are not expected to avoid areas with more people.

6.2 Results:

- 1) The density of dog scats detected on the transects, was strongly significantly correlated with the frequency of dog events recorded by separate visual counts at these survey locations (**Table 13**). This provides confidence in the use of the fox scat count methodology as a measure of fox abundance and activity in forest locations.
- 2) Despite confirming the earlier significant but weak association between the density of fox scats and density of dog scats ($r = 0.230$, $p < 0.002$, $n = 182$), there was no evidence of greater density of fox in areas with a greater frequency of dog events ($r = 0.089$, n.s.) (**Table 13**).
- 3) As hypothesised, magpies were sighted more frequently at locations closer to carparks (**Table 14**), but magpies did not show any relationship with proximity to urban areas. It should be remembered that no instances of magpies depredate a woodlark or nightjar nest were recorded by the nest camera study. There was no evidence that carrion crows were more frequent near carparks or at sites closer to urban areas. There was some evidence suggestive of a weak, positive association between fox and distance to urban areas (**Table 14**); i.e. foxes may be more abundant at sites more remote from urban development, although as tested here by simple correlation (without controlling for other confounding effects) the relationship was not significant ($p < 0.1$ but not < 0.05).
- 4) No evidence was found for any higher abundance of crows at locations in closer proximity to main roads (**Table 15**).
- 5) The frequency of crow sightings was not greater at survey points located closer to forest the nearest forest / farmland edge, when considered solely in terms of immediate proximity. However, when the extent of farmland within buffers of 500m and 1km was examined, there were weak but significant negative associations between crow frequency and percentage farmland (**Table 15**). This led to the hypothesis that crow are more abundant at locations with greater extent of forest and lesser extent of farmland in the local landscape and when tested the frequency of crow sightings at survey points was weakly positively related to the proportion of forest in surrounding buffers at scales of 500m, 1km and 1.5km ($r = 0.142$, $p = 0.055$; $r = 0.155$, $p = 0.036$; $r = 0.165$, $p = 0.025$, $n = 184$).
- 6) There was no evidence for any positive association between the abundance of crow, fox or kestrel and the frequency of recreational events at survey points across the forest (**Table 16**). All correlations between fox and crow and measures of recreational activity were very weak (ranging between $r = 0.04$ and $r = 0.09$) and were highly non-significant. Kestrel showed one marginal and weak positive association with the abundance of dog events, that was not significant. A biological explanation for such a relationship is not readily available.

6.3 Tests of effects of landscape, urban and human population in buffers on fox abundance at survey points

As fox were found to be one of the major predators of both nightjar and woodlark nests, attempts were made to construct generalised linear models of fox abundance in relation to the percentage of forest, percentage of farmland, and proximity to roads, and then use these as a base model with which to test any effects of percentage of urban area OR human population number. Models considered either human population density or urban area, but not both, within one model as they were strongly correlated (**Table 17**) – giving additional confidence in both measures.

Models were constructed to consider all effects at a single scale (i.e. all landscape and human effects at the same buffer scale) within buffers of 500m, 1.0 km, 1.5km and 2km (chosen to cover the likely range to which local fox abundance may respond in the short term). At each scale, full models were first fitted (including terms for distance to main road and % farmland, %forest in the appropriate scale buffers) then simplified by examination of model AICc and the Wald values of individual parameters. Minimal models obtained for each scale were then used as a base model with which to test the urban or population variable at that same buffer scale.

Contrary to expectation, no effects of % forest or % farmland were retained in any model at any buffer scale. In all cases, the null model was a choice between i) a model containing a term for proximity to roads (that was non significant as judged by Wald Chi-square) and a marginally better fitting model (as judged by slight reduction in AICc) that was an intercept only model. Consequently both models were used to sequentially test human population and urban extent variables at each buffer scale. There was no evidence of any support for either positive or negative urban or population effects at any scale from 500m to 2km (see **Table 18**).

7 Does the frequency of recreation events affect nest failure rates of woodlark and nightjar

7.1 Analysis of recreation effects on woodlark nest placement

Woodlark nests were located an average of 47.6 m from the closest ride. However, location was highly variable (SD 34.5 m); 13 of the 147 nests were located within 10 m of a ride and 7 were located within 5 m of a ride. There was no evidence that woodlark nested further from rides in patches that were more frequently used for recreation ($n=147$: linear regression of square-root of nest distance to ride against a) modelled frequency of dog events; $F_{1,145} = 0.792$, $p = 0.375$; b) modelled frequency of walker events; $F_{1,145} = 0.134$ $p = 0.715$).

7.2 Analysis of woodlark nest failure rates in relation to frequency of recreational visits and dogs

A total of 781 egg days and 1144 chick days were monitored. As these were large data sets, only separate models of egg and chick stage success are considered, and models pooling to consider 'nest days' were not undertaken as it is likely that daily survival rates, and the predators involved, differ substantially between the incubation and provisioning stages.

Analyses first considered models of egg success (see **Table 19**). Excluding five nests for which first egg dates were not estimated, an intercept only model provided a marginally better fit to the data than a model with a term for first egg date ($\Delta AICc = -0.704$). Therefore, the first egg date term was not included, which allowed the full set of nests to be considered in analysis of egg stage success. Considering the full set of nests, an intercept only model gave a better fit than a model that included a term for year ($\Delta AICc = -1.387$). The intercept only model was therefore selected as a base model. Tested by addition of terms into this model, there was no support for the hypothesis that either the frequency of dog events, or the total frequency of recreational events, affected woodlark nest success at the egg stage.

Models that solely considered failure due to predation of the clutch also provided no support for any effect of walkers ($\Delta AICc = +2.008$), dog events ($\Delta AICc = +2.001$), or total recreation events ($\Delta AICc = +1.833$) relative to a base intercept only model ($\Delta AICc = 0.000$; $AICc = 73.493$, $df = 105$, intercept Wald chi-square = 186.382, $p < 0.00001$).

For models of chick success, an intercept only model provided a substantially better fit than a model with a term for year ($\Delta AICc = -1.559$). The intercept only model was again used as a base model. Testing individual terms for frequency of dog events, total recreational events and walker events provided no evidence that these reduced the chick stage survival rate (see **Table 19**).

7.3. Analysis of woodlark hatching and fledging success in successful nests in relation to frequency of recreational events or dogs

It is possible that disturbance may cause a reduction in hatching or fledging success, due to frequent flushing or absences from the nest, or interference with provisioning, without actually causing outright failure. Such effects might be important if they reduce breeding productivity of otherwise successful nests.

Models of hatching and fledging success were constructed, relating numbers of eggs hatching to numbers laid (for nests that did not fail at the incubation stage and that hatched at least on egg), and numbers fledging to numbers hatch (for successful nests that fledged at least one chick).

Models were used to examine potential effects of walker events, dog events and total recreational events. There was no evidence for any effect of the frequency of recreation on woodlark hatching or fledging success per egg and per chick (**Table 20**).

7.4 Analysis of recreation effects on nightjar nest placement

For nightjar, nests were located an average of 60.9 m from the closest ride, but distance was highly variable (SD 32.5 m, minimum 9.4 m, maximum 135 m). There was no evidence that nightjar nested further from rides in those patches that were more frequently used for recreation ($n = 46$, linear regression of square-root distance from ride against a) modelled frequency of dog events, $F_{1,44} = 0.070$, $p = 0.792$; b) modelled frequency of walker events, $F_{1,44} = 0.257$, $p = 0.615$). Four nightjar nests were located within 20 meters of a ride, of these three were successful and the outcome of the fourth was not known.

7.5 Analysis of recreation effects on flushing rates of incubating nightjar

In 2126 hours of diurnal footage analysed from 22 nests, only seven flushing events were observed that were not directly explained by monitoring visits of the nest camera team (from known date/time of nest visits) (Wilshaw 2010). Of these seven, four were due to wildlife (three deer and one rat, of which one flush by a fallow deer resulted in nest predation). The cause was not visible and remained unknown for the remaining three flushing events.

Considering each nest as a replicate ($n = 22$), and excluding events due to nest or camera monitoring, mean flushing rate per hour (per nest) was not affected by the proximity of the nest to the closest forest ride (linear regression, $R^2 = 0.14$, $p = 0.09$); the non-significant trend was for greater flushing rates at nests located further away from rides and deeper into the tree crop (Wilshaw 2010).

The frequency of diurnal flushes of incubating nightjar recorded in Thetford Forest (this study) are compared to those detected for nightjar on Dorset heaths (1942 hours of footage from 8 nests: Langston et al., 2007a) below. For Thetford Forest, no instances of a dog flushing the incubating bird were detected, compared to two such observations from analysis of a similar duration of footage from nightjar nests in Dorset.

	Thetford Forest 2008 & 2009		Dorset Heaths 2003	
Cause of Flush	Number of flushes	Mean no. hr ⁻¹	Number of flushes	Mean no hr ⁻¹
Dogs	0	0.0000	2	0.0010
Unknown	3	0.0014	8	0.0041
Other Wildlife	4	0.0019	2	0.0010
Camera and or nest monitoring	5	0.0024	0	0.0000
Total flushes excluding monitoring	7	0.0033	12	0.0062

The ratio of explained (i.e. cause determined and visible on camera, and excluding monitoring visits as a cause) to unexplained events (cause of flushing event not visible) appears different between the two studies, being 4:3 in Thetford Forest and 4:8 in Dorset. Combining both explained (dogs and wildlife) and unexplained events, there was a higher overall frequency of flushing in Dorset (0.0062 events per hour compared to 0.0033 events per hour).

Specification of cameras differed among these two studies, as does the vegetation architecture surrounding nest sites. Thus although flushing could be detected in both studies, the certainty with which the cause would be recorded may differ depending on the field of view. However, a more likely explanation is a greater frequency in Dorset of a type of activity, or threat, that causes the incubating female to flush when the agent of disturbance is not immediately close to the nest, leading to greater frequency of unexplained flushing events.

7.6 Analysis of nightjar nest survival rates in relation to frequency of recreational events or dogs

For nightjar nests, 297 egg days, 430 chick days and overall a total of 522 nest days were monitored.

Models of egg stage success did not retain terms for year or first egg date that were non-significant and removed during model simplification. Thus the base model was an intercept only model. There was no support for any effect of dog events or total recreational events on nightjar nest success at egg stage (see **Table 21**). Similarly, chick stage success was not affected by lay date or year, and there was no evidence for a significant effect of either dog events or total recreational events.

The model of overall nest success, produced a similar result, with no evidence that either dog events or total recreational events affected nest outcome.

8 Analysis of survival rates of recently fledged woodlark juveniles and broods, in relation to visitor frequency

Of 54 broods with successful post fledging visits (i.e. with adults successfully located) conducted between 10-24 days after fledging: 40 were observed with one or more fledgling surviving and 14 (25.9%) apparently suffered entire brood loss; overall the mean proportion of fledglings surviving per brood was 0.55 ± 0.39 SD, and for surviving broods only ($n = 40$) the proportion of fledglings surviving was 0.74 ± 0.25 SD.

Available measures for the abundance of predators, recreational disturbance and distance to carpark and urban showed good variation; for all variables standard deviations were of similar magnitude to the mean (**Table 22**). This shows that broods were monitored across a range of locations that provide variation in potential disturbance, suitable to examine potential effects.

Models of the number of fledglings surviving suggested there was no overall difference between years and this term was removed (**Table 23**). The remaining terms were highly significant, with fewer fledglings surviving (or at least observed) as more time elapsed and more observed from initially larger broods. This base model was used to test the possible effects of adding individual terms for i) the abundance of different predator species and ii) measures of recreational activity. None of these terms were supported when tested. The only terms for which the model fit marginally improved (slight reduction in AICc) were terms for the numbers of fox scats, and for the number of dog events. A wald test was close to significant for the effect of dog events. However, the parameter for both fox and dog effects was positive – suggesting that had these effects been significant they would have enhanced survival. Thus these models provide no evidence to suggest a reduction in woodlark fledgling survival with increased levels of recreation.

An alternative set of models were constructed to examine the probability of brood survival as a binomial response (0 = apparent brood mortality, 1 = apparent brood survival) and incorporating the number of exposure days since fledging as the number of binomial trials (**Table 24**). Again this model did not suggest any difference in brood survival between years. Again, this base model was used to test the possible effects of adding individual terms for i) the abundance of different predator species and ii) measures of recreational activity. None of these terms were supported when tested. Thus these models provide no evidence to suggest a reduction in woodlark fledgling survival with increased levels of recreation.

Similarly, no evidence was found for any effect of proximity to car park or urban on post-fledgling survival in either set of models.

An important caveat, is the limited number of broods and even more limited number of locations for which broods were observed. With only 29 forest patches contributing, and some inevitable error and noise in the measures of visitor recreation and disturbance by dogs used to explore relationships, very subtle effects would not be detected. However, any strong negative effect of recreation on brood survival should be detected in these tests.

9 Synthesis: Likelihood of an impact of recreation on woodlark and nightjar breeding productivity

9.1 Assessment of potential impacts

1. This study has achieved a large sample size of nests, with 147 woodlark and 44 nightjar nests monitored by miniature digital infrared nest cameras over 2008 and 2009.

2. A robust sample of predation events were observed, 47 events for woodlark and 14 for nightjar. Of these the predator species was identified in all but 3 (6.4%) and 1 (7.1%) cases respectively.

3. The main nest predators of woodlark and nightjar have been identified.

4. For woodlark, the main predators were (in rank order): fox (20% of all observed events where the predator species was identified), kestrel (18%), adder (16%) and hedgehog (11%). Together these accounted for 65.9% of all predation. Additional predation of woodlark nests was observed by stoat (6.8% of identified events), and by jay, muntjac and rat (each contributing two events, or 4.5% of identified events), plus single instances of predation by carrion crow, pheasant, domestic cat, domestic dog, badger and unidentified small mammal [that may be woodmouse] (each 2.3% of identified events respectively). The average impact of adder may be greater than observed in this study, it is notable that only one adder predation event occurred in the unusually wet and cold spring of 2008, while 6 adder predation events were detected in 2009 (24% of all identified predation events in that year).

Thus woodlark are exposed to a very wide spectrum of predator species, including species that are statutorily protected (e.g. badger) or that are BAP species or other species of conservation concern (e.g. kestrel, adder, hedgehog) as well as species that are lethally controlled by some landowners (e.g. fox, stoat).

5. For woodlark, the single instance of predation by domestic cat occurred within 40m of the boundary of garden/outhouses associated with a house that adjoined restocked forestry patches containing two nesting territories: of two nests monitored on these territories one succumbed to the cat the other was predated by a jay.

6. For nightjar, all instances of predation where the predator was identified were due to mammalian predators, with badger (46%) and fox (31%) together contributing 77% and other single events due to fallow deer, weasel, and hedgehog (7.7% of identified events, each).

7. Video footage showed that one female nightjar successfully defended against a jay, and this nest was not predated, however carrion crow are a considerably larger and more threatening predator so this is threat display is unlikely to provide a defence against crow.

8. However, for nightjar no instances of predation by crow, or by any other diurnal avian predator, were observed in the 13 events for which the predator was identified.

9. Analysis of over 2000 hours of diurnal nest camera footage from 22 nightjar nests did not detect any instance of a female being flushed by a dog, compared to two such events detected with a similar duration of camera footage for eight nightjar nests on Dorset heathland. In Thetford Forest, overall flushing rate was low, approximately half that found in Dorset. Females incubating nests closer to rides did not flush more frequently than those incubating further from rides. Nightjar nesting in patches with a greater level of recreational activity did not nest further from rides.

10. Thus no support was found for the hypothesis that recreational disturbance exposes nightjar nests to predation by crows when females are flushed by dogs.

11. This study obtained counts of recreational visitors, dogs, other disturbance events, avian predators (kestrel, crow, jay) and measures of fox activity from scat transects, across a very large sample of forest locations (184 for avian predators and visitors, 182 for foxes, with overlap of both measures at 181 points). Surveys of recreational visitors and avian predators followed an intensive sampling schedule, with most points receiving a total of six hours of focal observation (one hour per visit on each of six different occasions through the breeding seasons of 2008 and 2009). A strong correlation between two independent measures of dog abundance (from dog scat density and modelled frequency of dogs from survey counts) provides evidence that the measures of dog distribution are robust. Measures of fox abundance at each of these survey locations were similarly intensive, with a mean of 1286 m² searched for fox scats per year per site, in each of the two years.

12. Statistical analysis of measures of recreational frequency and predator abundance provided no evidence for any relationship between visitor frequency at forest locations and the frequency of fox, carrion crow or kestrel at these locations. These analyses had considerable statistical power and therefore provide robust evidence that predator abundance / activity is not increased by recreational activity, at least at current levels of recreational activity.

13. A positive relationship was found between frequency of magpies at survey points and proximity to car parks, however magpie was not identified as a predator of woodlark and nightjar nests.

14. No relationship was found between abundance of foxes at locations within the forest, and the amount of urban landcover or human population in buffer distances of 500m, 1km, 1.5km, up to 2km from survey points.

15. Abundance of foxes could not be explained by extent of forest or farmland or by proximity to roads. It is likely that other factors, perhaps including the spatial distribution of keeping activity both within and adjacent to the Forest, are important in determining the level of the fox population.

16. No association was found between the abundance of crows at survey locations within the forest, and their proximity to main roads, urban settlement or car parks.

17. For nightjar, analyses of nest success, at egg stage, chick stage and overall nest success provided no evidence of reduced nest success in areas with a higher frequency of recreational activity. Although the limited number of nests available does restrict the power of this analysis, the results support the conclusion that there is no effect of recreation on nest success rates – of six P values (that measure the probability that the size of observed effects does not differ from that expected purely by chance) only one was < 50%. This conclusion is supported by apparent clusters of successful nests in some of the more popular parts of the forest, including parts of High Lodge and areas close to Brandon park (see **Map 5**)

18. For woodlark a large data set comprising 147 nests, 781 egg days and 1144 chick days allowed robust models of nest survival at egg and chick stages to be constructed. No effects of year or laying date were found. Testing various recreational variables (frequency of walkers, of dogs and of total recreational events) by introducing them into an intercept only model, provided no support for any effects of recreation on nest success rates at egg or chick stages. It is not just that no effects were found - these results provided strong evidence that no effect is present - of six tests of recreation or dog effects, all P values (i.e. the probability that the measured effect does not differ from chance) were >60%. Again, although anecdotal and non-quantitative this view is supported by apparent clusters of successful nests in popular parts of the forest including high Lodge, eastern parts of Elveden and Harling blocks

(see **Map 3**). Furthermore, woodlark nesting in territories located in patches with higher levels of recreational disturbance did not respond by placing their nests further from rides.

19. There was no evidence that greater frequency of recreational events (dogs, walkers, total events) reduced the productivity of successful woodlark nests, for example as may have been expected in recreational disturbance increased rates of partial predation, egg mortality through chilling or partial brood loss or reduction through chick starvation in otherwise successful nests. The per egg hatching rate in those nests that survived the incubation stage, and the per chick rate of fledging in those nests that fledged at least on chick, were not found to be related to levels of recreational event frequency. Again, evidence is strongly supportive of the conclusion that there is no effect, of six probability values, only one was < 30%, one between 30-60% and the remaining four were all >60%.

20. Analyses of the apparent survival of woodlark juveniles within 2-3 weeks of leaving the nest were undertaken. Although the statistical power of this test was not strong, it did consider information from 54 replicate broods across 29 different forest locations that showed a good variation in frequencies of recreational events. No evidence was found of any effect of the frequency of dog events, walkers, or total recreational events on immediate post-fledging survival. On the contrary, all measured effects were vanishingly small and highly non significant, or slightly indicative of a positive association with recreation.

21. The spatial distribution of depredation by different predator species suggested clustering of their impacts, for example of badgers in High Lodge and Elveden, of foxes and adders in Lynford and of stoats hedgehogs and small mammals around fragmented forest farmland boundaries (see **Map 4** and **Map 6**). Analysis of responses of productivity to spatial variation in recreational disturbance while controlling for the composition and local abundance of the predator fauna are beyond the scope of this study; as that would require a greater sample of nests as well as information on the distribution of other predators such as adders and hedgehogs in addition to the information on crow and fox distribution obtained in the current work. However, a compelling conclusion is that it is primarily the distribution of various predator species, rather than that of people, that is a key factor in nest risk while exposure to such a broad assemblage of potential predators allows predation to be ubiquitous across the landscape.

22. The majority of recreational survey points that we monitored, experienced a low level of recreational activity in 2008 and 2009 (i.e. the upper quartile was only 1.9 events per hour, thus 75% of surveyed points received less recreational activity than this; the upper 90%-tile was 3.8 events hr⁻¹ and the maximum 19 events hr⁻¹). The mean recreational rates (modelled total events, controlling for time of day and day of week) did not differ between the 184 surveyed points (i.e. a measure of the distribution of recreational rates across available forest habitat) and those measures associated with monitored nests of woodlark and nightjar (allowing duplicate entries for patches with multiple nests: $F_{2,374} = 1.377$, $p = 0.254$). Similarly a non-parametric Kruskal Wallis test showed the mean ranks of recreational rates did not differ between nightjar nests, woodlark nests, and available patches (chi-square = 1.228, 2df, $p = 0.541$). For woodlark, nests were found in patches at the higher limit of current recreational rate examined. For nightjar, the range of recreational activity in patches within which nightjar nests were found was below the full range of recreational activity observed in the forest (for nightjar nests: 90%-tile 3.1 events hr⁻¹, maximum 7.3 events hr⁻¹, equivalent to the 96%-tile of the available points). However as few nightjar nests were found (total $n = 46$) relative to the total number of patches monitored ($n = 184$) the range at nests is expected to be less than the range across available patches. A Mann-Whitney comparison of levels of recreational activity near nightjar nests and at all surveyed points is non-significant ($Z = 0.133$, $p = 0.895$). Therefore this does not provide evidence that nightjar are avoiding breeding in the busier patches.

23 Although no evidence was found that nightjar breed selectively in patches with lower levels of recreational activity, and although woodlark nests were found in the busiest patches, this study was not designed to examine effects of recreational activity on breeding distribution and abundance. It does not provide any evidence as to whether the density and abundance of nightjar and woodlark is lower in patches with greater levels of recreational activity, relative to numbers that would otherwise occur for the same area of suitable habitat if levels of recreational activity were less. It also does not provide evidence regarding potential effects of greater levels of future recreational activity, beyond those examined.

9.2 Conclusion and potential for mitigation

No indication has been found that current levels of recreational activity are having any detrimental impacts on the breeding success of those woodlark and nightjar that establish territories and attempt to breed.

However, it is important to recognise that if a considerable increase in levels of recreational activity were to occur, beyond those encountered during this study, that may result in detrimental effects on breeding productivity of nightjar and or woodlark. It is therefore necessary to repeat monitoring of recreational levels at intervals. Breeding productivity of woodlark and nightjar should be monitored, either on a continuous basis, or in response to evidence that levels of recreational activity have increased.

It is also important to improve the understanding of the potential impacts of recreational disturbance on the breeding distribution and settlement patterns of nightjar and woodlark in the SSSI and SPA. We were only able to study the breeding success of nightjar and woodlarks in those areas that they were attempting to breed. This study was not designed to examine whether woodlark or nightjar fail to occupy, or have lower abundance in, patches experiencing higher levels of recreational disturbance.

Assessment of potential impacts of recreation on the size of woodlark and nightjar populations requires understanding of whether current or future levels of recreation are causing or are likely to cause displacement of breeding territories. This requires analysis of the distribution of current and future modelled recreational rates across the forest, to determine what proportion of the area experiences (or may in the future experience) rates that are either considered likely to be detrimental (i.e. by extrapolation from work elsewhere) or have been shown to be safe or detrimental in the context of Thetford Forest (i.e. by analysis of woodlark and nightjar distribution in relation to levels of recreational activity in this SPA). If this shows potential for detrimental effects in parts of the Forest, then it is also important to examine what potential numbers of woodlark and nightjar these areas could otherwise be expected to support, as the occupancy of patches and mean density of these species is affected by factors such as soil type, stand management, crop age and patch location in relation to core forest or outlying blocks (Evans 2002; Wright 2006).

If no effect on either territory displacement or breeding productivity is detected or likely, then mitigation is not required.

If mitigation were required in the future, for example to compensate locally high levels of recreational activity, then mitigating measures could involve the creation of suitable habitat in areas that are more remote from access. There is a very strong probability that such areas would be settled and occupied, as the habitat requirements and type of interventions that provide suitable habitat for both species are well understood. Alternatively, the closure of some gateway access points, for example by embankment of car pull-overs and manipulation of ride cutting programmes, would be a useful approach in managing and guiding recreation away from existing or created areas of suitable breeding habitat.

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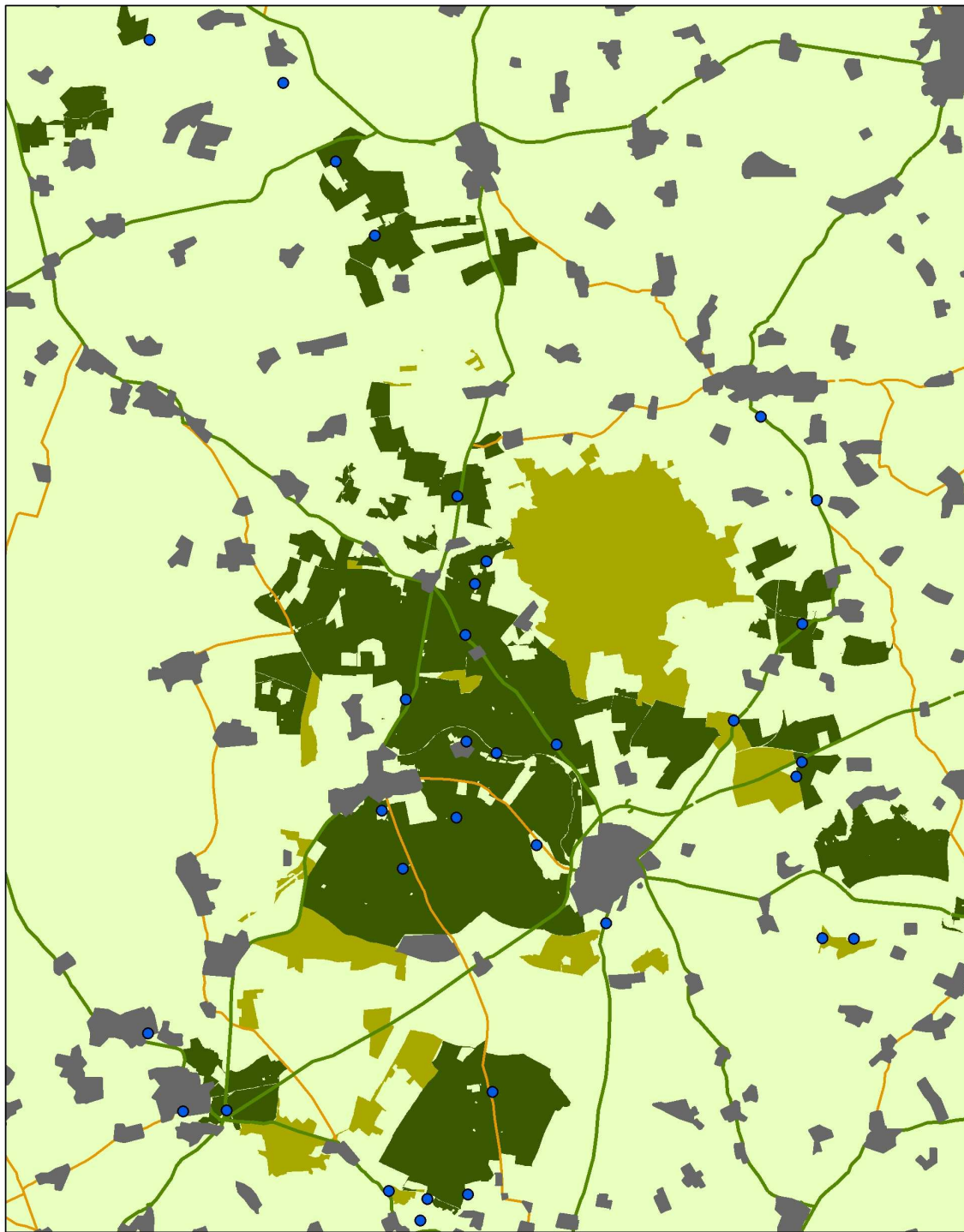
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MAPS

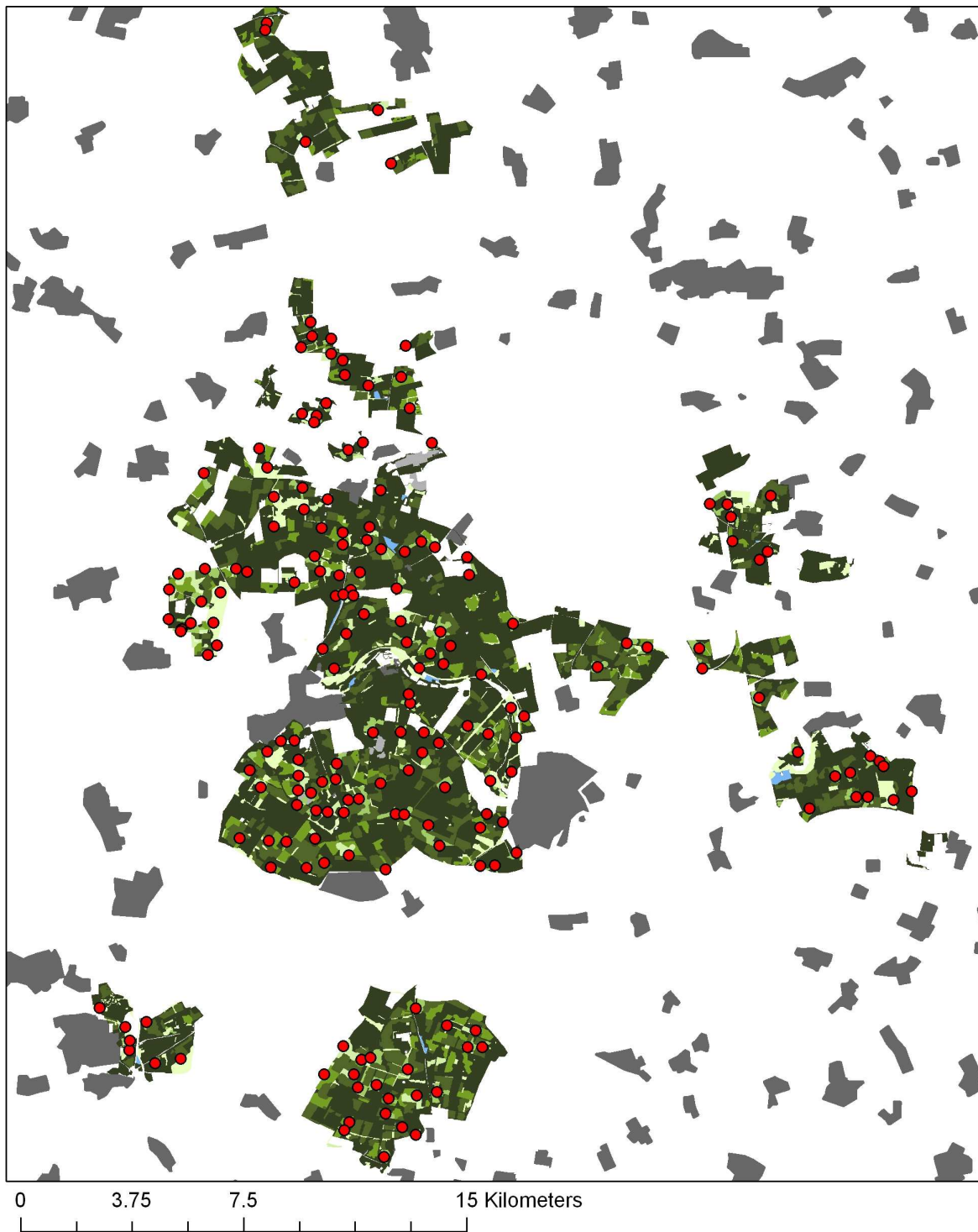


0 3.75 7.5 15 Kilometers

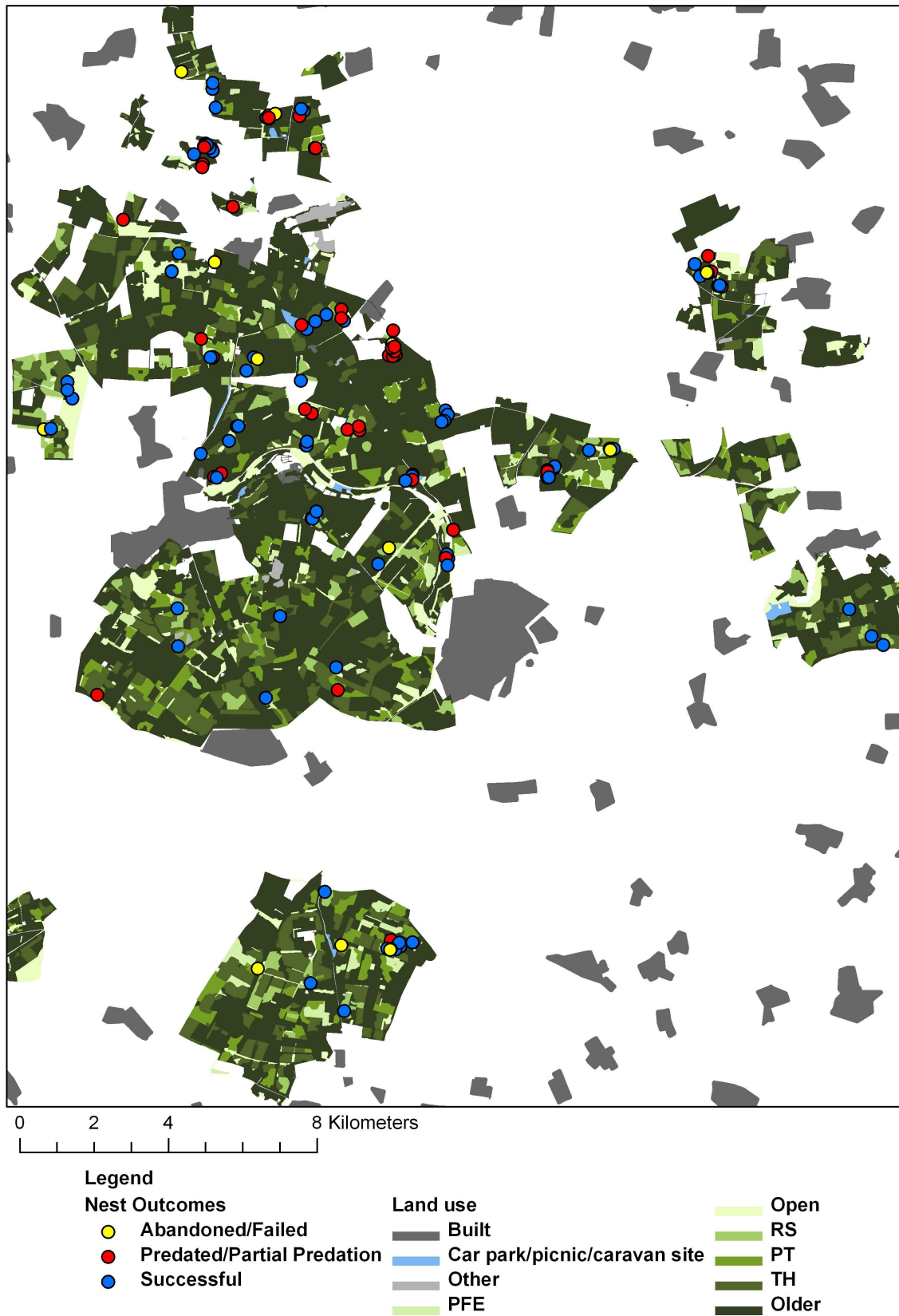
Legend

- Car Parks
- Urban Areas
- A roads
- B roads
- Heathland
- Forest

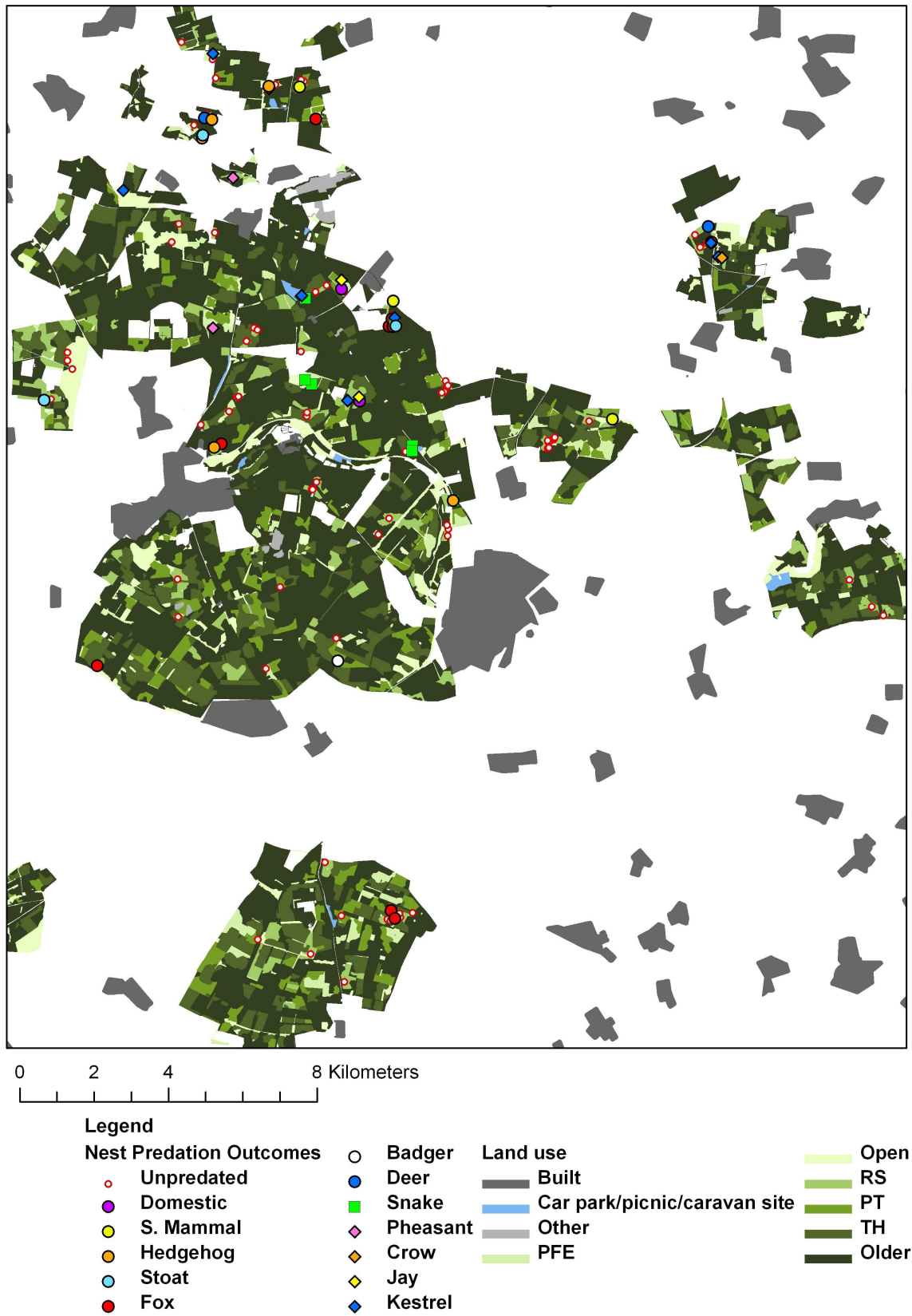
Map 1: Thetford Forest, also showing nearby urban areas, main roads and car parks.



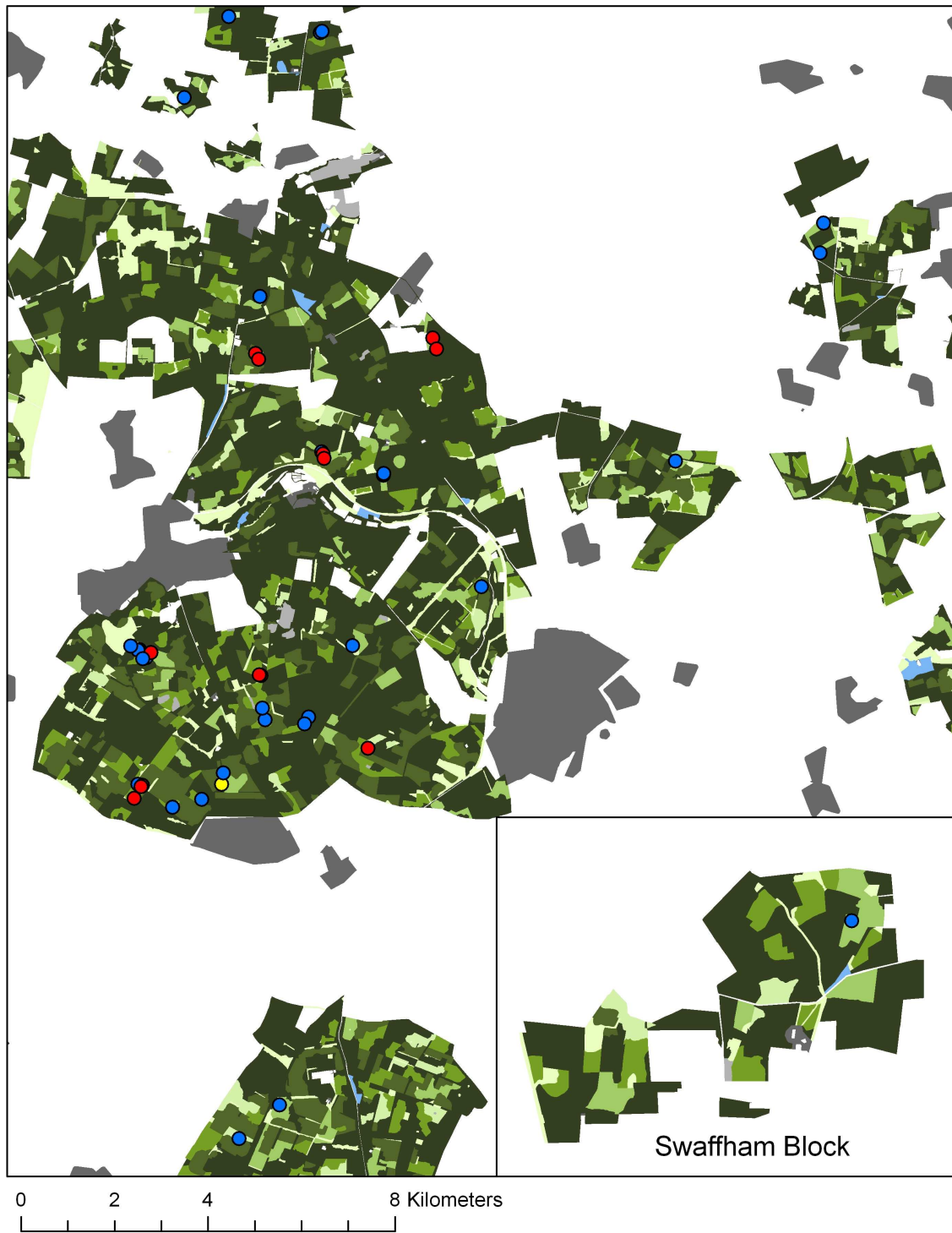
Map 2: Thetford Forest, showing distribution of visitor and predator survey points.



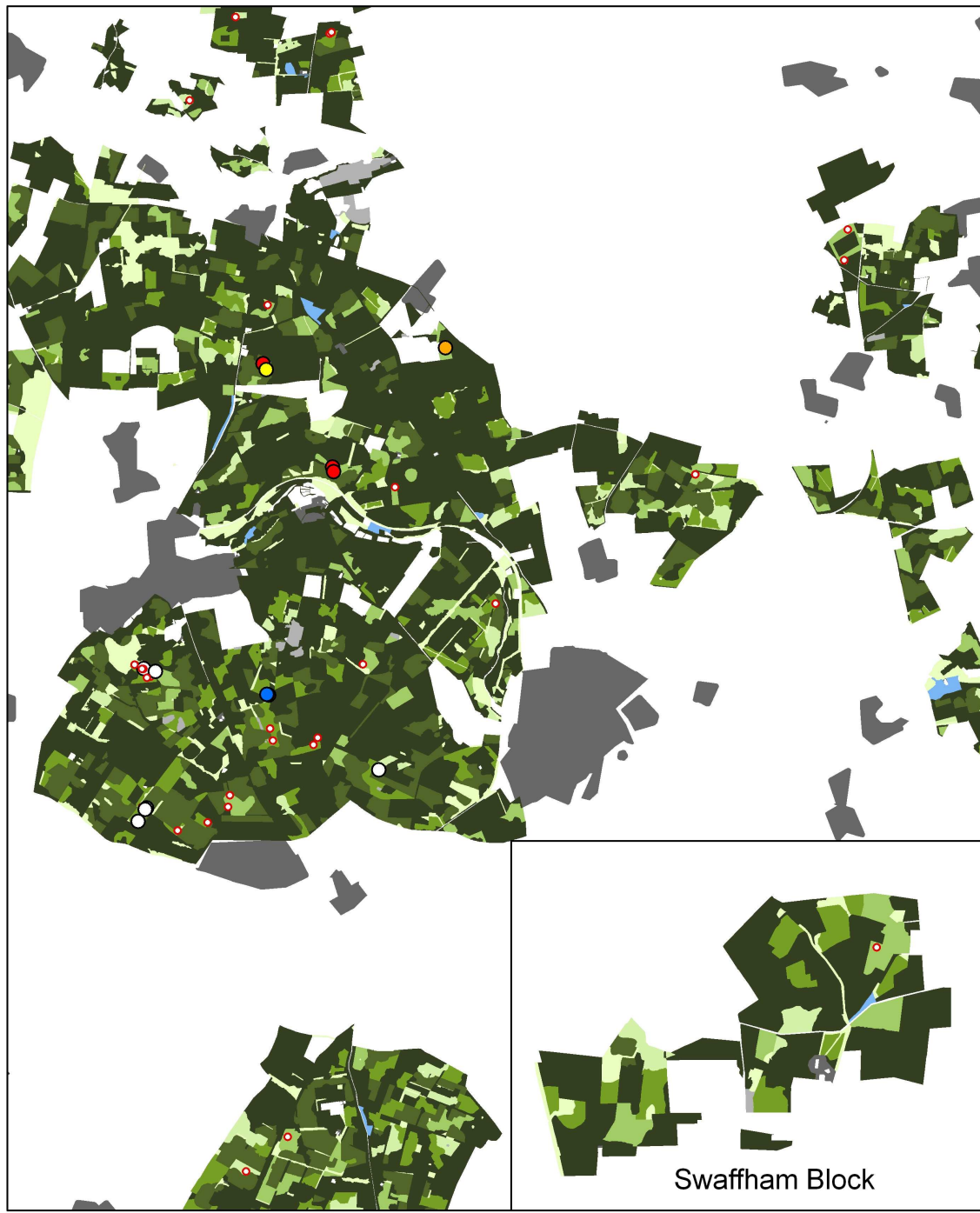
Map 3: Locations of woodlark nests monitored by nest cameras in 2008-09, showing outcome.



Map 4: Locations of woodlark nests depredated by different predators (either fully or partially predated) and those escaping predation, in 2008-09.



Map 5: Locations of nightjar nests monitored by nest cameras in 2008-09, showing outcomes. Note that Swaffham block is inset to a different scale.



Map 6: Locations of nightjar nests depredated by different predators in 2008-09: small mammal relates to weasel.

TABLES

Tables

Table 1 Distribution of survey points among outlying and core forest blocks of Thetford Forest SPA.

	<i>N</i>
Outlying small blocks in farmland context	
Swaffham	5
Didlington	17
Hockham	7
Croxton	3
Roudham	5
Harling	9
Mildenhall	7
Core forest blocks	
Mundford	29
Lynford	29
High Lodge	31
Elveden	21
Kings Forest	22
TOTAL	185

Table 2 Number of visitor / predator surveys conducted in each one-hour period (start time) during a) 2008, b) 2009.

a) 2008

Survey visit	Hour of observation (Start)													
	6 ¹	7	8	9	10	11	12	13	14	15	16	17	18	19
1	18	19	20	22	25	18	17	13	10	9	5	1	0	0
2	15	21	18	32	28	21	14	5	5	5	3	2	3	1
3	17	19	22	34	29	20	17	10	8	2	0	2	1	0
Totals	50	59	60	88	82	59	48	28	23	16	8	5	4	1

b) 2009

Survey visit	Hour of observation (Start)													
	6 ²	7	8	9	10	11	12	13	14	15	16	17	18	19
1	24	20	15	11	11	13	17	4	32	19	6	4	0	0
2	26	24	11	17	12	10	17	6	23	20	6	3	3	0
3	15	24	21	22	16	8	7	6	27	19	10	3	1	0
Totals	65	68	47	50	39	31	41	16	82	58	22	10	4	0

^{1,2} Indicate three and two counts respectively, that commenced <0600 hours.

Tables

Table 3 Landscape variables extracted in GIS

HUM_500m	number of humans in 500m buffer. Calculation with basis in the number of habitants per postcode
HUM_1000m	number of humans in 1000m buffer. Calculation with basis in the number of habitants per postcode
HUM_1500m	number of humans in 1500m buffer. Calculation with basis in the number of habitants per postcode
HUM_2000m	number of humans in 2000m buffer. Calculation with basis in the number of habitants per postcode
CarPark	distance in meters to the nearest car park
Farmland	distance in meters to nearest farmland edge
Roads	distance in meters to the nearest major road (A or B). Roads from OS Meridian 2
Urban	distance in meters to nearest urban area. Urban areas from OS Meridian 2
Urban500m	urban area in square kilometers intersected by a buffer of 500m
Urban1000m	urban area in square kilometers intersected by a buffer of 1000m
Urban1500m	urban area in square kilometers intersected by a buffer of 1500m
Urban2000m	urban area in square kilometers intersected by a buffer of 2000m
FL500_sMt	Farmland area in square meters intersected by a buffer of 500m
Ur500_sMt	Urban area in square meters intersected by a buffer of 500m
Fo500_sMt	Forest area in square meters intersected by a buffer of 500m
Ot500_sMt	Other type of land (e.g. roads, golf course) in square meters intersected by a buffer of 500m
FL500_per	Percentage of farmland area in a buffer of 500m
Ur500_per	Percentage of urban area in a buffer of 500m
Fo500_per	Percentage of forest area in a buffer of 500m
Ot500_per	Percentage of other type of land in a buffer of 500m
FL1000_sMt	Farmland area in square meters intersected by a buffer of 1000m
Ur1000_sMt	Urban area in square meters intersected by a buffer of 1000m
Fo1000_sMt	Forest area in square meters intersected by a buffer of 1000m
Ot1000_sMt	Other type of land (e.g. roads, golf course) in square meters intersected by a buffer of 1000m
FL1000_per	Percentage of farmland area in a buffer of 1000m
Ur1000_per	Percentage of urban area in a buffer of 1000m
Fo1000_per	Percentage of forest area in a buffer of 1000m
Ot1000_per	Percentage of other type of land in a buffer of 1000m
FL1500_sMt	Farmland area in square meters intersected by a buffer of 1500m
Ur1500_sMt	Urban area in square meters intersected by a buffer of 1500m
Fo1500_sMt	Forest area in square meters intersected by a buffer of 1500m
Ot1500_sMt	Other type of land (e.g. roads, golf course) in square meters intersected by a buffer of 1500m
FL1500_per	Percentage of farmland area in a buffer of 1500m
Ur1500_per	Percentage of urban area in a buffer of 1500m
Fo1500_per	Percentage of forest area in a buffer of 1500m
Ot1500_per	Percentage of other type of land in a buffer of 1500m
FL2000_sMt	Farmland area in square meters intersected by a buffer of 2000m
Ur2000_sMt	Urban area in square meters intersected by a buffer of 2000m
Fo2000_sMt	Forest area in square meters intersected by a buffer of 2000m
Ot2000_sMt	Other type of land (e.g. roads, golf course) in square meters intersected by a buffer of 2000m
FL2000_per	Percentage of farmland area in a buffer of 2000m
Ur2000_per	Percentage of urban area in a buffer of 2000m
Fo2000_per	Percentage of forest area in a buffer of 2000m
Ot2000_per	Percentage of other type of land in a buffer of 2000m

Tables

Table 4 Summary of Woodlark nest outcomes in 2008 and 2009

Outcome type	Number of nests		Percentage of nests	
	2008	2009	2008	2009
Successfully fledged \geq 1 young	42*	50*	64%*	62%*
Deserted	3	3	5%	4%
Chicks starved	5	4	8%	5%
Predated or part predated	20	27	30%	33%
Nest trampled	0	1	0%	1%
Total nests	66	81		

* Includes partially predated nests (i.e. where at least one chick fledged from the nest)

Table 5 Summary of Nightjar nest outcomes 2008 and 2009

Outcome type	2008		2009	
	Number of nests	Percentage of nests	Number of nests	Percentage of nests
Successfully fledged young	12	67%	15	58%
Predated	6	33%	8	30%
Abandoned ¹			1	4%
Outcome unknown			2	8%
Totals	18		26	

¹ one abandoned nest with infertile clutch – did not hatch and subsequently scavenged by Jay

Tables

Table 6 Summary of Woodlark nests predation events (including partially predated nests, indicated by *), in 2008 and 2009.

Predation agent	Nests at egg stage		Nests at chick stage	
	2008	2009	2008	2009
Adder		1	1*	5 ^{3*}
Badger			1	
Fox		1	3 ^{1,2*}	5
Hedgehog	1	2	1	1
Stoat	1		2	
Muntjac			1*	1
Rat	1		1	
Other small mammal			1	
Domestic Dog				1
Domestic Cat		1		
<i>Total Mammals</i>	<i>3</i>	<i>4</i>	<i>10</i>	<i>8</i>
Carrion Crow			1	
Jay			1	1
Kestrel			2	6
Pheasant	1			
<i>Total Birds</i>	<i>1</i>	<i>0</i>	<i>4</i>	<i>7</i>
Unknown	0	0	1	2
Total events	4	5	16	22

Notes:

¹ Carrion Crow near to nest 11am on 05/04, but adult woodlark at nest 7pm on 06/04 so Crow believed to have not predated nest; Fox then at nest later that night, taken as predation.

² Fox at nest when chicks 14 d.o. (ready to fledge) taken to be partial predation only, i.e. fledged at least one chick.

³ Adder at nest chicks of fledging age and seen to scatter (flew), but assumed to be partial predation, i.e. fledged at least one chick.

Table 7 Summary of Nightjar nest predation events in 2008 and 2009

	Egg stage		Chick stage	
	2008	2009	2008	2009
Badger	1	2*	1	2
Hedgehog		1		
Fox		2	2	
Weasel				1
Fallow Deer <i>Dama dama</i>	1			
Unknown			1	
Totals	2	5*	4	3

* 1 nest predated at hatching (one egg and one chick)

Tables

Table 8 Summary of Scat clearance transects, showing percentage of transects with scats for each species, on first and second visits in 2008 and 2009.

Species	Visit 1		Visit 2	
	2008	2009	2008	2009
Dog	31%	67%	34%	48%
Fox	45%	58%	39%	52%
Stoat	2%	7%	1%	1%
Hedgehog	13%	18%	6%	0%
Badger	2%	35%	1%	7%
n	178	171	178	175

Table 9 Structure of models used to estimate mean numbers of fox scats counted on transects radiating out from survey points.

Predator variable (dependent)	Mean ± SD	Range (min – max)	model (error, link)	AICc	ΔAICc	Dev / DF	parameter	Wald Chi-square	df	p
fox scats (count)	1.27 ± 2.15	0 - 15	Negative binomial, log	2281.18		0.924				
							Point	196.977	162	0.032
							Year (2008)	24.594	1	<0.001
							Visit	4.268	1	0.039
fox scats per km of transect	2.06 ± 3.70	0 - 40.92	Normal, identity	7458.19		10.943				
							Point	3658.021	181	<0.001
							Year	280.016	1	<0.001
							visit	20.592	1	<0.001
SQRT(fox scats per km of transect) Model 1	0.914 ± 1.109	0 - 6.40	Normal, identity	2316.82	+0.18	1.017				
							Point	305.331	181	<0.001
							Year	27.447	1	<0.001
							visit	3.967	1	0.046
SQRT(fox scats per km of transect) Model 2	0.914 ± 1.109	0 - 6.40	Normal, identity	2316.64	0.000	1.017				
							Point	304.804	181	<0.001
							Year	26.329	1	<0.001
							Datnumeric	4.141	1	0.042
SQRT (dog scats per km)	1.179, 1.823	0- 11.35	Normal, identity	2618.495	+5.244	1.589				
							Point	1385.214	182	<0.001
							Year	122.842	1	<0.001
							datnumeric	6.407	1	0.011
SQRT (dog scats per km)				2613.251	0.000	1.579				
							Point	1385.557	182	<0.001
							Year	126.089	1	<0.001
							visit	11.652	1	0.001

Tables

Table 10 Structure and parameters retained in minimal generalised linear models used to estimate mean numbers of avian predators observed at each of 185 survey points, over a total of 1064 visits over 2008 and 2009.

Predator variable (dependent)	Mean \pm SD	Range (min – max)	model (error, link)	AICc		Dev / DF	parameter	Wald Chi-square	df	p
SQRT(CrowT)	0.935, 1.230	0 - 10.54	Normal, identity	3576.499		1.332			875	
							Survey point	346.398	183	<0.000001
							Year(2008)	59.327	1	<0.000001
							Datnumeric	7.203	1	0.007000
							datesquared	6.544	1	0.011000
							Morning(10)	29.807	1	<0.000001
SQRT(JayM) Model 1	0.464, 0.756	0 - 4.0	Normal, identity	2844.130	+0.187	0.498			876	
							Survey point	150.412	183	0.963
							datesquared	3.540	1	0.060
							Datnumeric	2.758	1	0.097
							Morning(10)	8.211	1	0.004
SQRT(JayM) Model 2			Normal, identity	2843.943	0.000	0.500			877	
							Survey point	152.630	183	0.950
							datesquared	3.373	1	0.066
							Morning(10)	8.219	1	0.004
SQRT(Magpie)	0.250, 0.724	0 - 6.63	Normal, identity	2750.395		0.397			880	
							Intercept	68.808	1	<0.001
							Survey point	207.355	183	0.105
SQRT(Kestrel)	0.338, 0.648	0 - 3.46	Normal, identity	2650.610		0.372			880	
							Intercept	123.463	1	<0.001
							Survey point	118.564	183	1.000

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Table 11 Mean, standard error (SE) and maximum numbers of disturbance events (raw counts, untransformed) observed per hour, are shown for different time periods. In all cases the minimum number is zero. Recreational events are classed as dog events (unaccompanied, or accompanied by walkers, cyclist or vehicle), walker events (whether or not accompanied by a dog) and other events (cyclists, horse riders and vehicles). Sample size (N) is the total number of on hour survey watches conducted in each period. Hour group is a classification of periods based on the observed patterns of mean activity through the day.

Hour (start)	Hour group	N	Dog Events			Walker Events			Other Events		
			Mean	SE	Max	Mean	SE	Max	Mean	SE	Max
5	-	5	0.00	0.000	0	0.00	0.000	0	0.00	0.000	0
6	6+7	110	0.86	0.187	14	0.96	0.214	14	0.32	0.125	10
7	6+7	128	0.84	0.198	19	1.02	0.229	22	0.29	0.097	9
8	8+9	106	1.15	0.243	14	1.25	0.259	15	0.59	0.409	43
9	8+9	139	1.19	0.200	14	1.45	0.229	14	0.68	0.192	22
10	10	119	0.82	0.177	12	0.95	0.177	12	1.27	0.579	64
11	11-12	91	0.38	0.122	7	0.77	0.162	8	0.65	0.159	7
12	11-12	89	0.53	0.138	8	0.79	0.174	8	0.85	0.353	28
13	13-14	46	0.63	0.185	4	0.98	0.221	4	0.43	0.277	10
14	13-14	104	0.69	0.184	12	0.91	0.223	14	0.49	0.129	10
15	15+16	74	0.95	0.243	9	1.19	0.305	12	0.82	0.237	9
16	15+16	30	0.80	0.422	12	1.23	0.495	14	3.13	1.700	46
17	17	14	0.29	0.194	2	0.57	0.251	2	0.57	0.327	4
18	18	8	0.00	0.000	0	0.00	0.000	0	0.50	0.327	2
19	-	1	0.00	.	0	0.00	.	0	0.00	.	0
Total		1064	0.82	0.061	19	1.03	0.070	22	0.71	0.104	64

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Table 12 Structure and parameters retained in minimal generalised linear models used to estimate mean frequency of recreation events across 185 survey points, recorded during a total of 1064 one hour visits over 2008 and 2009.

Recreational disturbance variable (dependent)	Mean \pm SD	Range (min – max)	model structure	AICc	Δ AICc	Dev / DF	parameter	Wald Chi-square	df	p
SQRT(Dog events)	0.416 \pm 0.806	0-4.36	Normal, identity	2720.544		0.385			862	
							Survey point	336.562	183	<0.0000001
							DOW2	4.577	1	0.032
							Hour4Bcode	10.300	3	0.016
SQRT(Walk events)	0.516 \pm 0.883	0 – 4.69	Normal, identity	2784.148		0.462			863	
							Survey point	406.168	183	<0.0000001
							DOW2	7.207	1	0.007
							hour3Bcode	6.463	2	0.039
SQRT(Other events) Model 1	0.293 \pm 0.793	0 – 8.00	Normal, identity	2785.505	+0.639	0.461			862	
							Survey point	243.646	183	0.002
							DOW2	8.482	1	0.004
							hour4code	7.571	3	0.056
SQRT(Other events) Model 2			Normal, identity	2784.866	0.000	0.457			861	
							Survey point	242.921	183	0.002
							DOW2	8.401	1	0.004
							hour4code	7.771	3	0.051
							Year	3.614	1	0.057
SQRT(All events)	0.757, 1.094	0 – 8.00	Normal, identity	3054.251		0.773			862	
							Survey point	557.722	183	<0.00000001
							DOW2	17.503	1	0.000029
							Hour3Bcode	6.586	2	0.037
							Year	7.372	1	0.0066

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Table 13. Pearson correlations among the density of dog and fox scats and the frequency of dog events, at survey locations across Thetford Forest.

Slight differences in sample size varies result from a small number of locations suitable for visitor and avian predator counts not having rides suitable for scat transect surveys. Fox and dog scat densities are calculated per km of transect, using square root transformed data and is modelled across replicate visits, controlling for effects of year and visit (see **Table 9**).

		DogscatSqrtGLM	foxSqrtGLMMMMI
DogESqrtGLM	<i>r, P</i>	0.574, <0.0000000001	0.089, 0.232
	<i>N</i>	181	181
DogscatSqrtGLM	<i>r, P</i>		0.230, 0.00182
	<i>N</i>		182

Table 14. Correlations between the frequency of sightings of magpies and carrion crows at survey points and the density of fox scats on transects within Thetford Forest and the proximity of locations to a) car parks, b) urban areas.

		Distance to nearest CarPark (m)	Distance to nearest Urban (m)
Magpie_SQT_Anova	<i>r, P</i>	0.208, 0.004521	-0.078, 0.291
	<i>N</i>	184	184
CrowTSqrtGLM	<i>r, P</i>	-0.002, 0.974	-0.061, 0.413
	<i>N</i>	184	184
foxSqrtGLMMMMI	<i>r, P</i>	0.031, 0.675	0.127, 0.089
	<i>N</i>	181	181

Table 15. Correlations between the frequency of sightings of carrion crows at survey points and the proximity to main roads (A+B roads), forest-farmland edge, and the percentage of farmland within buffers of 500m and 1km around survey points.

		CrowTSqrtGLM
Distance to nearest main road (m)	<i>r, P</i>	-0.114, 0.124
	<i>N</i>	184
(Roads)		
Distance to nearest farmland edge (Farmland)	<i>r, P</i>	0.069, 0.355
	<i>N</i>	184
% farmland within buffer of 500 m (FL500_per)	<i>r, P</i>	-0.170, 0.0213
	<i>N</i>	184
% farmland within buffer of 1km (FL1000_persMt)	<i>r, P</i>	-0.201, 0.00622
	<i>N</i>	184

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Table 16. Correlations between the frequency of sightings of carrion crows at survey points, the density of fox scats on transects and frequency of kestrels (sightings), and the frequency of different classes of recreational events: walkers, dogs, 'other events' (that include cyclists, horse riders, moped and motorised vehicles) and all events occurring within the hour.

		CrowTSqrtGLM	foxSqrtGLMMMI	Kest_SQT_Anova
WalkESqrtGLM	<i>r, P</i>	0.064, 0.388	0.041, 0.587	0.117, 0.113
	<i>N</i>	184	181	184
DogESqrtGLM	<i>r, P</i>	0.075, 0.309	0.089, 0.232	0.124, 0.094
	<i>N</i>	184	181	184
OtherESqrGLMMMI	<i>r, P</i>	0.064, 0.389	0.062, 0.406	-0.015, 0.843
	<i>N</i>	184	181	184
TotalESqrtGLM	<i>r, P</i>	0.061, 0.413	0.059, 0.433	0.068, 0.361
	<i>N</i>	184	181	184

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Table 17 Correlations between measures of human population number (from postcode data) and urban extent (from OS Meridian data) within buffers of 500m, 1km, 1.5km and 2km around survey points located across Thetford Forest. Pearson correlations coefficients only are shown, all significances are $p < 0.000000001$, $n = 184$ for all correlations.

	HUM_500m	HUM_1000m	HUM_1500m	HUM_2000m	Ur500_per	Ur1000_per	Ur1500_per	Ur2000_per
HUM_500m	0.712							
HUM_1000m	0.689	0.942						
HUM_1500m	0.621	0.835	0.936					
HUM_2000m	0.642	0.831	0.821	0.741				
Ur500_per	0.584	0.871	0.869	0.765	0.869			
Ur1000_per	0.590	0.827	0.890	0.858	0.777	0.937		
Ur1500_per	0.585	0.766	0.863	0.917	0.719	0.824	0.945	
Ur2000_per								

Table 18 Models of fox abundance related to effects of human population density or urban extent in buffers of 500m, 1km, 1.5km and 2km around survey points.

Model	AICc	ΔAICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
normal error and identity link								
Base model 1	431.034	0.000	0.527				179	
				Intercept		22.518	1	<0.001
				Distance to main road		0.367	1	0.545
+ test effects: 500m buffer	433.041	2.007	0.529	+Ur500_per		0.061	1	0.805
	433.060	2.026	0.530	+HUM_500m		0.042	1	0.837
+ test effects: 1km buffer	433.070	2.036	0.530	+Ur1000_per		0.032	1	0.858
	433.100	2.066	0.530	+HUM_1000m		0.002	1	0.960
+ test effects: 1.5km buffer	433.042	2.008	0.529	+Ur1500_per		0.060	1	0.807
	433.079	2.045	0.530	+HUM_1500m		0.023	1	0.879
+ test effects: 2km buffer	432.975	1.941	0.529	+Ur2000_per		0.127	1	.722
	433.097	2.063	0.530	+HUM_2000m		0.005	1	.942
Base model 2	429.356	0.000	0.526				180	
				Intercept		86.209	1	<0.001
+ test effects: 500m buffer	431.392	2.036	0.529	+Ur500_per		0.009	1	0.927
	431.301	1.945	0.528	+HUM_500m		0.100	1	0.752
+ test effects: 1km buffer	431.287	1.931	0.528	+Ur1000_per		0.114	1	0.736
	431.359	2.003	0.529	+HUM_1000m		0.041	1	0.839
+ test effects: 1.5km buffer	431.226	1.87	0.528	+Ur1500_per		0.175	1	0.676
	431.400	2.044	0.529	+HUM_1500m		0.001	1	0.978
+ test effects: 2km buffer	431.122	1.766	0.527	+Ur2000_per		0.279	1	0.598
	431.384	2.028	0.529	+HUM_2000m		0.016	1	0.898

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Table 19 Tests of whether the frequency of recreational events affects woodlark nest success.

Models have binomial error, with the number of egg or chick days monitored per nest specified as the number of binomial trials.

Model	AICc	ΔAICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
Egg stage success: intercept only	246.875	0.000	0.951				105	
				Intercept	-2.026, 0.115	329.949	1	<0.00001
+ dogs events	248.679	+1.804	0.958				104	
				Intercept	-2.001, 0.123	264.630	1	<0.00001
				DogE_SQRT_GLM	0.091, 0.200	0.209	1	0.648
+ total events	248.671	+1.796	0.958				104	
				Intercept	-2.087, 0.174	144.624	1	<0.00001
				TotalE_SQRT_GLM	0.056, 0.119	.219	1	0.639
+ walker events	248.694	1.819	0.958					
				Intercept	-2.005, 0.120	277.354	1	<0.00001
				WalkE_Sqrt_GLM	0.083, 0.188	0.194	1	0.660
Chick stage success: Base model	233.754	0.000	0.479				125	
				Intercept	-2.425, 0.108	502.396	1	<0.00001
+ dogs events	235.610	1.856	0.482				124	
				Intercept	-2.443, 0.1183	426.331	1	<0.00001
				DogE_SQRT_GLM	-0.075, 0.194	0.150	1	0.698
+ total events	235.724	+1.970	0.483				124	
				Intercept	-2.451, 0.173	201.402	1	<0.00001
				TotalE_SQRT_GLM	0.022, 0.112	0.038	1	0.846
+ walker events	235.527	1.773	0.481					
				Intercept	-2.445, 0.117	439.738	1	<0.00001
				WalkE_Sqrt_GLM	-0.089, 0.185	0.232	1	0.630

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Table 20 Models testing whether the frequency of recreation events affects 1) woodlark hatching success¹ and 2) woodlark fledging success^{2, 3}.

Model	AICc	ΔAICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
Response variable :								
numbers of eggs hatching ¹ : considering only nests successful at the egg stage for which number of egg days>0								
Base model	260.904	0.000	0.208				78	
				number laid	0.313, 0.015	436.053	1	<0.000001
+ walker events	262.872	+1.968	0.208				77	
				number laid	0.315, 0.016	370.510	1	<0.000001
				WalKE_Sqrt_GLM	0.039, 0.105	0.139	1	0.709
+ dogs events	262.843	+1.939	0.208				77	
				number laid	0.316, 0.017	359.322	1	<0.000001
				DogE_SQRT_GLM	0.045, 0.111	0.167	1	0.683
+ total events	262.802	+1.898	0.178				77	
				number laid	0.305, 0.022	185.609	1	<0.000001
				TotalE_SQRT_GLM	0.0280.060	0.211	1	0.646
Response variable:								
numbers of chicks fledging ² : considering only nests successful at the chicks stage (fledging one or more chicks) for which Nu chick days >0 and numbers hatching are known								
Base model	287.279	0.000	1.795				76	
				intercept	-0.307, 0.359	0.732	1	0.392
				number hatching	0.312, 0.093	11.220	1	0.001
				year(2008)	-0.472, 0.172	7.521	1	0.006
+ walker events	288.064	+0.785	1.800				75	
				intercept	-0.344, 0.359	0.921	1	0.337
				number hatching	0.308, 0.093	11.048	1	0.001
				year(2008)	-0.464, 0.172	7.244	1	0.007
				+ WalKE_Sqrt_GLM	-0.179, 0.151	1.397	1	0.237
+ dog events	288.514	+1.235	1.806				75	
				intercept	-0.344,0.360	0.911	1	0.340
				number hatching	0.309, 0.093	11.135	1	0.001
				year(2008)	-0.467, 0.172	7.358	1	0.007
				DogE_SQRT_GLM	-0.156, 0.159	0.965	1	0.326
+ total events	289.364	+2.085	1.817				75	
				intercept	-0.336, 0.367	0.840	1	0.359
				number hatching	0.311, 0.093	11.093	1	0.001
				year(2008)	-0.469, 0.172	7.408	1	0.006
				TotalE_SQRT_GLM	0.029, 0.079	0.138	1	0.710

- 1 numbers of eggs hatching, relative to numbers laid [Models have Poisson error, loglinear link. Substituting negative binomial error for the model of fledging success improved the scale parameter to close to unity, but increased AICc by ΔAICc = + 4-5 units]
- 2 numbers of chicks fledging relative to numbers hatching; modelled with binomial error and (egg / chick / nest days) as the number of binomial trials for each nest
- 3 Models pass through the origin and therefore do not include an intercept term unless they include a categorical variable with more than one level, in which including an intercept improves interpretation of levels (e.g. year effect).

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Table 21: Models testing whether the frequency of dog events, walker events and total recreational events affects nightjar nest success ¹.

Model	AICc	ΔAICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
Egg stage: Base model	74.417	0.000	1.028				31	
				intercept	-2.431, 0.2129	130.418	1	<0.00001
+ dogs events	76.302	+1.885	1.058				30	
				intercept	-2.353, 0.2922	64.820	1	<0.00001
				DogE_SQRT_GLM	0.188, 0.4973	0.144	1	0.705
+ walker events	76.092	+1.675	1.051				30	
				intercept	-2.342, 0.254	85.368	1	<0.00001
				WalkE_Sqrt_GLM	0.256, 0.427	0.360	1	0.549
+ total events	75.435	+1.018	1.029				30	
				intercept	-2.750, 0.392	49.201	1	<0.00001
				TotalE_SQRT_GLM	0.307, 0.299	1.050	1	0.306
Chick stage: Base model	65.681	0.000	0.415				30	
				Intercept	-2.650, 0.199	177.035	1	<0.00001
+ dogs events	67.698	+2.017	0.430				29	
				Intercept	-2.660, 0.2844	87.454	1	<0.00001
				DogE_SQRT_GLM	-0.025, 0.504	0.002	1	0.961
+ walker events	67.699	+2.018	0.430				29	
				intercept	-2.654, 0.248	114.749	1	<0.00001
				WalkE_Sqrt_GLM	-0.014, 0.433	0.001	1	0.975
+ total events	67.678	+1.997	0.429				29	
				Intercept	-2.700, 0.387	48.593	1	<0.00001
				TotalE_SQRT_GLM	0.050, 0.328	0.023	1	0.879
Overall nest: Base model	45.268	0.000	0.351				23	
				intercept	-3.332, 0.2399	192.973	1	<0.00001
+ dogs events	47.035	+1.767	0.356				22	
				intercept	-3.220, 0.3196	101.492	1	<0.00001
				DogE_SQRT_GLM	0.292, 0.5830	0.252	1	0.616
+ walker events	46.967	+1.699	0.353				22	
				intercept	-3.248, 0.275	139.722	1	<0.00001
				WalkE_Sqrt_GLM	0.277, 0.486	0.323	1	0.570
+ total events	47.057	+1.789	0.357				22	
				Intercept	-3.525, 0.478	54.461	1	<0.00001
				TotalE_SQRT_GLM	0.170, 0.353	.231	1	0.631

¹ Models have binomial error, with the number of egg, chick or overall nest days for each nest specified as the number of binomial trials

Tables

Table: 22. Minimum, Maximim, Mean and Standard Deviation (SD) of measures of predators, recreational disturbance and proximity to urban and carpark, for the set of 54 fledged broods monitored for survival.

	Minimum	Maximum	Mean	SD
Fox_Sqrt_GLM_MMI	-0.2506	0.9198	0.2485	0.3379
DogScatSqrtGLM	-0.8499	0.8119	-0.2502	0.3993
CrowT_Sqrt_GLM	1.3680	3.4130	2.2489	0.4685
JayM_SQRT_Mean	0.0000	1.73	0.7330	0.4232
Mag_SQRT_Mean	0.0000	0.9024	0.1235	0.2022
Kest_SQRT_Mean	0.0000	1.7387	0.2896	0.4210
WalkE_Sqrt_GLM	-0.8582	0.7899	-0.3726	0.4816
DogE_SQRT_GLM	-0.8484	0.7812	-0.3903	0.4536
Other_SQRT_GLM_MMI	0.3695	4.5973	0.9023	1.1995
TotalE_SQRT_GLM	0.2110	4.4050	1.1551	1.1624
CarPark (m)	352.4412	3269.8794	1551.2356	714.5051
Urban (m)	331.7345	2639.2093	1493.9340	705.6576

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Table 23A Test of whether frequency of recreation and dogs affects survival rate of individual woodlark fledglings in the 2-3 weeks after leaving the nest.

Models test effects of the abundance of predators, visitors, dogs and distance to urban. Models are constructed using a set of 54 successfully fledged broods (16 in 2008, 38 from 2009). For base models, parameter estimates for all variables contained in the model are shown. For sequential models testing individual effects of disturbance and predator variables, only the test variable is shown, other terms are included as the base model. Wald test and associated P value, refer to the Type III test of effect within the model. Δ AICc is the change in AICc relative to the base model following addition of the tested term. Terms for which $P >> 0.05$, and for which Δ AICc is positive, or marginally negative, have no support for importance of their effect. Terms for which $P < 0.05$ and for which Δ AICc is less one or two units less than the base model (i.e. Δ AICc is negative), have some support. Values of parameters (+SE) are only shown for test variables receiving some degree of support.

Dependent variable = number of fledglings surviving from a successfully fledged nest, at the time of subsequent survey visit								
Mean of response = 1.74 ± 1.29 SD, range 0-4, n=54								
Model error: Poisson loglinear								
Model	AICc	Δ AICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
Full control model	173.713	+4.005	1.145				50	
				numberfledging		7.306	1	0.007
				daysafterfledge		3.082	1	0.079
				year(2008)		0.566	2	0.754
Base model	169.708	0.000	1.112				52	
				numberfledging	0.377, 0.019	20.417	1	<0.00001
				daysafterfledge	-0.044, 0.377	5.401	1	0.0201
Base model plus								
+ predator terms	171.944	+2.236	1.134	+ crowT_GLM		0.008	1	0.927
	171.922	+2.214	1.133	+ sqrtJayM		0.031	1	0.861
	171.457	+1.749	1.124	+ sqrtmagpie		0.521	1	0.470
	171.816	+2.108	1.131	+ sqrtkestrel		0.141	1	0.708
	169.226	-0.482	1.090	+ foxscats perkmGLM	+0.566, 0.309	2.272	1	0.132
+ recreation terms	170.568	+0.860	1.107	+ Walkerevents_GLM		1.437	1	0.231
	169.365	-0.343	1.083	+ dogeventsGLM	+0.359, 0.217	2.741	1	0.098
	171.875	+2.167	1.132	+ othereventsGLM		0.076	1	0.783
	171.876	+2.168	1.132	+ totaleventsGLM		0.078	1	0.780
	171.637	+1.929	1.128	+ dogscats perkmGLM		0.321	1	0.571
	171.930	+2.222	1.133	+ distancetourban		0.023	1	0.880
	171.583	+1.875	1.127	+ distancetocarpark		0.374	1	0.541

Tables

Table 24 Test of whether frequency of recreation and dogs affects survival rate of entire woodlark broods in the 2-3 weeks after leaving the nest.

Models test effects of the abundance of predators, visitors, dogs and distance to urban. Models are constructed using a set of 54 successfully fledged broods (16 in 2008, 38 from 2009). For base models, parameter estimates for all variables contained in the model are shown. For sequential models testing individual effects of disturbance and predator variables, only the test variable is shown, other terms are included as the base model. Wald test and associated P value, refer to the Type III test of effect within the model. Δ AICc is the change in AICc relative to the base model following addition of the tested term. Terms for which $P >> 0.05$, and for which Δ AICc is positive, or marginally negative, have no support for importance of their effect. Terms for which $P < 0.05$ and for which Δ AICc is less one or two units less than the base model (i.e. Δ AICc is negative), have some support. Values of parameters (+SE) are only shown for test variables receiving some degree of support.

Dependent variable = probability of brood surviving (binary response 0/1)								
Mean of response = 0.74 ± 0.44 SD, range 0-1								
Model: Binomial error, logit link, exposure days (since fledging) as the number of binomial trials								
Model	AICc	Δ AICc	Dev / DF	Variable	parameter estimate (B, SE)	Wald Chi square	df	P
Full control model	112.053	+2.644	0.567				51	
				intercept		29.862	1	<0.00001
				numberfledging		0.919	1	0.338
				year(2008)		0.174	1	0.677
Model 2	110.216	+0.807	0.560				52	
				intercept		30.154	1	<0.00001
				numberfledging		1.155	1	0.282
Base model	109.409	0.000	.572				53	
				intercept	-2.992, 0.162	340.964	1	<0.00001
Base model plus								
+ predator terms	111.053	+1.644	0.576	+ crowT_GLM		0.368	1	0.544
	111.394	+1.985	0.582	+ sqrtJayM		0.025	1	0.875
	111.307	+1.898	0.581	+ sqrtmagpie		0.116	1	0.734
	111.205	+1.796	0.579	+ sqrtkestrel		0.225	1	0.635
	110.246	+0.837	0.560	+ foxscats perkmGLM		1.168	1	0.280
+ recreation terms	111.292	+1.883	0.580	+ Walkerevents_GLM		0.129	1	0.719
	111.089	+1.680	0.577	+ dogeventsGLM		0.340	1	0.560
	111.325	+1.916	0.581	+ othereventsGLM		0.097	1	0.755
	111.162	+1.753	0.578	+ totaleventsGLM		0.269	1	0.604
	111.130	+1.721	0.577	+ dogscats perkmGLM		0.281	1	0.596
	111.385	+1.976	0.582	+ distancetourban		0.033	1	0.855
	111.414	+2.005	0.583	+ distancetocarpark		0.004	1	0.948