Report

footprint ECOLOGY

Further assessments of the relationship between buildings and stone curlew distribution

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Summary

This report updates previous work on the effect of buildings and roads on stone curlews in the Brecks. Stone curlews are an interest feature of the Breckland Special Protection Area (SPA) and previous work has found reduced densities of stone curlew nesting attempts on arable land close to buildings. This report focuses on the effects of buildings on the distribution of breeding stone curlew in the Brecks, and includes new analysis and uses additional survey data compared to previous studies.

Overview and trends over time

Data on 5116 stone curlew breeding attempts, located during the period 1985-2011, across the Brecks are considered. Numbers of stone curlews have steadily increased since the mid 1980s; the increases have been particularly associated with birds nesting on arable and improved or rough grassland habitats (outside semi-natural habitat). As the population has increased, more breeding attempts (and a higher proportion of them) have been found outside the SPA, suggesting the range has changed over time and birds have expanded into new areas (rather than densities merely increasing in already occupied areas). Around half the breeding attempts within the study area are on arable land. Densities on semi-natural habitats are (in most years) higher than the other habitats, however within semi-natural areas there is marked variation in use, with many areas of semi-natural habitat supporting no breeding attempts.

Buffers around all settlements

Variation in density was assessed in relation to 500m distance bands around all settlements. Looking across all years, at groups of years and individual years there is consistently a significantly lower density of breeding attempts in the arable land close to settlements. Depending on the year, time period and how settlements are defined this effect is significant at distances out to 2000m. The pattern of reduced nest density near settlements is not clear on semi-natural habitats (matching results from the previous work). Field size varies with distance from settlement, with bigger fields occurring further from settlements. There is no evidence that breeding density is different in bigger fields and no evidence that birds particularly avoid (or show a preference) for nest sites close to field boundaries. Contrary to the findings in the previous work, there is no evidence that, as the population has increased, that a greater proportion of breeding attempts have been found close to settlements (i.e. as the population has increased, more birds have not bred closer to settlements).

Buffers around individual settlements

We extracted data for individual settlements, determining the land area closer to a given settlement than any other settlement in the study area (voronoi polygons). This allowed us to check that reduced densities were present across multiple settlements. There was a consistent pattern of lower densities on the arable land around each settlement and out to the 1000-1500m band, adding further weight to the other results. The estimated median reduction in relative density in the 0-500m and 500-1000m bands was nearly 90% and just over 50% respectively. There was also an effect of settlement size, in that larger settlements tended to be associated with a greater reduction in density on the surrounding arable land within the 0-500m band. This would suggest that additional building will always be associated with a reduction in stone curlew nest numbers; but that the effect is smaller the more buildings are already present.

Initial Models

Previous work had found significant effects of existing roads and buildings on the density of stone curlew breeding attempts. Initial investigative modelling therefore started with these two variables (roads and buildings) and involved the use of quasi-Poisson GLM on total 1988-2011 numbers of breeding attempts on suitable arable land in 500m grid cells. Models initially included a single

buildings variable and a distance to road variable. Building variables involved a normal weighted kernel and different weightings of buildings with distance were tested. For both the road and building variable different forms (such as square root) were tested. These models showed the density of breeding attempts on arable land to be related to the amount of nearby buildings (both number and especially area) and the distance from trunk roads. The predicted impact of a building is greater where the present area of nearby buildings is low (i.e. greater impact for isolated buildings) and suggests that the total area covered by the nearby buildings has some influence over and above the simple number of nearby buildings. The best normal kernel weighting for buildings was one with a standard deviation of 1250m, suggesting buildings over a wide area (2000m and beyond) have a cumulative impact on nest density within each 500m grid cell.

Consideration of other variables alongside housing

Summarising the density of breeding attempts in categories relating to **distance to road** and the amount of buildings suggests effects of buildings on density but no consistent pattern for roads (when all roads are considered). Looking at the data for **trunk roads** only (A11, A14 or A47), regardless of the level of buildings, the density of breeding attempts was always lowest in the subset of areas within 0.5 km of the nearest trunk road and highest in the areas furthest from the nearest trunk road, indicating effects of both trunk roads and buildings.

The **amount of nearby woodland** is weakly negatively correlated with the amount of nearby buildings. Nest density on arable land tends to be lower where there is more woodland nearby, especially amongst those otherwise favourable areas not near many buildings. **Distance to the nearest field boundary** (from a series of points within arable land in each 500m cell) is not correlated with the amount of nearby buildings. Distance to field boundary (as measured) is not related to average density of breeding attempts on arable land. The observed negative association between density on arable land and amount of nearby buildings is not caused by any particular **influence of Thetford** and the distance of arable land from this large town. The density of breeding attempts on arable land was higher on arable land near **to semi-natural grassland**, and this was the case in areas with low or high levels of nearby buildings. However, density was not related to actual extent of semi-natural habitat in the same or neighbouring 500m cells: in other words higher breeding attempt densities (on arable land) were associated with the presence of semi-natural grassland nearby, rather than the extent of semi-natural grassland.

Additional modelling

More complex models were developed that included different additional variables to our ‘best’ model based on area of nearby buildings and distance to trunk road. Woodland cover (level of woodland within the grid cell and in surrounding 500m cells) had a significant negative effect on the density of breeding attempts when included with our building and road variables in the models. None of the other variables (in bold above) enhanced the fit of the initial models.

We also considered different building types. Buildings were classified using Ordnance Survey MasterMap (which maps all buildings) and AddressBase Premium (which classifies buildings to type) products. Within the study area we were able to classify in total nearly 30,000 residential properties, just under 2500 commercial buildings and 71 agricultural buildings. In addition 185 buildings were classified as ‘other types’ (i.e. very wide range of different buildings including places of worship, schools, public conveniences, hospitals, bus shelters). Furthermore some 29,000 buildings were unclassified. These buildings would all be ones without an address of their own (i.e. no mail) and were typically very small (smaller than residential). We believe these buildings would include garden sheds, greenhouses, ancillary buildings etc.

Effects of different building types were considered within the models by comparing different combinations of building types. These comparisons indicate a consistent negative effect of residential and other/unclassified buildings. We could not find a detectable effect for commercial buildings and the 71 agricultural buildings tended to be associated with areas of relatively higher nest densities. We therefore find no evidence of a negative impact of agricultural or commercial buildings, but suggest that some caution is required due to the small sample sizes (for agricultural and commercial buildings) and difficulties in classification.

We also tested the effect of the area of buildings in different non over-lapping buffers around individual cells. Effects of the area of buildings were found out to 2000m, supporting other analyses.

The effects of buildings, trunk roads and amount of woodland are still highly significant within the model, once adjusted for spatial clumping (autocorrelation) of breeding attempts within the pattern of the buildings, roads and other features.

Implications

Implications of the results are discussed in detail. Planning policy currently includes a 1500m zone around areas used by stone curlews; within this zone the presumption is that development will result in a likely significant effect on the SPA and therefore development should only proceed if it can show no adverse effect on the integrity of the SPA.

Our latest analyses provide strong support for the continuation of a 1500m zone around the areas capable of supporting stone curlews. Within this zone it would seem that additional development would have a likely significant effect on the SPA. The effect of development is predicted to be more pronounced in areas with no existing development. Where there is existing development close to suitable stone curlew habitat, or high levels of development already, then further development has relatively little additional impact. This would suggest that ‘infill’ developments in larger settlements will have much less impact than equivalent sized developments in undeveloped areas.

While we did not (and could not) explicitly test different mitigation measures (such as screening, different light levels etc.), the analyses provide no support that trees or other screening may act as mitigation and avoid any impacts. Analyses indicate that the effect of buildings is from residential properties as opposed to other building types. The 1500m zone should therefore apply to residential development. We do however suggest some caution with regards other development types and suggest that applications for any non-residential development buildings close to the SPA should be carefully considered on an individual basis.

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Cover photograph of a stone curlew courtesy of James Lowen.

1. Introduction

Breckland SPA and Stone Curlews

1.1 The Breckland Special Protection Area (SPA) is classified as an SPA in accordance with the European Birds Directive (Council Directive 79/409/EEC on the conservation of wild birds, replaced by Council Directive 2009/147/EC in 2009). This European legislation requires Member States to classify sites that are important for bird species listed on Annex 1 of the European Directive, which are rare and/or vulnerable in a European context, and also sites that form a critically important network for birds on migration.

1.2 The Breckland SPA qualifies under the Birds Directive by supporting populations of European importance of nightjar, woodlark and stone curlew. Stone curlews are summer migrants, associated with open, bare habitats, and within the Brecks they occur on heathland, grassland and arable sites. In 1998 (the year given in the SPA Review) the Breckland SPA supported some 142 pairs of stone curlew, some 75% of the UK population. In 2009 there were an estimated 361 breeding pairs in the UK, with 236 (65%) of these in eastern England (where most breeding is in the Brecks) (Holling & Rare Breeding Birds Panel 2011).

1.3 Where the nature conservation interest is designated as a European Protected site (SPA or SAC or Ramsar) there are particular implications. European sites are protected through the provisions of the Conservation of Natural Habitats and Species Regulations 2010 (SI no. 490), which transpose both the Habitats Directive (Council Directive 92/43/EEC) and the Wild Birds Directive (Council Directive 2009/147/EC) into UK law.

1.4 Regulation 61 ensures that competent authorities can only agree to a plan/project which is likely to have a significant effect (alone or in-combination) after having determined that it will not adversely affect the integrity of any European site (subject to imperative reasons of over-riding public interest and consideration of alternative solutions) through an appropriate assessment. Regulation 61 applies to all European sites and ensures that new development and strategic development plans must therefore consider and address any impacts to European sites.

1.5 Also relevant is Article 6(2) of the Habitats Directive, which requires Member States to take appropriate steps to avoid, in the SACs and SPAs, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated. Article 6(2) states that "member states shall take appropriate steps to avoid..... deterioration of natural habitats.... as well as disturbance of the species..."; the wording therefore puts a responsibility on the member state to address such issues where they arise.

1.6 Furthermore in 2012, regulation 9A was added to the Conservation of Habitats and Species Regulations 2010 which, in summary, requires the local planning authorities to take steps they consider appropriate to secure the objective of the preservation, maintenance and re-establishment of a sufficient diversity and area of habitat for wild birds in the UK, for example by means of the upkeep, management or creation of such habitat, whether in or outside a SPA.

Favourable Conservation Status and conservation objectives for Breckland SPA

1.7 The purpose of the network of European sites, the Natura 2000 network, is to ensure that the habitats and species for which the sites are designated or classified are maintained or restored at a 'favourable conservation status' in their natural range. This objective is repeated throughout the various Articles of the Habitats Directive, and at Article 1(i) of the Directive a definition of favourable conservation status for species is given, stating that the conservation status will be taken as favourable when all three of the following points are met.

- Population dynamics data on the species concerned indicate that it is maintaining itself on a long term basis as a viable component of its natural habitats.
- The natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future.
- There is, and will probably continue to be a sufficiently large habitat to maintain its populations on a long term basis.

1.8 The three criteria for achieving favourable conservation status all relate to ecological judgements, based on evidence, regarding the long term prospects for the species in question. They relate to securing the natural range of the species and providing sufficiently large habitat. The criteria are about achieving a state of resilience and secured longevity for the habitat or species across Europe, to which each European site in the overall network contributes.

1.9 In 2012 Natural England produced a new approach to conservation objectives for European sites, founded on achieving the overall aims of the Directives, i.e. each site achieving its conservation objectives will contribute to the overall aim of favourable conservation status for all qualifying habitats and species across their natural range. Conservation objectives seek to guide site management and assist in the appropriate assessment of plans and projects.

1.10 The overarching objectives, relevant to Breckland SPA[1] are to

"Avoid the deterioration of the habitats of the qualifying features, and the significant disturbance of the qualifying features, ensuring the integrity of the site is maintained and the site makes a full contribution to achieving the aims of the Birds Directive. Subject to natural change, to maintain or restore:

- *The extent and distribution of the habitats of the qualifying features;*
- *The structure and function of the habitats of the qualifying features;*
- *The supporting processes on which the habitats of the qualifying features rely;*
- *The populations of the qualifying features;*
- *The distribution of the qualifying features within the site*."

[1] From http://www.naturalengland.org.uk/Images/UK9009201-Breckland-SPA_tcm6-32217.pdf

Previous research relating to impacts of urban development and stone curlews in the Brecks

1.11 Previous research, undertaken in 2008 (Sharp *et al.* 2008)[2] looked at the distribution of stone curlew nests in the Brecks in relation to buildings and roads over the period 1988-2006. The results showed a clear avoidance of buildings, such that lower nest densities were found in areas with more buildings nearby. These results have had widespread implications for strategic planning. Planning policy has developed to ensure no adverse effect on integrity to the Breckland SPA by setting out a zone of 1500m from the SPA boundary. Within this zone planning permission will only be granted provided it is demonstrated by an appropriate assessment the development will not adversely affect the integrity of the SPA. Furthermore, stone curlews do also nest outside the SPA boundary. Where they are nesting near the boundary it logically assumed that the nesting pairs will be part of the same population and linked to the SPA. There is consequently a need to ensure adequate protection for these birds, and a 1500m zone has therefore also been applied to areas outside the SPA. For these areas outside the SPA, where Annex 1 birds are using 'supporting habitat' i.e. land out with the boundary but performing a 'supporting' function for the SPA, it is potentially possible to provide mitigation, for example through habitat enhancement work.

1.12 The subsequent Habitats Regulations Assessment of the Core Strategy, undertaken jointly by Footprint Ecology and David Tyldesley and Associates (Liley *et al.* 2008) primarily drew upon the evidence within the commissioned research reports to support the assessment,in order to propose the mitigation measures set out within Core Strategy policy CP10, including the 1500m buffer zone. Similar precautionary policies containing a 1500m buffer have been incorporated into planning strategies for Forest Heath, Kings Lynn & West Norfolk and St Edmundsbury.

1.13 For any Habitats Regulations assessment, up to date evidence underpinning conclusions drawn is essential, and five years since the original work commenced, the availability of up to date survey data presents an opportunity to review findings. In addition to this, it is also recognised that the original work left some unanswered questions. At the Examination of Core Strategy in the Summer of 2009 the Inspectors were convinced by the evidence presented, and their endorsement of the approach was founded on their appreciation of the precautionary principle embedded in the Habitats Regulations. Importantly however, the Inspectors also made careful note of the further work to be done.

1.14 At several points during the Inspector's report, reference is made to 'an incomplete understanding of stone curlew behaviour.' Furthermore, the Inspector refers to the precautionary advice from both Natural England and the RSPB who '*acknowledge the relatively poor understanding of the bird's behaviour and admit that this hinders possible mitigation measures which might permit a less restrictive approach to development... and...*

[2] The original work will be set out in a peer reviewed paper (Clarke *et al.*, in press) which will also provide public access to the original data (with all spatial references removed).

recognise the need to improve their understanding of the interaction between human activity and stone curlews.'

1.15 The Inspectors highlighted some concerns with regard to the application of the 1500m buffer. Concern was raised that the fact that the stone curlew survey data was not freely available, and whilst recognising the sensitivity, the Inspector indicated that this inevitably led to questions regarding the validity of the data and how it had been used. The Inspector also pointed out that the 1500m zone lacks subtlety as it contains habitats that are unsuitable for ground nesting birds.

1.16 Despite airing some concerns in the report, the Inspector's overall conclusion was that the precautionary principle must be applied, and agreed that the 1500m buffer and all other mitigation measures needed to be incorporated into the plan, and that the evidence was sufficiently robust to support the mitigation package being proposed.

1.17 The Inspector's report advised that '*urgent work, including careful monitoring, is essential to provide a better understanding of interactions between stone curlews and human settlement and to develop practical and effective mitigation measures*.'

Aims and objectives

1.18 This report has therefore been commissioned to update the previous study and provide that better understanding. Given the very large land area affected by this planning policy and the implications for development it is clearly important

- to check whether the avoidance is still apparent (and at what distance), especially following recent increases in stone curlew numbers and
- to understand in more detail the mechanisms underlying the lower stone curlew densities.

1.19 Further understanding of the patterns of avoidance may provide the opportunities to allow certain kinds of development or identify possible mitigation measures. While complex studies involving tracking birds and exploring factors relating to nest site choice in relation to the built environment could be undertaken, such work would be costly and would be difficult to undertake. We therefore rely on existing datasets and the aims of this study are to:

- Use the most recent stone curlew and housing/building data to assess the current impact of existing development
- Compare different building types to explore whether, for example, it is possible to differentiate the impacts of agricultural and residential buildings
- Explore and check other possible factors that may account for the observed pattern, using data on field size and land use
- Test for spatial autocorrelation to determine whether these can provide additional explanatory information.

2. Methods

Soil Data

2.1 Previous work has shown the importance of particular soil types (Green, Tyler, & Bowden 2000; Sharp *et al.* 2008). Suitable soils were defined following the original report, and therefore the data from the previous work were used to define a 'study area', which was comprised of the following soil types:

Table 1: Suitable soil types used to define initial study area

Subgroup	Name
5.51	sandy drift with siliceous stones
3.43	light loamy lithoskeletal chalk
5.54	sandy chalky drift
5.11	light loamy material over lithoskeletal chalk
5.21	sandy chalky drift

500m grid

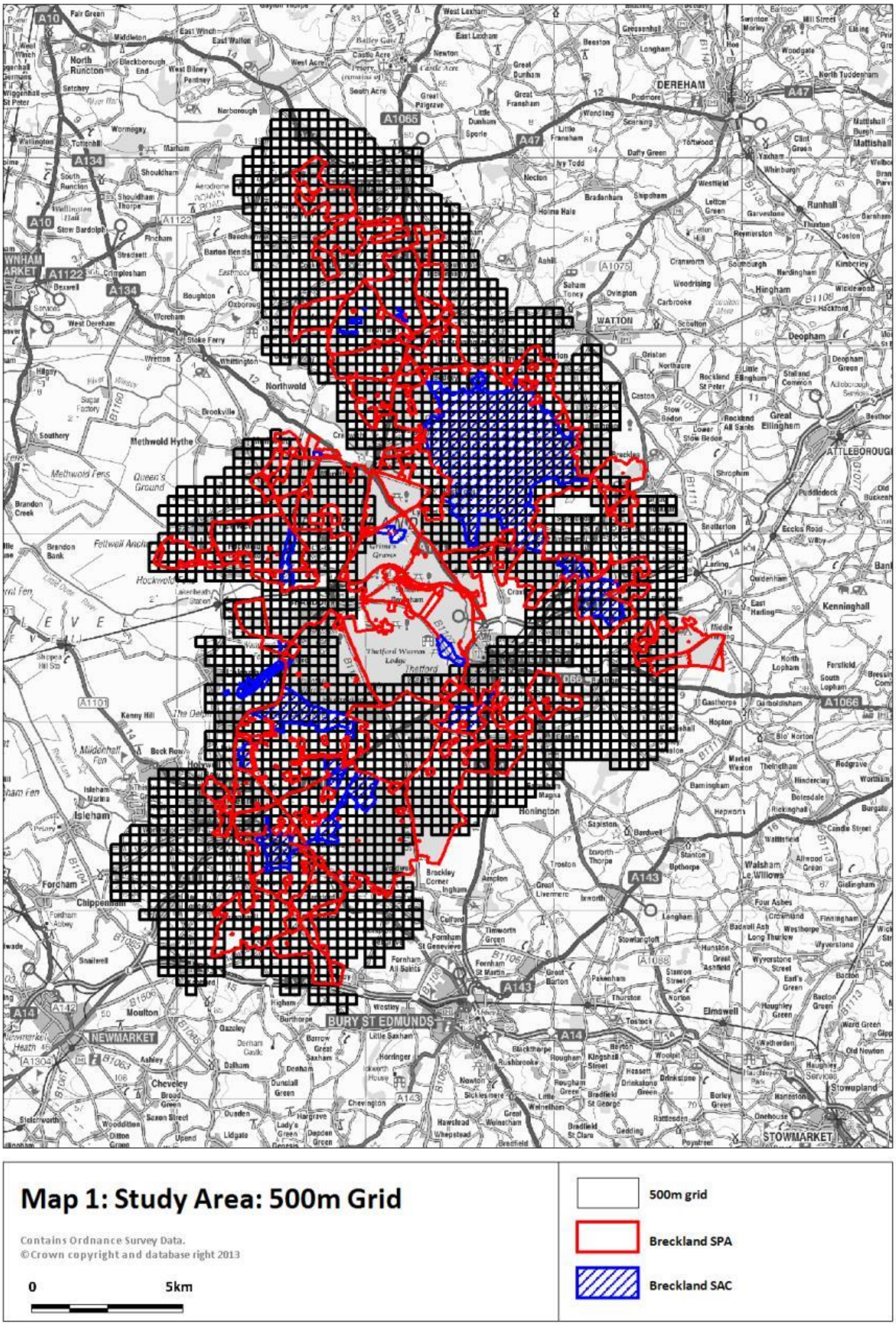
2.2 A grid of 500m cells, aligned to the Ordnance Survey National Grid, was created to cover the suitable soil layer, resulting in a grid of 2927 different cells (of which 1737 cells intersect the SPA boundary). This grid forms the 'study area' and is shown in Map 1. It encompasses most of the SPA (areas of the SPA that lie outside the study area are forested areas that support nightjar and woodlark rather than stone curlews) and it also encompasses a wide area of arable around the edge of the SPA. This grid cell size was chosen to make the subsequent nest distribution spatial modelling computationally tractable, while still giving adequate accuracy in terms of distances from nests to buildings and roads.

Stone Curlew Data

2.3 Data on the locations of individual breeding attempts were provided by Professor Rhys Green (University of Cambridge/RSPB) as a spreadsheet with grid references for the period 2007-2011. This updates the original data used in the first analyses (which covered the period 1985-2007). The RSPB have employed professional surveyors each year and survey coverage is considered to be "virtually complete" (e.g. Holling & Rare Breeding Birds Panel 2011). The data used in the analysis includes that collected by the RSPB but also includes data (collated by Professor Green) from individual estates who do not allow RSPB to conduct surveys on their land. The majority of the data relate to nest locations, but also include some cases where no nest was found but adults were observed with recently hatched chicks. Where we refer to nests or nest density within the rest of the report we are including these observations of adults with chicks (which were not differentiated within the data).

2.4 The 2007-11 data were merged with the original data to give a single data set comprising over 5000 breeding locations. Grid references varied in precision, and included six figure, eight figure and ten figure grid references. All six and eight figure grid references were modified to end in "5", thereby giving the mid point of the respective grid. For example a six figure grid reference is accurate to the nearest 100m, and by adding the 5 to the end the nest when plotted in the GIS was plotted to the centre of a 100m grid cell.

2.5 Survey coverage (nest finding) was not consistent across the study area. All areas were surveyed in all years up to and including 1994. In subsequent years some areas were not surveyed in every year. Survey coverage is shown in Map 2, with the different colours indicating the level of missing years. Data for all areas in 2001 was patchy and incomplete due to the Foot and Mouth outbreak.



Map 1: Study Area: 500m Grid

Contains Ordnance Survey Data.
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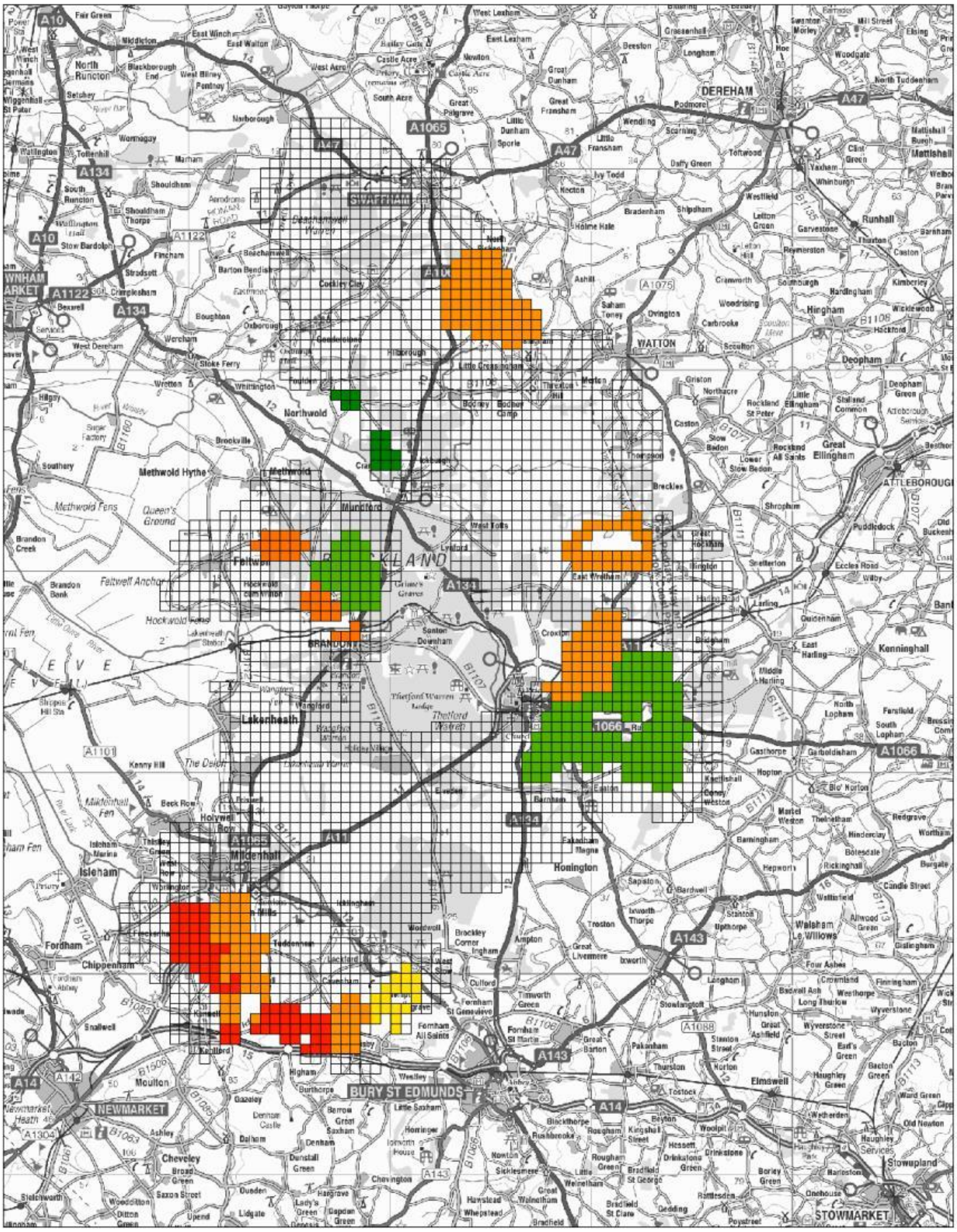

Map 2: Survey Coverage

Contains Ordnance Survey Data.
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0 5km

Survey coverage 1994-2011
Colours show number of missing years

- 16 to 18 (66)
- 12 to 14 (29)
- 10 to 12 (210)
- 6 to 8 (18)
- 2 to 4 (173)
- 1 to 2 (15)
- complete coverage all yrs (2416)

Land-use/Habitat types

2.6 Semi-natural habitat was identified using the boundaries of the Breckland SAC, downloaded from the Natural England website. Landcover data (CEH) were used to define arable land and other habitat types.

2.7 Landcover data (CEH) were provided under licence by CEH and are shown in Map 3. These data were in the form of polygons each with a broad habitat type and within each broad type a number of sub-categories. Arable land was defined as a broad category "Arable and horticulture", with two further subcategories ("Arable bare" and "Arable unknown").

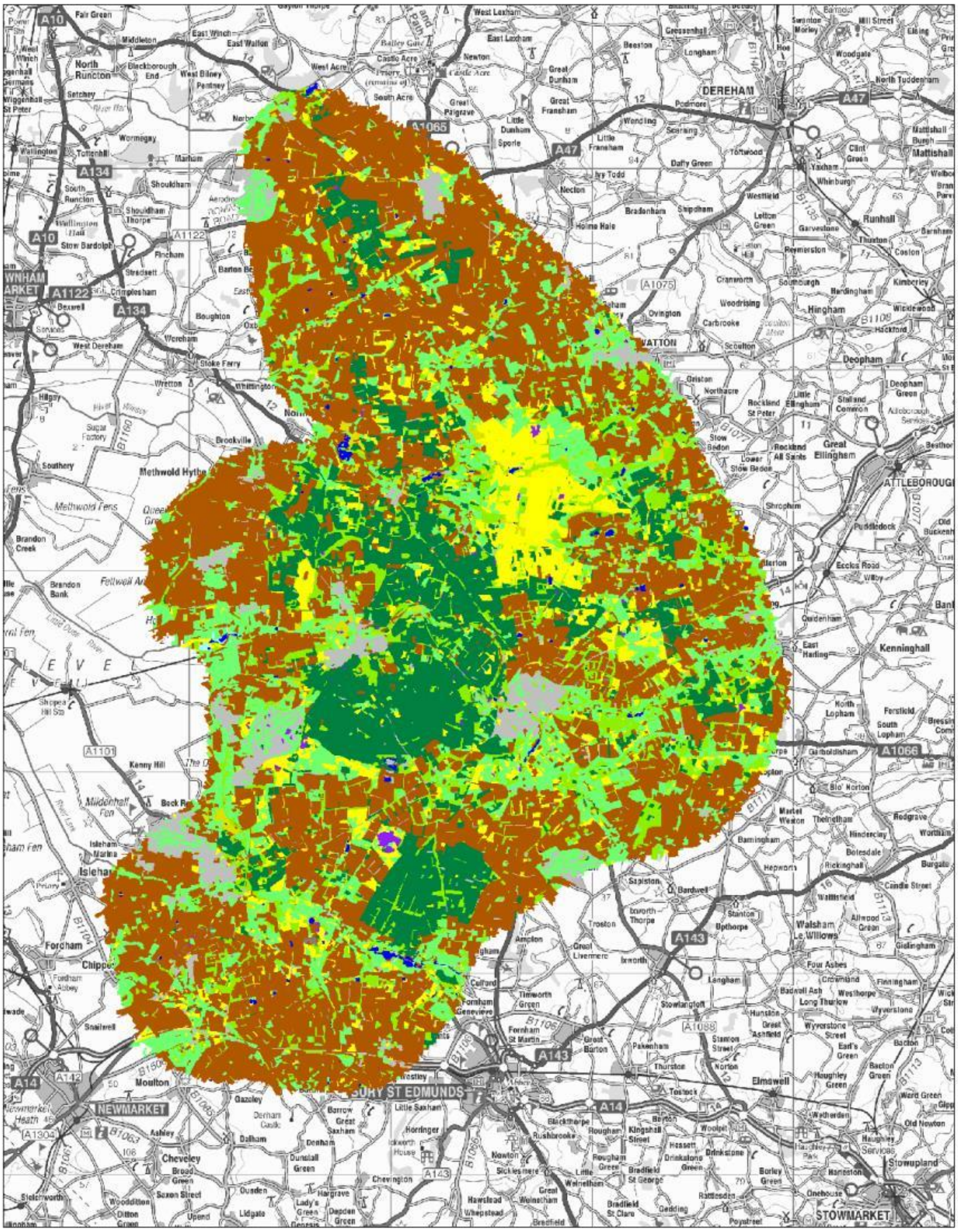
2.8 All nests within the study area were assigned into one of three habitat categories: 'Semi-natural' (i.e. within the SAC); 'Arable' (outside the SAC and within a landcover polygon categorised as arable and horticulture) or 'Other'.

2.9 Woodland (area of woodland within and around grid cells) was calculated by using the combined area of deciduous[3] and coniferous[4] woodland (but excluding landcover parcels categorised as 'felled'). The following woodland variables were extracted from the GIS:

- Area of woodland within each 500m grid cell
- Area of woodland within each 500m grid cell and the adjacent 8 cells

2.10 The amount of semi-natural habitat within and around each grid cell were extracted from the GIS in a similar fashion, i.e. the area of semi-natural within each grid cell and the area of semi-natural within each grid cell and the adjacent 8 cells.

[3] Parcels within the landcover data categorised as Bh "Broad leaved, mixed and yew woodland"
[4] Parcels within the landcover data categorised as Bh "Coniferous woodladn"



Map 3: Landcover Data

0 5km

Broad Landcover Categories (number of parcels)

- Arable and horticulture
- Broad leaved, mixed and yew woodland
- Built up areas and gardens
- Calcareous grassland
- Coniferous woodland
- Dwarf shrub heath
- Fen marsh and swamp
- Freshwater
- Improved grassland
- Inland rock
- Neutral grassland
- Rough low-productivity grassland
- Supra-littoral sediment

Buildings and definition of 'settlements'

2.11 Buildings were extracted from OS MasterMap (provided under licence by Breckland District Council) to generate a single GIS layer showing all buildings.

2.12 These individual buildings were classified using the Ordnance Survey Addressbase Premium data, provided under licence by Breckland Council. The Addressbase Premium product comprises point data, derived from the National Land and Property Gazetteer, Ordnance Survey's OS MasterMap Address Layer and the Royal Mail Postcode Address File. Each point has a Unique Property Reference Number (UPRN) and the points represent all local authority, Ordnance Survey and Royal Mail addresses, current (approved) addresses, and alternatives for current addresses (reflecting differences in versions of addresses in current use), provisional addresses (proposed planning developments) and historic information for each address, where available. It also includes "Objects without Postal Addresses" (OWPAs) which are objects such as recreation ground/open space, public convenience, church or car park that do not receive mail. The AddressBase Premium data therefore provides a GIS layer representing all buildings with addresses and additional buildings that do not necessarily receive mail.

2.13 The AddressBase Premium classification for buildings includes 563 different classifications, these include post boxes, stupas, caves, springs, bollards, helipads and bus shelters as well as 25 different types of residential building and a range of other building types. In order to provide a simple classification for each building type, we cross-referenced the Mastermap building layer with the AddressBase Premium data, such that any building which contained a point in the AddressBase layer was classified as either "Agricultural", "Commercial", "Residential" or "Other". Any building that did not contain a point from the AddressBase layer was classified as "Unassigned". We show some examples of how these two datasets relate in Figure 1, which shows a residential area (near Thetford), an industrial area (outskirts of Thetford) and a rural area.

Figure 1: Mastermap buildings layer and AddressBase Premium data for three different parts of the study area. Top: industrial estate on the edge of Thetford; Middle: rural/farm example; Lower: towards the centre of Thetford. Black dots are UPRN data, Mastermap Buildings are coloured as shown in the legend.

2.14 Sharp et al. (2008) used a manual method to derive a GIS layer of 'settlements' by discarding what were considered isolated individual or small groups of buildings on the MasterMap buildings database. For the current analyses, we developed an objective repeatable method of defining settlements based on the following steps: An individual MasterMap Premium building was considered to be part of a 'settlement' if there were at least B_{Min} other buildings (of any type) within a distance of 250m, where B_{Min} was set to 10 or 50 buildings. Individual buildings which did not satisfy the criteria were excluded from the derived settlement layer of the GIS which was used to calculate distance from nearest 'settlement' for all land. The overall Mastermap layer included 202,585 buildings (this is including the area beyond our study area). Some 35,191 'isolated' buildings were deleted from this based on our 50 buildings threshold and some 5865 based on our 10 buildings threshold[5]. The use of the 10 building threshold therefore resulted in a settlement layer that was relatively similar to the all buildings layer.

2.15 Using our 'settlement' GIS layers (derived using the 50 or 10 building threshold within 250m), we generated distance bands at 500m intervals within the GIS, allowing us to divide the study area into different bands reflecting distance from the nearest settlement. This approach was similar to the original work, with the only difference being that isolated buildings were deleted automatically using our 50 or 10 building threshold, rather than manually. The settlement layer is shown in Map 4, and the colouring indicates the different derived 'settlement' layers. Within Map 4, all buildings are shaded in grey, settlements defined by the 10 building threshold are orange and those defined by the 50 building threshold are red. In Map 5 we show the 50 building threshold settlement layer and the 500m distance bands.

2.16 For each distance band, the number of nests (by year) and the area of different habitat types were extracted. Any areas with incomplete survey coverage were not included. This allowed us to determine stone curlew density within each distance band according to habitat type.

2.17 Stone curlew nest density in each 500m distance band was measured by dividing the total number of nests found on arable land in that distance band by the total area (in km^2) of such land. This was done for three types of time periods (i) all years combined nests (1988-2011), (ii) each 4-5 year period (1988-92, 1993-96, 1997-2000, 2002-06, 2007,11) and (iii) each individual year (excluding 2001).

2.18 If there was no real effect or association of distance to nearest settlement on nest density (our statistical null hypothesis), then, based on the observed total number of nests on suitable arable land in a time period, the stone curlew numbers in each distance band should be (roughly) proportional to the total suitable arable area that is within that distance band of settlements. By comparing the observed nest numbers in

[5] These isolated buildings were therefore deleted from the buildings layer to allow us to consider individual settlements but it should be noted that the models and later analyses (see para 2.28) all buildings were included.

each distance band with the expected number (based on this assumption of no effect of distance from settlement) we can derive Chi-square goodness-of-fit tests of the statistical significance of departures from this null model of stone curlew nest density on arable land being independent of distance from any settlement.

2.19 However, it is of great interest to be able to estimate the maximum distance from settlements over which there is a statistically significant detectable reduction in nest density compared to areas further from the nearest settlement.

2.20 This was assessed using successive Chi-square tests that compared the nest density in a distance band with the average nest density in all higher distance bands combined. Thus we first compared nest density in 0-500m with average nest density in 500-3500m, then density in 500-1000m with average density in 1000-3500m, then density in 1000-1500m with average density in 1500-3500m and finally density in 1500-2000m with average density in 2000-3500m. This is done by comparing observed and expected number of nests in each distance band class where the expected is based on the proportion of all suitable arable land in that distance band class. The highest distance band for which nest density was lower than average density in higher distance bands and the difference was statistically significant (i.e. Chi-square test $p < 0.05$) suggests the maximum distance at which we can detect an effect (or association) of buildings with nest density.

2.21 All of these analyses were carried out with settlements defined by all individual buildings with a minimum of either 10 or 50 other buildings within a distance of 250m.

2.22 We refined the approach further by taking our settlement layer (we used the layer derived using the 50 building threshold) and dividing the study area so that all land area was attributed to the nearest settlement, resulting in a GIS layer of Thiessen (or Vornoi) polygons. These polygons essentially divide the study area into a number of non-overlapping regions, with a polygon for each 'settlement'. Each settlement's polygon defines the land area that is closer to that settlement than any other settlement.

2.23 In order to derive these polygons we took the 500m distance band (generated using the 50 building threshold) and within this assigned a settlement name (or unique ID if too small a cluster to be named on the Ordnance Survey 1:50,000 scale map) to each building. Clusters of buildings were primarily identified visually using the 500m distance band and areas where the 500m distance band formed a complete (or nearly complete) circle. Each building within each cluster was then converted to point data within the GIS, and individual voronoi polygons drawn for each building, these were then merged using the field defining the settlement name. This led to 81 settlements and their voronoi polygons. Within each voronoi polygon, individual distance bands were then drawn around each cluster of buildings, with distance bands drawn at 500m, 1000m and 1500m. This allowed us to extract the number of nests (and area of respective landcover types) within each distance band from each settlement, with the knowledge that the land in each distance band was 'unique' to one settlement, i.e. the land within the distance band was closer to that (named) settlement as opposed to any other settlement. The number of buildings within each settlement was also extracted, using OS Mastermap data. The vornois are shown in relation to settlement distance bands in

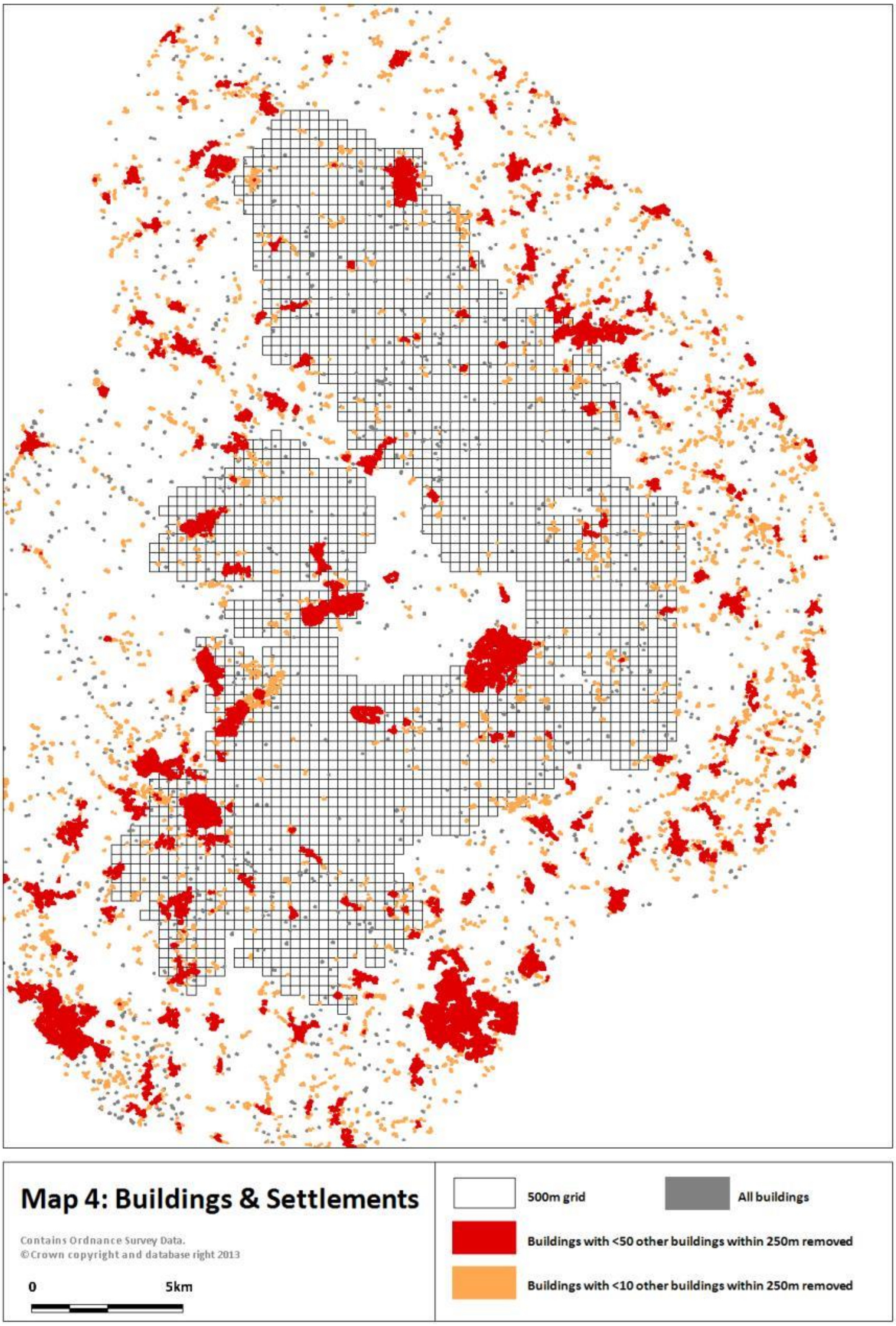
Map 6. For each individual settlement, we calculated the number of nests (1988-11) in each 500m distance band from the nearest building in that settlement up to the voronoi polygon boundary so that each nest was only used in the analysis for one settlement. Only nests from areas surveyed in all years were used.

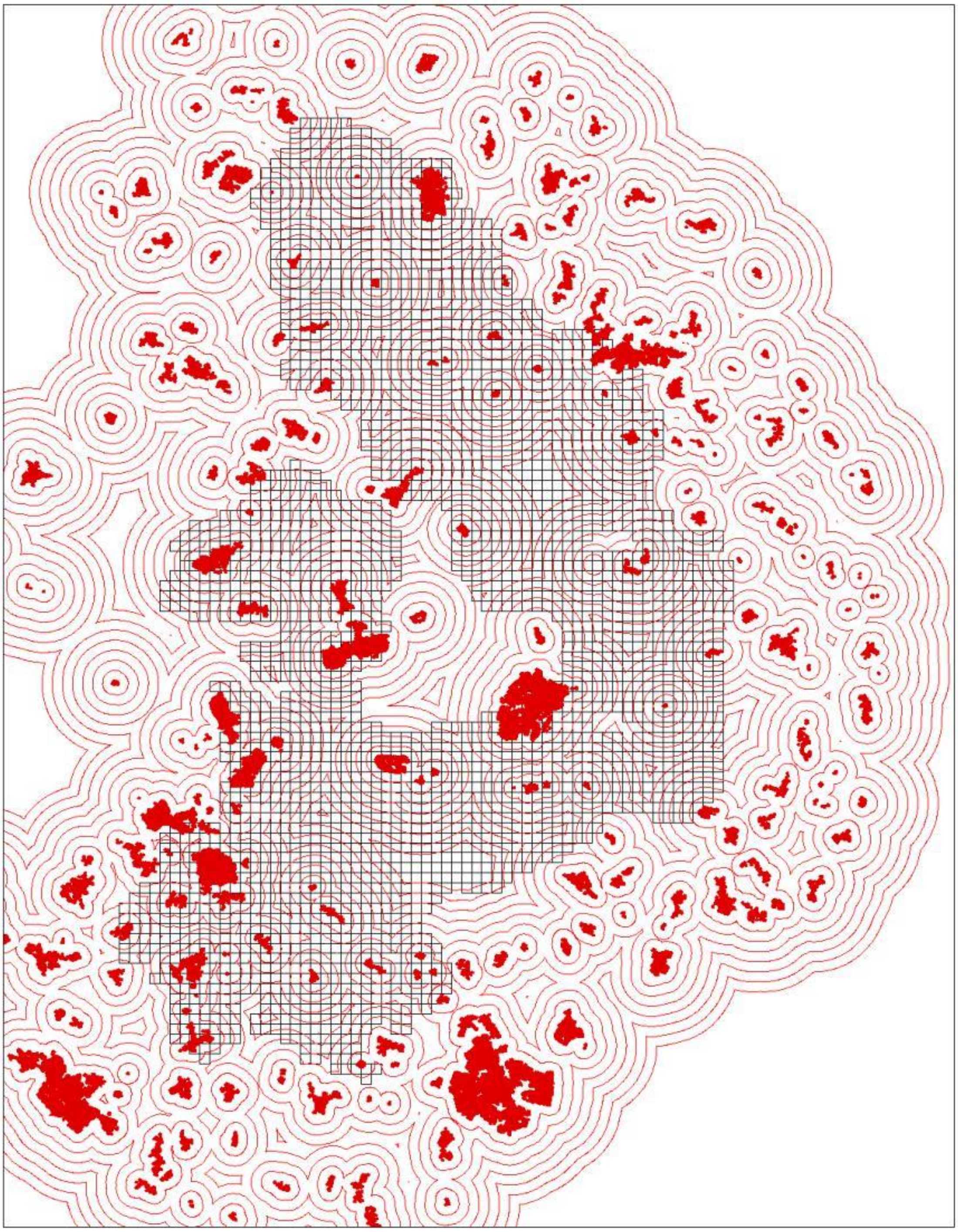
2.24 For each individual ‘settlement’, we also calculated the area of arable land (surveyed in all years) in each 500m distance band from that settlement), allowing us to calculate average nest density in each distance band within its voronoi polygon. We calculated the ratio of nest density within 0-500m to average nest density at greater distances (within the settlements voronoi polygon boundary) and similar for nest density in the 500-1000m band relative to further away.

2.25 Binomial statistical tests were used to assess whether the percentage of settlements with lower nest density within 0-500m than further away (i.e. with nest density ratios < 1) was statistically significantly greater than the 50% expected if there was no overall effect of settlements on nest density. A more powerful test involves ranking the extents to which the settlement nest density ratios deviate above and below the null hypothesis value of one. This was done using the Wilcoxon signed ranks test on the logarithms of nest density ratios (to make the null hypothesis distribution symmetrical about zero). Because of the low numbers of nests around many individual settlements, nest density within a distance band was often zero and/or ratios were undefined.

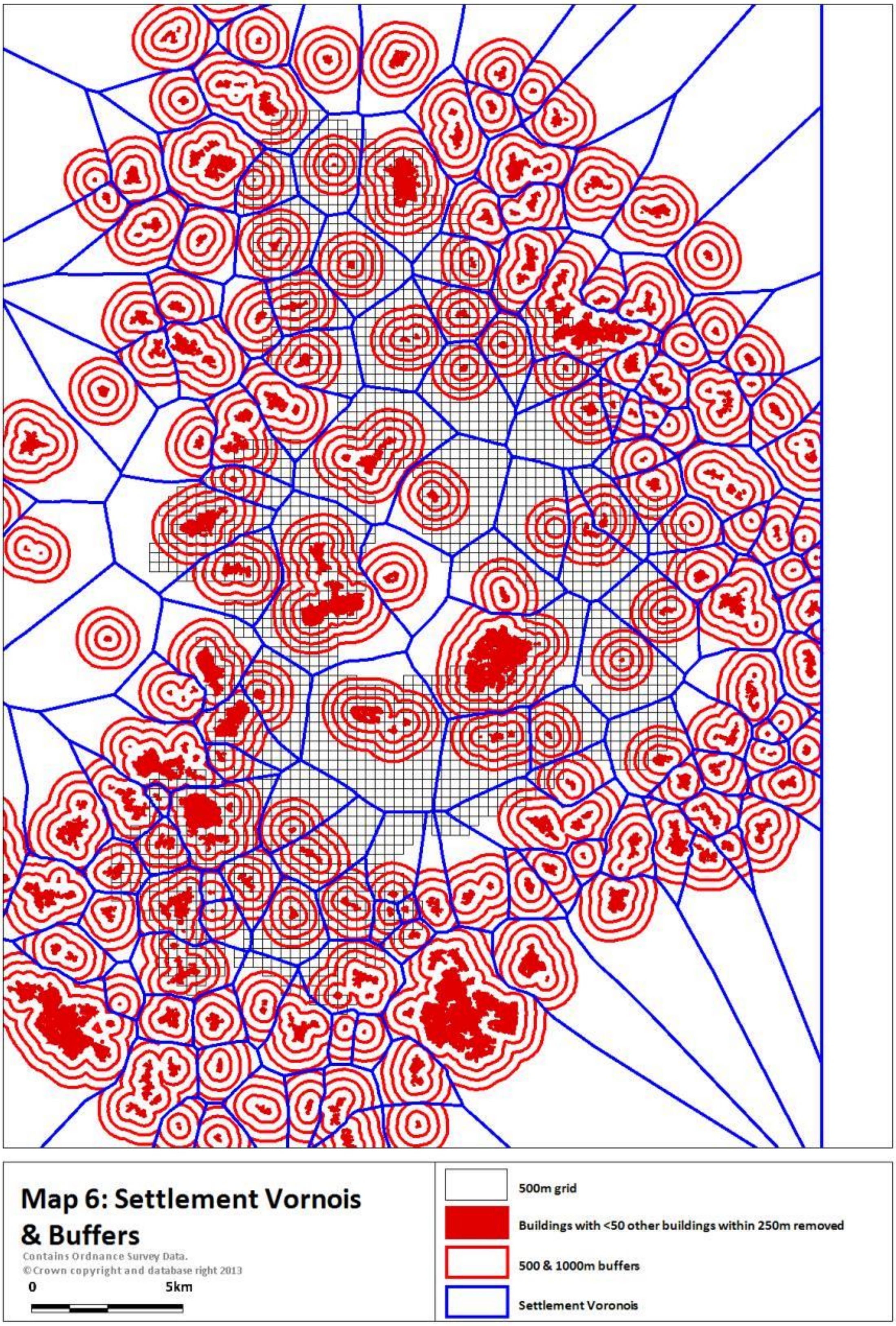
2.26 Based on average density on all arable land in the study area over the study period, two or more nests over the study period would be expected in 25ha of arable land. In any of these analyses, settlements with less than 25ha in the closest distance band were therefore excluded from the analysis and tests, as obviously were those with no nests recorded within any of the relevant distance bands. To avoid losing the information in zero densities for the ranked log ratio tests, ratios of zero were set to just less than the lowest observed non-zero ratio.

2.27 Similar tests were used to assess for reduced nest densities in 500-1000m and 1000-1500m bands relative to further away. This led to sample sizes of 38, 37 and 32 settlements in tests for reduced nest densities relatively to further away in the 0-500m, 500-1000m and 1000-1500m bands respectively. The relationships between nest density ratio and settlement size (number of buildings) were also assessed.


Map 4: Buildings & Settlements
Contains Ordnance Survey Data.
©Crown copyright and database right 2013
0
5km
500m grid
All buildings
Buildings with <50 other buildings within 250m removed
Buildings with <10 other buildings within 250m removed



Map 5: Settlement Buffers


Map 6: Settlement Vornois & Buffers
Contains Ordnance Survey Data.
©Crown copyright and database right 2013
0
5km
500m grid
Buildings with <50 other buildings within 250m removed
500 & 1000m buffers
Settlement Voronois

Local building density variables

2.28 For each 500m cell, we calculated the total number and area of buildings of each main type (residential, commercial, agricultural, other, unclassified) and in total in successive 100m distance bands around each of the 500m cells. These 100m distance bands were drawn out to a distance of 3000m from every 500m cell. Buildings within a cell were classed as at distance zero.

2.29 Local building density of each building type was calculated using the same normal kernel distance-weighted approach of Sharp *et al* (2008). In other words, for each 500m cell a value was generated that reflected the total volume (or number) of buildings around the cell. This total value was the sum of the number of buildings (or area of buildings) within different distance bands from the 500m cell, with the value for each band adjusted by a weighting reflecting the distance from the cell.

2.30 Although it is not known how any effect of buildings on stone curlews diminishes with distance, we used a half-normal kernel weighting determined by a standard deviation (SD) *s*, where *s* ranged from 250m to 2000m, in steps of 250m. The weight W_{ik} given to a band *k* at a distance D_{ik} from 500m cell *i* was $W_{ik} = exp(-(D_{ik}/s)^2)$. Then the value of the local building density variable for 500m cell *i* is a weighted sum of the number or area of buildings in all bands, namely $XB_{Ni} = \sum_k W_{ik} B_{Nk}$ and $XB_{Ai} = \sum_k W_{ik} B_{Ak}$ for local building density based on number and area of buildings respectively. For computational efficiency and tractability, the summation is limited to bands within two standard deviations (*s*) of the 500-m cell *i* (i.e. where $D_{ik} \leq 2s$).

2.31 When $D_{ik} = 0$, the weight is 1.0, at distances D_{ik} of *s* and 2*s*, the weighting W_{ik} is reduced to 0.368 and 0.018 respectively. Larger values of *s* cause the predictor variable X_i to be influenced by the amount of buildings over greater distances (Figure 2).

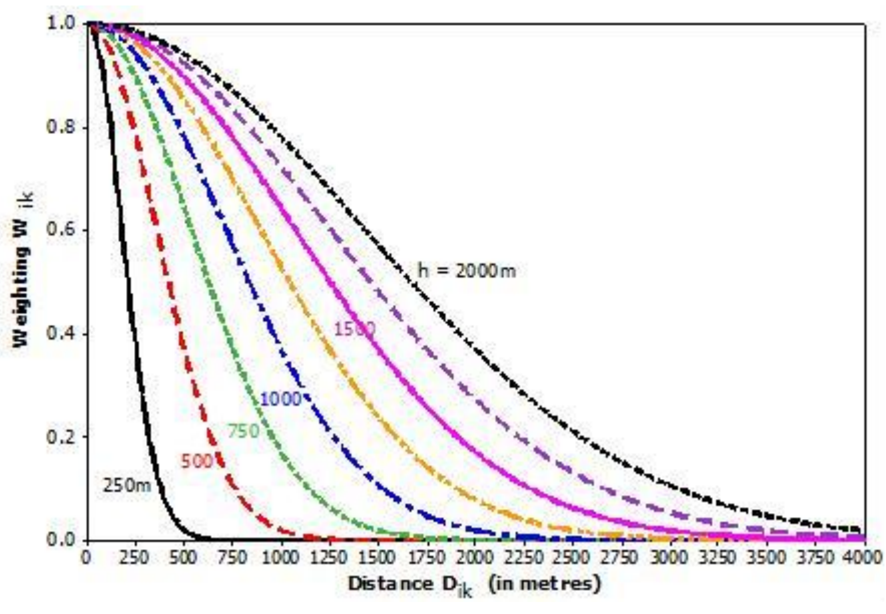


Figure 2: Weighting (W_{ik}) given to the amount of buildings in 50m cell (k) at distance D_{ik} from a 500m cell of stone curlew nest numbers, as a function of the weighting standard deviation *s* (where *s* = 250m, 500m, ... ,2000m)

2.32 We called the variables obtained by the kernel weighting procedure "local densities", where the adjective "local" refers to the region (defined by *s*) of expected influence of buildings.

Distance from Thetford

2.33 Distance to Thetford was calculated for all grid cells, using a Thetford settlement boundary, extracted from the OS builtup areas GIS layer (Open Source data). Grid cells where the centre of the cell fell within the Thetford boundary were classified as zero and for all other grid cells the distance measurement extracted from the GIS was the distance from the centre of the cell to the nearest part of the Thetford boundary.

Roads

2.34 A road layer, generated in the original work and extracted from OS Mastermap data, were used to determine which grid cells were intersected by roads, and for those not intersected by roads, the distance from the edge of each grid cell to the nearest road. A separate file of A roads was extracted from the Open Source OS Meridian 50k vector data, and objects were merged to give a single line for each a road. The distance from the edge of each grid cell to the nearest point of each individual A road was then determined.

2.35 From these distances, two road variables were derived: distance to the nearest A-road and distance to the nearest Trunk A-road (i.e. A11, A14 or A47).

Field Sizes and proximity to field boundaries

2.36 Close visual scrutiny of the CEH Landcover parcels indicated that they were not a reliable dataset from which to determine field boundaries. Visual inspection showed that individual fields were often comprised of multiple CEH Landcover patches. We therefore used data relating to Rural Land Registry 'RLR' Parcels, provided under licence by Natural England.

2.37 In order to derive a variable for our models which described the proximity of field boundaries to different parts of each grid square, we extracted all RLR parcels which were within arable land (described using the CEH Landcover data) and intersected our study area (based on the 500m grid cells). These parcels were converted from regions within the GIS (i.e. polygons) to lines (polylines), to give a GIS layer that was arable boundaries. Within each of our 500m grid cells we generated 25 points, evenly spaced at 100m intervals (these points were essentially the central points of a 100m grid, aligned to the Ordnance Survey National Grid). Taking all points that were within arable land (from Landcover data) we measured the distance to the nearest boundary in our arable boundary file. The mean value for each 500m grid square was used within the models.

2.38 We also considered field size separately by extracting all RLR parcels that where within arable (as defined by Landcover data) and intersected our 500m grid. Duplicate parcels (some parcels were in the data file multiple times), were removed and the number of nest records (if any) were extracted for each parcel. This allowed us to compare parcels with and without nests. We also generated distance bands around field boundaries, by converting the field boundary file to polylines and buffering these. Taking distance bands that fell within RLR parcels we then extracted the number of nests in each distance band and the area of each band. Only land surveyed in all years was used and, only nests that were accurately plotted (8 or 10 figure grid references) were used in this analysis.

2.39 As a further check we extracted parcel data within each settlement distance band, for each band extracting data on each land parcel that intersected the settlement band. This allowed us to check whether field size varied with distance from settlement.

Spatial Modelling of Nest Density

2.40 The simple analyses described above are not entirely satisfactory because they consider the effects of proximity to buildings and roads separately and ignore possible confounding effects between the two variables. We therefore performed an analysis to take both variables into account together. This was only done for arable land, because of the spatial variation in habitat quality on semi-natural grassland. Stone curlews select semi-natural grassland that is short and they avoid areas with tall swards (Green, Tyler, & Bowden 2000). In order to consider semi-natural grassland comprehensively within the analysis, data describing vegetation height in each area of grassland in each year would be required. Such data are not available.

2.41 We measured distance from each 500m cell to (i) the nearest settlement (as defined above), (ii) the nearest A-road and (iii) the nearest Trunk A-road. Shortest distances were set to zero if the feature was present within the 500m cell. For building variables we used the half-normal kernel weightings described above.

2.42 Generalised linear modelling (GLM) analyses were used to relate each of these half-normal kernel weighted building (X_H) density variables to the stone curlew nest density in each 500-m cell. The aim was to find the distance weightings which best described the observed data. Modelling nest density per unit area of suitable land rather than merely the presence/absence of a nest per 500m cell enabled any derived models to be used to predict the effects of different amounts of buildings (and/or road traffic) on stone curlew nest density (on suitable land) and thus nest numbers. Specifically, we fitted quasi Poisson log-linear GLM models.

2.43 Initial model selection was based on fitting GLM models with Poisson errors using one buildings variable and one distance to road variable. Models were fitted using all possible combinations of *s* for the buildings. Additional candidate variables included distance to nearest settlement, distance to nearest Trunk road and distance to nearest A-road (including trunk roads). Effects of any extra-Poisson residual dispersion in nest numbers were allowed for by re-fitting models using quasi-Poisson errors which increases the Poisson-likelihood-based standard errors (SE) of the regression model coefficients $\{\beta_H , \beta_R\}$ by a factor ($\sqrt{q}$), where q is the estimate of the Poisson variance dispersion parameter.

2.44 The relative fits of these alternative two-variable (one buildings, one road) GLM models were assessed and compared by their quasi Akaike Information Criterion (QAIC) defined by QAIC = - 2 (Log Likelihood)/q + 2k where k is the number of parameters in the fitted model (including the intercept and estimated q) (Burnham et al 2011). A smaller value of QAIC indicates a better model fit to the observed data. The increases (ΔQAIC) in QAIC for any model above that for the best fit model were used to estimate the relative likelihood (exp(-ΔQAIC/2)) and relative probabilities (Akaike weights) of the different models assessed and then these weights were used in calculating model-averaged estimates of the parameter for each explanatory variable (Burnham, Anderson, & Huyvaert 2011). GLM models were fitted using the glm function, QAIC, Akaike weights and model-average parameters were computed using the AICcmodavg package, all within the R software package (version 2.15.2).

2.45 The relative fits of these alternative two-variable (one buildings, one road) GLM models were assessed and compared by their quasi Akaike Information Criterion (QAIC) defined by QAIC = - 2 (Log Likelihood)/q + 2k where k is the number of parameters in the fitted model (including the intercept and estimated q) (Burnham, Anderson, & Huyvaert 2011). A smaller value of QAIC indicates a better model fit to the observed data. The increases (ΔQAIC) in QAIC for any model above that for the best fit model can be used to estimate the relative likelihood (exp(-ΔQAIC/2)) and relative probabilities (Akaike weights) of the different models assessed (Burnham, Anderson, & Huyvaert 2011). GLM models were fitted using the glm function in the R software package (version 2.15.2).

Spatial correlation

2.46 A potential problem with many species data is that there may have a spatial component. This can result in spatial autocorrelation which causes problems for statistical methods that make assumptions about the independence of residuals (a residual is the difference between an observed and a predicted value). Spatial autocorrelation occurs where the presence of some quantity (e.g. a nest) makes its presence in neighbouring areas more or less likely. If there is spatial autocorrelation in data it will lead to a spatial correlation of residuals, for example positive residuals will tend to occur together. Spatial autocorrelation of residuals can influence the reliability of any such statistical models relating environmental factors to species' distributions, both in terms of accuracy of statistical significance of effects and accuracy of the effect sizes (i.e. model coefficients).

2.47 We used Generalised Linear Mixed Models (GLMM), which are an extension of Generalised Least Squares (GLS) to cope with errors/residuals which are both non-normal (such as our (quasi) Poisson nest count errors) and non-independent (e.g. spatially correlated, as here). Bolker *et al.* (2009) provide a useful discussion of the range of different software options to fit GLMM in general, but conclude that no single approach is optimal for all problems but depends on the importance of hypothesis testing, accurate unbiased parameter estimating and prediction. Beale *et al*. 2010 used a wide range of simulated data with varying strengths and varying spatial scales of exponential-decay spatial auto-correlation to assess the accuracy (bias and sampling precision) of various models and fitting methods on parameter estimates and hypothesis test Type I error rates. They concluded that as spatial autocorrelation increased, ignoring it by fitting Ordinary Least Squares (OLS) models led to over-estimation of (absolute values of) predictor variable parameter estimates and much too high Type I error rates. In contrast, GLS models, even fitted with a slightly different (spherical) form of autocorrelation structure was one of several model methods providing "generally good overall performance" (Beale *et al.* 2010). Unfortunately their study was based solely on normally distributed correlated errors, well fitted by GLS; however GLMM are the extension to GLS for non-normal errors.

2.48 We fitted GLMM extensions of the non-temporal GLM model involving buildings and road variables that included and allowed for a spatial auto-correlation (r) between model residuals which declined with distance d apart of nest observation cells in accordance with either an exponential decay ($r = \exp(-d/w)$ or Gaussian ($r = \exp((-d/w)^2)$ function. Model parameters (including w) were fitted by maximising the penalised quasi-likelihood using the glmmPQL function of package MASS in R, which can incorporate a range of such spatial correlation structures. However, such model fitting using glmmPQL on our stone curlew nest data was slow. Therefore GLMM were only fitted to the combinations of buildings and road variables which gave the best fits from the initial analyses.

2.49 As a separate approach to adjusting for broad scale spatial variation in nest density , we re-fitted the best-fitting GLM models with an additional spatial blocking factor represent the study area 500m cells group into a grid of square blocks of 20 by 20km, 10 by 10 km, 5 by 5km or 2.5 x 2.5km, referenced to the National Grid. The model parameters for the housing, road and any other explanatory variables involved in these models broadly represent their average within-block relationship with nest density. The smaller the spatial block size, the finer scale of spatial clumping of nests with the study area that is incorporated and allowed for in the models. Obviously, if we had a separate block for every 500m cell, the block differences would explain all of the variation in nest density.

GIS

2.50 GIS data handling was conducted using Quantum GIS Version 1.8.0 and MapInfo Version 9.5.1. All spatial queries and the generation of the maps within this report were undertaken using MapInfo.

Summary of data sources

2.51 We summarise the data sources used and referred to within the report in Table 2.

Table 2: Summary of data used in analysis/referred to in rest of the report

Data	Source
Suitable soils	Boundary file derived from NatMap Vector Data in previous work
Semi Natural Habitat	SAC boundary file; from Natural England website
Arable Land	From CEH Landcover data; excluding area within SAC
Buildings	OS Mastermap provided by Breckland Council; classified using AddressBase Premium provided by Breckland Council
Thetford settlement boundary	Boundary file from OS Open Source data relating to built-up areas.
Field boundaries and field areas	RLR Parcels provided by Natural England
'Settlements'	Derived from OS Mastermap and filtered to remove isolated buildings
Stone Curlew nests	Nest locations provided by Rhys Green/RSPB
Survey coverage	Polygons provided by Rhys Green showing areas where surveys were not conducted in all years. For each mapped polygon data on yearly coverage was provided.

2.52 For individual grid cells the following data were collated and included in the model:

- Area and number of buildings (categorised by building type) surrounding the cell, expressed using our half-normal kernel weighting
- Number of buildings at different distance bands (500m) from each cell
- Area of arable land within cell
- Distance to nearest road
- Distance to nearest A road
- Distance to Thetford
- Distance to nearest settlement (settlement defined using our 50 buildings within 250m threshold)
- Area of woodland within cell
- Area of woodland in adjacent cells
- Average distance to RLR parcel boundaries (extracted using points spaced at 100m intervals on arable land)
- Average size of RLR parcels (extracted using points spaced at 100m intervals on arable land)
- Area of semi-natural habitat within cell
- Area of semi-natural habitat in adjacent cells

Structure of Later Sections

2.53 We structure the results sections as follows:

- **Overview of nest data, including habitats and trends over time**: this considers the number of nests found by year, number of nests within the SPA, habitat selection and trends over time.
- **Overview of data on field size and building size**: this section is mostly simple data summaries. We review the data on field size, checking field size within our

500m settlement distance bands and presenting data on nest densities by field size categories and nest sites in relation to distance from field boundaries. We also summarise data relating to our building classification.

- **Stone curlew nest density in distance bands around settlements**: this section considers nest densities within the different settlement distance bands (single distance bands drawn around all settlements). It also includes the results relating to individual settlements (the voronoi polygons) and changes in use of distance bands over time.
- **Initial Modelling**: the previous work found significant effects for buildings and roads. We therefore consider different combinations of road and building variables to derive the best simple model to build on in later analyses.
- **Overview of data within 500m grid and consideration of nest densities in relation to buildings and other variables**: in this section we consider the additional variables that are considered in the model. We present a series of two-way tables, summarising stone curlew nest density in relation to buildings (using the building variable selected in the previous section) and an additional variable.
- **Inclusion of additional variables and combinations of variables to our initial model**: this section includes the additional variables (considered in the previous section) to the initial model, and also tests building areas at different distance bands, different building types and considers spatial autocorrelation.

2.54 The first section of the results (Section 4 of the report) therefore uses nest data and habitat data, but does not consider buildings at all. Section 5 gives an overview of data on field size and buildings; it is mostly simple data presentation. Section 6 uses our ‘filtered’ settlement layers; isolated buildings are not considered in this section and the data are not summarised using 500m grid cells. The remaining results (sections 7-9) use the 500m grid cells and all buildings to model nest density in relation to buildings, major roads and a range of other factors including building type.

3. Results: Overview of Nest Data, including habitats and trends over time

Overview of Nest Data

3.1 In total across all years, 5116 nest locations fell within the study area (defined by our 500m grid). Data are summarised by year and precision in Appendix 1. For the period 2008-2011 some 1184 nests were found, which is the new data that was not available for the previous analyses.

Nests locations with respect to habitat

3.2 Nests were categorised by habitat as found on semi-natural habitat (as defined by the SAC boundary), arable land (from Landcover, excluding parts of the SAC identified in the landcover as arable) or other habitats. Based on our definition of habitat types, our study region comprising 2927 500m cells (total area 731.75 km^2) included 326.9 km^2 'Arable' (45%), 73.7 km^2 'Semi-natural' habitats (10%) and 331.2 km^2 'other' habitat types (45%).

3.3 A total of 2610 (51%) nests were on arable, 1303 (25%) nests were on semi-natural habitats and 1203 (24%) nests were in 'other habitats', primarily grassland habitats (Table 3).

Table 3: Number of nests by land cover type, all years combined. Semi-natural are all nests that fall within the SAC boundary. Data includes all nests.

Broad Landcover Category	Landcover Subcategory	area (ha)	Number of Nests				% Land area	% Nests
			Semi Natural	Arable	Other	Total Nests		
Arable and horticulture	Arable bare	15003.7	3	1609	0	1612	20	32
Arable and horticulture	Arable unknown	18010.4	8	1001	0	1009	25	20
Broad leaved, mixed and yew woodland	Deciduous	3982	11	0	41	52	5	1
Broad leaved, mixed and yew woodland	Mixed	3007.3	2	0	33	35	4	1
Broad leaved, mixed and yew woodland	Scrub	20.7	0	0	0	0	0	0
Built up areas and gardens	Bare	173.8	1	0	3	4	0	0
Built up areas and gardens	Suburban	2029.1	4	0	16	20	3	0
Built up areas and gardens	Urban	198.4	0	0	1	1	0	0
Built up areas and gardens	Urban industrial	605.7	0	0	4	4	1	0
Calcareous grassland	Calcareous grassland	8.7	0	0	0	0	0	0
Coniferous woodland	Conifer	9555.5	6	0	73	79	13	2
Coniferous woodland	Felled	1130.8	0	0	6	6	2	0
Dwarf shrub heath	Heather and dwarf shrub	141	31	0	0	31	0	1
Dwarf shrub heath	Heather grass	53	2	0	7	9	0	0
Fen marsh and swamp	Fen marsh and swamp	5	0	0	0	0	0	0
Freshwater	Lake	236.7	0	0	8	8	0	0
Freshwater	River	5.8	0	0	0	0	0	0
Improved grassland	Hay	37.6	0	0	0	0	0	0
Improved grassland	Improved	11300.6	459	0	434	893	15	17
Inland rock	Despoiled land	56.5	0	0	12	12	0	0
Neutral grassland	Neutral grassland	527	0	0	10	10	1	0
Rough low-productivity grassland	Rough low-productivity grassland	7270.9	776	0	555	1331	10	26
Supra-littoral sediment	Sand dune	2.4	0	0	0	0	0	0
TOTAL		**73362.6**	**1303**	**2610**	**1203**	**5116**	**100**	**100**

3.9 Excluding the nests from areas where survey coverage was not complete (i.e. no data for some years) there were a total of 4916 nests (i.e. 200 nests (4%) were in the areas with incomplete survey coverage). Looking at these data allows comparison of numbers over time. Numbers of nests found per year show an increasing trend, with a notable dip in 2001 when limited field work was conducted due to foot and mouth disease (Figure 3).

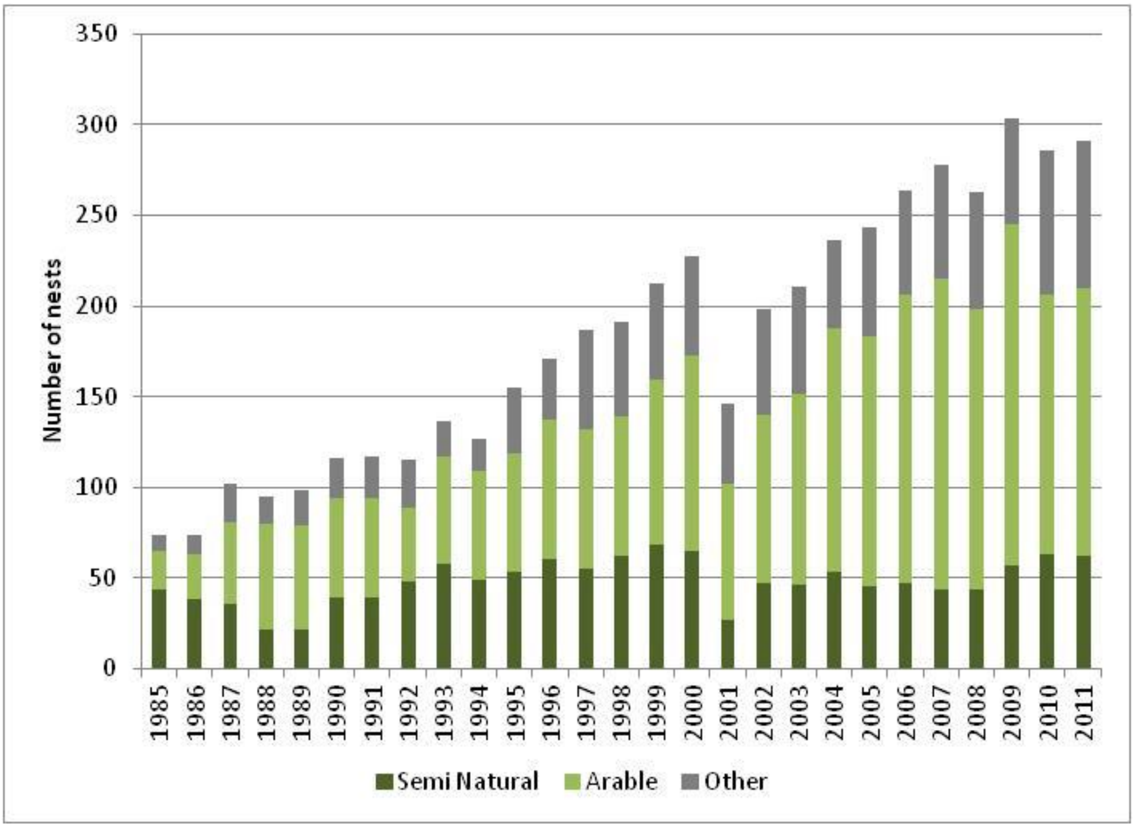


Figure 3: Nest numbers by year by habitat. Only data for areas with complete survey coverage is shown

3.10 The number of nests on semi-natural habitats has remained approximately constant (with some marked fluctuations) whereas the number of nests on arable and other habitat types have steadily increased during the study period, although there was a marked dip in arable nests in 2010 (Figure 4).

3.11 In Figure 5 we show trends in density over time for arable, semi natural and 'other ' habitats. In order to calculate nest density in these 'other' habitat types we have used only nests that fell within Improved Grassland or Rough Low Productivity Grassland (from CEH Landcover) and calculated the density using the area of these habitats. The area is constant for all years (the plots are derived using areas with complete survey coverage only). It can be seen that nest densities on semi-natural (the SAC) are virtually always higher than densities on grassland or arable.

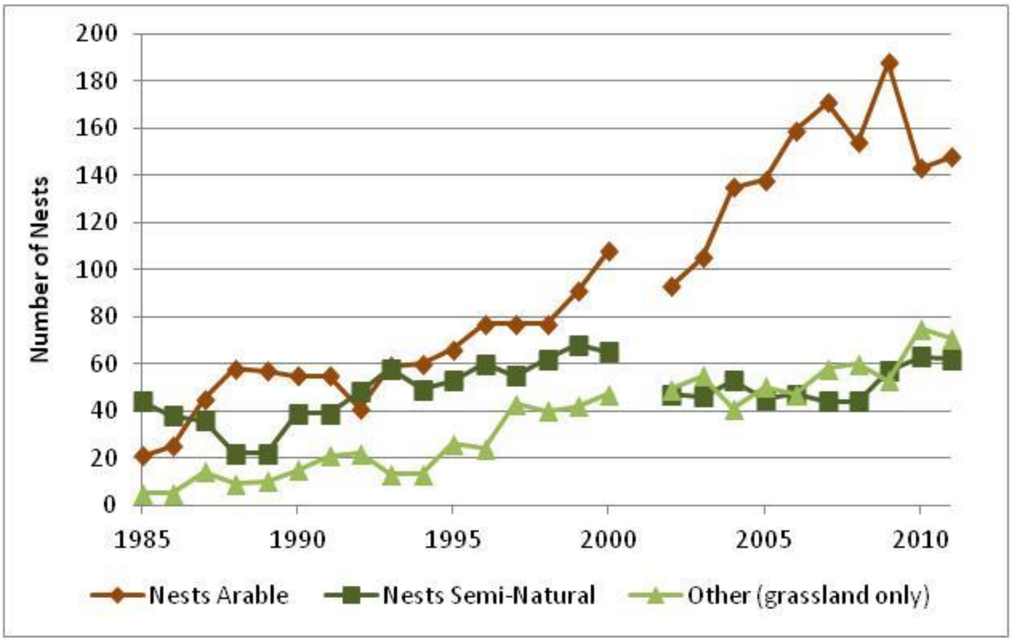


Figure 4: Trends in number of nests on arable, semi-natural and other habitats. For other the numbers of nests plotted are those in CEH Landcover categories of "Rough Low-productivity Grassland" and "Improved Grassland" only. Plots are derived using nests and landcover data from areas with complete survey coverage in all years.

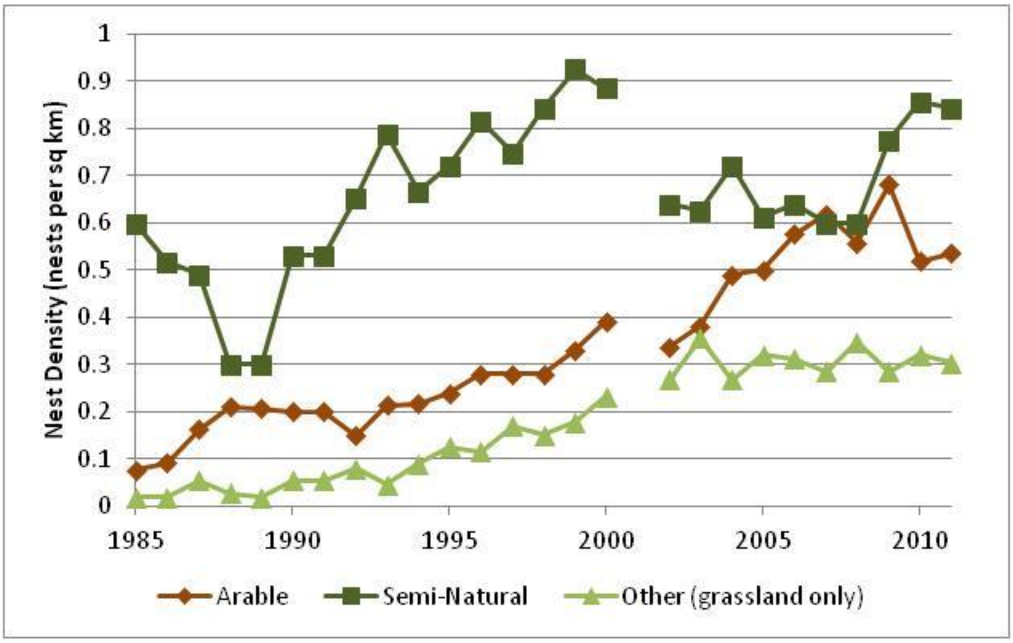


Figure 5: Trends in nest density (per km^2) on arable, semi-natural and other habitats. For other the numbers of nests plotted are those in CEH Landcover categories of "Rough Low-productivity Grassland" and "Improved Grassland" only. Plots are derived using nests and landcover data from areas with complete survey coverage in all years.

3.12 Of the 4916 nests from the areas with survey coverage in all years, 4387 (89%) were within the SPA boundary. Trends are shown in Figure 6 and in Figure 7 we show the proportion of nests by year within and outside the SPA. The percentage of nest records outside the SPA has increased over time, particularly since around 2000 (Figure 7), with the proportion of nests outside the SPA ranging from 3% (in 1985) to 24% (in 2011).

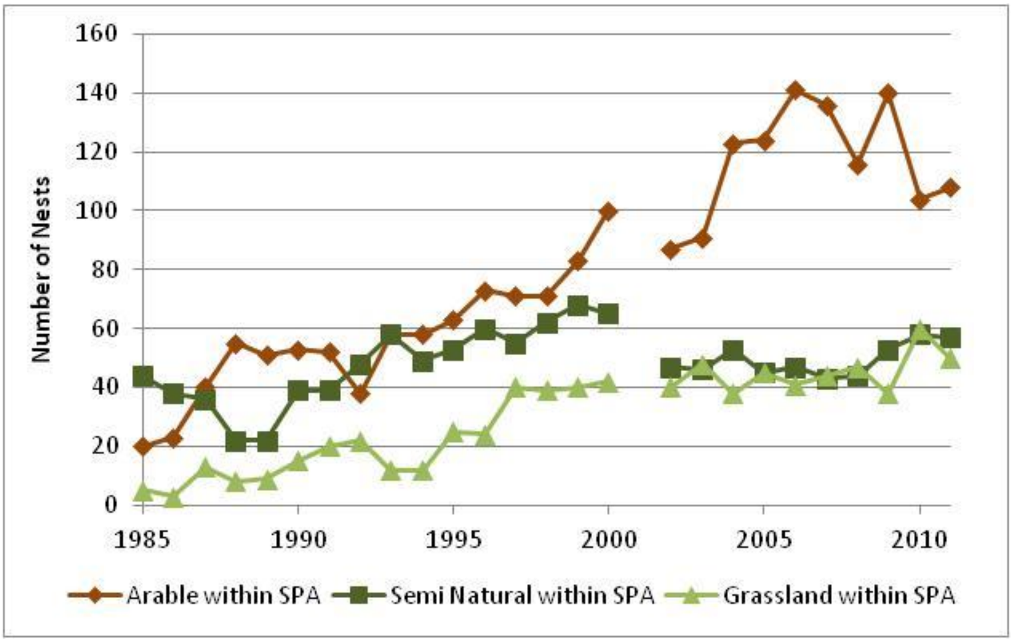


Figure 6: Trends in the number of nests on arable, semi-natural and other habitats within the SPA only. Grassland within the SPA includes only the CEH Landcover categories of "Rough Low-productivity Grassland" and "Improved Grassland". Plots are derived using nests and landcover data from areas with complete survey coverage in all years within the SPA.

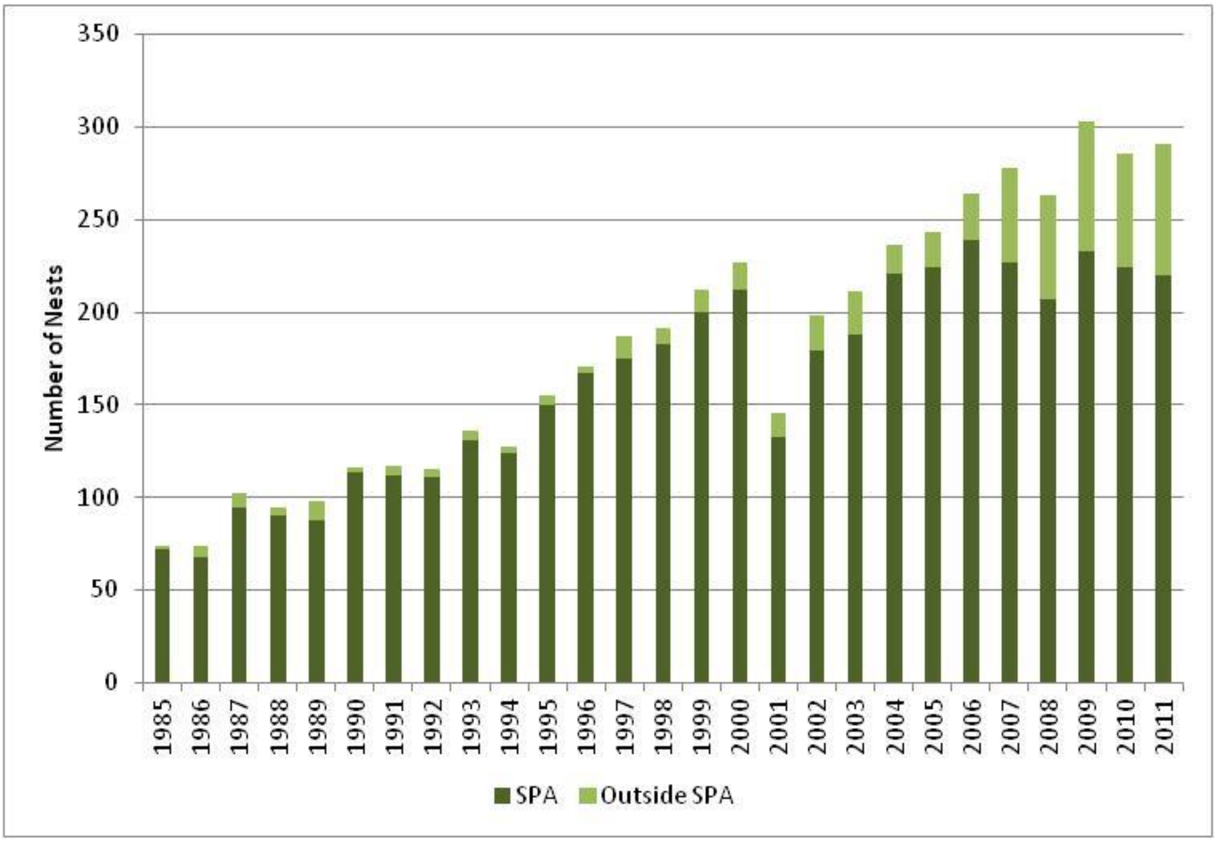


Figure 7: Numbers of nests over time inside and outside the SPA. Data for areas with complete survey coverage in all years only

3.13 In Figure 8 we show the number of grid cells occupied by year, both within and outside the SPA. Only areas with complete survey coverage in all years are shown. It can be seen that the distribution has expanded over time, with the number of occupied grid cells reaching a maximum of 2013 cells in a single year (2009) and the number of occupied cells in a given year closely matching the total number of nests. There was a strong correlation between the number of occupied grid cells and the number of nests in a single year (Person correlation coefficient =0.995; p<0.001), suggesting that as the number of pairs increases the distribution is expanding with birds spreading rather than local density increasing.

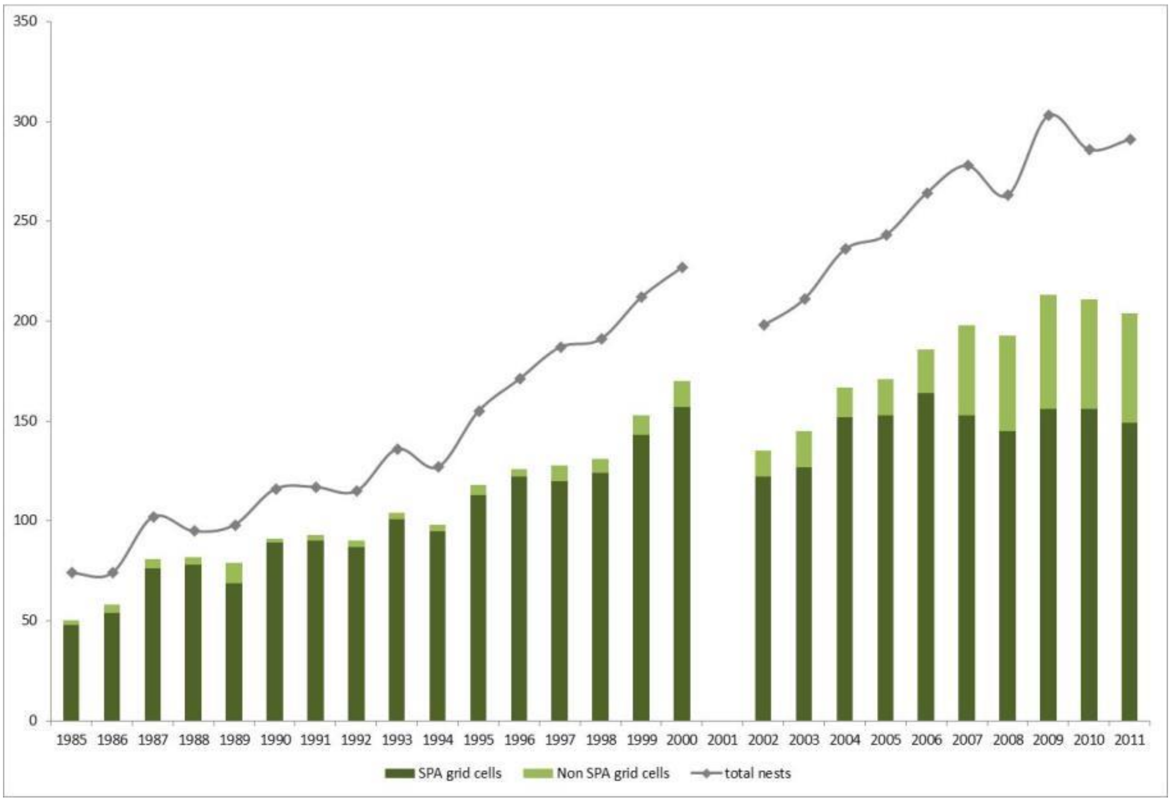


Figure 8: Number of grid cells occupied (bars) and number of nests (line) per year. Data for grid cells with complete survey coverage in all years only.

Key findings:
In total, 5116 nest locations are included in the analysis covering the period 1985-2011.

- Roughly half (51%) of all the nests were on arable, a quarter (25%) nests were on semi-natural habitats and another quarter (24%) were in 'other habitats', primarily grassland (outside the semi-natural).
- Nest densities are highest (in most years) on semi natural habitats.
- Densities have fluctuated markedly over time on the semi natural areas however, whilst on arable and other habitats they have tended to increase over time.
- While the majority of nest records are within the SPA, the proportion of nest records falling outside the SPA boundary has increased over time and the population appears to be spreading.

4. Results: Overview of data on field size and building size

Field sizes in relation to settlements

4.1 In later models we use a measure of either the mean or the maximum distance from points (evenly spaced on a 100m grid) to the nearest RLR parcel boundary. Grouping points within individual parcels, both measures significantly correlated with parcel area (Pearson correlation coefficients=0.759 and 0.852 respectively; $p<0.001$).

4.2 Using the settlement distance band layer (derived using >50 buildings within 250m) within the GIS we extracted all RLR parcels (that fell within our arable, as defined by the CEH Landcover data) and that intersected the distance bands within our study area. There were significant differences in the area of field parcels in different distance bands, (Kruskall Wallis H=111.78; 6 df; $p<0.001$) and in the distance from our 100m points to the edge of RLR parcel boundaries (Kruskall Wallis H=230.73; 6 df; $p<0.001$). The median field area in the 500m distance band was 6.8 ha and for the 3500m distance band it was 14.4ha, with distances increasing across distance bands (Figure 9).

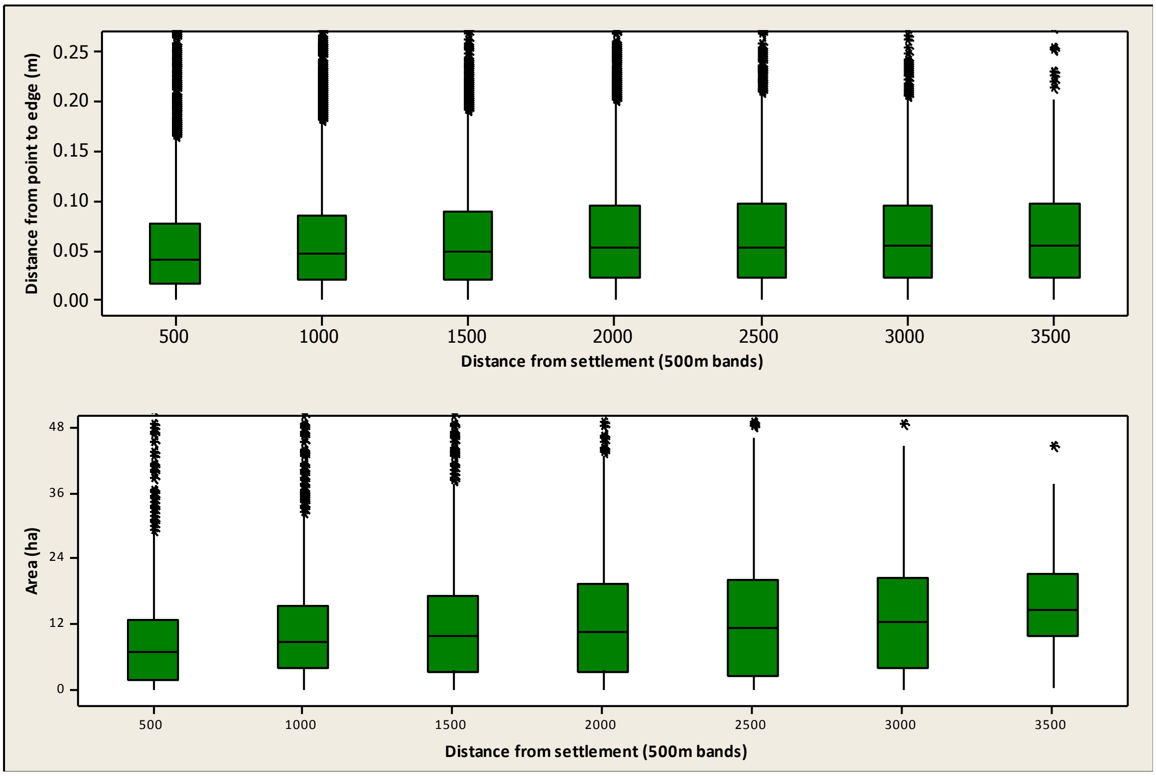


Figure 9: Field area and distance from 100m points to edge of RLR boundary in relation to distance from settlement (500m bands; settlements defined using the 50 buildings within 250m threshold). Both y axis are truncated. Horizontal lines indicate the median for each category; boxes show the 25-75% range. The whiskers show the upper and lower limits and the asterisks indicate outliers (unusually large or small observations).

Field sizes and use by nesting stone curlews

4.3 In total there were 3047 different RLR parcels that intersected arable land (defined by landcover data) and intersected our study area. A total of 659 of these parcels had supported at least one stone curlew nest (data from all years 1988-2011, whole study area) and the number of nests within this layer was 2656.

4.4 While there were many smaller fields, these accounted for a relatively small part of the study area (because of their small size). For example 61% of parcels were 10ha or less in size, these accounted for 22% of the area and held 18% of the nests (Table 4). There were statistically significant differences in nest density on arable land between the different field sizes (Chi-square goodness of fit test, χ^2_{10}= 62.23, p<0.001). For fields of 10ha or more (which is 87% of the fields), nest density is relatively consistent at around 0.09 nests per ha (Test for differences: χ^2_7= 7.18, p = 0.41).

Table 4: Nesting attempts by field size. Field size data from RLR GIS layer. Categories are in 2.5ha bins (categories listed according to upper limit of category).

Field size categories (max)	number parcels	Total area (ha) within study area	% total area	total nests 1988-2011	% total nests	Average annual nest density per km^2)
Less than 2.5ha	912	719.642	2	39	1	0.24
5ha	285	1075.774	4	47	2	0.19
7.5ha	358	2238.701	7	144	5	0.28
10ha	317	2736.93	9	257	10	0.41
12.5ha	272	3050.802	10	302	11	0.43
15ha	227	3104.377	10	261	10	0.37
17.5ha	177	2892.177	10	261	10	0.39
20ha	95	1800.613	6	152	6	0.37
22.5ha	105	2224.195	7	224	8	0.44
25ha	83	2001.573	7	184	7	0.40
above 25ha	216	8304.61	28	785	30	0.41
TOTAL	**3047**	**30149.39**	**100**	**2656**	**100**	0.38

Nest locations in relation to distance from field boundary

4.5 Field boundaries within the RLR parcel data were extracted for arable land within the study area, and 50m distance bands generated around the edges of these parcels to explore whether there is evidence that birds tended to nest away from the edges of fields. Only nests where the location (grid reference) was recorded to at least 8 digit precision (see Appendix 1) were used, and the number of nests was extracted within the land area (surveyed in all years) within each settlement distance band. In total 1071 nests were used and there was no significant difference in the proportion of nests in each distance band accounting for the area in each distance band (Chi Square goodness-of-fit test; χ^2_4=2.40; p=0.663). Nest densities are summarised in Table 5.

Table 5: Stone curlew nest density in arable RLR parcels, by distance from edge of parcel (i.e. field boundaries).

Distance from RLR parcel boundary (m)	Area (ha)	Total Number of nests	Nest Density (birds per ha)
50	12,740	565	0.044
100	7237	327	0.045
150	2921	115	0.039
200	1027	49	0.047
250	288	15	0.052
TOTAL	24,213	1071	0.044

Key findings: Field size varies with distance from settlement, with bigger fields occurring further from settlements. There is no evidence that nest density is different in bigger fields and no evidence that birds particularly avoid (or show a preference) for nest sites close to field boundaries.

Overview of the Buildings Data and Sizes of Individual Buildings

4.6 Based on the MasterMap Premium database and building type classification for the study region, there were 29,565 residential buildings, 2365 commercial buildings, only 71 classed as agricultural, 185 as 'other' types and 28,549 were 'unclassified.

4.7 There were significant differences in the size of buildings within our different categories (Kruskal-Wallis H=20095.12; 4 d.f., $p<0.001$). Agricultural buildings (of which there were only 71) tended to be the largest. Residential buildings were smaller than all the other categories apart from those buildings which were 'unassigned'. Unassigned were the smallest (with 50% of them under 18 m^2 in size), however some were also exceptionally large (maximum nearly 11,500 m^2). Building sizes are summarised in Table 6 and Figure 10.

Table 6: Building sizes by category

Building Type	Mean Size (m^2)	Standard Error	Median	Minimum	Maximum	Count (% of total)
Agricultural	507.091	68.6548	290.508	28.5683	3,916.4	71 (0.1%)
Commercial	490.440	23.9427	148.485	3.4428	18,723.6	2,388 (3.9%)
Other	293.306	51.5313	177.881	4.3545	7,362.5	185 (0.3%)
Residential	75.745	0.3462	63.853	3.3494	2,861.9	29,651 (48.7%)
Unassigned	70.475	1.5637	17.896	0.7126	11,496.1	28,614 (47.0%)

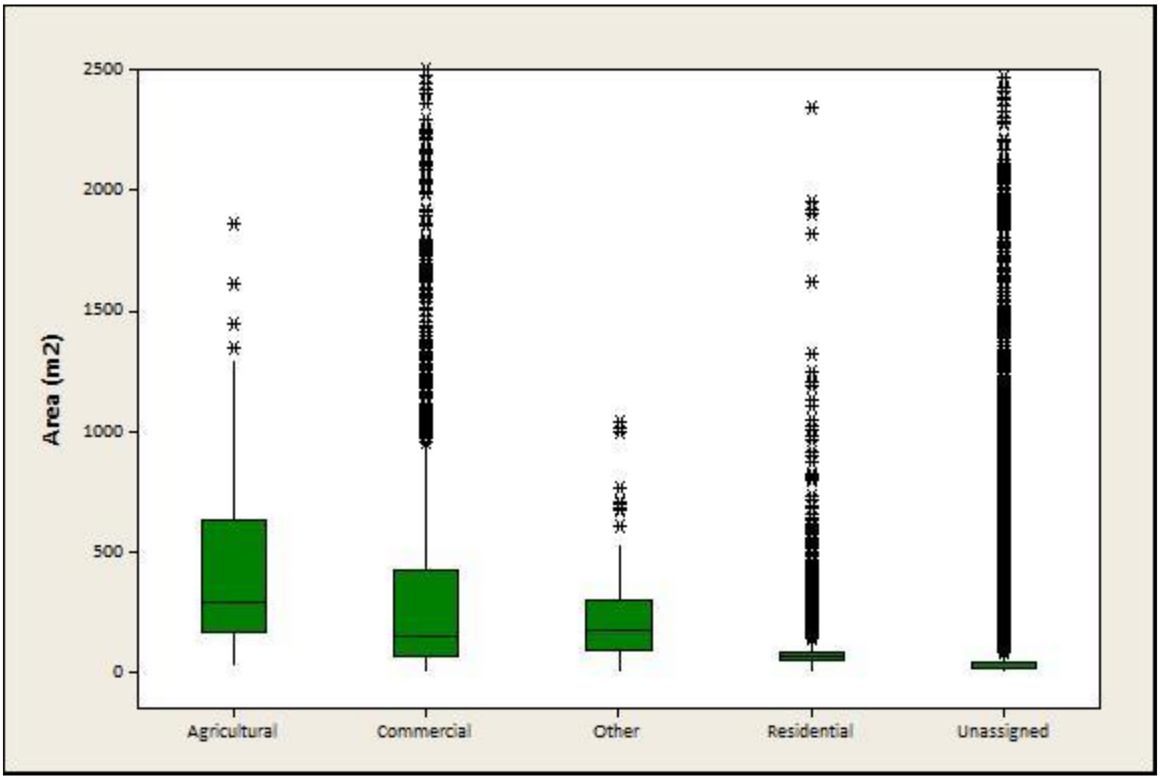


Figure 10: Building sizes by category. Y axis is truncated. Horizontal lines indicate the median for each category; boxes show the 25-75% range. The whiskers show the upper and lower limits and the asterisks indicate outliers (unusually large or small observations).

Key Findings: Building size varies between the different classes of buildings used in later analyses. Buildings which have not been classified (described as 'Unassigned') are mostly very small (for example garden sheds, greenhouses etc.) and make up a high proportion of the number of buildings.

5. Results: Stone Curlew nest density in distance bands around settlements

Assessing distance from settlements over which nest density is reduced on arable land

5.1 Stone curlew nest density on arable land with the study region appears to increase with distance from the nearest settlement (based on a threshold of other 50 buildings within 250m) (Figure 11). This general relationship is observed for each 4-5 year period over the last 24 years, even though nest numbers on arable land have more than doubled. Any changes over time in the distance over which reduced nest densities can be detected statistically are summarised below.

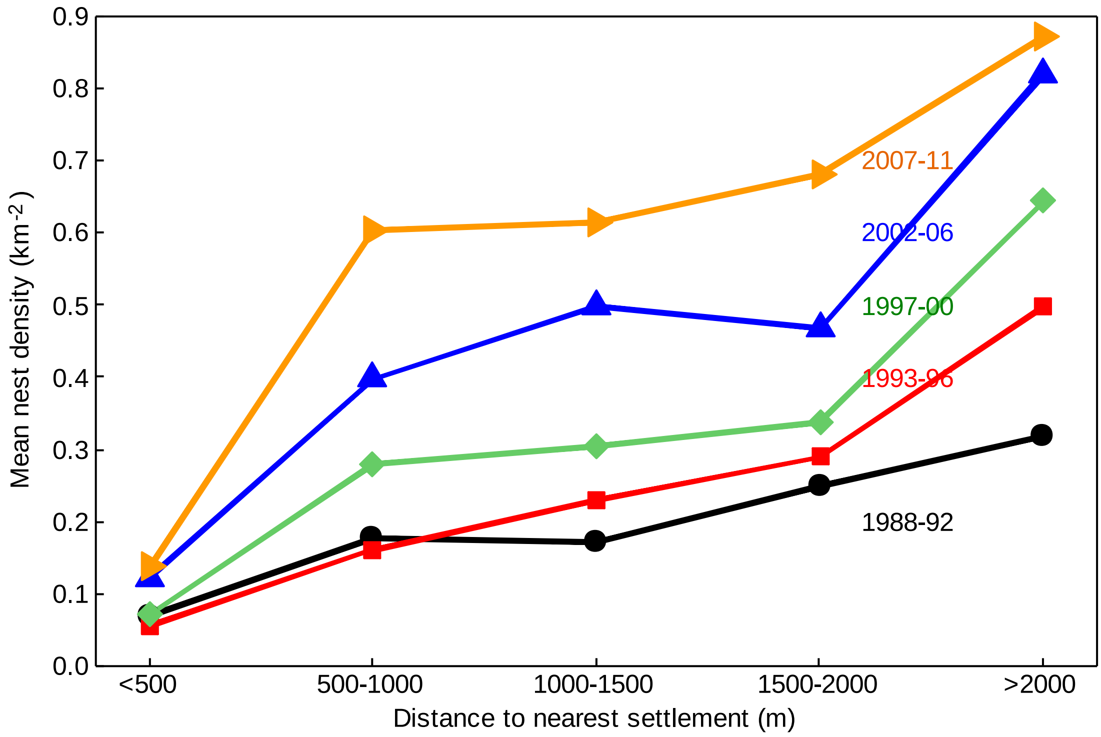


Figure 11: Average stone curlew nest density (per km^2) on annually surveyed arable land at different distance bands from the nearest settlement (defined by a threshold of 50 other buildings within 250m) for each 4-5 year period over 1988-2011.

5.2 Successive Chi-square tests were used to assess the maximum distance band in which nest density was statistically significantly lower than average nest density in arable land at all greater distances from the nearest settlement (settlements defined using our threshold of buildings with 50 other buildings within 250m). This was done for all years combined, each 4-5 year period and for each individual year (

5.4 Table 7).

5.5 When nest numbers were combined across all 23 study years, lower nest densities were detected (i.e. test *P* < 0.05) up to 2000m from the nearest settlement (although not shown in the table, no effects were ever detected beyond 2000m). When based on nest total in successive 4-5 year periods, nest densities were detectably lower up to 1500m in the earliest 1988-92 period, but up to 2000m in all subsequent periods (Table 7).

5.6 Analyses of the individual year data, which inevitably involve far fewer total nests and hence have lower statistical power to detect effects, revealed statistically significant (i.e. test *P* < 0.05) lower nest densities with the first 500m (or further) for all except two (9%) of the 23 years. Even in these two years (1991, 1992), observed nest density still tended to increase with distance from settlement. Within the individual year analyses, the maximum distance from the nearest settlement at which lower densities were detected were 500m in 13 (57%) of the 23 years, 1000m in six years (26%), 1500m in 1996 and 2000m in 2006 (Table 7).

5.7 These analyses were repeated using a more inclusive definition of settlements which included any building which had at least 10 other buildings within 250m (Table 8). This less restrictive definition of settlements added in numerous smaller, isolated, clusters of buildings which reduced the distance to the nearest 'settlement' for many areas of arable land. In particular, using a threshold of 50 buildings led to 18% and 25% of arable land being within 500m and 500-1000m respectively of the nearest 'settlement'; in contrast with the less strict threshold of 10 buildings, the corresponding percentages were 49% and 34%, such that 83% of all arable land was within 1000m of a 'settlement' and less than 0.1% was greater than 2000m (compare Table 7 and Table 8).

5.8 Using the less restrictive definition of settlements (>10 buildings within 250m), the all years combined tests detected highly significant (i.e. test *P* <0.001) reductions in nest density up to and including the maximum testable distance band of 1000-1500m (Table 8). It should be noted that this definition of 'settlements' will include buildings with relatively few other buildings, and therefore there are more 'settlements' (importantly many of which will be very small, such as clusters of farm buildings). Much more of the study area is therefore classified as near 'settlements'. For example the proportion of the study area within 500m of a 'settlement' using the 50 buildings threshold is 18% and using the less restrictive 10 buildings thresholds it is 49%.

5.9 Analyses of total nest with 4-5 year periods detected reduced nest densities up to 1000m and 1500m in the 1988-96 periods, but in the later three periods covering 1997-2011, nest densities were only statistically lower within the first 500m of these more inclusively defined 'settlements'. Analyses of individual year nest numbers in each distance band also detected statistically lower densities in just the first 500m in 15 (65%) of the 23 years (including all years from 2004 onwards), but up to 1000m in 1991. No effects were detected in the seven other years, six of which were before 1997 when total nest numbers, and thus statistically power, were lower (Table 8).

Table 7: Average density (km-2) of stone curlew nests on areas (km2) of annually surveyed suitable arable land within each band of distance (m) to the nearest "settlement" (defined by ≥50 other buildings within 250m); together with the upper limit of the maximum distance band for which nest density is statistically lower (Chi-square test P value <0.05) than average nest density in the combined higher distance bands (P value for each test given in brackets)

Period	Total nests (N)	Distance band to nearest "settlement" (m)					Max distance (m) with lower nest density
		<500	500-1000	1000-1500	1500-2000	2000-3500	
All Years	2310	0.094 (<0.001)	0.333 (<0.001)	0.373 (<0.001)	0.413 (<0.001)	0.636	2000
1988-92	265	0.069 (<0.001)	0.177 (0.045)	0.172 (0.002)	0.249 (0.162)	0.318	1500
1993-96	262	0.056 (<0.001)	0.162 (<0.001)	0.231 (<0.001)	0.289 (0.001)	0.499	2000
1997-00	352	0.071 (<0.001)	0.28 (0.002)	0.304 (<0.001)	0.338 (<0.001)	0.644	2000
2002-06	628	0.122 (<0.001)	0.397 (<0.001)	0.498 (0.009)	0.467 (<0.001)	0.82	2000
2007-11	803	0.138 (<0.001)	0.604 (0.046)	0.615 (0.008)	0.682 (0.020)	0.871	2000
1988	57	0.041 (0.005)	0.236 (0.879)	0.185 (0.191)	0.214 (0.177)	0.365	500
1989	57	0.041 (0.005)	0.221 (0.655)	0.2 (0.270)	0.3 (0.850)	0.279	500
1990	55	0.061 (0.016)	0.177 (0.274)	0.2 (0.270)	0.3 (0.850)	0.279	500
1991	55	0.122 (0.177)	0.132 (0.075)	0.169 (0.081)	0.236 (0.193)	0.386	0
1992	41	0.081 (0.174)	0.118 (0.264)	0.108 (0.064)	0.193 (0.392)	0.279	0
1993	59	0.041 (0.004)	0.162 (0.077)	0.185 (0.039)	0.279 (0.169)	0.451	500
1994	60	0.081 (0.023)	0.132 (0.023)	0.262 (0.494)	0.172 (0.010)	0.472	1000
1995	66	0.081 (0.012)	0.162 (0.035)	0.277 (0.401)	0.193 (0.009)	0.515	1000
1996	77	0.02 (<0.001)	0.191 (0.014)	0.2 (0.001)	0.515 (0.774)	0.558	1500
1997	77	0.081 (0.004)	0.25 (0.209)	0.215 (0.014)	0.3 (0.030)	0.601	500
1998	77	0.061 (0.001)	0.294 (0.572)	0.246 (0.087)	0.3 (0.104)	0.515	500
1999	90	0.061 (<0.001)	0.265 (0.057)	0.262 (0.005)	0.386 (0.026)	0.73	500
2000	108	0.081 (<0.001)	0.309 (0.029)	0.492 (0.640)	0.364 (0.017)	0.73	1000
2002	93	0.061 (<0.001)	0.25 (0.024)	0.461 (0.920)	0.343 (0.122)	0.558	1000
2003	104	0.061 (<0.001)	0.412 (0.612)	0.431 (0.636)	0.429 (0.454)	0.537	500
2004	135	0.122 (<0.001)	0.397 (0.024)	0.631 (0.856)	0.45 (0.015)	0.859	1000
2005	138	0.183 (<0.001)	0.442 (0.093)	0.461 (0.029)	0.6 (0.116)	0.88	500
2006	158	0.183 (<0.001)	0.486 (0.036)	0.508 (0.006)	0.515 (<0.001)	1.266	2000
2007	171	0.041 (<0.001)	0.692 (0.594)	0.754 (0.956)	0.665 (0.283)	0.859	500
2008	153	0.203 (<0.001)	0.501 (0.103)	0.554 (0.087)	0.579 (0.026)	0.987	500
2009	188	0.223 (<0.001)	0.795 (0.891)	0.692 (0.311)	0.75 (0.362)	0.923	500
2010	143	0.162 (<0.001)	0.427 (0.030)	0.569 (0.196)	0.6 (0.116)	0.88	1000
2011	148	0.061 (<0.001)	0.604 (0.644)	0.508 (0.053)	0.815 (0.556)	0.708	500
Area (km^2) (%)		49.3 (18%)	67.9 (25%)	65.0 (24%)	46.6 (17%)	46.6 (17%)	

Table 8 Average density (km-2) of stone curlew nests on areas (km2) of annually surveyed suitable arable land within each band of distance (m) to the nearest "settlement" (defined by ≥10 other buildings within 250m); together with the upper limit of the maximum distance band for which nest density is statistically lower (Chi-square test P value <0.05) than average nest density in the combined higher distance bands (P value for each test given in brackets)

Period	Total nests (N)	Distance band to nearest "settlement" (m)				Max distance (m) with lower nest density
		<500	500-1000	1000-1500	1500-2500	
All Years	2310	0.258 (<0.001)	0.437 (0.001)	0.486 (<0.001)	0.914 (0.051)	1500
1988-92	265	0.136 (<0.001)	0.217 (0.028)	0.285 (0.105)	0.503 (0.500)	1000
1993-96	262	0.182 (<0.001)	0.256 (0.026)	0.319 (0.003)	0.800 (0.447)	1500
1997-00	352	0.222 (<0.001)	0.379 (0.078)	0.498 (0.326)	0.343 (0.619)	500
2002-06	628	0.329 (<0.001)	0.548 (0.147)	0.580 (0.001)	1.189 (0.300)	500
2007-11	803	0.400 (<0.001)	0.736 (0.359)	0.717 (<0.001)	1.600 (0.229)	500
1988	57	0.156 (0.068)	0.209 (0.113)	0.319 (0.248)	0.686 (0.725)	0
1989	57	0.089 (<0.001)	0.272 (0.146)	0.393 (0.407)	0.686 (0.725)	500
1990	55	0.163 (0.186)	0.24 (0.824)	0.197 (0.296)	0.457 (0.774)	0
1991	55	0.126 (0.008)	0.209 (0.044)	0.393 (0.883)	0.457 (0.774)	1000
1992	41	0.148 (0.987)	0.157 (0.729)	0.123 (0.591)	0.229 (0.839)	0
1993	59	0.141 (0.010)	0.293 (0.775)	0.221 (0.085)	0.686 (0.725)	500
1994	60	0.163 (0.058)	0.230 (0.187)	0.27 (0.005)	1.143 (0.649)	0
1995	66	0.185 (0.073)	0.230 (0.051)	0.369 (0.111)	0.914 (0.684)	0
1996	77	0.237 (0.197)	0.272 (0.146)	0.418 (0.947)	0.457 (0.774)	0
1997	77	0.163 (<0.001)	0.345 (0.210)	0.516 (0.390)	0.229 (0.839)	500
1998	77	0.200 (0.015)	0.366 (0.750)	0.344 (0.662)	0.229 (0.839)	500
1999	90	0.237 (0.011)	0.345 (0.073)	0.541 (0.748)	0.686 (0.725)	500
2000	108	0.289 (0.008)	0.46 (0.463)	0.590 (0.314)	0.229 (0.839)	500
2002	93	0.230 (0.003)	0.439 (0.979)	0.418 (0.463)	0.686 (0.725)	500
2003	104	0.319 (0.123)	0.376 (0.138)	0.491 (0.099)	1.143 (0.649)	0
2004	135	0.334 (<0.001)	0.596 (0.354)	0.639 (0.033)	1.600 (0.591)	500
2005	138	0.348 (<0.001)	0.627 (0.689)	0.639 (0.262)	1.143 (0.649)	500
2006	158	0.415 (0.001)	0.700 (0.633)	0.712 (0.164)	1.372 (0.619)	500
2007	171	0.363 (<0.001)	0.899 (0.539)	0.762 (0.446)	1.143 (0.649)	500
2008	153	0.393 (<0.001)	0.721 (0.813)	0.541 (<0.001)	2.058 (0.542)	500
2009	188	0.548 (0.009)	0.794 (0.779)	0.712 (0.005)	2.058 (0.542)	500
2010	143	0.326 (<0.001)	0.648 (0.262)	0.762 (0.214)	1.372 (0.619)	500
2011	148	0.371 (<0.001)	0.616 (0.103)	0.811 (0.269)	1.372 (0.619)	500
Area (km^2) (%)		134.9 (49%)	95.7 (34%)	40.7 (15%)	4.6 (2%)	

Key findings: We compared nest density on arable land across a series of 500m buffers around settlements.

- Across all years, groups of years and individual years there is consistently a significantly lower density of nests in the arable land close to settlements.
- With data combined across all years, significant effects are found up to 2000m from settlements (defined using our 50 buildings within 250m radius threshold); similarly using nest data for 4-5 year periods, effects are found up to 2000m for all but one period.
- Using data from individual years (far less statistical power) the density of nests in the 500m band was always the lowest.
- Significant effects were found in all but 2 years and at distances ranging from 500m – 2000m. Using the less restrictive definition of settlements (>10 buildings within 250m), significant effects were found out to a maximum distance of 1500m.

Assessing nest density in relation to distance from individual settlements

5.11 Considering individual settlements (the voronois), the average 1988-11 nest density on arable land within 500m of a settlement was less than the average nest density on arable land further from the settlement (but within the settlement voronoi polygon limits) in 34 (89%) of the 38 settlements which had at least 25 hectares of arable land within 500m and some nests within their voronoi polygon (Figure 12). This is statistically significantly greater than the 50% expected if there was no influence of settlement distance (Binomial test P<0.001). Seventeen of the 38 settlements had no nests on the arable land within 500m, but did further away within the settlement's voronoi boundary (of which 12 had nests in the 500-1000m band). The median of these 38 nest density ratios was only 0.092, equivalent to an 88% reduction in nest density for the 0-500m distance band. Wilcoxon signed rank test of log ratios distribution centred on zero was also significant (test P<0.001).

5.12 There was a significant negative correlation between the nest density ratio (0-500m versus further away from settlements) and settlement size (total number of buildings) (Spearman rank correlation r_S = -0.362, P = 0.026, n=38). This suggests that settlement size influences the amount of impact and that larger settlements tend to be associated with a greater reduction in nest density on arable land within the surrounding first 500m.

5.13 The average 1988-11 nest density on arable land within 500-1000m of a settlement was less than the average nest density on arable land further from the settlement (but within the settlement voronoi boundary) in 27 (73%) of the 37 settlements which had at least 25 hectares of arable land within 500-1000m and some nests within the 500m to voronoi boundary area (Figure 13). This is significantly greater than 50% (Binomial test P = 0.008). Five of these 37 settlements had no nests on arable land within 500-1000m and the median ratio of nest density in 500-1000m to that further away was 0.439, equivalent to a 56% reduction in nest density. Wilcoxon signed rank test of log ratios distribution centred on zero was also highly significant (test P<0.001).

5.14 The Spearman rank correlation between the nest density ratio (500-1000m versus further away from settlements) and settlement size was still negative, but not significant (r_S = -0.189, P = 0.262, n = 37).

5.15 In the final test distance band, the average 1988-11 nest density on arable land within 1000-1500m of a settlement was less than the average nest density on arable land further from the settlement (but within the settlement voronoi boundary) in 22 (69%) of the 32 settlements with at least 25 hectares of arable land in both distance bands and some nests in the 1000m to voronoi polygon boundary area (Figure 14). This is just statistically significantly greater than 50% (Binomial test P=0.050). However, on taking account of how different the nest ratios were from one, the median density ratio was observed to 0.544 and a Wilcoxon signed rank test of the log ratios distribution (being centred on zero) was significant (test P=0.013).

5.16 It is interesting to note that Bodney Camp and East Wretham 'settlements' are amongst those few settlements that appear to have no impacts on nearby nest densities (see Figures 12-14). Both are predominantly army camps with fluctuating building occupancy rates.

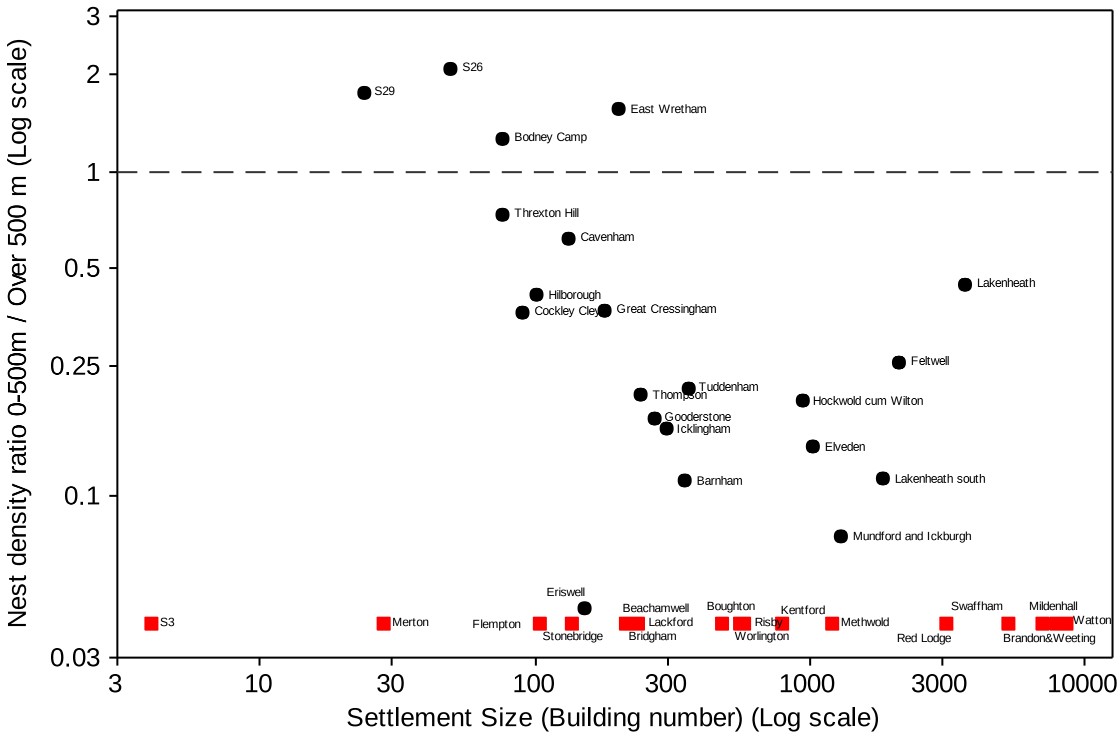


Figure 12: Ratio of average 1988-11 nest density on arable land within 0-500m to average nest density on arable land further from the same settlement (within the settlement's voronoi polygon) in relation to the settlement size (number of buildings); both axes on log scale; red squares denote settlements with no nests in closest distance band.

5.17 Examples of the data for individual settlements (of a range of different sizes), are shown in Figure 15, which shows the amount of arable land (with survey data) and the nest density within each distance band.

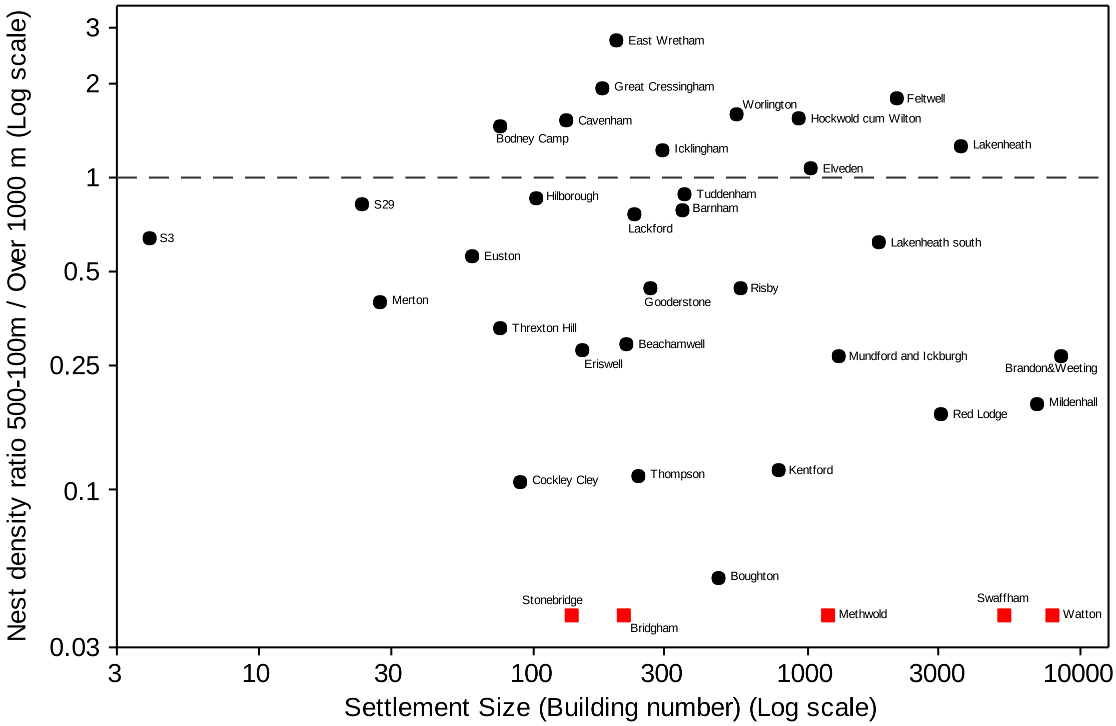


Figure 13: Ratio of average 1988-11 nest density on arable land within 500-1000m to average nest density on arable land further from the same settlement (within the settlement's voronoi polygon) in relation to the settlement size (number of buildings); both axes on log scale; red squares denote settlements with no nests in closer distance band

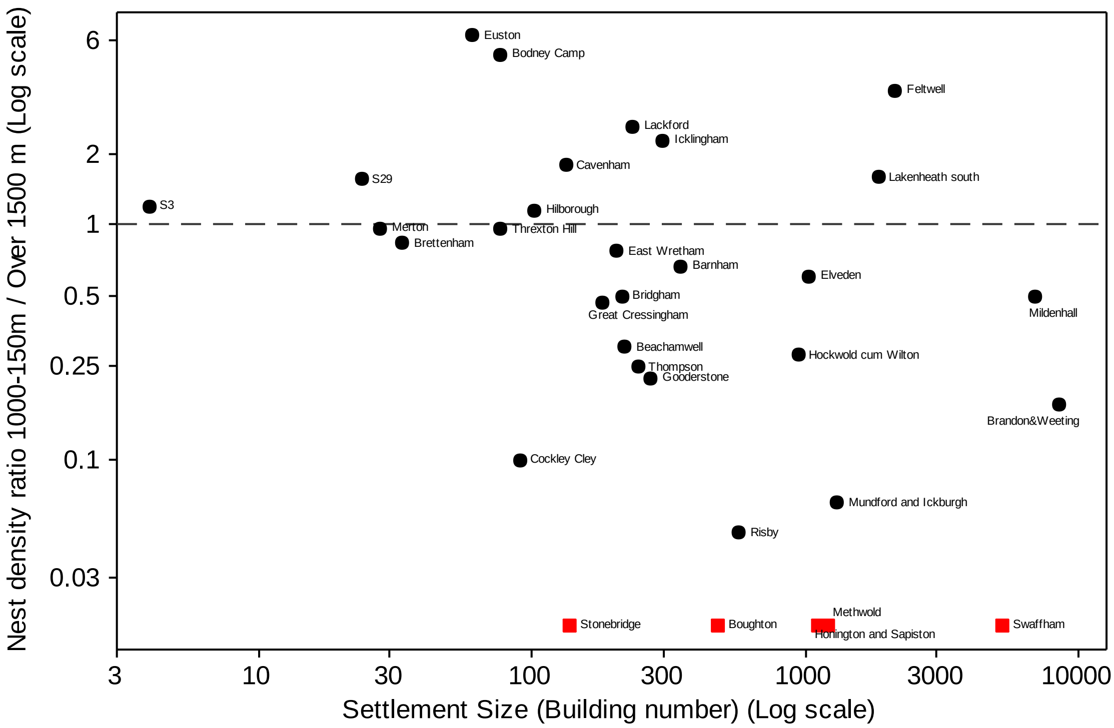


Figure 14: Ratio of average 1988-11 nest density on arable land within 1000-1500m to average nest density on arable land further from the same settlement (within the settlement's voronoi polygon) in relation to the settlement size (total number of buildings of all sizes and types (including unknown); both axes on log scale; red squares denote settlements with no nests in closer distance band

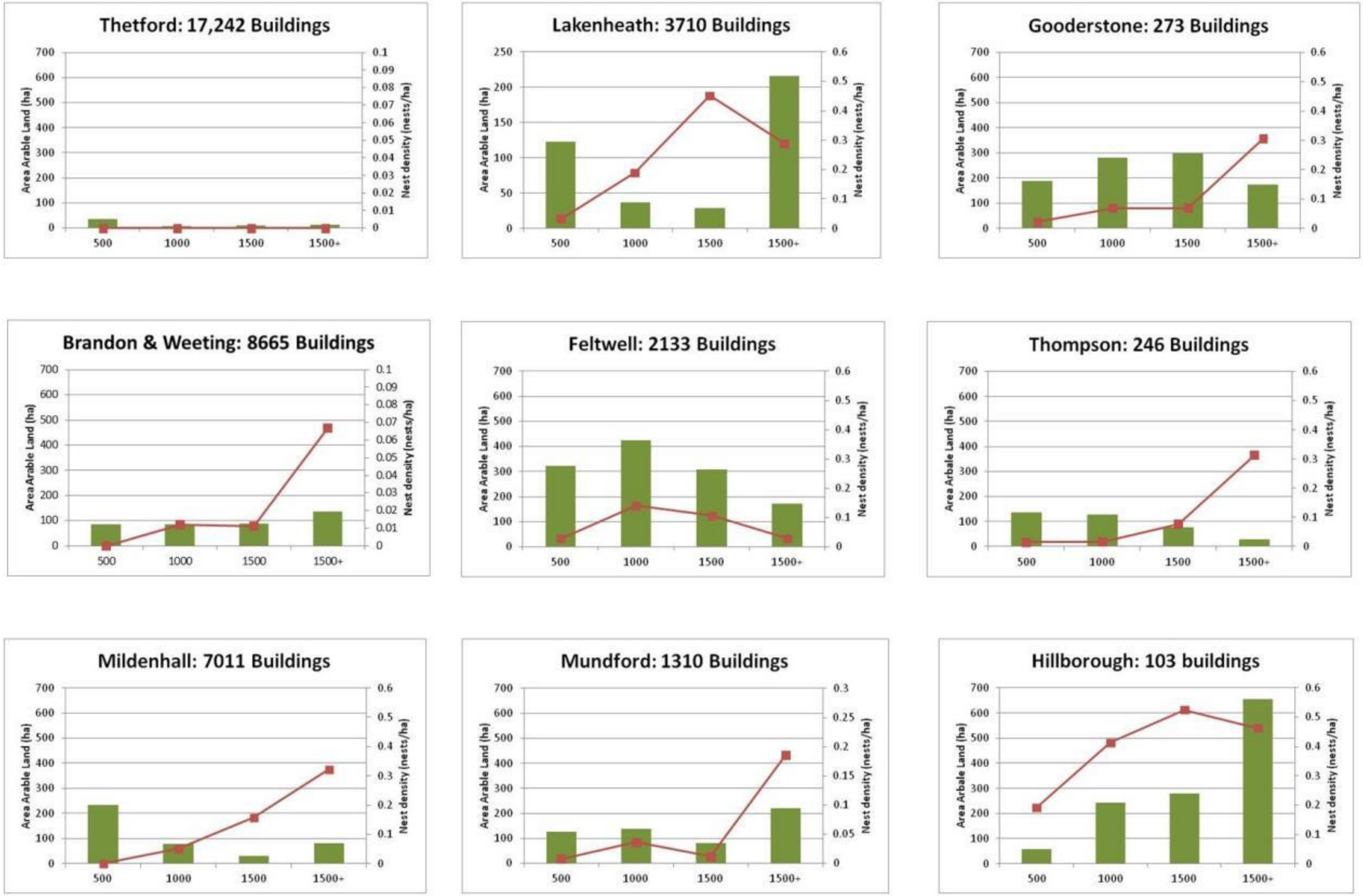


Figure 15: Example plots for a selection of individual settlements. Each plot shows the areas of arable (green bars) and nest density (red lines) in distance bands away from individual settlements. Note scales differ between plots. The number of buildings is the total number of buildings (of all sizes and types, including unknown) within Mastermap.

Key Findings: The study area was divided into individual parcels around each settlement and nest density on arable land at different distance bands (500m bands) compared.

- There was an overall statistically significant tendency across individual settlements for nest density on arable land to be lower in each 500m band up to 1500m, when compared to all arable land further away than that distance band (but still closest to that settlement than any other settlement).
- The estimated median reduction in relative nest density in the 0-500m and 500-1000m was nearly 90% and just over 50% respectively.
- Settlement size influences the amount of impact and larger settlements tend to be associated with a greater reduction in nest density on arable land within the surrounding first 500m.

These results are important as they show that the reduced densities of nests occur close to settlements across the study area, including settlements that vary markedly in size and character.

Trends in proportion of nests close to settlements

5.18 Sharp *et al.* (2008) found, using their manually-derived definition of 'settlements', that the percentage of all nests which occurred on land within 500m of the nearest settlement increased from around 5% in the late 80s to 11-14% by the 2003-06, as the total nest number more than doubled. However, the percentage within 500m of settlements was always much less than the 30% expected from the proportion of all suitable arable land in the study region which was within 500m of the nearest settlement.

5.19 Using our automatically-derived definitions of settlements from the 2007 MasterMap buildings data layer, there were no apparent trends over 1988-2011 in the proportion of all nests on arable land which occurred within 500m of the nearest settlement (Figure 16). This was true irrespective of whether a threshold of 10 or 50 other buildings within 250m was used to define buildings which were to be treated as part of a settlement (correlations with time were -0.07 and -0.22 respectively; both $p>0.30$).

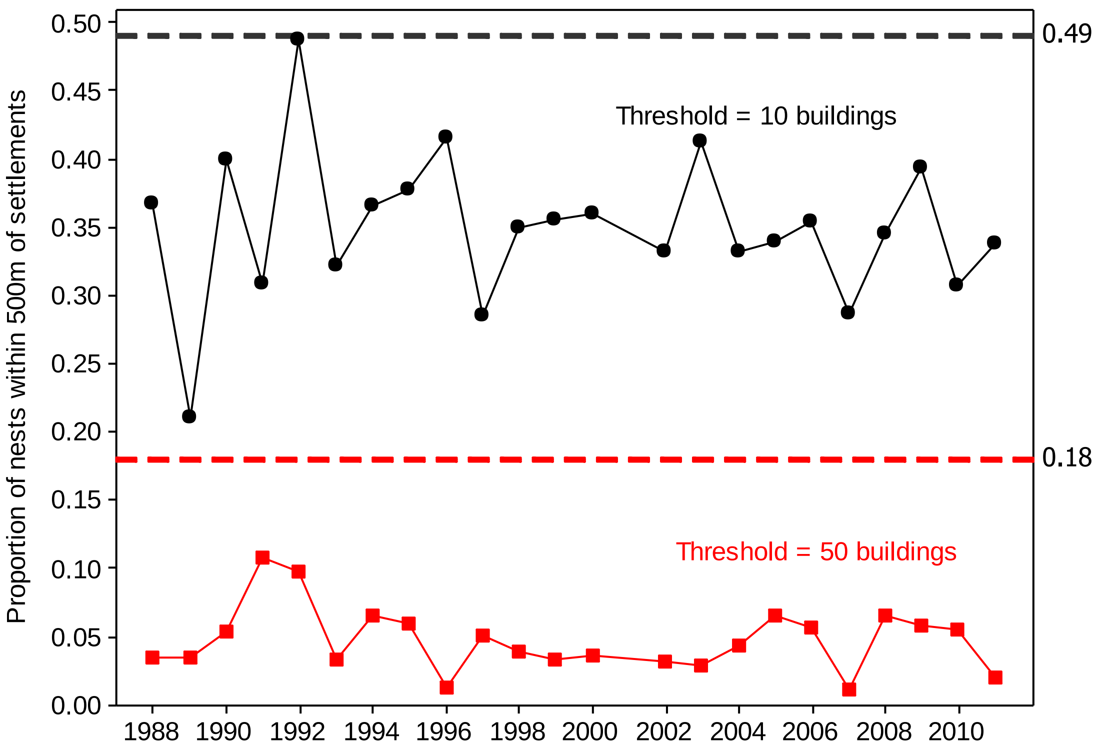


Figure 16 Trends (1988-11) in the proportion of all nests on annually surveyed suitable arable land occurring within 500m of nearest settlement (based on building thresholds of either 10 (black circles) or 50 (red squares) other buildings within 250m); horizontal dashed lines indicate expected proportions (0.49 and 0.18 respectively) if there was no effect of distance from settlements on nest distribution

Key Findings: Contrary to the findings in the previous work, there is no evidence that, as the stone curlew population has increased, a greater proportion of nests have been found close to settlements. In other words, as competition for territories has increased, birds have not tended to nest close to settlements.

Assessing distance from settlements over which nest density is reduced on semi-natural land

5.20 Similar analyses on suitable semi-natural land show the observed relationship between nest density and distance from the nearest settlement is more complex and less clear (Figure 17). Nest density is highest on those areas of semi-natural land at intermediate distances (1000-1500m) from the nearest settlement. This is a similar pattern to that observed by Sharp *et al* (2008). The pattern may be due to the large variability in precise habitat type and quality between different often fragments of land classified within the SAC as semi-natural grassland. Close scrutiny of the nest data within the GIS indicates that many areas of semi-natural habitat have never held a nest. Looking within our 500m grid cells, 488 cells overlap the semi natural layer and have survey coverage in every year. Of these cells, only 169 have at least one nesting attempt recorded on semi-natural habitat, and the majority of cells (319, 65%) have no nesting attempts on semi-natural. There are therefore relatively few areas of semi-natural habitat where birds have nested, but some individual grid cells have held very high numbers of nests, with a maximum of 152 nests (across all years, on semi-natural) for a single grid cell. By contrast, for arable land, the most nests in a single cell (across all years) was 29.

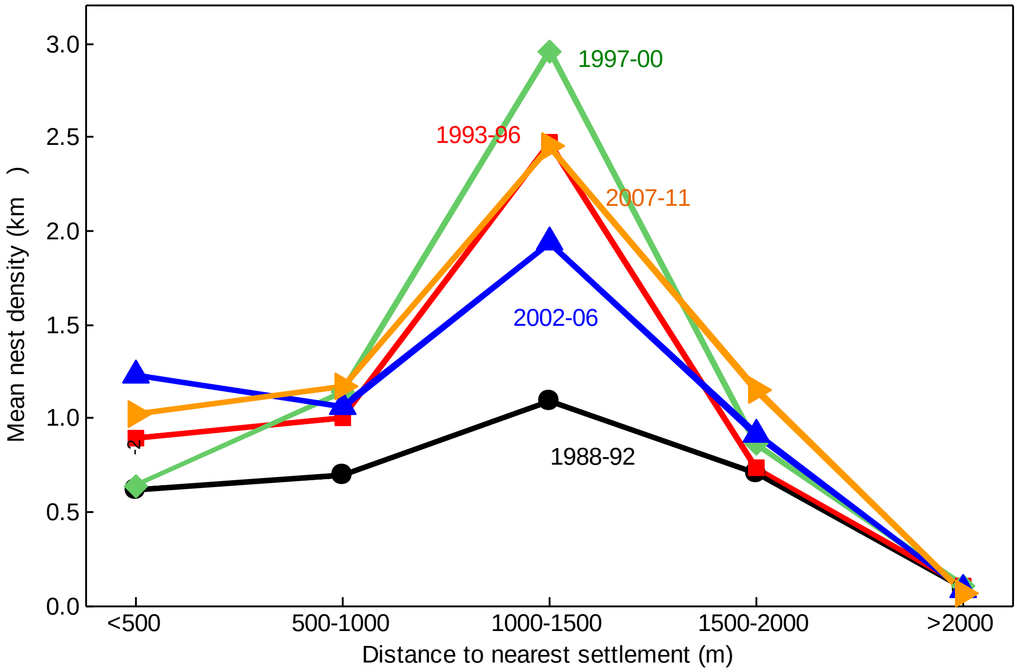


Figure 17: Average stone curlew nest density (per km^2) on annually surveyed semi-natural land at different distance bands from the nearest settlement (defined by a threshold of 50 other buildings within 250m) for each 4-5 year period over 1988-2011.

Key Findings: The pattern of lower nest densities close to settlements is less clear for semi-natural habitats. Use of semi-natural habitats appears to be highly clumped in space and large areas of semi-natural habitat have no nest records. Other (unmeasured) factors such as vegetation height may be driving the use of these areas.

6. Results: Initial Modelling

Modelling nest density in relation to nearby buildings and roads

6.1 Initial investigative modelling involved total 1988-2011 nest numbers on suitable arable land in each 500m cell in relation to a buildings variable and a distance to road variable. These quasi-Poisson GLM models were restricted to those 500m cells with data available on stone curlews nest distribution for every year 1988-2011 (excluding 2001 foot and mouth year).

6.2 The buildings variables considered were distance to nearest 'settlement' (defined by buildings with >50 other buildings within 250m) and the local buildings density based on either the total number or total area of all buildings, where local buildings density was defined using the normal kernels with each of a range values of standard deviations (referred to as '*S*' and ranging from 250-2000, see Figure 2). Local buildings number density and local buildings area density using standard deviations of *S* are denoted $BTotN_S$ and $BTotA_S$ respectively.

6.3 Each model also included either distance to nearest A-road or distance to nearest trunk road. Because the effect of an increase in distance to either settlements or roads is likely to be less at greater distances from potentially suitable nest sites, the distance variables were assessed in the models using their untransformed, square root or double square root (square root of square root) transformed values. Effects of increases in local buildings density may also be less when the number or area of nearby buildings is already considerable; therefore local buildings density variables were also considered in transformed form.

6.4 Trial GLM quasi-Poisson models were used to assess the relative fit of all models based on their model QAIC values (a smaller value indicates better fit). A comparison of fits of the best two-variable models of each type described is summarised in Table 9.

6.5 In all models, distance to the nearest A-road was often non-significant and always far less effective than distance to trunk road and this variable is not discussed further. The best form of distance to road variable (for all values of total building kernel SD) was the double square root of the distance to the nearest Trunk road.

6.6 The local buildings density variables whether based on number or total area of buildings were better predictors of nest density than simple distance to nearest 'settlement'. This suggests that the 'size' of the nearby settlement or amount of buildings is important.

6.7 The local buildings number density variable for each value of *S* gave a much better model fit (lower QAIC) when used in the square root form irrespective of whether based on buildings number or area (e.g. square root of $BTotN_{1250}$ was better than $BTotN_{1250}$). A similar result was found by Sharp et al. (2008). However, the stronger double square root transformation gave better fits (Table 9).

6.8 The local building density variable based on area of nearby buildings gave a better GLM fit (lower QAIC values) than the equivalent kernel density variable based on number of nearby buildings for all values of *S* (Table 9). The reduction in model QAIC obtained by using area rather than just number of buildings in any specific model was at least 32; under GLM model assumptions this indicates that the model based on area of buildings is definitely a better fit to the data to that based on buildings numbers (Burnham et al 2011).

6.9 This provides evidence to suggest that the total area covered by the nearby buildings has some influence over and above the simple number of nearby buildings.

Table 9: Comparison of fits of alternative two-variable (one building and one road) quasi-Poisson models for total 1988-2011 nest numbers on annually surveyed arable land; optimum normal kernel SD for indicated buildings number or area local density variable was always 1250m; Sqrt and DSqrt denote square root and double square root; ΔQAIC denotes increase in model QAIC (quasi Akaike Information Criterion measuring lack of fit) above that of overall best fit model (highlighted in bold), for which quasi-Poisson dispersion parameter = 4.0

Buildings variable		Distance to nearest Trunk road		
		Raw	Square root	Double square root
Distance to nearest settlement	Raw	240.0	218.0	207.5
	Square root	213.7	192.3	182.1
	Double square root	201.8	180.7	170.4
Buildings number local density	Raw	132.9	120.5	115.4
	Square root	72.8	59.2	54.4
	Double square root	53.1	37.6	32.3
Buildings area local density	Raw	91.6	85.2	82.5
	Square root	25.6	19.9	18.0
	Double square root	9.2	2.2	**0.0**

6.10 The best-fitting models (i.e. minimum QAIC of 1615.9) from this optimisation involved the double square root of the distance to the nearest trunk road and the double square root of the local total building density variable based on a normal kernel SD of 1250m (Table 9). Models with slightly larger (1500m) or smaller (1000m) SD gave slightly poorer fits (increase in QAIC (ΔQAIC) = 5.9 and 9.9 respectively; such that based on Akaike weights, the relative probability of the models based on SD of 1000m 1250m and 1500m were 0.0, 99.7 and 0.3 respectively, indicating that using a SD of 1250m definitely provides the best fit to the data – amongst this choice of models assessed).

6.11 The better fit using this double square root transformation in the GLM implies that although the area of local building is important, the effect of an increase in local building area on nest density is likely to be greater when the current area of nearby building is low.

6.12 Generalised Additive Models (GAM) were also fitted (using R software function 'gam') to the optimum two-variable model involving the double square root (DSqrt) of local building area density (BTotASD1250) and double square root (DSqrt) of distance to nearest Trunk road. GAMs fit complex non-parametric, smooth, non-linear (and potentially multi-curved) relationships that maximise likelihood fit to the observed data. The best fit GAM relationships for the optimum two transformed variables were approximately and adequately linear over the main part of their range covering nearly all 500m cells (Figure 18). For ease of predictive model understanding and to permit subsequent fitting of models with spatially correlated residuals, it was therefore concluded to be adequate to use the simpler GLM form of this model with these optimally-transformed variables.

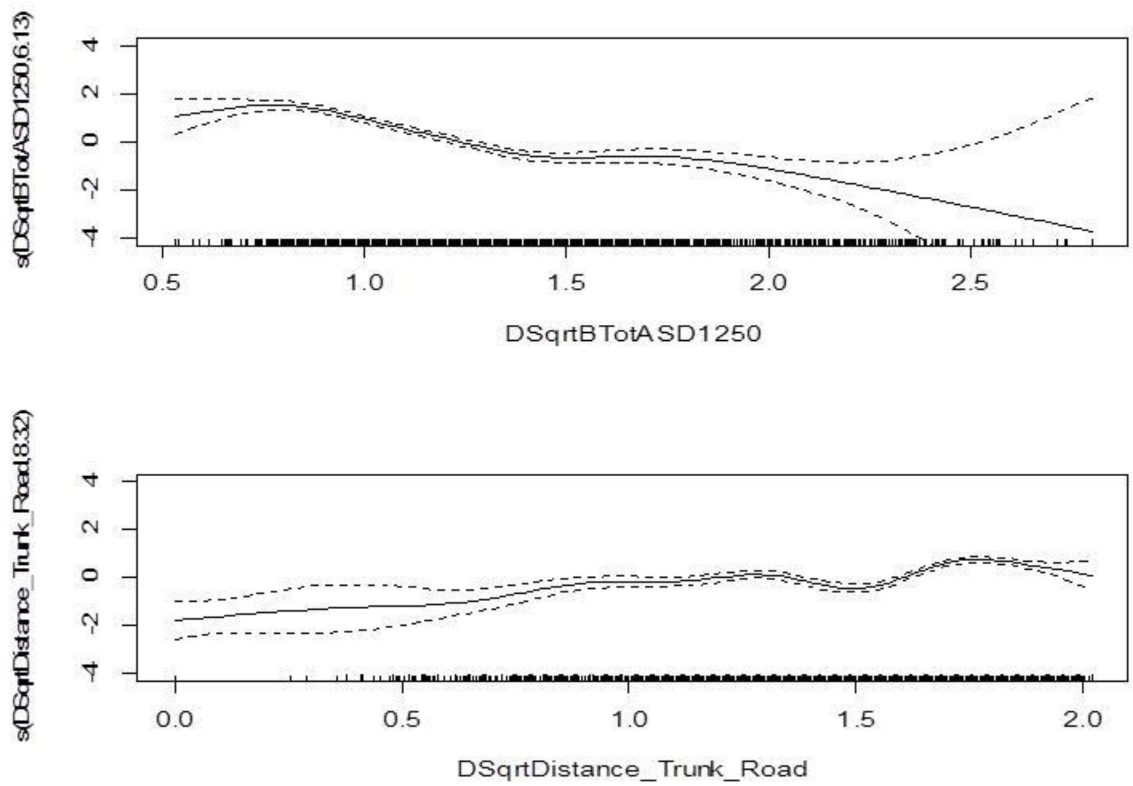


Figure 18: Plot of GAM model best-fitting non-parametric smoothed curves for relationship between 1988-2011 average nest density and the double square root of the local kernel density for area of all buildings (SD =1250m) (DSqrtBTotASD1250) and the double square root of the distance to the nearest Trunk road (marks above x-axis denote distribution of individual 500m cell x-variable values)

6.13 The best-fit quasi-Poisson model relating 1988-2011 total nest numbers on the arable land area (denoted ‘$Area_{Arable}$’) per 500m cell to the double square root of total building area density with S=1250m (denoted DSqrt($BTotA_{1250}$)) and the double square root of the distance to the nearest trunk road (denoted DSqrt($Distance_{Trunk}$)) is given by model equation (M1):

$$Log_e(Nests_{2007\text{-}11}) = Log_e(Area_{Arable}) \underset{\{0.265\}}{-0.768} \underset{\{0.179\}}{- 2.836}\, DSqrt(BTotA_{1250}) \underset{\{0.133\}}{+ 1.163}\, DSqrt(Distance_{Trunk})) \qquad (M1)$$

where estimated standard errors of parameters are given below in brackets{}. Both model terms are highly statistically significant (both quasi-Poisson F test P <0.001). The estimate of the quasi-Poisson dispersion parameter k was 4.04, indicating over-dispersion relative to Poisson, as allowed for and incorporated into these and later models.

Model fit and the observed data

6.14 A comparison of the observed average 1988-2011 annual nest densities with that predicted from equation M1 is summarised in Figure 19 for all areas of arable land surveyed every year in 500m cells classified by the local buildings area density and their distance from the nearest trunk road. The area of arable land and the observed and predicted numbers of nests in each land classification band, upon which the nest densities are based, are given in Table 10. There is a reasonably good general agreement between predicted and observed nest densities showing the pattern of nest density decreasing with the area of local buildings and also with closeness to trunk road.

Table 10: Observed / Predicted 1988-2011 total nest numbers for the total area of arable land (km^2 in brackets) of 500m cells surveyed each year in different bands of distance from the nearest Trunk road and the buildings area local density (kernel *S* = 1250m); predictions based on model equation M1. Derived observed and predicted nest densities shown in Figure 19

Distance to Trunk road	Buildings area local density (kernel *S* = 1250m)					
	<1	1-2	2-4	4-8	8-75	All
<0.5	38 / 32.2 (4.5)	30 / 20 (5.6)	1 / 14.3 (6.6)	3 / 7.8 (7.9)	0 / 2.4 (5.3)	72 / 76.5 (30)
0.5-1.5	98 / 82.8 (6)	37 / 44.2 (6.8)	43 / 29.5 (8)	26 / 10 (5.4)	2 / 3.7 (5.1)	206 / 170.2 (31.1)
1.5-3	123 / 148.3 (8.8)	102 / 90.2 (9.8)	104 / 51.2 (10.9)	36 / 22.8 (8.6)	2 / 8.1 (8.7)	367 / 320.6 (46.8)
3-6	81 / 110 (5.6)	87 / 215.9 (20.5)	107 / 117.5 (17.3)	14 / 12.7 (3.5)	16 / 3.2 (4.1)	305 / 459.3 (51)
6-17	576 / 465.3 (16.8)	482 / 417.3 (26.5)	98 / 234.7 (26.3)	73 / 86.8 (16.5)	87 / 35.4 (14.8)	1316 / 1239 (100.8)
Overall	**916 / 838.7 (41.6)**	**738 / 787.5 (69.1)**	**353 / 447.2 (69.1)**	**152 / 140 (41.8)**	**107 / 52.7 (38)**	**2266 / 2266 (259.6)**

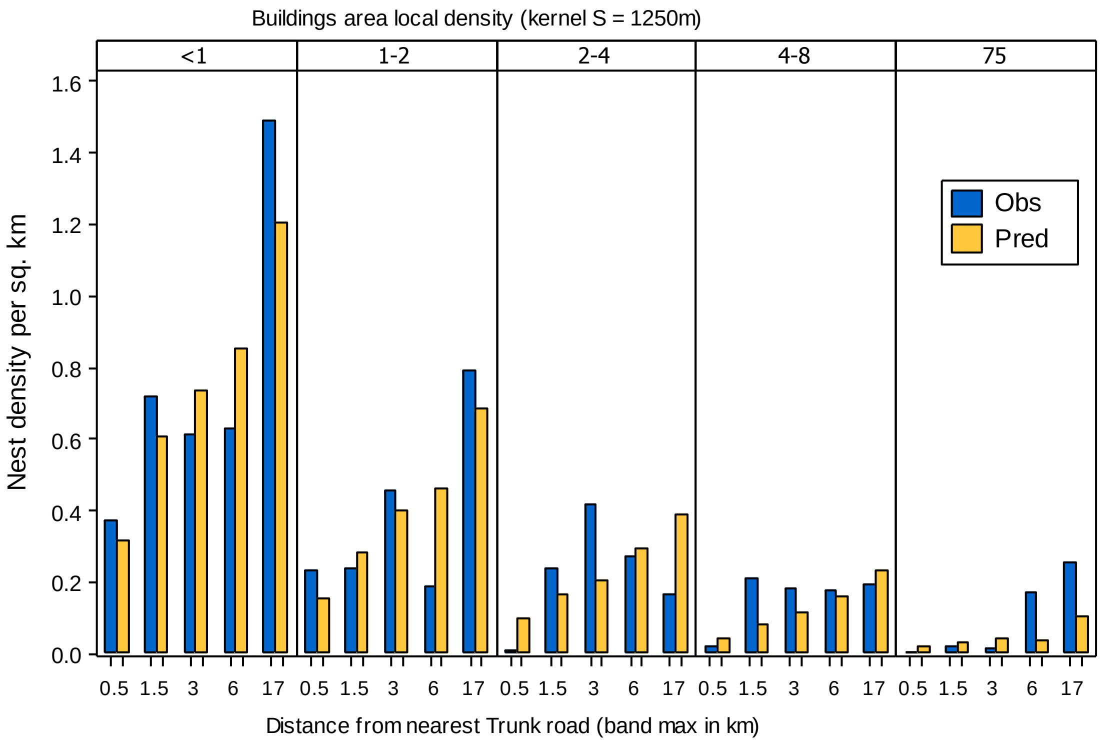


Figure 19: Observed and predicted (from equation M1) average 1988-2011 nest density (per km^2) on annually surveyed arable land in 500m cells classified by the distance (in km) to the nearest trunk road and the local buildings area density (using kernel *S*=1250m); values denote class band maxima.

Key Findings: This section considers models just involving building and road variables. Nest density on arable land was related to the amount of nearby buildings and the distance from trunk roads. Area of buildings gave a better predictor than number of buildings. The impact of increased building area is predicted to be greater where the present area of nearby buildings is low. For the building data, weighted normal kernels using a standard deviation of 1250m (i.e. the weighting represented by the yellow line in Figure 2) are found to provide the best fit compared to other weightings. These models are developed further (by adding additional variables) in section 9.

7. Results: Overview of data within 500m grid and consideration of nest densities in relation to buildings and other variables

7.1 In this section we consider nest density within our 500m grid in relation to buildings and other variables. Initial models developed in the previous section indicate that a normal weighted kernel of 1250m provides the best fit. We therefore consider nest density in relation to this weighting of buildings providing a series of two-way tables which show nest density in relation to buildings and the other variables.

Local building density and distance to nearest A-road

7.2 All 500m cells in the study area with some suitable arable land that were surveyed for stone curlew nests in each year 1988-2011 (excl. 2001) were classified by the area of nearby buildings and their distance from the nearest A-road. The area of nearby buildings was defined by the sum of the area of buildings within each distance band from the cell distance-weighted by the normal kernel with standard deviation *S* of 1250m (referred to as 'buildings area local density' and denoted $BTotA_{1250}$). Across the Breckland study region as a whole, for areas within any given distance band from the nearest A-road, some areas have high and some low numbers of nearby buildings, although there was some tendency for areas with few buildings to have relatively more sub-areas further from any A-road (Table 11 bottom).

Table 11: Average 1988-2011 annual stone curlew nest density (per km2) on annual surveyed arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the distance (km) to the nearest A-road ($Dist_{A\text{-}road}$), together with arable land area (km^2) and (in brackets) total 1988-2011nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km^{-2})		Distance to nearest A-road (km)				
		<0.4	0.4 – 1.2	1.2 - 2.3	2.3 - 7.8	Overall
Buildings area (S = 1250m)	<1	0.607	1.136	1.024	0.908	0.956
	1-2	0.405	0.576	0.544	0.347	0.464
	2-4	0.083	0.381	0.278	0.187	0.222
	4-8	0.121	0.131	0.168	0.221	0.158
	8-75	0.021	0.048	0.046	0.368	0.123
	Overall	**0.201**	**0.438**	**0.528**	**0.358**	**0.379**

Area arable land (km^2) (total nests in 1988-2011)		Distance to nearest A-road (km)				
		<0.4	0.4 – 1.2	1.2 - 2.3	2.3 - 7.8	Overall
Buildings area (S = 1250m)	<1	6.1 (85)	8.0 (209)	17.4 (410)	10.2 (212)	41.6 (916)
	1-2	13.4 (125)	18.7 (248)	15.4 (193)	21.5 (172)	69.1 (738)
	2-4	16.7 (32)	14.4 (126)	15.0 (96)	23.0 (99)	69.1 (353)
	4-8	12.6 (35)	11.3 (34)	6.7 (26)	11.2 (57)	41.8 (152)
	8-75	12.4 (6)	9.9 (11)	5.7 (6)	9.9 (84)	38 (107)
	Overall	**61.3 (283)**	**62.3 (628)**	**60.2 (731)**	**75.8 (624)**	**259.6 (2266)**

7.3 Table 11 shows the average annual nest density (per km^2) on suitable arable land over the periods 1988-2011 for these 500m cells classified by buildings area local density ($BTotA_{1250}$) and distance to nearest A-road. Average nest density declines consistently with the area of nearby buildings. Average annual nest density decreased from 0.956

km^{-2} in areas with few nearby buildings ($BTotA_{1250}$ <1) to only 0.123 km^{-2} in areas with the greatest area of nearby buildings ($BTotA_{1250}$ >8) (Table 11). Average nest density in areas with the smallest areas of buildings nearby ($BTotA_{1250}$ < 1) was about twice that in areas with the next greatest local density of buildings.

7.4 Nest density is generally lower for areas within 400m of the nearest A-road, but at greater distances then is no consistent pattern. Amongst arable areas within 400m of the nearest A-road, nest density was highest (0.607 km^{-2}) amongst the 6.1 km^2 with the smallest buildings area nearby and lowest (0.021 km^{-2}) amongst the 12.4 km^2 where there are most buildings nearby (Table 11). In areas further from the nearest A-road, nest density is amongst the highest in areas near the least nearby buildings area ($BTotA_{1250}$ < 1) and relatively low in areas near the greatest buildings areas, but there are anomalies at this level of breakdown (Table 11).

Key Findings: This particular analysis treats all A-roads as equal, regardless of whether the nearest is a trunk road (A11, A14 or A47) or a much less busy A-road. Nest density is generally lower for areas within 400m of the nearest A-road, but at greater distances there is no consistent pattern.

Local building density and distance to nearest Trunk-road

7.5 The three trunk roads (A11, 14 and A47) pass near or around the main settlements and also through the intervening countryside. This means that, in terms of distance from the nearest Trunk road (denoted $Dist_{T\text{-}road}$), across the Breckland study region as a whole, for areas within any given distance band, there are some areas with high and others with low numbers of nearby buildings (Spearman rank correlation between $BTotA_{1250}$ and $Dist_{T\text{-}road}$ is only -0.14). This lack of inter-correlation and confounding suggests it should be possible to disentangle their effects (or at least association) with nest density.

Table 12: Average 1988-2011 annual stone curlew nest density (per km2) on annual surveyed arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the distance (km) to the nearest Trunk road ($Dist_{T\text{-}road}$), together with arable land area (km^2) and (in brackets) total 1988-2011 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km^{-2})		Distance to nearest Trunk -road (km)					
		<0.5	0.5-1.5	1.5-3	3-6	6-17	Overall
Buildings area (S = 1250m)	<1	0.370	0.716	0.608	0.629	1.488	0.956
	1-2	0.232	0.238	0.453	0.185	0.792	0.464
	2-4	0.007	0.235	0.414	0.268	0.162	0.222
	4-8	0.017	0.211	0.182	0.174	0.193	0.158
	8-75	0.000	0.017	0.010	0.172	0.256	0.123
	Overall	**0.105**	**0.288**	**0.341**	**0.260**	**0.568**	**0.379**
Area arable land (km^2) (total nests in 1988-2011)		**Distance to nearest T-road (km)**					
		<0.5	0.5-1.5	1.5-3	3-6	6-17	Overall
Buildings area (S = 1250m)	<1	4.5 (38)	6.0 (98)	8.8 (123)	5.6 (81)	16.8 (576)	41.6 (916)
	1-2	5.6 (30)	6.8 (37)	9.8 (102)	20.5 (87)	26.5 (482)	69.1 (738)
	2-4	6.6 (1)	8.0 (43)	10.9 (104)	17.3 (107)	26.3 (98)	69.1 (353)
	4-8	7.9 (3)	5.4 (26)	8.6 (36)	3.5 (14)	16.5 (73)	41.8 (152)
	8-75	5.3 (0)	5.1 (2)	8.7 (2)	4.1 (16)	14.8 (87)	38.0 (107)
	Overall	**30.0 (72)**	**31.1 (206)**	**46.8 (367)**	**51.0 (305)**	**100.8 (1316)**	**259.6 (2266)**

7.6 There is a stronger relationship between nest density and distance from the nearest Trunk A-road (Table 12). For the areas with any particular band of buildings area local density ($BtotA_{1250}$), whether high or low, the nest density was always lowest in the subset of areas within 0.5 km of the nearest trunk road and highest in the areas furthest from the nearest trunk road.

7.7 In areas within 500m of a Trunk road, there were almost no nests, except in the subset of areas not near many buildings (i.e. $BTotA_{1250} < 2$) (Table 12). This suggests that stone curlews almost completely avoid nesting on otherwise suitable arable land if it is very near to both a Trunk road and a large area of buildings.

Key Findings: Looking at the data for trunk roads only (A11, A14 or A47), regardless of the level of buildings, the nest density was always lowest in the subset of areas within 0.5 km of the nearest trunk road and highest in the areas furthest from the nearest trunk road. Stone curlews almost completely avoid nesting on otherwise suitable arable land if it is very near to both a Trunk road and a large area of buildings

Influence of nearby woodland

7.8 The type of habitats surrounding or adjacent to potentially suitable stone curlew nesting areas and the extent to which these habitats or features form a visibility barrier to these nesting birds may have some influence on the attractiveness or quality of particular areas for nest location and for incubating eggs (and brood rearing).

7.9 One such type of feature could be the presence of woodland close to a potential nest site. Stone curlews may perceive very close woodland and trees as a potential danger which could harbour egg or chick predators or offer perching sites for any predatory birds. If potentially suitable nesting habitat close to settlements tended to have more woodland than suitable habitats further away from settlements, then, if nearby woodland influenced stone curlew nest density, this would at least partly explain the observed association between nest density and the distance from settlements or amount of nearby buildings.

7.10 For each 500m cell, we measured the percentage cover of woodland (a) within the cell (denoted $\%Woodland_{cell}$) and (b) within the cell and the eight surrounding 500m cells (referred to for convenience as 'percentage woodland surrounding a cell' and denoted $\%Woodland_{9cells}$). The amount of woodland within a 500m cell and $\%Woodland_{9cell}$ are weakly negatively correlated with the nearby buildings area local density ($BTotA_{1250}$) (Spearman rank correlation is -0.24 and -0.29 respectively).

7.11 Those 500m cells containing more woodland have some tendency to have lower nest densities on the arable land within the cells (Table 13). Overall average 1988-2011 nest density was highest (0.462 km^{-2}) in cells with no woodland and lowest (0.256 km^{-2}) in cells with the most (i.e. >17%) woodland cover.

7.12 For arable land areas with few buildings nearby ($BTotA_{1250}$<1), average nest density was always highest (1.734 km^{-2}) in cells with no woodland and lowest (0.332 km^{-2}) in cells with the most woodland (i.e. >17% cover), but the nest density in cells with intermediate levels of woodland was inconsistent (Table 13). When there was no woodland in the 500m cell, average nest density declined with buildings area local density from 1.734 ($BTotA_{1250}$ <1) to 0.200 km^{-2} ($BTotA_{1250}$ >8).

Table 13: Average 1988-2011 annual stone curlew nest density (per km^2) on annually surveyed suitable arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the percentage cover of the cell by woodland ; together with arable land area (km^2) and (in brackets) total 1988-2011 nests in each class.. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km^{-2})		% woodland in cell				
		0	1-5	5-17	17-100	Overall
Buildings area (S = 1250m)	<1	1.734	0.681	0.895	0.332	0.956
	1-2	0.474	0.558	0.565	0.288	0.464
	2-4	0.146	0.274	0.207	0.278	0.222
	4-8	0.189	0.124	0.176	0.111	0.158
	8-75	0.200	0.036	0.021	0.077	0.123
	Overall	0.462	0.366	0.389	0.256	0.379
Area arable land (km^2) (total nests in 1988-2011)		**% woodland in cell**				
		0	1-5	5-17	17-100	Overall
Buildings area (S = 1250m)	<1	12.6 (504)	11.4 (179)	7.6 (157)	9.9 (76)	41.6 (916)
	1-2	18.2 (198)	16.7 (214)	15.5 (202)	18.7 (124)	69.1 (738)
	2-4	20.9 (70)	17 (107)	14.5 (69)	16.7 (107)	69.1 (353)
	4-8	16.8 (73)	11.9 (34)	7.6 (31)	5.5 (14)	41.8 (152)
	8-75	19.4 (89)	7.2 (6)	6.3 (3)	5.1 (9)	38 (107)
	Overall	**87.9 (934)**	**64.2 (540)**	**51.6 (462)**	**56 (330)**	**259.6 (2266)**

7.13 The 500m cells surrounded by more woodland may have a tendency to have lower nest densities on the arable land (Table 14). Overall average 1988-11 nest density on annually surveyed arable land was highest (0.474 km^{-2}) in cells with <3% surrounding woodland cover and lowest (0.216 km^{-2}) in cells with the most (i.e. >15%).

Table 14: Average 1988-2011 annual stone curlew nest density (per km^2) on annually surveyed suitable arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the percentage cover of woodland in the 9 surrounding cells ; together with arable land area (km^2) and (in brackets) total 1988-2011 nests in each class

1988-2011 average nest density (km^{-2})		% woodland in surrounding 9 cells				
		<3	3-7	7-15	15-100	Overall
Buildings area (S = 1250m)	<1	1.697	0.912	0.652	0.446	0.956
	1-2	0.759	0.517	0.474	0.207	0.464
	2-4	0.130	0.287	0.309	0.156	0.222
	4-8	0.083	0.238	0.265	0.096	0.158
	8-75	0.177	0.057	0.050	0.077	0.123
	Overall	0.474	0.402	0.385	0.216	0.379
Area arable land (km^2) (total nests in 1988-2011)		**% woodland in surrounding 9 cells**				
		<3	3-7	7-15	15-100	Overall
Buildings area (S = 1250m)	<1	11.9 (466)	9.3 (196)	9.5 (143)	10.8 (111)	41.6 (916)
	1-2	15.8 (276)	15.7 (187)	15.7 (171)	21.9 (104)	69.1 (738)
	2-4	18.8 (56)	16.8 (111)	18.7 (133)	14.8 (53)	69.1 (353)
	4-8	16.8 (32)	9.1 (50)	9 (55)	6.8 (15)	41.8 (152)
	8-75	20.4 (83)	9.2 (12)	4.4 (5)	4 (7)	38 (107)
	Overall	**83.8 (913)**	**60.2 (556)**	**57.3 (507)**	**58.3 (290)**	**259.6 (2266)**

7.14 Where there was very little (i.e. <3%) woodland cover surrounding 500m cells, average nest density declined with building area local density from 1.697 to 0.177 km^{-2}. In those otherwise favourable areas of arable land away from most buildings (i.e. $BTotA_{1250}$<1), nest density decreases strongly with the amount of surrounding or nearby woodland (from 1.697 to 0.446 per km^2) (Table 14).

7.15 This negative association on nest density with the presence and amount of immediately nearby woodland (i.e. within the same 500m cell and the surrounding cells) is assessed further in GLM models below.

Key Findings: The amount of nearby woodland is weakly negatively correlated with the amount of nearby buildings. Nest density on arable land tends to be lower where there is more woodland nearby, especially amongst those otherwise favourable areas not near many buildings. The highest nest densities on arable land occur on areas not near many buildings or woodland.

Influence of field size and distance to land parcel boundary

7.16 Stone curlews may have some tendency to avoid nesting on areas of otherwise suitable arable land if they are close to the field boundaries (including fences and hedges) or to other features which may reduce their distance of visibility and increase their perceived risk of danger from potential predators.

7.17 Larger fields may provide not only more opportunity for stone curlews to nest away from field boundaries and associated visibility restrictions, but also tend to have other features which makes them more (or less) attractive to nesting stone curlews. For example, (unmeasured) crop types may influence stone curlew nesting densities and crop type may vary with field size.

7.18 We used the Rural Land Registry (RLR) data and land parcels to describe field boundaries. We placed a 100m grid of points placed over the study region. For each of our 500m cells, we measured the area of the RLR parcel encompassing each individual grid point on LCM arable land within the study region and calculated the average RLR parcel area for arable points within the 500m cell. This provided a measure of average 'field size' surrounding the nests on arable land within the 500m cell.

7.19 For each of our 500m cells, we also measured the distance from each point that was on LCM arable land to the nearest RLR parcel boundary of parcels that included any LCM arable, and calculated both the average and maximum distance to land parcel edge for each 500m cell. The arable land in relatively small fields (i.e. land parcels) will all be close to the boundary and have small average and maximum point distances to boundaries. Arable land in 500m cells that are part of relatively large fields will have some land points at relatively large distances from the nearest boundary.

7.20 There was a weak negative Spearman rank correlation of -0.16 (P <0.001) between average parcel area and the buildings area local density ($BTotA_{1250}$), indicating a slight tendency for larger fields to be away from the most intense areas of buildings.

However, there was no consistent tendency for average density to be higher on arable land in larger fields (RLR parcels) (Table 15).

Table 15: Average 1988-2011 annual stone curlew nest density (per km²) on annually surveyed suitable arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the average area of RLR 'arable' parcels (in km²) encompassing individual 100m grid points on arable land within the cell ; together with arable land area (km²) and (in brackets) total 1988-2011 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km⁻²)		Average RLR 'arable' parcel area (km²)				
		0.10	0.17	0.30	1.80	Overall
Buildings area (S = 1250m)	<1	0.845	0.929	0.999	1.086	0.980
	1-2	0.562	0.516	0.525	0.228	0.478
	2-4	0.230	0.224	0.186	0.293	0.226
	4-8	0.118	0.119	0.199	0.233	0.162
	8-75	0.000	0.076	0.141	0.428	0.125
	Overall	0.298	0.383	0.424	0.435	0.391
Area arable land (km²) (total nests in 1988-2011)		**Average RLR 'arable' parcel area (km²)**				
		0.1	0.17	0.3	1.8	Overall
Buildings area (S = 1250m)	<1	3.6 (69)	13.4 (286)	15.6 (359)	8.1 (202)	40.7 (916)
	1-2	10.7 (138)	21.5 (255)	23.7 (286)	11.3 (59)	67.1 (738)
	2-4	13.2 (70)	20.8 (107)	20.8 (89)	12.5 (84)	67.2 (350)
	4-8	7.3 (20)	13.6 (37)	14.0 (64)	5.6 (30)	40.5 (151)
	8-75	8.6 (0)	10.8 (19)	11.7 (38)	4.7 (46)	35.7 (103)
	Overall	**43.3 (297)**	**80 (704)**	**85.8 (836)**	**42.1 (421)**	**251.2 (2258)**

7.21 Neither the average nor maximum distances of arable land from the nearest RLR land parcel boundary was correlated with the nearby buildings area local density ($BTotA_{1250}$) (Spearman rank correlation is -0.11 and -0.09 respectively). The amount of land in each category of distance to parcel boundary is roughly independent of the area of nearby buildings (Table 16 and Table 17).

Table 16: Average 1988-2011 annual stone curlew nest density (per km²) on annually surveyed suitable arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1000m) and the average distance (m) from grid points on arable land within the cell to the nearest RLR 'arable' parcel boundary; together with arable land area (km²) and (in brackets) total 1988-2011 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km⁻²)		Average distance to nearest RLR 'arable' parcel boundary (m)				
		<50	50-70	70-90	90-1056	Overall
Buildings area (S = 1250m)	<1	0.829	1.054	1.082	0.696	0.958
	1-2	0.510	0.491	0.481	0.165	0.465
	2-4	0.251	0.175	0.292	0.165	0.222
	4-8	0.107	0.135	0.512	0.077	0.158
	8-75	0.079	0.107	0.231	0.257	0.123
	Overall	0.324	0.401	0.536	0.267	0.380
Area arable land (km²) (total nests in 1988-2011)		Average distance to nearest RLR 'arable' parcel boundary (m)				
		<50	50-70	70-90	90-1056	Overall
Buildings area (S = 1250m)	<1	11.2 (213)	17 (412)	8.6 (214)	4.8 (77)	41.6 (916)
	1-2	24.7 (290)	24.4 (275)	13.4 (148)	6.6 (25)	69 (738)
	2-4	28.2 (163)	24.9 (100)	9.8 (66)	6.1 (23)	68.9 (352)
	4-8	17 (42)	16.4 (51)	4.4 (52)	4 (7)	41.8 (152)
	8-75	18.2 (33)	11.4 (28)	4.7 (25)	3.6 (21)	37.9 (107)
	Overall	**99.3 (741)**	**94 (866)**	**40.9 (505)**	**25 (153)**	**259.2 (2265)**

Table 17: Average 1988-2011 annual stone curlew nest density (per km^2) on suitable arable land for the 500m cells classified by the total number of nearby buildings (normal kernel with S=1000m) and the maximum distance (m) from 100m grid points on arable land within the cell to the nearest RLA 'arable' parcel boundary; together with arable land area (km^2) and (in brackets) total 1988-2011 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km^{-2})		Maximum distance to nearest RLR 'arable' parcel boundary (m)				
		<110	110-150	150-200	200-1156	Overall
Buildings area (S = 1250m)	<1	0.582	1.272	0.922	0.757	0.958
	1-2	0.557	0.519	0.363	0.404	0.465
	2-4	0.249	0.253	0.135	0.266	0.222
	4-8	0.105	0.190	0.123	0.244	0.158
	8-75	0.084	0.079	0.202	0.195	0.123
	Overall	0.306	0.449	0.353	0.384	0.380
Area arable land (km^2) (total nests in 1988-2011)		Maximum distance to nearest RLR 'arable' parcel boundary (m)				
		<110	110-150	150-200	200-1156	Overall
Buildings area (S = 1250m)	<1	6.7 (90)	14.1 (413)	13.7 (291)	7.0 (122)	41.6 (916)
	1-2	14.5 (186)	24.2 (289)	19.6 (164)	10.7 (99)	69 (738)
	2-4	17.3 (99)	23.9 (139)	18.6 (58)	9.2 (56)	68.9 (352)
	4-8	10.0 (24)	14.6 (64)	11.7 (33)	5.5 (31)	41.8 (152)
	8-75	11.4 (22)	13.1 (24)	8.2 (38)	5.1 (23)	37.9 (107)
	Overall	**59.9 (421)**	**90 (929)**	**71.8 (584)**	**37.5 (331)**	**259.2 (2265)**

7.22 There was no evidence for higher nest densities in arable areas further from land parcel boundaries (Table 16 and Table 17). Average nest density showed no overall trends with either the average or maximum distance from points within the arable land to land parcel (mostly field) boundaries.

Key Findings: Field size and distance to the nearest field boundary (from a series of gird points within arable land in each 500m cell) are only very weakly negative correlated with the amount of nearby buildings. Surrounding field size and distance to field boundary (as measured) are not related to average nest density on arable land.

Influence of distance from Thetford

7.23 It was thought that the relationship between nest density and nearby buildings density detected by Sharp *et al*. (2008) may have been at least partly due to the particular influence of the largest development forming Thetford town and/or the special nature of the arable and non-arable land surrounding Thetford. To assess this, we derived a new variable representing the distance of each 500m cell from a polygon boundary we formed to encompass the limits of Thetford town. All areas of potentially suitable arable land close to Thetford were surveyed each year up to 2000, but some areas were not surveyed in some or all years after 2000. Therefore our analysis for this variable was based on the arable land in all 500m cells, but only using nest counts over the period 1988-2000.

7.24 15% of the 47.5 km^2 of arable land with the highest category of the building area local density variable occurs within 8km of Thetford, but only 5.7% within 4km (Table 18).

The overall Spearman rank correlation between buildings area local density and distance from Thetford over the study area was 0.19.

7.25 There was no consistent special effect of distance from the major town of Thetford on average 1988-2000 stone curlew nest density on arable land (Table 18). The strong negative relationship between nest density and local buildings area was still clear amongst all the 253 km^2 of arable land more than 8km from Thetford town limits.

Table 18: Average 1988-2000 annual stone curlew nest density (per km^2) on suitable arable land for the 500m cells classified by the total area of nearby buildings (kernel S=1250m) and the distance from Thetford town (km); together with arable land area (km^2) and (in brackets) total 1988-2000 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2000 average nest density (km^{-2})		**Distance from Thetford town (km)**			
		<4	4-8	8-30	Overall
Buildings area (S = 1250m)	<1	0.051	0.176	0.799	0.595
	1-2	0.122	0.019	0.251	0.199
	2-4	0.156	0.028	0.191	0.166
	4-8	0.319	0.128	0.078	0.096
	8-75	0.028	0.033	0.096	0.086
	Overall	0.136	0.077	0.257	0.220
Area arable land (km^2) (total nests in 1988-2000)		**Distance from Thetford town (km)**			
		<4	4-8	8-30	Overall
Buildings area (S = 1250m)	<1	3.0 (2)	13.6 (31)	35.9 (373)	52.5 (406)
	1-2	7.6 (12)	15.9 (4)	66.8 (218)	90.3 (234)
	2-4	5.9 (12)	10.9 (4)	63.7 (158)	80.6 (174)
	4-8	2.9 (12)	6.6 (11)	46.6 (47)	56.1 (70)
	8-75	2.7 (1)	4.7 (2)	40.1 (50)	47.5 (53)
	Overall	**22.1 (39)**	**51.6 (52)**	**253.2 (846)**	**326.9 (937)**

Key Findings: The observed negative association between nest density on arable land and amount of nearby buildings is not caused by any particular influence of Thetford and the distance of arable land from this large town. The strong negative relationship between nest density and local buildings area was still clear amongst the arable land more than 8km from Thetford town limits.

Influence of nearby semi-natural grassland

7.26 The availability of nearby alternative suitable stone curlew nesting (and feeding) habitats may make an area of arable more attractive for stone curlews. Green *et al*. (2000) found that the area of short semi-natural grassland within 1km of an arable field had a positive influence on the nest density within the arable field (see Table 9 in Green *et al.* 2000). To assess this in our study, for each 500m cell, we calculated the percentage ($PSemiNatGrass_{9cells}$) of the total area in the cell and surrounding eight 500m cells which was classified in our study as suitable semi-natural grassland (defined as the SAC).

7.27 Most (71%) arable land is not close to any semi-natural grassland (i.e. none occurs with the same 500m cell or the eight surrounding cells ($PSemiNatGrass_{9cells}$ is zero). However, the amount of semi-natural grassland within the cell and surrounding cells is negatively correlated (r_S = -0.35) with the nearby buildings area local density ($BTotA_{1250}$).

7.28 Areas of arable land within 500m cells that are close to some semi-natural habitat do tend to have higher nest densities (Table 19). Overall average 1988-11 nest density on arable land near ($PSemiNatGrass_{9cells}$ > 0) and not near some semi-natural habitat was 0.811 and 0.275 km^{-2} respectively. This was true within arable land near to low or high levels of buildings, even though nest density was declining with nearby building area (Table 19).

7.29 However, in those relatively small areas of arable land near semi-natural habitat, nest density did not seem to increase or be related with the amount of semi-natural habitat within the cell and the immediately surrounding 500m cells (Table 19).

Table 19: Average 1988-2011 annual stone curlew nest density (per km^2) on annually surveyed suitable arable land for the 500m cells classified by the buildings area local density (kernel S=1250m) and the percentage cover of the surrounding 9 cells by semi-natural grassland ; together with arable land area (km^2) and (in brackets) total 1988-2011 nests in each class. Grey shading indicates the five cells with the highest nest density.

1988-2011 average nest density (km^{-2})		**% semi-natural grassland in surrounding 9 cells**				
		0	1-10	10-90	>90	Overall
Buildings area (S = 1250m)	<1	0.828	1.542	0.566	1.092	0.956
	1-2	0.390	0.898	0.698	0.822	0.464
	2-4	0.150	0.391	0.855	0.635	0.222
	4-8	0.127	0.322	0.576	0.469	0.158
	8-75	0.112	0.219	0.160	0.198	0.123
	Overall	0.275	0.953	0.637	0.811	0.379
Area arable land (km^2) (total nests in 1988-2011)		% semi-natural grassland in surrounding 9 cells				
		0	1-10	10-90	>90	Overall
Buildings area (S = 1250m)	<1	21.3 (406)	10.9 (388)	9.4 (122)	20.3 (510)	41.6 (916)
	1-2	57.4 (515)	7.5 (154)	4.3 (69)	11.8 (223)	69.1 (738)
	2-4	58.9 (204)	4.8 (43)	5.4 (106)	10.2 (149)	69.1 (353)
	4-8	38.0 (111)	1.6 (12)	2.2 (29)	3.8 (41)	41.8 (152)
	8-75	33.4 (86)	3.2 (16)	1.4 (5)	4.6 (21)	38.0 (107)
	Overall	**209.1 (1322)**	**28.0 (613)**	**22.6 (331)**	**50.6 (944)**	**259.6 (2266)**

Key Findings: Most arable land does not have semi-natural habitat nearby. Nest density on arable land was higher on arable land near to some semi-natural grassland, and this was the case in areas with low or high levels of nearby buildings. However, nest density was not related to actual areal extent of semi-natural habitat in the same or neighbouring 500m cells: in other words higher nest densities (on arable land) were associated with the presence of semi-natural grassland nearby, rather than the extent of semi-natural grassland.

Modelling influence of additional environmental variables

7.30 In a previous section (section 6) we tested various building and road variables and describe an initial model involving one building and one road variable. In this section we consider adding additional variables to this 'basic'model. A range of quasi-Poisson GLM models relating nest density to the optimum buildings and road variables and one or more other local environmental features were used. These assess both the influence of other nearby features and their impact on the significance and strength of the previously detected relationship (M1) of nest density with buildings area local density (DSqrt($BTotA_{1250}$)) and distance to nearest trunk road (DSqrt($Dist_{T\text{-}road}$).

7.31 None of the variables described above representing 'distance from Thetford', 'area of semi-natural grassland (SAC) in surrounding 9 cells' or the average or maximum 'distance to RLR parcel boundary' were statistically significant in any of the quasi-Poisson GLM models when tested by F tests for reductions in residual deviance (all test P >0.05). This is in agreement with our two-way table analyses above of these variables in relation to nest density and nearby buildings area.

7.32 Including the area of woodland in the 500m cell and its eight surrounding cells ($PWoodland_{9cells}$) gave a significant improvement in GLM model fit (F=96.6, $P < 0.001$). Neither quadratic (F = 1.34, $P = 0.25$) or gam (F = 2.52, $P = 0.12$) non-linear terms for the area of woodland gave any further statistically significant improvement in model fit; a plot of the fitted gam curve for area of woodland confirming a linear relationship.

7.33 The best-fit quasi-Poisson model for 1988-2011 total nest numbers on the arable land area (denoted '$Area_{Arable}$') per 500m cell involved the double square root of total building area density (DSqrt($BTotA_{1250}$)), the double square root of the distance to the nearest trunk road (DSqrt($Distance_{Trunk}$)) and the percentage cover of woodland in the nine surrounding cells ($PWoodland_{9cells}$), as given by model equation (M2):

$$\begin{aligned} Log_e(Nests_{1988\text{-}11}) &= Log_e(Area_{Arable}) \\ &\quad \underset{\{0.267\}}{-0.250} \; \underset{\{0.175\}}{-\; 2.967}\, DSqrt(BTotA_{1250}) \underset{\{0.133\}}{+\; 1.163}\, DSqrt(Distance_{Trunk})) \underset{\{0.0050\}}{-0.0412}\, PWoodland_{9cells} \qquad (M2) \end{aligned}$$

with QAIC = 1522.4 and dispersion parameter q estimate of 3.95. Notice that estimated model parameters for the buildings area and distance to trunk roads variables are little changed from those for equation (M1); this is because these variables are only very weakly correlated with the amount of nearby woodland($PWoodland_{9cells}$) within our Brecks study region.

Key Findings: The only other assessed additional environmental feature which was detected to influence nest density was the area of woodland in the immediate surroundings

8. Results: Further modelling – buildings areas within specific distance bands, influence of building type and spatial autocorrelation

8.1 In Section 6 we described initial models involving building and road variables. In section 7, we considered the influence of additional environmental explanatory variables in our models and concluded that only the amount of surrounding woodland was associated with reduced nest densities. In this further modelling section we assess:

- the area of buildings within successive individual distance bands
- the influence of building type (residential, commercial, agricultural)
- spatial autocorrelation in nest densities.

Modelling effect of total buildings area in individual distance bands

8.2 Modified forms of model (M2) were assessed by replacing the optimum normal kernel buildings area variable (with S = 1250m) with variables representing the area of buildings in each successive 500m band of distance from the focal 500m cell. This provides a further statistical test of the effect of buildings in individual distance bands over and above the effect of the closer buildings.

8.3 In models involving the square root of the area of all buildings in each 500m distance band from a 500m cell, adding buildings areas in successive 500m distance bands improved model fit (i.e. lower QAIC) up to and including a distance band of 1500-2000m (Table 20; model QAIC = 1536.1, dispersion parameter q = 4.20). Adding buildings area in the 2000-2500m distance band to this model did not improve fit (QAIC = 1537.6, improvement F test P = 0.49).

Table 20: Fitted quasi-Poisson GLM model for 1988-11 average nest density based on building areas within individual distance bands from 500m cells; parameter estimates, their standard errors (SE) and statistical significance *P* values;)

Variable	Parameter Estimate (*b*)	SE(*b*)	*P*
Log_e (AreaArable)	1 (fixed)	---	---
(Intercept)	-2.148	0.226	<0.0001
Sqrt(BTotArea0-500)	-0.854	0.117	<0.0001
Sqrt(BTotArea500-1000)	-0.436	0.107	<0.0001
Sqrt(BTotArea1000-1500)	-0.308	0.096	0.0014
Sqrt(BTotArea1500_2000)	-0.248	0.075	0.0009
DSqrt(Distance to Trunk road)	1.218	0.137	<0.0001
% Woodland Area in 9 cells	-0.043	0.005	<0.0001

8.4 The parameter estimates for the model involving building areas in 500m bands up to 2000m were all negative (and statistically significant), indicating higher area of buildings in each distance band is associated with lower nest densities. Moreover, the parameter estimates (which were unconstrained) decreased with distance band from -0.854 in 0-500m to -0.248 in 1500-2000m. This is as might be expected, indicating the effect of buildings on nest density decreases with distance. It provides support for the use of our kernel-type weighting of buildings area by distance, for which the optimum model (M2) was an even better fit (i.e. with a lower QAIC value of 1522.4 compared to a QAIC value of 1536.1 for the model with band-specific variables in Table 20).

Key Findings: The area of buildings was shown by model fitting to have a decreasing but statistically significant negative effect on nest density on arable land in each 500m distance band up to 2000m.

Influence of type of buildings in specific distance bands

8.5 It is important to understand whether the detected influence of nearby buildings on stone curlew nest density varies according to the type and use of buildings. Unfortunately, only 71 buildings were classified as agricultural, although numerous unclassified buildings might be considered on the ground to be agricultural. This relatively small number makes it difficult statistically to distinguish the effect of agricultural buildings from that of other buildings.

8.6 We have already shown that the area of nearby buildings is a better predictor of nest density than just the number of nearby buildings. The median size of identified agricultural buildings was 290 m^2, which was twice that of commercial buildings (median 148 m^2) and over four times that of residential buildings (64 m^2) (Table 6).

8.7 There is no single 'correct' way to develop models and to assess and represent the effect of individual buildings types on stone curlew nest density. Therefore, we have tried several approaches, as summarised below.

Assume single effect of combined area of subset of building types (kernel S = 1250m)

8.8 Model (M2) was re-fitted by replacing the total buildings area local density variable based on a standard deviation S of 1250m with the equivalent buildings areas local density variable using the same S of 1250m but with buildings areas based on the combined area of different subsets of the buildings types (residential, commercial, agricultural and all 'other' (which includes both MasterMap Premium other categories and all 'unassigned' buildings). The idea is that if the model fit improves or does not get worse by excluding a particular type of building, then that type of buildings may not be associated with any detectable effect on nest density.

8.9 A reverse but similar approach is to assess how the model fit improves by adding the area of a type of building to the buildings area local density variable. If fit improves then that building type might be judged to have some influence on nest density distribution. All 16 possible such models (together with model (M2) are summarised in rank order of fit (in terms of QAIC) in Table 21.

8.10 The model based on the combined area of residential buildings and the many 'other' (mostly unclassified) buildings gave the best fit amongst all such models. This model was an improvement over model (M2) involving the combined area of all types of buildings (ΔQAIC = 26.9).

8.11 A model involving only the area of the 'other' (mostly unassigned) buildings also gave a better fit than model (M2) with reduction in QAIC = 11.4 (=26.9 – 15.5). This highlights our problem of trying to distinguish effects of building type when the high proportion of unassigned buildings is associated with reductions in nest density.

Table 21: Comparison of the relative fits of variations of model (M2) in which the buildings area local density variable (using s = 1250m) is based on the combined area of each of all possible subsets (denoted by ✓) of the building types (Residential, Commercial, Agricultural, 'Other/Unclassified') ; all models also involve DSqrt($Dist_{T\text{-}road}$) and $PWoodland_{9cells}$ as in model (M2). Akaike weight gives relative probability that each model is the best for the observed data amongst this set of models; QAIC measures model lack of fit relative to the best-fitting (top) of these models which involves combined area of residential and unclassified buildings only (top) for which fit is much better than model (M2)

Residential	Commercial	Agricultural	'Other' and unclassified buildings	ΔQAIC	Relative probability of model (Akaike weight)	
✓			✓	0	1.0	
✓		✓	✓	13.3	0.0	
			✓	15.5	0.0	
✓	✓		✓	15.5	0.0	
✓	✓	✓	✓	26.9	0.0	Model (M2)
	✓		✓	31.7	0.0	
		✓	✓	37.2	0.0	
	✓	✓	✓	48.2	0.0	
✓				105.3	0.0	
✓	✓		✓	115.7	0.0	
✓		✓		126.7	0.0	
✓	✓	✓		130.5	0.0	
	✓			157.1	0.0	
	✓	✓		201.7	0.0	
		✓		380.9	0.0	
				384.2	0.0	

8.12 Based on the model relative probabilities (Akaike weights) derived from the ΔQAIC values for these specific 16 models, the following model based on the combined area of residential and unassigned buildings (denoted $BResOthA_{1250}$) is definitely the best fit:

$$\text{Log}_e(\text{Nests}_{1988\text{-}11}) = \text{Log}_e(\text{Area}_{\text{Arable}}) \\ \underset{\{0.134\}}{-0.199} \underset{\{0.093\}}{-3.241}\,\text{DSqrt}(\text{BResOthA}_{1250}) + \underset{\{0.068\}}{1.271}\,\text{DSqrt}(\text{Distance}_{\text{Trunk}})) \underset{\{0.0025\}}{-0.0417}\,\text{PWoodland}_{9\text{cells}} \qquad (M3)$$

Assume separate effects of areas of individual building types (all with kernel *S* = 1250m)

8.13 The previous models assume the effect of each type of building was either zero or the same as the other types having an effect. This is very restricting. Therefore we also assessed a suite of models allowing for a separate effect of the area of each building type. The independent effect of each building type was included in the models using the square root of the normal kernel local density (with S = 1250m) for the area of that building type.

8.14 The results are informative (Table 21). Although the best-fitting models (in terms of minimum QAIC) involved all four categories of building or all except commercial buildings, the parameter values for individual building types reveal the consistency and direction of the association with nest density. The parameter for area of residential buildings was always negative with a weighted model-average estimates of-0.771 and standard error of 0.163 giving approximate 95% confidence limits of -0.771 +/- 2SE = -1.090 to -0.452, indicating a negative influence of residential buildings on nest density on arable land. Similarly for the 'other/unassigned' buildings area for which the best model-averaged parameter has confidence limits of -1.617 to -1.014.

8.15 The effect of the area of commercial buildings on nest density was inconsistent in the various models, sometimes negative, sometimes positive (in the models also involving residential and unassigned buildings). Overall, the best fitting model involving commercial buildings area had a parameter estimate of 0.219 with confidence limits of -0.182 to 0.620. These limits encompass zero and therefore indicate no detectable effect of commercial buildings.

Table 22: Comparison of the relative fits of models involving the square root (Sqrt) of the buildings area local density variables (using s = 1250m) for each of all possible subsets of building types (Residential, Commercial, Agricultural, 'Other/Unclassified') ; all models also involve DSqrt($Dist_{T\text{-}road}$) and $PWoodland_{9cells}$. QAIC measures lack of fit relative to the best-fitting (top) of these models. Each row denotes a model with the parameter estimates of the types involved; bottom row indicates the model-averaged estimates (and their standard errors) based on the Akaike weight giving the relative probability that each model is the best for the observed data amongst this set of models

Residential	Commercial	Agricultural	'Other' and unclassified buildings	ΔQAIC	Relative probability of model (Akaike weight)
-0.739		**1.606**	**-1.299**	0	0.61
-0.821	0.219	1.553	-1.342	0.9	0.39
-0.773	0.317		-1.355	15.5	0.0
-0.651			-1.293	15.9	0.0
	-0.303	1.450	-1.701	23.3	0.0
		1.324	-1.862	24.0	0.0
				26.1	Model (M2) 0.0
			-1.797	34.8	0.0
	-0.169		-1.706	35.8	0.0
-1.427	-0.440	1.838		94.9	0.0
-1.635		1.756		97.2	0.0
-1.409	-0.341			114.7	0.0
-1.571				115.4	0.0
	-2.034	1.857		180.2	0.0
	-1.943			200.5	0.0
		0.919		379.3	0.0
-0.771 (0.163) -1.090 : -0.452	0.219 (0.205) -0.182 : 0.620	1.585 (0.369) 0.861 : 2.310	-1.315 (0.154) -1.617 : -1.014	Model-averaged estimate (with unconditional SE) 95% confidence limits	

8.16 The estimated parameter for the effect of the area of agricultural buildings in all such models was always positive and the average across the best fit models gave 95% confidence limits for this parameter of 0.861 to 2.310 (Table 22). This suggests that overall the buildings in the MasterMap layer, identified as agricultural in AddressBase

Premium, are not associated with reductions in stone curlew nest density on arable land; but moreover they tend to be associated with areas of relatively higher nest densities.

Key Findings: It is difficult to separate and quantify the effects of individual building types on nest density distribution. However,

- Models involving the combined area of just the residential and the many 'other' mostly unassigned buildings gave the best model fit.
- The reduced nest density found around buildings is particularly related to residential buildings
- Only 71 buildings were classified as 'agricultural', but they are associated with relatively higher levels of nest density.
- The area of commercial buildings has no consistent influence on nest density.

Assessing and allowing for spatial autocorrelation

8.17 Stone curlew may have some preference to nest in, or avoid, particular areas for reasons other than the measured and assessed factors. We have investigated additional factors, such as distance to field parcel boundary (related to size of field) and the amount of nearby woodland and nearby SAC , but there may still be residual spatial autocorrelation in nest densities within the arable land because of other factors which make a site attractive or successful for stone curlew nesting. Stone curlews may also like to be near to other nesting stone curlews, which would also cause spatial correlation in the residual (unexplained) pattern in nest distribution.

8.18 Spatial autocorrelation was assessed by re-fitting the optimal GLM models as Generalised Linear Mixed Models (GLMM) using function glmmPQL in the R software to allow for spatial correlation in the model residuals to decline with an exponential function (exp(-*d*/*w*)) of distance *d*. The parameter *w* (to be estimated as part of maximising the model fit) measures the distance over which the spatial autocorrelation occurs. Each such GLMM takes 2-3 hours to fit iteratively. This is why we were not able to assess spatial auto-correlation in all of the above assessed models, but only in the optimal quasi-Poisson GLM-based models.

8.19 Optimal GLM model M2 was re-fitted as a GLMM using the 1988-2011 total nests per annually-surveyed 500m cell (Table 23). After allowing for spatial autocorrelation, each of the three predictor variables still had highly statistically significant relationships with nest density (all P <0.001). Relative to GLM model M2, the GLMM parameter estimates were each slightly reduced in size, while the standard errors (SE) of the parameters were increased because of the reduced confidence due to the non-independence (i.e. spatial autocorrelation) of the model residuals.

Table 23 GLMM parameters (α ± SE(α); β ± SE(β), t, $P(t)$) for model equation type M2 for nest density in relation to the double square roots (DSqrt) of total building area local density ($BTotA_{1250}$) and distance to nearest Trunk road ($Dist_{T\text{-}road}$) and percentage cover of nearby woodland ($PWoodland_{9cells}$), fitted to 1988-2011 total nests on annually-surveyed arable land; w = GLMM parameter estimate (in metres) for spatial auto-correlation exponential ($r = \exp(-d/w)$ decay rate

Model Period Intercept α ± SE(α)	Total Building area DSqrt($BTotA_{1250}$) β ± SE(β); t, *P*	Distance to Trunk–road DSqrt($Dist_{T\text{-}road}$) β ± SE(β); t, *P*	%Woodland cover nearby $PWoodland_{9cells}$	W (m)
GLM 1988-11				
-0.250 ± 0.267	-2.967 ± 0.175; 17.10, <0.001	1.163 ± 0.133; 8.76, <0.001	-0.0412± 0.0050; 8.26, <0.001	---
GLMM 1988-11				
-0.679 ± 0.472	-2.653 ± 0.292; 9.08, <0.001	1.126 ± 0.238; 4.73, <0.001	-0.0329± 0.0064; 5.14, <0.001	445
GLMM 2007-11				
-1.725 ± 0.476	-2.5516 ± 0.298; 8.43, <0.001	1.057 ± 0.235; 4.50, <0.001	-0.0381± 0.0081; 4.74, <0.001	267

8.1 Optimal model M3, a variant of model M2 based on the combined area of residential and 'other/unassigned' buildings instead of total building area, gave very similar results, when re-fitted as a GLMM with spatially auto-correlated residuals (Table 24). This is re-assuring in terms of the significance of parameters for model M3 after allowing for spatial effects, but not too surprising, as the buildings area variable in M3 was still based on 96% of all buildings (Table 6).

Table 24: GLMM parameters (α ± SE(α); β ± SE(β), t, *P*(*t*)) for model equation type M3 for nest density in relation to the double square roots (DSqrt) of the combined residential and other/unassigned building area local density ($BResOthA_{1250}$) and distance to nearest Trunk road ($Dist_{T\text{-}road}$) and percentage cover of nearby woodland ($PWoodland_{9cells}$), fitted to 1988-2011 or 2007-11 total nests on annually-surveyed arable land; w = GLMM parameter estimate (in metres) for spatial auto-correlation exponential (*r* = exp(-*d*/*w*) decay rate

Model Period Intercept α ± SE(α)	Residential+Other Building area DSqrt($BResOthA_{1250}$) β ± SE(β); t, *P*	Distance to Trunk–road DSqrt($Dist_{T\text{-}road}$) β ± SE(β); t, *P*	%Woodland cover nearby $PWoodland_{9cells}$	W (m)
GLM 1988-11				
-0.199 ± 0.134	-3.241 ± 0.179; 34.9, <0.001	1.271 ± 0.132; 9.65, <0.001	-0.0417± 0.0049; 8.58, <0.001	---
GLMM 1988-11				
-0.583 ± 0.456	-2.940 ± 0.299; 9.84, <0.001	1.223 ± 0.234; 5.22, <0.001	-0.0337± 0.0063; 5.40, <0.001	435
GLMM 2007-11				
-1.701 ± 0.460	-2.721 ± 0.304; 8.96, <0.001	1.146 ± 0.232; 4.94, <0.001	-0.0387± 0.0079; 4.92, <0.001	264

8.2 As a further check of the stability of the model, the GLMM was re-fitted using just the most recent 2007-11 nest numbers on the annually-surveyed 500m cells. The parameters estimates for the three variables are slightly different, but still all highly significant (all $P < 0.001$) (the intercept term changes because it naturally depends on the total nest in the years involved). The spatial auto-correlation exponential decay parameter *w* was estimated to be 445 in the full-data GLMM model. This can be interpreted to estimate that the spatial correlation between model residuals (standardised as observed minus predicted / SE(predicted)) for nest numbers in adjacent cells 500m apart is 0.32; while for cells 1000m apart, autocorrelation is 0.10.

8.3 As another approach to checking for spatial patchiness of nests irrespective of the distribution of arable land, buildings, roads and woodland, we formed a factor to represent spatial blocks of the study region. The study region was divided into 2.5km, 5km, 10km or 20km square blocks registered to the national grid. Quasi Poisson GLM model M2 was then re-run with an additional explanatory factor to represent each of the 10km or 20km spatial blocks. Any gross spatial differences in nest density on arable between the blocks will then be allowed for before assessing the strength of any remaining (i.e. average within-block) relationship between nest density and the three environmental factors.

8.4 There were highly significant differences in nest density between the spatial blocks at each spatial scale of 20km, 100km, 5km and 2.5km (all P <0.001).

8.5 Within this overall spatial pattern of variability in nest density, the relationship between nest density and each of the nearby buildings, woodland and distance to trunk road variables is still highly significant (all $P < 0.001$). However, the estimates of the model parameters tend to reduce and their standard errors (the uncertainty) increase as an ever finer spatial blocking pattern is allowed for and eliminated, and especially after removing the finer detail 5km and 2.5km block variation (Table 25).

8.6 This reduction in size of parameter estimates suggests there is some finer scale natural spatial pattern, but there statistical significance indicates that their individual relationships with nest density remain within these spatial blocks.

Table 25: Allowing for differences in 1988-11 nest density on arable land within 2.5km, 5km 10km or 20km square blocks of the study region: quasi-Poisson GLM parameters (α ± SE(α); β ± SE(β), t, *P*(*t*)) allowing for block effects relation to the double square roots (DSqrt) of total building area local density ($BTotA_{1250}$) and distance to nearest Trunk road ($Dist_{T\text{-}road}$) and percentage cover of nearby woodland ($PWoodland_{9cells}$)

Spatial block size	Total Building area DSqrt($BTotA_{1250}$) β ± SE(β); t, *P*	Distance to Trunk–road DSqrt($Dist_{T\text{-}road}$) β ± SE(β); t, *P*	%Woodland cover nearby $PWoodland_{9cells}$
None	-2.967 ± 0.175; 17.10, <0.001	1.163 ± 0.133; 8.76, <0.001	-0.0412± 0.0050; 8.26, <0.001
20km	-2.975 ± 0.169; 17.54, <0.001	1.779 ± 0.197; 9.05, <0.001	-0.0373± 0.0048; 7.76, <0.001
10km	-2.630 ± 0.187; 14.06, <0.001	1.717 ± 0.238; 7.20, <0.001	-0.0374± 0.0052; 7.25, <0.001
5km	-2.183 ± 0.198; 10.99, <0.001	1.382 ± 0.262; 5.27, <0.001	-0.0333± 0.0050; 6.61, <0.001
2.5km	-1.713 ± 0.240; 7.13, <0.001	1.327 ± 0.313; 4.23, <0.001	-0.0291± 0.0047; 6.22, <0.001

Key Findings: There is an overall spatial pattern to the variability in nest density on arable land. Allowing for spatial pattern either by incorporating increasing finer scale (20km, 10km, 5km or 2.5km) square spatial blocks into models, or by allowing for spatial autocorrelation in unexplained nest numbers, reduces estimates of the size of effects of the nearby building, trunk road and woodland variables and increases the parameter uncertainty. However, all three variables are still highly significant, once adjusted for spatial autocorrelation.

9. Discussion

Overview

9.1 This report updates the previous work of Sharpe *et al.* (2008), provides new insights and improves our understanding relating to the distribution of stone curlews in the Brecks. We highlight the following key findings:

- Around half the nests within the study area are on arable land.
- Numbers of stone curlews have steadily increased since the mid 1980s; the increases have been particularly associated with birds nesting on arable and improved or rough grassland habitats (outside semi-natural habitat).
- As the population has increased, more nests (and a higher proportion of nests) have been found outside the SPA, suggesting the range has changed over time and birds have expanded into new areas (rather than merely densities increasing in already occupied areas).
- Densities on semi-natural habitats are (in most years) higher than the other habitats, however within semi-natural areas there is marked variation in use, with many areas of semi-natural habitat supporting no nests.
- Across all years, groups of years and individual years there is consistently a significantly lower density of nests in the arable land close to settlements. Depending on the year, time period and how settlements are defined this effect is significant at distances out to 2000m, but the effect declines with distance.
- The pattern of reduced nest density near settlements is not clear on semi-natural habitats (this matches results from the previous work and is discussed in more detail below).
- Field size varies with distance from settlement, with bigger fields occurring further from settlements. There is no evidence that nest density is different in bigger fields and no evidence that birds particularly avoid (or show a preference) for nest sites close to field boundaries (note that field boundaries are mapped using RLR boundaries and do not necessarily reflect the presence of features such as hedges).
- Using an approach that was not tried in the previous work, we separated out individual settlements and looked at nest densities in the land area unique to each settlement (vornoi polygons). This showed a consistent pattern of lower densities on the arable land around each settlement, adding further weight to the other results.
- From the analysis associated with the voronoi polygons, average nest density declined in distance bands 0-500m, 500-1000m and 1000-1500m. The estimated median reduction in relative nest density in the 0-500m and 500-1000m bands was nearly 90% and just over 50% respectively.
- Using the data from the voronoi polygons, settlement size influences the amount of impact in that larger settlements tend to be associated with a greater reduction in nest density on the surrounding arable land within 500m.
- Contrary to the findings in the previous work, there is no evidence that, as the stone curlew population has increased, that a greater proportion of nests have

been found close to settlements. This may be due to the different definition of settlements, the inclusion of survey effort and the data available from a larger number of years.

- Initial models – similar to previous work - show nest density on arable land to be related to the amount of nearby buildings (both number and especially area) and the distance from trunk roads. The predicted impact of increased building area is greater where the present area of nearby buildings is low and suggests that the total area covered by the nearby buildings has some influence over and above the simple number of nearby buildings.
- Effects of the area of buildings were found out to beyond 2000m when the areas of buildings in different bands were tested within the models.
- Summarising nest density in categories relating to distance to road and the amount of buildings suggests effects of buildings on nest density but no consistent pattern for roads (when all roads are considered). Looking at the data for trunk roads only (A11, A14 or A47), regardless of the level of buildings, the nest density was always lowest in the subset of areas within 0.5 km of the nearest trunk road and highest in the areas furthest from the nearest trunk road.
- The amount of nearby woodland is weakly negatively correlated with the amount of nearby buildings. Nest density on arable land tends to be lower where there is more woodland nearby, especially amongst those otherwise favourable areas not near many buildings. Woodland cover was also significant when included with our building and road variables in the models.
- Field size and distance to the nearest field boundary (from a series of points within arable land in each 500m cell) are only very weakly negative correlated with the amount of nearby buildings. Surrounding field size and distance to field boundary (as measured) are not related to average nest density on arable land.
- The negative association between nest density on arable land and amount of nearby buildings is not caused by any particular influence of Thetford (which is by far the largest settlement in the area).
- Nest density on arable land was higher on arable land near to semi-natural grassland, and this was the case in areas with low or high levels of nearby buildings. However, nest density was not related to actual areal extent of semi-natural habitat in the same or neighbouring 500m cells: in other words higher nest densities (on arable land) were associated with the presence of semi-natural grassland nearby, rather than the extent of semi-natural grassland.
- Using the Mastermap data in combination with the AddressBase Premium data, we identify in total nearly 30,000 residential properties, just under 2500 commercial buildings and 71 agricultural buildings. In addition 185 buildings were classified as ‘other types’ (i.e. very wide range of different buildings including places of worship, schools, public conveniences, hospitals, bus shelters). Furthermore some 29,000 buildings were unclassified. These buildings would all be ones without an address of their own (i.e. no mail) and were typically very small (smaller than residential). We believe these buildings would include garden sheds, greenhouses, ancillary buildings etc.

- Effects of different building types were considered within the model by comparing different combinations of building type. By comparing models involving different combinations of building variables (i.e. combinations involving the area of residential, commercial, agricultural and other/unassigned buildings) it is possible to gain an indication of which type of building is linked to the effect. Residential and other/unassigned have a consistent negative effect within the models. By contrast there is no detectable effect of commercial buildings and stone curlew nest densities are relatively higher around the 71 agricultural buildings.
- The effects of buildings, trunk roads and amount of woodland are still highly significant within the model, once adjusted for spatial autocorrelation (in other words, the inclusion of measures of spatial clustering does not majorly affect the results, indicating that the analysis is not skewed by some underlying pattern or clustering within the datasets used).

Limitations

Survey coverage

9.2 Nest data used within this study were largely collected by the RSPB, but the dataset includes nests from a range of areas where the RSPB staff were not allowed access to undertake survey work, and instead the landowner provided the data themselves. There are gaps in survey coverage, and these are mapped and the analyses adapted to ensure areas with no survey effort are not included as areas with no nesting attempts. We are aware that some landowners do collect data and that it may be possible to add to the survey records used in the analysis, however, despite this the completeness of this data set, reflecting over 5000 nest locations and extending back to the mid 1980s is impressive. The size of the dataset and extent of geographical coverage adds weight to the conclusions drawn.

9.3 It is possible to check the extent to which the gaps in survey coverage (shown in Map 2) may have an influence on the overall data. Prior to 1995, all areas were surveyed. The nest data from 1985-1994 includes a total of 1094 nests, of which 40 (3.6%) were in areas where there was partial survey effort in later years. Looking just at those arable nests for this period, there were 504 arable nests in total, of which 28 (5.6%) where in areas with partial survey effort in later years. While we have accounted for survey coverage in the analysis, it would appear that the number of missed nests within this study (and the previous one) is relatively small.

Habitat

9.4 We have defined our study area initially using soil type. We have then split our analysis and approach by partitioning nests in to one of three categories – arable, semi-natural or 'other'. The semi-natural habitat we have defined using the Breckland SAC boundary, the arable is defined using CEH Landcover data and then 'Other' includes a range of habitats. We recognise some problems with this approach.

9.5 Arable land is split by within Landcover into two sub-categories: 'arable bare' and 'arable unknown'. From Table 3 it can be seen that 'arable bare' has a higher density of nests (20% of the study area and 32% of nests) compared to 'arable unknown' (25% of the study area and 20% of the nests). The Landcover data are from a single year (2007), and crop type and use will vary over time, hence using all arable rather than restricting our analysis to 'arable bare' would seem justified. It is clear however that there will be some variation in the use of arable land depending on crop type and landuse in a particular year. By pooling data across multiple years we anticipate that such effects are minimised in the analysis.

9.6 Areas of semi-natural habitat will vary markedly in their suitability for stone curlews to nest in, due to the habitats present and their condition. This is clear from the data that shows very patchy distribution of stone curlew nests on semi-natural habitats. Some areas support very high nest densities – far higher than that recorded on arable land – and also many areas of semi-natural habitat have supported no nests at all. The grassland areas will vary in their suitability according to the amount of heather, vegetation height (which is influenced by grazing levels) etc. It would be difficult to further refine habitat suitability within semi-natural habitat without detailed fieldwork. For example heather and grass heaths are best treated as a single complex with a mosaic of vegetation type (Rothera 1997), within which their suitability for stone curlews will vary. Heather-rich heathland (areas with continuous dense heather will be largely unsuitable for stone curlews) is not typical, but does occur in some areas such as Cavenham Heath, Knettishall Heath and at Hopton Point in the Stanford Training Area (Rothera 1997).

9.7 Our 'other' category includes a range of habitats that will also vary in their suitability for stone curlews. In particular it is clear that the landcover categories of rough low-productivity grassland and improved grassland are used by stone curlews. The proportion of nests on 'other' habitats does however appear relatively high. For example Green *et al.* (2000) describe the nesting habitat for all stone curlew nests in the UK for the period 1985-89 and give 57% as occurring on arable, 42% occurring on "short-semi-natural grassland and heath", 1% on "Others" and 2% in plantations of young trees. The differences come from our use of the SAC to define semi-natural grassland, whereas Green *et al.* (2000) used field data to define "short" semi-natural grassland. Green *et al.* would therefore have included areas within the SAC (if short) but also other areas outside the SAC (not all SSSIs are in the SAC and not all areas of grassland are designated).

9.8 Ideally we would have had some measure of habitat structure rather than type, as stone curlews select sparsely vegetated ground and sites are abandoned when vegetation becomes too tall (Green & Griffiths 2009). We are not aware of any dataset that could provide this information, especially given the time and spatial scale of this study.

Definition of settlements

9.9 In the original study by Sharpe *et al.* 2008, clusters of buildings were grouped into individual settlements manually. In this study we define 'settlements' by excluding individual buildings which do not have other buildings nearby. This was achieved using a 'threshold' of 50 or 10 other buildings within 250m, i.e. two different definitions.

9.10 The Mastermap GIS layer is very detailed, showing individual buildings, such as outbuildings, greenhouses etc. This means that the use of 10 buildings within 250m as a threshold resulted in only a few isolated buildings being excluded, and therefore this 'settlement' definition included many individual farms and was relatively similar to one that included all buildings. As a result of many buildings within the countryside being included, there was relatively little arable land that was not close to buildings. The use of the 50 building threshold resulted in many more buildings being excluded but – from visual inspection of the maps – also included small villages and hamlets. Land which is more than 1500m from 'settlements' defined using the 50 buildings threshold will often be within 1000m of 'settlements' defined using the 10 buildings threshold. If only larger settlements have an effect over a given distance, then it would be expected that the 10 building threshold would, on average, have an effect over smaller distances.

9.11 We have used both layers through the report as the comparisons between the two are useful. However, it should be recognised that the 50 buildings threshold is the layer that is much more akin to showing 'settlements'.

9.12 Individual settlements will vary in character for example Bodney Camp and East Wretham are predominantly army camps with fluctuating building occupancy rates. The approach of the voronois allows us to consider individual settlements as independent observations; it is important that the reduced density of stone curlews is shown across multiple settlements, widely differing in size and character.

Focus on nests

9.13 We focus on the distribution of breeding attempts (predominantly nests) within the study area. This is because we have good data on nest locations (covering a wide area and timescale). We do not consider the birds' home range, breeding success or site fidelity, all of which would be useful further areas to explore in relation to buildings and urban development.

9.14 We assume that the number of nests is proportional to the number of nesting stone curlews, and that the reduced nest densities therefore indicate lower densities of nesting pairs in relation to buildings, roads etc. Individual stone curlews may nest more than once in a given season, particularly if the first attempt fails, for example through predation. The number of nests in a given location may therefore in part be influenced by nest failure rates. This possible confounding factor can be excluded for the effect of proximity to roads on stone curlew nest density because other studies have found no effect of proximity to roads on breeding success (Day 2003). Comparison of the number of nests with the number of known pairs in the area (R. Green, *pers. comm)* suggests the association we observed between nest density and proximity to buildings is too large to be explained even by an extreme negative effect of proximity on failure rates.

Classification of building types

9.15 The classification of building types indicates a particular effect of residential and unassigned/other buildings. This is an important and new finding. There are however some limitations relating to the classification of buildings. It was disappointing that the classification of buildings left so many unassigned. The agricultural buildings included in the analysis are a small sample of particularly large agricultural buildings, there are clearly many more agricultural buildings within the Brecks and many of the unassigned buildings should probably fall into this category. Similarly commercial buildings formed a relatively small proportion (less than 4%) of all the buildings.

9.16 The settlement analyses used all buildings, regardless of their type and we found reduced densities of stone curlews around buildings in general. This highlights the problem of separating the effect of different building types when they overlap in distribution – for example settlements will contain a mix of both residential and non-residential building types.

Explaining why stone curlew nest densities are related to the amount of buildings

9.17 An issue with the original analysis has been the fact that the work did not indicate why there is such a clear association (over relatively large distances) between nest density and buildings. A range of possible mechanisms could be involved, for example the birds may simply be selecting 'open' habitats in which to nest, or the avoidance may be linked to high levels of people (and therefore disturbance) in the landscape around buildings, obstruction of sight lines (of birds wary of potential predators or disturbers), increased predator abundance, presence of pets (such as cats), increase noise and increased light levels (the birds are active at night).

9.18 This is important, as if the avoidance were triggered by an issue such as lighting, then solutions (such as minimising light pollution in new developments) could resolve any issues. The research presented here does provide some insights that are helpful, but the mechanism is still not clear. The results show a significant negative effect of woodland in addition to buildings. This would lend support to stone curlews selecting open areas and open parts of the landscape.

9.19 The results also indicate that the area of buildings is even more important than the number of buildings or a simple measure of proximity to the nearest settlement. Reductions in nest density increase with settlement size and the total area of buildings, yet the predicted impact of extra buildings are greater when the level of existing buildings is low. The area of buildings (at least for residential buildings) is likely to be linked to numbers of people, numbers of pets, reduced sight lines etc. in that, as the area of buildings increases, these impacts will also increase. In comparing the different building types it is residential buildings that appear to be particularly associated with the lower stone curlew densities. This would again suggest that something about residential buildings – such as the presence of pets, people, noise etc. may be important.

9.20 A range of studies have now considered impacts of urban development on birds (see Chace & Walsh 2006 for review). Some of the most interesting of recent studies have highlighted that some species may be predisposed to tolerate, or even thrive in urban environments while others may be not be able to tolerate such environments (Bonier, Martin, & Wingfield 2007; Møller 2009).

9.21 In a comparative study of birds' flight responses, Møller (2008) suggests that the distance at which birds respond to humans (by taking flight) is a means of assessing general risk aversiveness of different species. He states that species with long flight distances should more often suffer from disruption of their activities by potential predators (including humans), than species with short distances, resulting in declining reproductive success and hence declining population size of such species if disturbance happens more often. Long flight distances suggest that individuals need large amounts of space for their body size, resulting in the prediction that species with long flight distances should have a higher frequency of declining populations than species with short flight distances, which he demonstrates. While the stone curlew was not one of the species included in Møller's work, stone curlews do respond to human presence at particularly large distances (see Taylor, Green, & Perrins 2007 for a review) and they have also declined across Europe. Møller's later paper (2009) considers the characteristics of bird species which occur in urban environments, and shows that, among other factors, colonisation of urban areas by birds is associated with short flight distances. Møller argues that a specific subset of bird species, with particular characteristics, is likely to occur in urban environments and that urban bird species can be considered to be pre-adapted to novel environments. Stone curlews are perhaps particularly intolerant of urban development, and as such ideas relating to specific mitigation for new development (such as reducing lighting, limiting access to surrounding countryside or screening) may be misleading.

9.22 This study has built on the previous work (Sharp *et al.* 2008) and the new analyses involving effects around individual settlements has increased our confidence in the previous conclusions. The main fruitful future research would be long and complex field-based studies to explore and understand the underlying mechanisms.

Spatial variation

9.23 We have tried to limit spatial variation through including a large study area within uniform soils. Within this we have focused on a particular habitat type (arable land) which is likely to show relatively little variation across the study area (compared to other habitat types such as semi-natural grassland).

9.24 Visual inspection of the data from semi-natural habitats shows that a very high proportion of nests occur at a few semi-natural sites, in particular reserves such as Weeting Heath. This makes consideration of semi-natural habitats particularly difficult with our approach. Such marked aggregations mean that the stone curlew distribution in semi-natural habitats is very clumped in space. Semi-natural habitat will vary with management, grazing intensity and is comprised of a range of vegetation communities. Marked aggregations of birds will also influence distribution as there is increasing evidence that individuals of a variety of bird species use the presence of conspecifics as one of many habitat cues to select potential breeding sites (see Colwell 2010 for discussion). These factors do not mean that urban development does not also have an impact in relation to semi-natural habitat, it is that there are other (potentially confounding) factors which would be difficult to include in the analyses.

9.25 The inclusion of spatial autocorrelation in our models is an improvement on the original study in 2008, which lacked such tests. After the inclusion of spatial autocorrelation, there are still significant negative effects of buildings, woodland and trunk roads on arable nest density.

Accuracy of nest locations, and proximity of nests to field boundaries

9.26 We were lucky to have such a complete and large dataset to use in these analyses. This has allowed detailed analyses, such as the voronois, which would not be possible with a less complete or comprehensive dataset.

9.27 The accuracy with which nest locations have been recorded has increased over time (Appendix 1), and GPS units now allow accurate recording of locations within the field. The use of 500m grid squares in the modelling, the choice of 500m bands around settlements and the way in which we have split the data into different blocks of years should mean that the variation in accuracy of nest recording has little or no impact on the main results.

9.28 One particular area of concern is, however, the accuracy of nest locations in relation to our consideration of nests and field boundaries (Table 5), where we extracted nest locations by 50m bands. Only nest locations recorded to at least 8 figure grid references were used in relation to the bands. In our models analysing nests within 500m grid cell, we used grid points at 100m intervals within arable land, with a measurement from each point to the nearest boundary. Thus approach takes into account shapes of fields and ensures that the biologically meaningful measurement – proximity (average or maximum) to the edge – is considered in the models.

9.29 While we have therefore tried to limit the impact of nest recording accuracy and included proximity to boundaries within our models, there are also other limitations with our approach. Some arable nests are on plots specially cultivated for stone curlews, which are nearly always at the edge of the field. This provision of good nesting substrate near to the field edge would tend to cancel out the natural effect of any edge avoidance or field selection. We did not have data on which nests were within such stone curlew plots, but this may be a useful check in future analyses. Furthermore we were unable to classify field boundaries, and these may differ markedly. The RLR boundaries used within our analysis will include many boundaries that simply divide areas with different crops (i.e. no physical boundary is necessarily present), whereas others may include hedges or trees. Hence some mapped edges probably have hedgerows and trees and others do not, which would weaken the ability of the analysis to determine any real tendency to avoid hedges.

Implications for planning

9.30 The analysis set out within this report revisits and builds on the previous work undertaken to underpin the mitigation strategy applied by Breckland Council to meet its duties as competent authority under the Habitats Regulations, with regard to the consideration of plans and projects that the Council is undertaking or authorising, in combination with other relevant plant/projects..

9.31 Using the models we can test some hypothetical development scenarios and explore the effect on the number of stone curlew nests that would be expected in a given area, providing a means of considering the combined effect of development in different locations. We established a hypothetical grid of 25 500m grid cells, and assumed that all cells were entirely comprised of arable land. We then considered the effect of different areas of buildings, as shown in Figure 20. Within the figure the 25 grid cells are shown, and we then consider the effect of combinations of development at eight different locations, labelled S-Z. All these locations fell outside the grid, either right on the edge (locations X, Y, and Z) or at different distances (W and S are 500m from the grid, T is 2km from the grid). The results are shown in Table 26, where 31 different scenarios are considered. All scenarios consider no woodland and no roads within the area. The predictions are generated using Model M3.

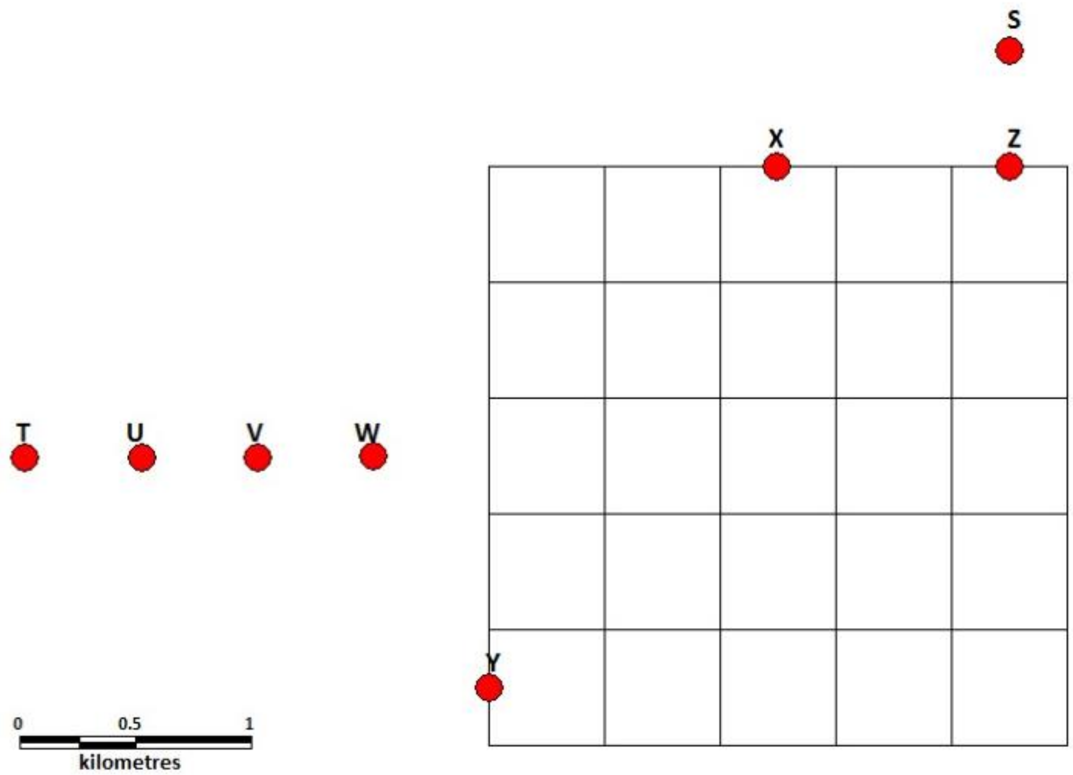


Figure 20: Hypothetical grid and settlements

Table 26: Results of different development scenarios (based on Figure 20). Predictions generated using Model M3; the buildings variable (BResOthA1250) was set such that any cell with values of less than 0.078 was set to 0.078 (the minimum observed value). The final column shows the % change in relation to the first scenario (with no development at all). The shading in this column reflects the scale of change.

SCENARIO	Area of buildings (per ha)								Total ha buildings	Total nests	% change from 1
	S	T	U	V	W	X	Y	Z			
1	0	0	0	0	0	0	0	0	0	26.9	
Range of development sizes at single location (Z)											
2	0	0	0	0	0	0	0	1	1	17.3	36
3	0	0	0	0	0	0	0	2	2	13.1	51
4	0	0	0	0	0	0	0	3	3	10.8	60
5	0	0	0	0	0	0	0	4	4	9.2	66
6	0	0	0	0	0	0	0	5	5	8.1	70
7	0	0	0	0	0	0	0	10	10	5.3	80
8	0	0	0	0	0	0	0	20	20	3.4	87
Same total building area (1ha) at different location											
9	1	0	0	0	0	0	0	0	1	20.5	24
10	0	0	0	0	0	1	0	0	1	14	48
11	0	0	0	0	1	0	0	0	1	18.1	33
12	0	1	0	0	0	0	0	0	1	26.9	0
13	0	0	1	0	0	0	0	0	1	25.1	7
14	0	0	0	1	0	0	0	0	1	21.9	19
15	0	0	0	0	0	0	1	0	1	17.3	36
Adding new development away from existing development at Z											
16	0	0	0	0	0	1	0	1	2	10.9	59
17	1	0	0	0	0	0	0	1	2	14.9	44
18	0	1	0	0	0	0	0	1	2	16.6	38
19	0	0	1	0	0	0	0	1	2	14.8	45
20	0	0	0	1	0	0	0	1	2	15.5	53
21	0	0	0	0	1	0	0	1	2	10.3	62
22	0	0	0	0	0	0	1	1	2	9	66
Different amounts of development at multiple locations											
23	1	1	1	1	1	1	1	1	8	4.6	83
24	0	0	0	0	1	1	1	1	4	5.4	80
25	0	5	0	0	1	1	1	1	9	5.3	80
26	0	0	5	0	1	1	1	1	9	5	81
27	0	0	0	5	1	1	1	1	9	4.5	83
28	0	0	0	0	6	1	1	1	9	3.8	86
29	5	5	5	5	5	5	5	5	40	1	96
30	0	20	20	0	0	0	0	0	40	16.8	37
31	0	5	5	0	0	0	0	0	10	19.8	26

9.32 The results of the hypothetical scenarios are revealing in that they show:

- There is a greater impact when there are buildings in an area where previously no buildings were present. In scenarios 2-8, development is all at the edge of the grid (location Z). Scenario 2 involves 1ha of development and there is a 36%

reduction in nests compared to the no development scenario (Scenario 1). By comparison, with 4ha of development at the same location (Scenario 5) there is a 66% reduction in nests, while with 5ha of buildings (Scenario 6) the reduction in nests is 70%.

- The numbers of nests predicted with a single hectare of development at S or W (both 500m from grid) are similar. There is however a bigger impact associated with W (Scenario 11) as this location is closer to more cells than S (Scenario 9).
- Comparison of scenarios 12 and 13 indicates that development at 1500m from the grid has a small influence (7% reduction) compared to development at 2000m (negligible change), when no other development is present.
- Scenarios 16-22 provide examples of effects of adding new buildings and therefore the cumulative effect of development: each scenario can be thought of as adding 1ha of new development at various distances from existing development of 1ha (at Z, on the edge of the arable land). Each scenario involves the same total area of buildings (2ha), split evenly between 2 different locations. Scenario 22 predicts the fewest stone curlew nests: 66% fewer nests than with no development at all. Scenario 22 involves 1ha of development at Y and Z, i.e. opposite corners of our grid.
- The impact of widely spaced development compared to the same area developed in a single location can be seen in scenarios 29 and 30. Both involve 40ha of development. With 5ha of development at each of the 8 locations, virtually no nests are predicted (96% reduction). If the same amount of development is set back at locations T and U (1500m and 2000m from our grid) then the reduction in nests is 37% (Scenario 30).

9.33 The examples in Table 26 illustrate the difficulties in assessing – piecemeal - individual development applications. The examples indicate that the least impact of increased building will be where the new building occurs away from the areas where birds are nesting and where there are already buildings. Consideration of our examples would suggest that settlements in the region 5-10ha or more have already reduced stone curlew densities to such an extent that the effect of additional buildings is relatively slight. For settlements of this size 'infill' is therefore likely to have little effect but might be essentially compounding a potentially existing adverse effect.

9.34 Our analyses show that the effect of buildings seems to be particularly linked to residential development, and residential development should therefore be the focus of planning policy to protect the SPA.

Relevance of the increasing population of stone curlews

9.35 It is apparent from the survey data that stone curlew numbers are increasing in the Breckland area (e.g. Figure 7). This is positive, but there is some cause for concern, given that the numbers within the SPA have remained relatively constant since 2000 (dark green in Figure 7). In fact the data suggests that the distribution is spreading (Figure 8), with more nests occurring on arable land and 'other' habitats beyond the SPA (Figure 5) over time. It is relevant to note that birds are spreading in space and yet the avoidance of built development is still present, i.e. as the population increases birds are not spreading into the areas close to development.

9.36 A larger population is likely to be more resilient to impacts than a smaller population, and a quantity of loss would have greater ramifications for a small population, leaving it far more vulnerable to other impacts than a larger population suffering the same quantity of loss. The ability of a European site interest feature to withstand an impact, based on its size, is therefore relevant to a competent authority's consideration of the potential impact of any plan or project. Whilst this is the case, it is important to distinguish this from an assumption that expanding interest features can automatically sustain some loss.

9.37 SPAs with increasing population numbers can understandably attract questions regarding the opportunity for otherwise damaging plans and projects to come forward, because it appears that there is some capacity for damaging or removing some of the site interest without having an adverse effect on site integrity. To put it simply, it can be concluded that the number of birds over and above the population figure at site classification are 'free game' and to cause the loss of some of these would be acceptable because there will still be more birds than the site had to start with.

9.38 As such questions are understandable and inevitable, it is important to explore these a little further, and give more detailed explanation as to why it is considered that such an approach is not in accordance with the requirements of the legislation. Firstly, it is important to bear in mind the primary objectives of the European legislation, where the words 'to maintain or restore' are repeated throughout. Likewise, European guidance[6] on the application of the Directives similarly repeats the objective of maintaining or restoring. On reading the European legislation and guidance, it seems apparent that the intention of the protected site network is to protect assets, but that there is also a requirement to restore those assets so that they achieve population levels that best enable them to maintain their populations into the long term.

9.39 Furthermore it is considered that the legislation and supporting European guidance assumes that sites may well be in a deteriorated state at site designation or classification, even if the minimum designation criteria are met. There is great emphasis placed on restoration, and it is suggested that it would therefore follow that the intention of the Directives is not merely to achieve a particular status for a site in line with the date of its formal designation. .

9.40 It is therefore suggested that as a minimum, achievement of favourable conservation status should be taken to be the achievement of densities of birds (associated with SPAs) that represent stable or increasing populations and should also have regard for population levels that could be sustained across the natural range of the species in question. Given that both the Habitats and Birds Directives set out duties for wider

[6] European Communities 2000, Managing Natura 2000 sites – The Provisions of Article 6 of the 'Habitats' Directive 92/43/EEC

supporting habitat in addition to that within site boundaries, it is further suggested that achieving favourable conservation status should not necessarily stop at site boundaries, particularly when natural ranges extend significantly beyond the site in many cases.

9.41 It is also important to note that the achievement of favourable conservation status, at either an individual site level or in contributing to the overall status of a particular habitat or species, is a collective effort between public bodies, land owners and managers, businesses, charities and local wildlife groups. This work takes place in order to contribute to Member State duties for the conservation and restoration of the European site network. There may therefore be some potential issues measures implemented to achieve stable and increasing populations of a species then being used as mitigation measures to ensure that a plan or project does not have an adverse effect on site integrity.

9.42 Other authors (Landscape Science Consultancy 2011) have argued that because individual fields tend not to be occupied in every year, there must be vacant suitable arable nest sites annually. The inference is then that any impact of development or disturbance is simply a redistribution of birds rather than any population impact. This argument fails to appreciate that stone curlew territories are typically large and cover multiple fields. Individual fields would therefore not be expected to support nests on an annual basis. Stone curlews are migrants and territories will shift each year; individual birds have been shown to switch between habitats and different locations over time (Green & Taylor 1995; Green & Griffiths 2009). Ecological theory suggests that, as population size increases, individuals will choose to breed on poorer quality sites and eventually some will delay breeding and instead wait for good quality territories to become available (Kluyver & Tinbergen 1953; Kokko & Sutherland 1998; Gunnarsson *et al.* 2005). In the Brecks, it would seem that the semi-natural grassland provides the preferred habitat, and supports the highest densities. As the population has increased, nest density has increased on arable land in particular, but rather than nest in areas close to buildings, birds are spreading out over a wider geographic area.

Recognising what constitutes an adverse effect (alone and in-combination)

9.43 Regulation 61 of the Habitats Regulations (transposing Article 6(3) of the Habitats Directive) requires a competent authority to undertake an appropriate assessment for any plan or project that is likely to have a significant effect on a European site, either alone or in-combination with other plans or projects. Defining what constitutes a significant effect alone, and likewise what would need to be the sum of a number of plans or projects where effects were insignificant alone, can be very difficult for SPA interest features with large or increasing population numbers, where it could be argued that the loss of one or two birds would be ‘lost in the noise’ of population fluctuations to the extent that the impact would not be measurable, and therefore *de minimis* (i.e. so insignificant that it would not contribute to an in-combination assessment). For interest features with small or declining populations, small losses could be significant alone, and would certainly contribute to an in-combination effect.

9.44 At the screening for likelihood of significant effects stage, it is a matter of being precautionary, but with sound justification for erring on the side of caution. If there is the potential for loss of an interest feature, over and above a level that would be *de minimis*, and a scientific basis for that assumption, a more detailed appropriate assessment should be undertaken. The precautionary approach applies where there is a lack for scientific evidence to rule out impacts, but where there is a logical scientific basis for concluding that there is a possibility of impacts. Once the appropriate assessment has been completed, it is the decision as to whether there is an adverse effect on site integrity that becomes the most critical issue. In the case of the Breckland SPA there is no information on how many birds the SPA should support and it is necessary to refer back to the conservation objectives (see introduction, paragraph 1.10).

9.45 As a result of the work presented here it is clear that residential buildings in different locations will have different levels of impact. For example, a large new development, directly adjacent to arable land that otherwise has little or no buildings close by, would have a larger effect compared to a single building within an existing large settlement some distance from suitable arable land. The in-combination effect of multiple developments, each having a small effect, is difficult to quantify. The analysis undertaken continues to indicate that there is an impact, at least to 1500m, and it is therefore suggested that the mitigation strategy in place continues to represent the most suitable way to continue to prevent adverse effects on site integrity, whilst not preventing any individual development coming forward with information to demonstrate that its specific nature or location means that it would not contribute to the range of factors that are influencing nesting density. From the analyses undertaken, it is concluded that any proposal that is not able to demonstrate that it will not contribute, continues to present a risk to the stone curlew population, in combination with other plans or projects. It is further concluded that, despite remaining information gaps and possible limitations, there continues to be sound scientific justification for this approach.

9.46 One possible option for identifying levels of impact of different potential building scenarios, both alone and in-combination could be to use the model equations to predict the numbers of nests in individual grid cells. It could be possible to establish a series of linked spreadsheets which could automatically compute the effect of development in different locations. Such an approach could allow different combinations of buildings to be tested, but would not indicate what level of impact resulted in unacceptable harm to the SPA.

Teasing apart the difference between volumes of buildings or proximity to buildings

9.47 The modelling results indicate that stone curlew density is related to the amount of nearby buildings and that the number of buildings, but particularly the area is important. The predicted impact of the area of nearby buildings has some influence over and above the simple number of nearby buildings. Because this indicates the potential for any increase in building area to contribute to an in-combination effect, It is difficult to translate this result into planning guidance or development control, but it would seem to suggest that applications that involve bigger areas of development (in terms of building footprint) would have a greater impact on nest density than smaller ones, and this is something that would be factored into the suggested use of the model equations if taken forward.

Distance at which an effect occurs

9.48 The analyses show reduced densities of stone curlews in areas near buildings. The density of birds nesting in areas near buildings is not zero, and both the data used here and anecdotal evidence (e.g. from landowners[7]) shows that low densities of birds occur in areas within 500m of buildings. The effect of buildings also tails off with distance, with the orange line in Figure 2 representing the weighting that worked best within the models. Given a gradual 'tailing off' with distance, it is clearly difficult to set a particular distance at which no likely significant effect would occur.

9.49 Results of different analyses indicate a range of different distances depending on the time periods used and definition of a settlement. Analysis of individual years and 4-5 periods of data suggest effects out to between 500m and 2000m. Analyses of the combined years' data based on individual settlements and the modelling using the weighted kernel variables all indicate effects out to 1500m. Data from a single year has less statistical power due to the smaller number of nests involved, and while (virtually always) significant tend to show effects out to smaller distances than when all years are combined or when total nests over periods of 4-5 years are considered.

9.50 We generated two separate settlement layers. One settlement layer was defined by eliminating buildings that had less than 50 other buildings within 250m; the second layer was derived in the same way but using a threshold of 10 buildings (within 250m). The 10-threshold layer is therefore less restrictive, includes more buildings and is closer to the data on all buildings (that we used in the later models). The 10-threshold layer therefore includes smaller hamlets and small clusters of buildings. Looking across all years, the successive chi-square tests indicate significant effects out to 2000m using the 50-threshold layer and out to 1500m using the 10-threshold layer. This (and subsequent analyses) suggest that the level of avoidance is related to the size of the settlement.

9.51 Size of settlement was also relevant in the analysis relating to individual settlements and the voronoi polygons. The best fitting normal kernel weighting in the models was using a standard deviation of 1250m. This weighting (shown as the orange line in figure 1 of Sharpe *et al.* 2008) assigns a weight of 1 to buildings at a distance of 0m and almost nothing (weighting of 0.018) by 2500m.

9.52 The selection of 1500m for the existing buffer in place around the SPA was informed by the previous work. As it has been demonstrated that existing development is affecting nesting density, it is assumed that allowing further potential impacts to take place in the 1500m buffer will lead to further reductions in the carrying capacity of affected parts of

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[7] A summary of landowner observations based on a questionnaire was provided by Natural England

the SPA that fall within 1500m of the impact. If that impact is permanent, such as a new housing development, then the further reduction in carrying capacity is permanent. Each time this happens, the effect could be relatively small, but contributes to continual and permanent damage to the SPA. It was for these reasons that policies were put in place to set out a presumption against development in the buffer, with the option for an individual development to come forward with its own Habitats Regulations Assessment, noting that exceptions may occur where impacts could be ruled out.

9.53 Permanent effects on habitat supporting SPA interest within an SPA are considered to be an adverse effect on site integrity. The revised analysis reinforces the requirement for this buffer, and in fact does indicate that impacts can be detected at 2000m from the SPA boundary. Taking an overview of the different approaches we suggest 1500m is an appropriate distance. Given different impacts with different sizes of settlement/levels of development, there is certainly strong evidence to support the continued use of a 1500m and large developments (particularly if no other development is present in the area) beyond 1500m are also likely to require appropriate assessment.

Types of building

9.54 The difficulties in classifying buildings mean that some caution is required in interpreting the results. However there is a strong indication that the negative effect of buildings is particularly linked to residential development. We suggest therefore that residential development should be the clear focus of the 1500m zone.

9.55 The positive effect of agricultural buildings is interesting. Only 71 agricultural buildings were classified, and these tended to be very large buildings. There are clearly many more agricultural buildings within the Brecks, and it is therefore important to recognise that our analyses potentially 'missed' lots of agricultural buildings, which were potentially included as commercial buildings or 'other/unclassified'. It is possible to speculate on why the results indicate more stone curlew nests in the vicinity of the 71 classified agricultural buildings. The large buildings may well be associated with particular farming practices, particularly rural areas, and farms with relatively few people.

9.56 Other/unclassified buildings were also significant and had a negative effect on stone curlew nest density. This category would include a wide assortment of different building types. Given the difficulties in classification we suggest that proposals for non-residential development should, in the future, be subject to individual assessment.

Potential for mitigation

9.57 Mitigation measures have been considered, at least in part, in earlier paragraphs. The results from our available evidence and data were unable to provide any support that measures such as screening, presence of hedgerows or tree planting around developments may reduce the impact of buildings. While we have not directly considered lighting, there is also no available evidence to suggest that measures to reduce lighting levels around buildings may reduce any impacts.

Conclusions

9.58 In conclusion, the results strengthen the continued use of Breckland Council's mitigation strategy already in place. Planning policies currently in place within the Breckland Core Strategy set out a 1500m zone around the SPA where there is a presumption against development. The results presented here support this zone, for residential development. The option for individual Habitats Regulations Assessments, where an applicant considers they have enough information to demonstrate that a proposal will not contribute to impacts on stone curlew, remains open, as does the option for individual level assessment where a proposal is within 1500m of habitat used by breeding stone curlew, but where that habitat falls outside the actual SPA boundary. There remains the potential for individual projects to demonstrate that there is no contribution to overall impacts, and we have suggested a potential way of identifying locations where individual assessment work may be more beneficial and where it may be of little merit. There still appears to be little opportunity to mitigate for any impacts that are identified within the 1500m zone around the SPA.

10. References

Beale, C.M., Lennon, J.J., Yearsley, J.M., Brewer, M.J. & Elston, D.A. (2010) Regression analysis of spatial data. *Ecology Letters*, **13**, 246–264.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H. & White, J.-S.S. (2009) Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution*, **24**, 127–135.

Bonier, F., Martin, P.R. & Wingfield, J.C. (2007) Urban birds have broader environmental tolerance. *Biology Letters*, **3**, 670–673.

Burnham, K.P., Anderson, D.R. & Huyvaert, K.P. (2011) AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. *Behavioral Ecology and Sociobiology*, **65**, 23–35.

Chace, J.F. & Walsh, J.J. (2006) Urban effects on native avifauna: a review. *Landscape and Urban Planning*, **74**, 46–69.

Colwell, M.A. (2010) *Shorebird Ecology, Conservation, and Management*. University of California Press.

Day, T.C.F. (2003) *The Effects of Disturbance from Roads on Stone Curlews in Southern England.* Darwin College, University of Cambridge,, Cambridge.

Green, R.E. & Griffiths, G.H. (2009) Use of preferred nesting habitat by stone curlews Burhinus oedicnemus in relation to vegetation structure. *Journal of Zoology*, **233**, 457–471.

Green, R.E. & Taylor, C.R. (1995) Changes in Stone Curlew Burhinus oedicnemus distribution and abundance and vegetation height on chalk grassland at Porton Down, Wiltshire. *Bird Study*, **42**, 177–181.

Green, R.E., Tyler, G.A. & Bowden, C.G.R. (2000) Habitat selection, ranging behaviour and diet of the stone-curlew (Burhinus oedicnemus) in southern England. *Journal of Zoology, London*, **250**, 161–183.

Gunnarsson, T.G., Gill, J.A., Petersen, A., Appleton,, G.F. & Sutherland, W.J. (2005) A double buffer effect in a migratory shorebird population. *Journal of Animal Ecology*, **74**, 965–971.

Holling, M. & Rare Breeding Birds Panel. (2011) Rare Breeding Birds in the UK in 2009. *British Birds*, **104**, 476–537.

Kluyver, H.N. & Tinbergen, L. (1953) Territory and regulation of density in titmice. *Archives Neerlandaises de Zoologie*, **10**, 265 – 286.

Kokko, H. & Sutherland, W.J. (1998) Optimal floating and queuing strategies: consequences for density dependence and habitat loss. *American Naturalist*, **152**, 354 –366.

Landscape Science Consultancy. (2011) *Investigation of Nesting Site Selection and Distribution of the Population of Stone Curlew Around Thetford, Norfolk.* for Shadwell Estates.

Liley, D., Hoskin, R., Underhill-Day, J. & Tyldesley, D. (2008) *Habitat Regulations Assessment: Breckland Council Submission Core Strategy and Development Control Policies Document*. Footprint Ecology / David Tyldesley Associates / Breckland Council.

Møller, A.P. (2008) Flight distance and population trends in European breeding birds. *Behavioral Ecology*, **19**, 1095 –1102.

Møller, A. (2009) Successful city dwellers: a comparative study of the ecological characteristics of urban birds in the Western Palearctic. *Oecologia*, **159**, 849–858.

Rothera, S. (1997) *Breckland Natural Area Profile*. English Nature Natural Area Profile, English Nature.

Sharp, J., Clarke, R.T., Liley, D. & Green, R.E. (2008) *The Effect of Housing Development and Roads on the Distribution of Stone Curlews in the Brecks*. Footprint Ecology / Breckland District Council.

Taylor, E.C., Green, R.E. & Perrins, J. (2007) Stone-curlews Burhinus oedicnemus and recreational disturbance: developing a management tool for access. *Ibis*, **149**, 37–44.

Appendix 1: Nest Numbers by Year and Mapping Precision

This table summarises the number of nests for each year within the study area and the precision with which nests was mapped.

Year	6 figure OSGR	8 figure OSGR	10 figure OSGR	Total
1985	76			76
1986	76			76
1987	104			104
1988	96			96
1989	105			105
1990	120			120
1991	123			123
1992	123			123
1993	139			139
1994	132			132
1995	159			159
1996	176			176
1997	191			191
1998	200			200
1999	224			224
2000	237			237
2001	152			152
2002	62	24	121	207
2003	62	1	154	217
2004	69	3	171	243
2005	78	1	176	255
2006	94		189	283
2007	97		197	294
2008	83		201	284
2009	73	1	237	311
2010	91	6	194	291
2011	96	5	197	298
Total	**3238**	**41**	**1836**	**5116**