The effect of housing development and roads on the distribution of stone curlews in the Brecks

Evidence to support the Appropriate Assessment of development plans and projects in Breckland

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Summary

We combine data describing the nest location of stone curlews with data on the locations of new housing, road data and traffic data to explore the effect of housing and roads on the spatial distribution of stone curlews over the period 1988 - 2006. This work has been commissioned by Breckland District Council to inform the potential impact of new housing within the district, and in particular in the vicinity of Thetford.

We differentiate between arable and semi-natural habitats and focus on stone curlews breeding on arable land, as this habitat is likely to be more uniform and less subject to variation in habitat quality, management etc. Over the study period the number of stone curlew nests has increased steadily (from 83 in 1988 to 246 in 2006). This increase is most marked on arable land, while birds nesting on SSSIs have shown a slight decline since 2002. On arable land the birds occur at relatively low densities and there has been considerable turnover and change in the precise areas which hold nests in each year.

During the study period the number of houses within and around the study area has also increased, from c.150,000 houses in 1988 to c.210,000 houses in 2006.

Within every single year from 1988 to 2006, the stone curlew nest density (per ha of suitable arable land) was significantly lower on land within 0-500m of the nearest settlement than in successive distance bands. Annual nest densities on arable land 500-1000m from settlements were also lower than densities at subsequent distance bands in 14 of the 18 years over the period 1988-2006. This consistency across the whole study period provides strong long-term evidence of some negative impacts or association of housing on stone curlews densities on arable land. The proportion of all nests (within a given year) which are nesting within 500m or within 500-1000m of any "settlement" has steadily increased over the past two decades, indicating that the avoidance of housing, while always highly significant, has decreased in more recent years.

We also found a significant avoidance of trunk roads. We grouped yearly data into four different periods (1988-92; 1993-96, 1997-2000, 2002-06) and for all four periods, the nest density on arable land within 500m of a trunk road was statistically lower than densities at greater distances. Over the first (1988-1992) and last (2002-2006) periods, there was also statistically significant differences between nest densities on land in the 500-1000m band relative to those at greater distances from trunk roads. With all years' data combined, the total nest numbers involved are sufficient for effects to be detectable up to 1500m. A similar analysis of nest density in relation to distance from non-trunk A-roads was carried out and showed a negative impact of the presence of non-trunk A-roads on stone curlew nest density up to a distance of 500m.

We developed a Poisson regression model to allow us to predict the number of stone curlew nests (on arable land) within a grid of 500m cells across the whole of the Breckland area where suitable soil types occur. Various combinations of housing, road and traffic variables were tested, with a range of different weightings (based on a half-normal kernel distribution) applied to each variable. The best predictive model for stone curlew nest density on suitable arable land within each 500m cell involved the weighted normal kernel variables for the housing (square root, with standard deviation=1000m), daily traffic (with standard deviation=1000m) and presence of A-roads (with standard deviation =250m). Using this model we predict the number of stone curlew nests on arable land that would be expected were the north and south Thetford extensions to take place, and we also test the effect of these developments in combination with an increase in road traffic of 35%.

The impact of both developments together, in combination with a road traffic increase of 35%, would be c.5 nests fewer per year (on arable land), a reduction of around 3%.

These results have implications for future development in Breckland. We highlight the following key results that will have consequences for strategic planning within the District:

- New housing development may need to be at least 1500m, and potentially 2000m from any arable land suitable for stone curlews for there to be no effect on stone curlew distribution
- There is a negative impact of trunk roads on stone curlew nest density on arable land up to a distance of at least 1000m, and maybe up to 2000m.
- There is a negative impact of the presence of non-trunk A-roads on stone curlew nest density on arable land up to a distance of 500m.
- There is no reason to suggest that similar avoidance of roads and housing does not occur on semi-natural habitats, but we err from highlighting specific distances.

Acknowledgements

This report was commissioned by Breckland District Council. We are grateful to Andrea Long and Natalie Beal for their support throughout the contract.

The stone curlew data is provided by the RSPB, we are grateful to Lucy Arnold (RSPB) for collating these data for us. We also thank Andrew Dodd and Steve Jones (both RSPB) for useful discussion and comment.

Collating the housing and traffic data from across numerous local authority boundaries has been a challenge and, particularly for the early years, far from straightforward. We are grateful to all those who have helped us source traffic and housing data.

Introduction

Breckland SPA qualifies under Article 4.1 of the Birds Directive (79/409/EEC) by supporting populations of European importance of nightjar, woodlark and stone curlew. Stone curlews are summer migrants, associated with open, bare habitats, such as some heaths, downland and some arable. In 1998 (the year given in the SPA citation), the Breckland SPA supported some 142 pairs of stone curlew, some 75% of the UK population.

There is a growing body of evidence that development adjacent to heathland sites can impact deleteriously on the interest features of such sites (Liley et al., 2006, Underhill-Day, 2005). These studies have primarily focused on nightjars, woodlarks and Dartford warblers. For nightjar and woodlark, studies looking at housing levels have found negative correlations between the amount of housing surrounding sites and the number of birds present on those sites (Liley and Clarke, 2003, Liley et al., 2006, Mallord, 2005). Detailed field studies have variously shown disturbance from recreational access to impact settlement patterns, breeding success and timing of breeding (see Liley and Clarke, 2002, Liley and Clarke, 2003, Mallord, 2005, Murison, 2002).

The principal work on stone curlews and disturbance has been the work by Liz Taylor at Salisbury Plain (see Taylor et al., 2007), which has shown that settlement patterns are influenced by disturbance and that incubating birds respond to potential disturbance events (such as an approaching dog walker) at distances in excess of 500m. Other work has shown a clear avoidance by stone curlews of otherwise suitable habitat adjacent to major roads (Green et al., 2000). Road traffic data has been used to further explore this avoidance and analysis (Day 2005) shows an effect of major roads with a strong tendency for avoidance to increase over time in parallel with traffic flows.

The East of England Plan (the Revision to the Regional Spatial Strategy for the East of England), was published in May 2008. This provides an allocation for a minimum of 15,200 new houses to be built in Breckland District during the period 2001 to 2021, with associated growth in employment, transport and services. The allocation includes some 6000 new homes within Thetford. Thetford will develop as a key centre for development and change, building its role as an employment and service centre, well connected to major centres such as Norwich, Cambridge, and London. With approximately 1000 houses delivered to date and with estimated capacity from existing sites within the town being in the order of 700, it is envisaged that approximately 4300 houses will need to come forward on Greenfield sites on the periphery of the Thetford by 2021, and potentially a further 1500 dwellings between 2021 and 2026. Two potential areas have been identified to accommodate new development; one to the north of the town which is separated from the surrounding countryside by the A11, the other to the south-east of the town, in an area that supports a concentration of stone-curlews.

It is clear that future development within the Breckland area has the potential to adversely affect the interest features of the designated European site (the SPA). The East of England Plan1 recognises that "key issues for delivery include the development of green infrastructure and management measures to protect sensitive breeding bird populations from disturbance and avoid harm to designated European sites and their qualifying features". With respect to stone curlews, increased levels of housing and traffic may result in areas of otherwise suitable habitat being avoided and this has important consequences. Plans or projects likely to have a significant effect on a European Site must be subject to an Appropriate Assessment, a tough test whereby the competent

[1] Para 13.78

authority must demonstrate that the implementation of the plan / project, at whatever level, would not adversely affect the integrity of European sites. The Appropriate Assessment of the Breckland Core Strategy will need to investigate the impactso f this scale of development and the cumulative effects of other plans and projects acting in-combination with development in Breckland District.

This work has been commissioned in order to determine the effect of new housing and road traffic increases on stone curlews. Our approach has been to look across the whole SPA, and use existing data (collected since 1988 by the RSPB) on stone curlew nest locations, data on new housing (planning data provided by the relevant local authorities) and road traffic data. We combine these data, within a GIS, to determine the impact of roads and housing on the distribution and abundance of stone curlews in the Brecks.

Methods

Data Sources

Bird data

Data on the specific location of stone curlew nests, to the nearest 50m, from 1985 to 2006 within the Breckland region is owned by the RSPB and was loaned for the purpose of this study. Since the mid-1980s the RSPB has employed fieldworkers to monitor stone curlew breeding on arable, semi-natural grassland and SSSI land in the Breckland region. The fieldworkers locate the nests by visual scanning of areas used for nesting in previous years and other potential habitat, and watching the parents from a distant vantage point. Systematic searches for other pairs were also carried out in April and May by playing taped calls at night and returning by day to check areas from which birds were heard to call in response, and also in response to land owners and managers (Green, 1995). Although monitoring of the Breckland stone curlew population started in 1985, the coverage of the region (and therefore also the data) is considered to be complete from 1988 onwards (Green, pers. comm.). Complete data is only currently available until 2006. The occurrence of foot and mouth disease in 2001, with associated restrictions to access of both agricultural and natural areas, resulted in an incomplete dataset for that year, and has therefore been removed from analyses.

Soil data

As described above, there is a strong association in the spatial distribution of stone curlew and certain sandy soil types found within the region in both arable and semi-natural habitats (Green et al., 2000). To select suitable stone curlew habitat, the study area was filtered for these soil types. This was completed using a copy of the National Soil Map for the study area from the National Soil Resources Institute (NSRI) at Cranfield University. The soil types selected were rendzinas (soil code 3.4), brown calcareous sands (5.2) and brown sands (5.5).

Crop data

Stone curlews tend to nest on either spring-sown crops or short semi-natural grassland (Green et al., 2000). In 1997, as part of a larger study, all arable fields, grassland fields and SSSIs were surveyed and mapped by the RSPB, the data for which has also been loaned as part of this study. For arable fields the type of crop was recorded, while for grassland and SSSIs the length of the sward (short/long) and the type of ley was recorded. As the overarching land use within the Breckland region is unlikely to have changed significantly throughout the period 1988 to 2006, the data was used to split the stone curlew nest observations into those on semi-natural grassland and SSSIs and those on arable land.

Housing data

Information about the specific location of buildings and residential development was collected. Ordnance Survey mastermap data[2] were used to locate the current distribution of buildings within the study area. This was completed by using MapInfo (Pitney Bowes, 2007) to filter all of the Mastermap layers for buildings. Unfortunately it was not possible to distinguish between residential and commercial buildings.

To explore the past impact that housing development may have had on the spatial distribution of stone curlews, it was necessary to find the specific location of new housing that had been built between 1988 and 2006. This was completed using details from past successful planning applications, acquired from the district councils within the study area and mapping their specific

[2] Provided under licence by Breckland District Council

location using the filtered Mastermap data. Only developments of at least three new properties were used. For Breckland District the information was acquired directly from the planning department, while for all other district councils their online planning database was used to extract the information (see Box 1). From this information it was possible to show graphically, in MapInfo, where new housing developments had come in. In the absence of completion dates, and the potential disturbance caused by construction, it was estimated that the impacts of a housing development would be experienced from a standard one year after planning permission was granted.

In addition to information from planning applications on site-specific developments, each district council also provided information about housing completions on a parish basis. For Breckland and East Cambridgeshire data was available from 1988 to 2007, for Kings Lynn and West Norfolk from 2000 to 2007 and for all districts within Suffolk from 1994 to 2007. Also, housing and housebuilding estimates on a district-wide basis were also obtained from the Office of National Statistics through the department for Communities and Local Government. This information allowed a more strategic review of house building within the study area.

Box 1. Web addresses of the online planning applications for each district council (except Breckland District Council)

Forest Heath District Council -
http://195.171.177.73/Northgate/PlanningExplorer/GeneralSearch.aspx
East Cambridgeshire District Council -
http://pa.eastcambs.gov.uk/PublicAccess/tdc/DcApplication/application_searchform.aspx
Kings Lynn and West Norfolk District Council - http://online.west-norfolk.gov.uk/publicaccess/propdb/property/property_searchform.aspx
St Edmundsbury District Council -
http://www.stedmundsbury.gov.uk/swiftlg/apas/run/wphappcriteria.display

Road and traffic data

Information about the specific location of roads was collected from the Ordnance Survey Mastermap data. This was completed by using MapInfo (Pitney Bowes, 2007) to filter all of the Mastermap layers for road surfaces. The trunk and non-trunk A-roads were identified from Ordnance Survey maps.

Traffic data was acquired from the TRADS system (http://trads.hatris.co.uk/), part of the Highways Agency. It provides access to traffic flow information collected from England's motorway and major trunk road network. At the time of access, bi-directional data was available for a number of sections of the A11 and A14 from September 2002 to early 2008. The data downloaded included the hourly traffic flows for every day in every month for each year. This data was translated into month-by-month average daylight, darkness and total daily traffic flows. Since stone curlew tend only to nest between the months of March and August (Brown and Grice, 2005), only data for these months was used in analyses.

Defining the study area

The study area was determined by the distribution of the Breckland population of stone curlew. All observed nests between 1985 and 2006 were mapped in MapInfo and a 5 km buffer was drawn around the points. The resulting overall study area limits are shown in Map 1.

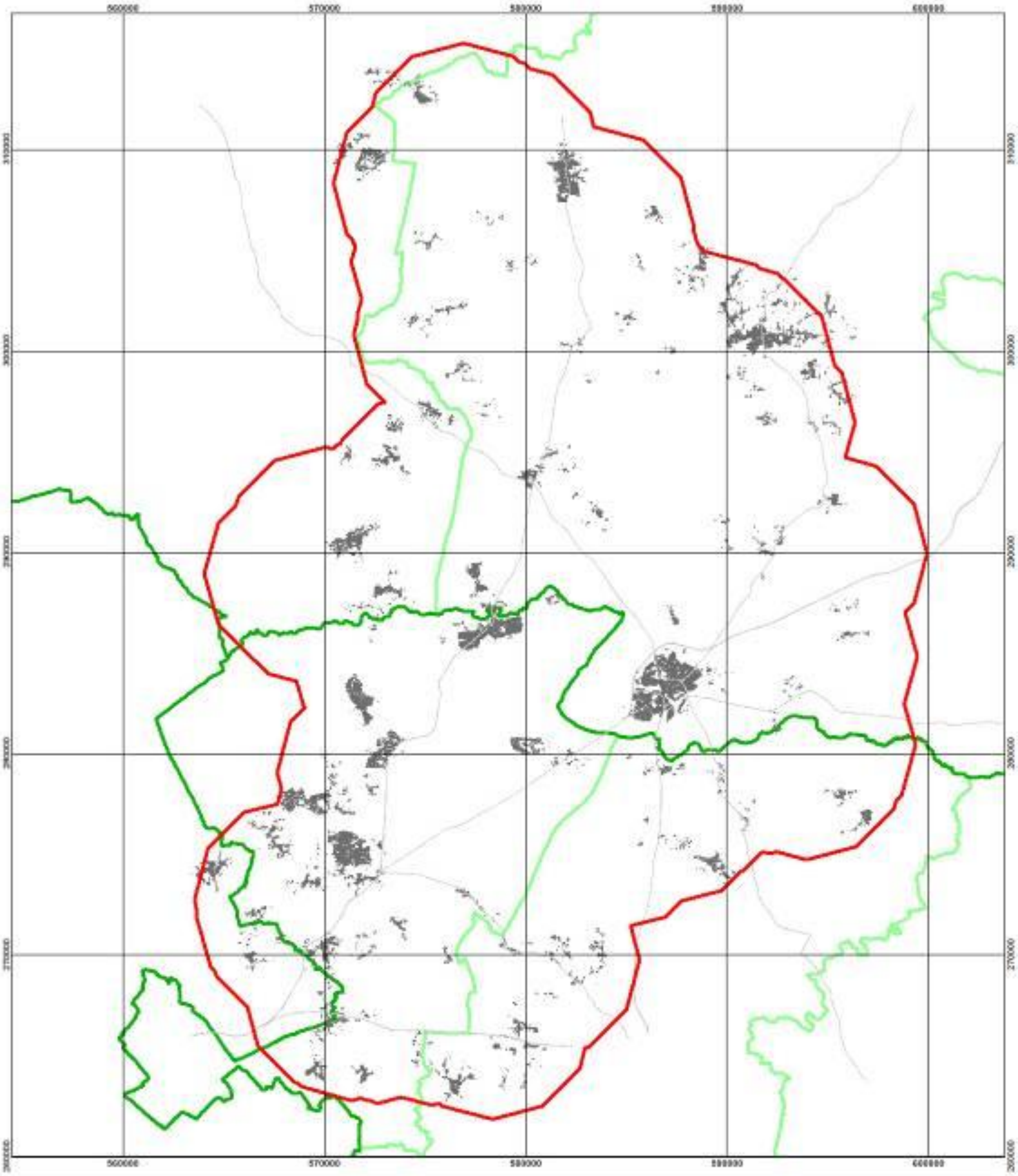
Defining suitable stone curlew habitat and stone curlew nest density

As described by Day (2003), stone curlews occur at markedly different densities and their individual behaviour and fitness are probably influenced by different factors between arable and semi-natural habitats. Arable fields are often uniform in character and, with consideration of the crop and soil type, their entire area can be considered to be of equal habitat quality for nesting stone curlew. In contrast, semi-natural habitats occur as large fragments throughout the landscape and have relatively variable habitat characteristics among sites and across their areas because of factors such as grazing and invasion by bracken or scrub (Day, 2003). It is therefore prudent to consider these two habitats separately.

The information about landscape use was then filtered by suitable soil type using MapInfo (Pitney Bowes, 2007). The resulting polygons within the study area can be seen in Map 2.

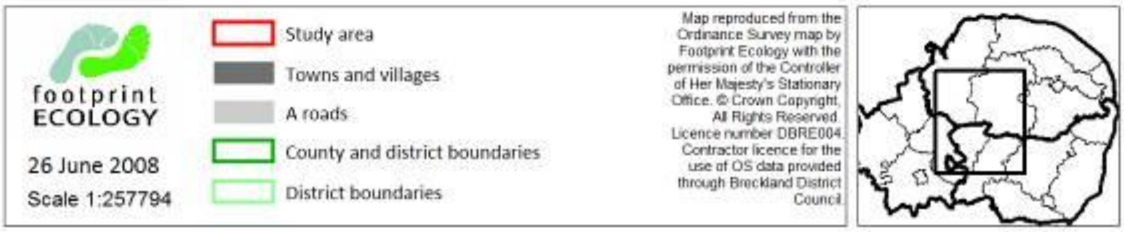
Estimates of stone curlew nest density were restricted to those areas of suitable soil types and habitat within the overall study area. More specifically, for the reasons described above, the nests found on arable and semi-natural grassland/SSSI were analysed separately. Separate annual estimates of nest density were derived for the areas of arable land and areas of semi-natural grassland/SSSI.

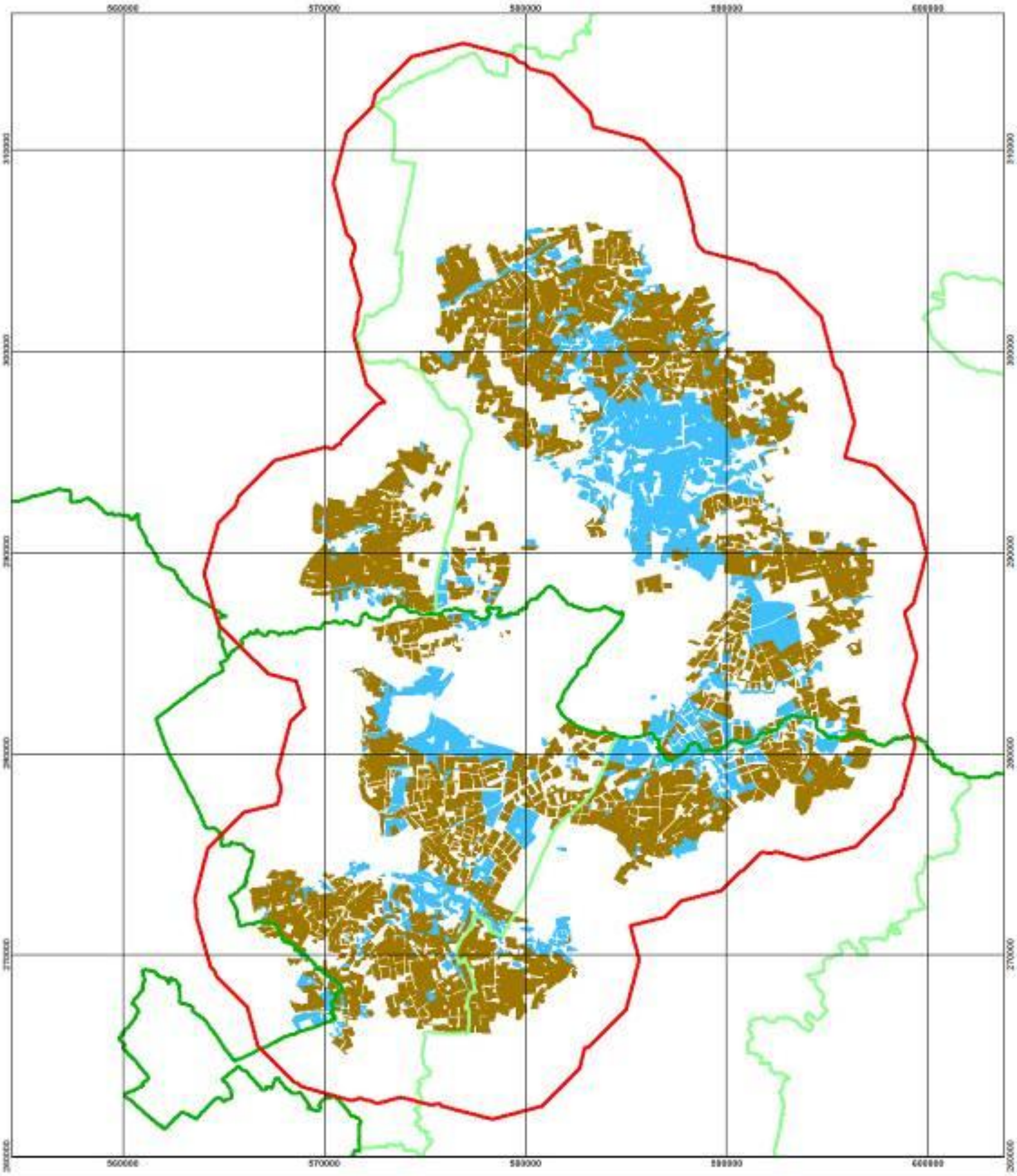
However, most of our statistical analyses have been restricted to stone curlew nests on arable habitats, which are perceived to be less susceptible to a range of unmeasured factors influencing habitat quality for nesting stone curlews.



Map 1: Study area, showing county and district boundaries, towns and A roads

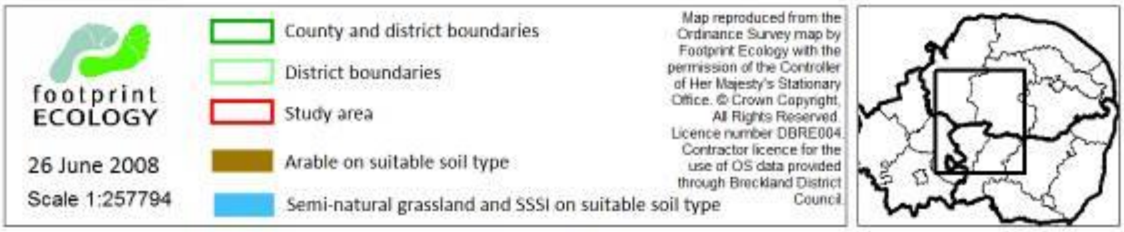
The effect of housing development and roads on the distribution of stone curlew





Map 2: Arable, semi-natural grassland and SSSI on suitable soil type within the study area

The effect of housing development and roads on the distribution of stone curlew



Measures of isolation from housing and roads/traffic

We used two approaches to help assess the relationship between stone curlew nest density and the amount of nearby housing or roads/traffic. Firstly the yearly densities of stone curlew nests on suitable habitat were calculated across the whole study area. Secondly the densities, across all years, of stone curlew nests within different distance bands from features such as towns and roads were calculated.

Defining current "Settlements" (towns and villages)

Using the latest-available Mastermap buildings layer in MapInfo, within the study area, a subset layer which we refer to as "settlements" was defined, by including towns and villages but excluding farm buildings, small settlements with only a small number of buildings and isolated developments. Towns and villages that were used include, but are not limited to, Thetford, Brandon, Lakenheath, Weeting, Feltwell, Mundford, Watton, Swaffham, Hockham, Rushford, Hengrave and Mildenhall.

Distance from current "Settlements"

Around these "settlement" areas, buffers were drawn at regular 500m band intervals up to 4.5 km away. All points within the study area were assigned to a band representing its distance to the nearest settlement. The overall number, habitat area and thus density of stone curlew nests within each distance band was calculated separately for the two different habitat types (arable and semi natural grassland) for each year between 1988 and 2006, excluding 2001.

Distance from Roads

Using the Mastermap roads layer in MapInfo, within the study area, all A-roads, both trunk roads and non-trunk roads, were selected while all others were removed. For each road, individually, grouped as trunk and non-trunk roads and all A-roads, buffers were drawn around them at 500 m intervals up to 3 km. Within these 500 m distance bands the number and density of stone curlew nests across each year from 1988 to 2006, excluding 2001, was calculated for the two different habitat types.

Initial statistical analyses assessed the variation in nest density with distance band to either housing or roads.

Developing a statistical model

Subsequent analyses involved developing a statistical model to relate the density of stone curlew nests to measures of the amount of "nearby" housing or roads/traffic, where nearby was defined in various ways.

Stone curlews per 500m grid cell

Within the whole study area, a grid of 500 m wide square cells was constructed using MapInfo. These cells were then filtered to select those having any part within arable habitat on suitable soil type. For each of these cells the number of stone curlew nests found each year was calculated. Using this grid cell size made for nests made the subsequent spatial modelling tractable, while still giving adequate accuracy in terms of distances to housing/roads.

Our analyses concentrate on nests on suitable arable land. Across all years (1988-2006), only 3.8% of all 500m cells on suitable arable land had any nests. The number of 500m cells with one or more nests varied from 49 in 1990 to 146 in 2006. Of those cells with any nests the vast majority(84%) had only one nest, 13% (197 cases) had two nests, while the 34 cases of three nests, 6 of four and one case of nine nests in one 500m cell in 2003.

Buildings and roads within 50m gird cells

Separately a grid of 50 m wide square cells was also constructed within MapInfo; for each 50m cell we extracted information on the extent of buildings, presence of roads and amount of road traffic present.

The area of buildings within each 50 m cell was calculated. This was based on the latest-available Mastermap building layer and gave a value for 2007. For all other years from 1988 to 2006 the area of buildings was calculated by working backwards, year by year, by subtracting any recorded housing development that had occurred in each year from the following year's total. In this way a year-on-year value for the area of buildings was obtained for each cell.

For roads a number of variables were measured for each cell in the 50 m square grid of cells. Firstly the presence (scored 1) or absence (scored 0) of a non-trunk A-road within the cell, secondly the presence (1) or absence (0) of a trunk A-road and thirdly data about the volume of traffic along a section of trunk A-road passing through the cell. The traffic volume variables entailed the month-by-month average daylight, darkness and total daily traffic flows averaged across all the years for which data was available.

Weighted normal kernel estimates of nearby housing and road/traffic density

Rather than relate the stone curlew nest distribution amongst the 500m cells to their distance to the nearest housing/road or necessarily subjective measure of "settlement", it makes sense to try to derive variables measuring the amount of housing or roads/traffic within the vicinity of each 500m cell, where the variable increase with the amount of housing/roads/traffic, but where less weight (i.e. importance) is given to housing/roads/traffic at increasing distances from the 500m cell.

To do this, MapBasic algorithm code (within Map Info) was then constructed which queried the spatial relationship between the 500 m wide square cells containing data on stone curlew nests and the 50 m wide square cells containing data on buildings and road factors.

For each 500 m cell (i), we calculated the distance D_{ik} to each 50m cell. Each 500m and 50m cell is represented as a polygon and the distance D_{ik} is the shortest distance between the two polygons, so all 50m cells either inside or touching the 500m cell are given a distance D_{ik} of zero.

For each 50m cell (k), let Q_k denote the value of the housing/road/traffic predictor variable for that cell (e.g. area of housing, presence of A-road or average total daily traffic). Although it is not known exactly how any effect of housing or roads diminishes with distance, we used a sensible commonly-used weighting based on a half-normal kernel distribution with a standard deviation (h). The weight (W_{ik}) given to a 50 m cell (k) at a distance D_{ik} from 500m cell (i) was:

$$W_{iK} = exp(-D_{i,k}^2/h^2).$$

Then the value of the predictor variable (X_i) for the 500m cell (i) is a weighted sum of the Q_k values across all cells, namely:

$X_i = \sum_k W_{i,k} Q_k$

When $D_{ik} = 0$, the weight is 1.000, at distances D_{ik} of h and $2h$, the weighting is reduced to 0.368 and 0.018 respectively. For computational efficiency/tractability, the summation ($\sum_k$) is limited to 50m cells within two standard deviations (h) of the 500m cell i (i.e. where $D_{i,j} \leq 2h$).

A range of values of h were used ranging from 250m, in steps of 250m up to 2000m. Larger values of h cause the predictor variable X_i to be influenced by the amount of housing/roads over greater distances (Figure 1).

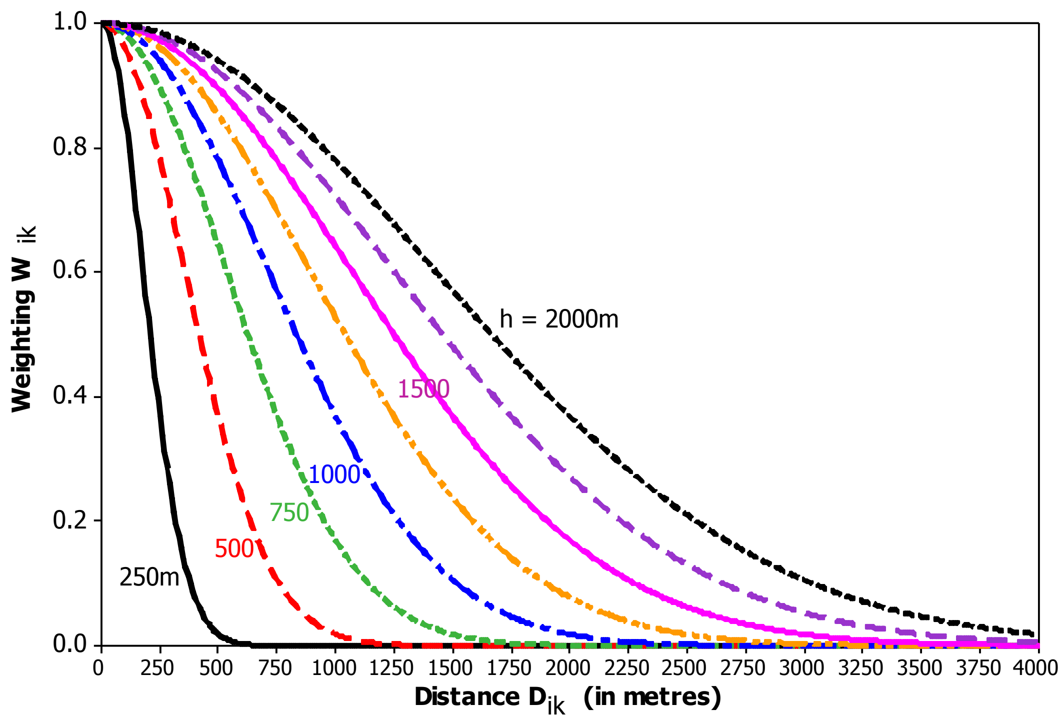


Figure 1 Weighting (W_{ik}) given to the amount of housing/roads/traffic in 50m cell (k) at distance D_{ik} from a 500m cell of stone curlew nest numbers, as a function of the weighting standard deviation h (where h = 250m, 500m, ... ,2000m)

Regression models based on weighted housing/road density variables

Statistical correlation and generalised linear regression model (GLM) analyses (McCullagh and Nelder 1989) were used to relate each of these weighted normal kernel housing and road/traffic predictor variables to the occurrence of stone curlew nests in each 500m cell with the aim of finding the distance weightings h at which correlations are statistical significant and also strongest.

Although the vast majority of the 2142 500m cells in the study area have either no nest or only one nest in any one year, there were 197 occasions with two nests, 34 with three nests, 6 with four nests and one cell with nine nests in one year. We decided that, rather than just model the probability of a 500m cell containing one or more nests, it was best to model and try to predict the average density of stone curlew nests per 500m cell (i.e. per 0.25 km^2). Any derived models could then potentially be used to predict the effects of proposed increases in housing and also road traffic on stone curlew nest number.

The specific GLM models fitted were Poisson regression models with a log link relating the number of nest in a 500m cell to a weighted normal kernel housing density variable (at each value of h in turn), or a weighted normal kernel road/traffic density variable (at each value of h in turn), or a combination of both one housing and one road/traffic variable.

The relationships were assessed using Generalised Linear Models (GLM) (McCullagh and Nelder, 1989), treating the number of stone curlew nest on a 500m cell as having a Poisson distribution with mean equal to the model prediction for the cell and assuming a multiple linear relationship between the logarithm of nest numbers and the housing/road/traffic variables. When errors are Poisson with no extra variability the residual mean deviance (k) of the fitted model is roughly one. If residual variability is greater than that expected for a Poisson error distribution (i.e. when k is appreciably greater than one), then the standard errors (SE) of the regression model coefficients obtained by fitting a Poisson likelihood are automatically increased by the appropriate factor ($\sqrt{k}$) (McCullagh & Nelder 1989, p199-200).

The predictive part of these log-linear Poisson error models were thus of the form:

$$\log_e N_i = \log_e A_i + \alpha + \beta_H X_{Hi} + \beta_R X_{Ri} + \beta_T X_{Ti}$$

where N_i = number of stone curlew nests on 500m cell i, A_i = Area (in hectares) of arable land on suitable soil type in the 500m cell, X_{Hi} , X_{Ri} and X_{Ti} = weighted normal kernel densities (at selected values of s) of the housing, roads and/or traffic variables for this cell and α_0, β_H , β_R and β_T are the estimates of the corresponding regression coefficients. The overall fits of such models were assessed and compared by their Likelihood Ratio (LR) Chi-square statistics (-2logLR) of the ratio of the statistical likelihood of fitted model relative to that for a null model with only a constant term. The statistical significances of each term were assessed by comparing the estimated values of β_H and β_R with their SE (to give test statistics of the form $t = \beta_H / \mathrm{SE}(\beta_H)$ (McCullagh and Nelder, 1989).

GLM models were fitted using the SPSS statistics package (Version 16, 2007).

Results

Stone curlew numbers over time

From 1988 to 2006 the total number of stone curlew nests found within the Breckland region has steadily increased from 83 in 1988 (62 on arable land and 21 on SSSI/semi-natural grassland) to 246 in 2006 (193 on arable land and 53 on SSSI/semi-natural grassland (Figure 2). However, since 2002 there has been a decline in the number of nests found on semi-natural grassland/SSSI while on arable land the number has continued to increase.

The number of nests on arable land is consistently greater than that on non-arable land, however this is in part due to the large area of arable land available compared to semi-natural grassland/SSSI. Therefore when this is translated into nest density, as seen in Figure 3, it can be seen that density is often greater on semi-natural grassland/SSSI than on arable land. Again the density on both habitats has continued to increase from 1988 to 2006, however there has been a recent decline in nest density on semi-natural grassland/SSSI.

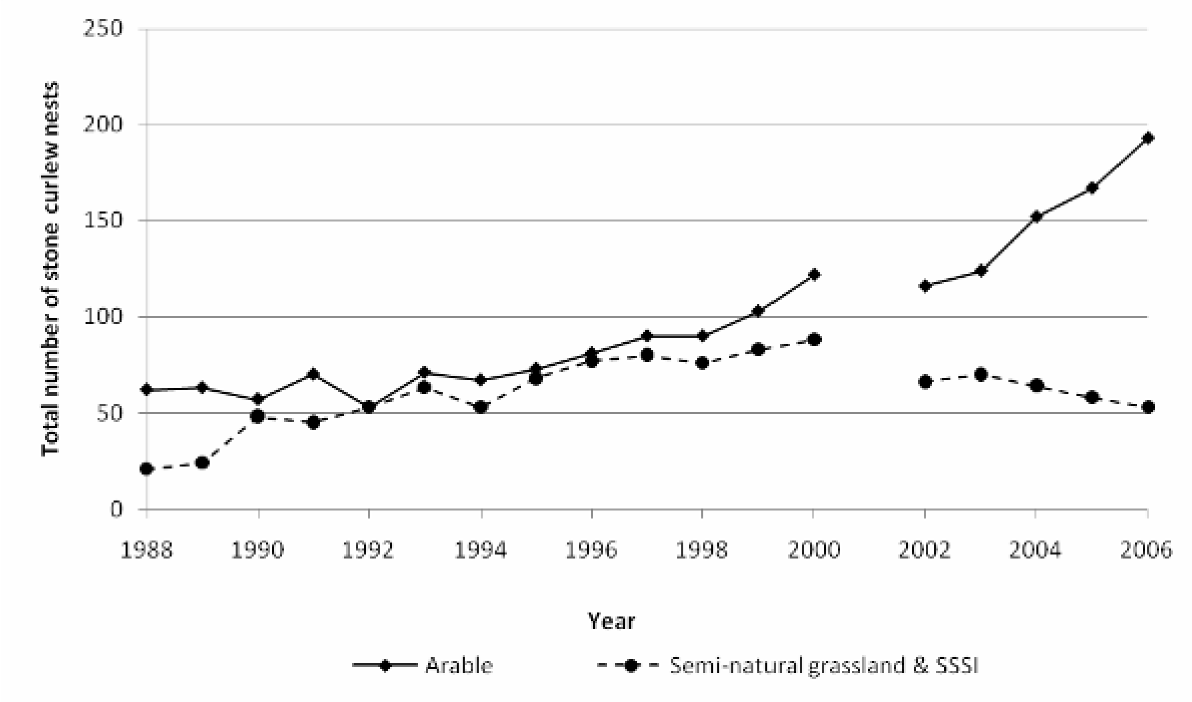


Figure 2: Total number of stone curlew nests found on arable and semi-natural grassland/SSSI within the Breckland region from 1988 to 2006.

Green *et al.* 2000, showed a strong association in the spatial distribution of stone curlew and certain sandy soil types in both arable and semi-natural habitats. Figure 4 shows the number of stone curlew nest found on each soil subgroup. It reconfirms the findings of Green *et al.* 2000, who showed that stone curlew nests have a strong association with rendzinas (soil code 3.4), brown calcareous sands (5.2) and brown sands (5.5). In this case the soil subgroups are further refined. The largest number of nests was found on soil subgroup 3.43 – brown rendzinas, followed by 5.54 – argillic brown sands, 5.51 – typical brown sands and 5.21 – typical brown calcareous sands. A significant number of nest were also found on soil subgroup 5.11 – typical brown calcareous earths.

Analysis of stone curlew nest density has been restricted to areas with these suitable soil types.

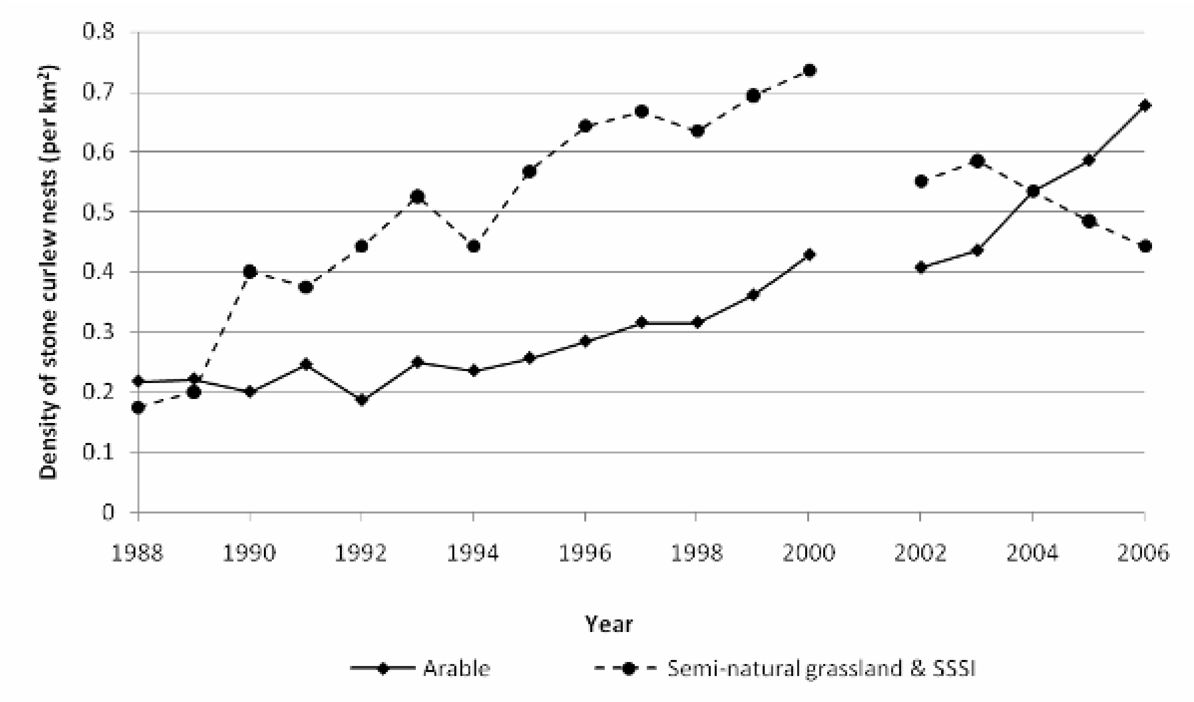


Figure 3: Density of stone curlew nests found on arable and semi-natural grassland/SSSI within the Breckland region from 1988 to 2006.

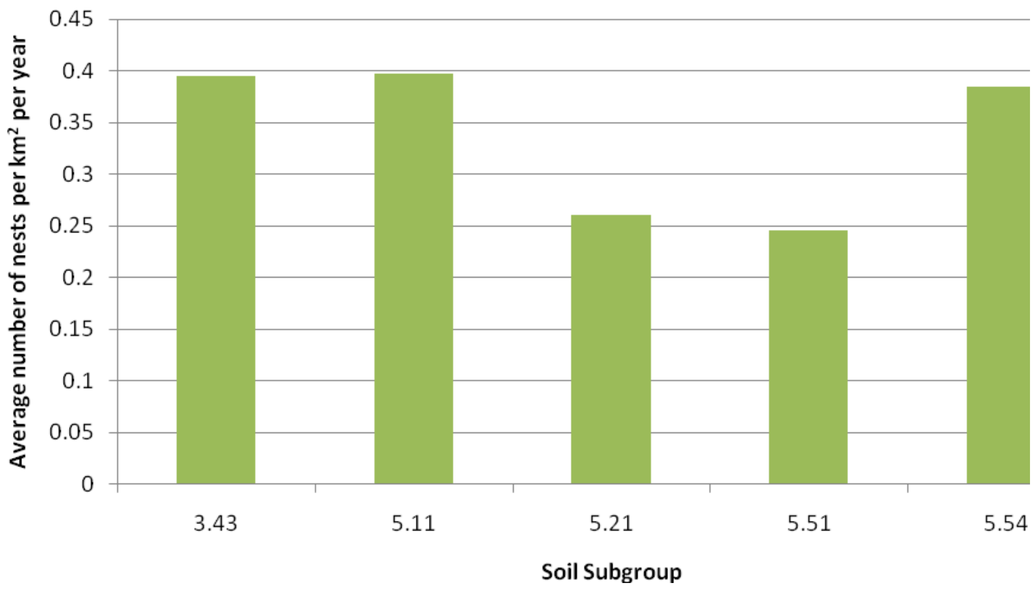


Figure 4: Average number of nests observed on each soil subgroup type per km^2 per year.

Stone curlews nests in 500m cells over time

As described in the methods section, a grid of 500 m wide square cells on arable land of suitable soil type was created.

Figure 5 shows (in red) the number of cells per year in which stone curlew nests were observed. There is a steady increase over the period 1988 to 2006 which closely follows that of total stone curlew nests (shown in black in Figure 5). This indicates that as the number of nesting attempts (and the inferred population size) increases, the stone curlews are spreading out into new cells instead of just increasing their density within previously occupied cells. This is further illustrated in Figure 6 which shows how the total number of cells in which a nest has been found in at least one year since 1988 has increased steadily with time.

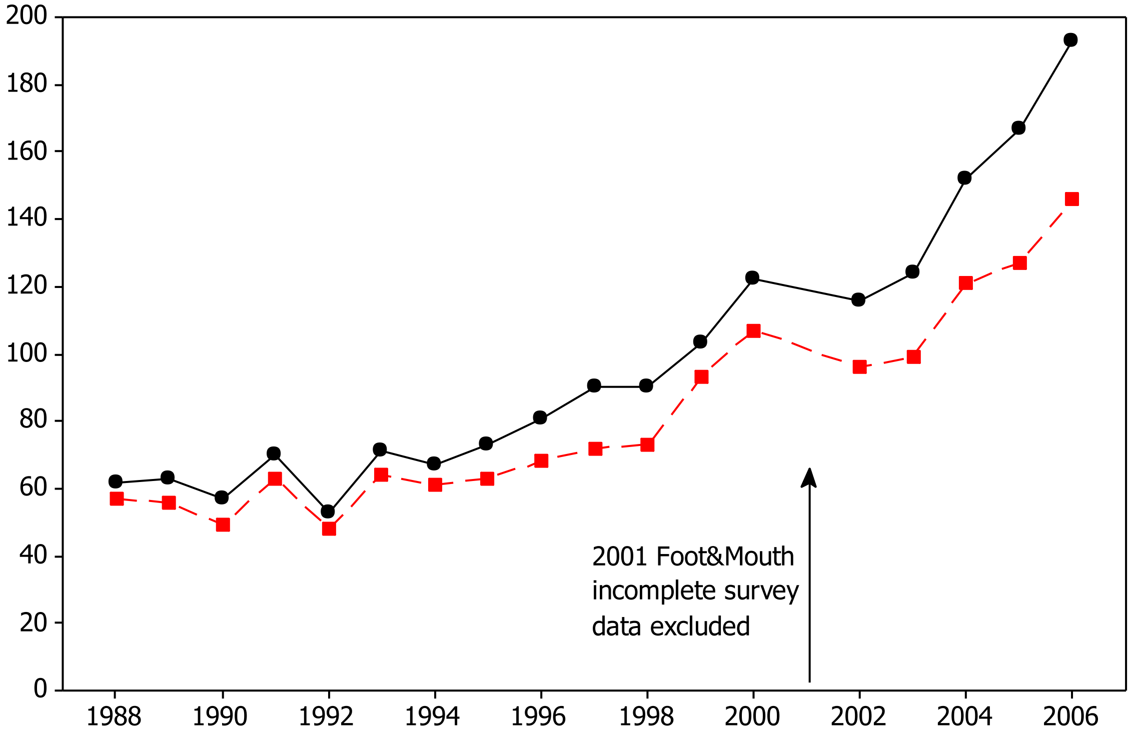


Figure 5 Annual total numbers of stone curlew nests (black) and 500m grid cells with nests (red); restricted to areas of suitable arable land

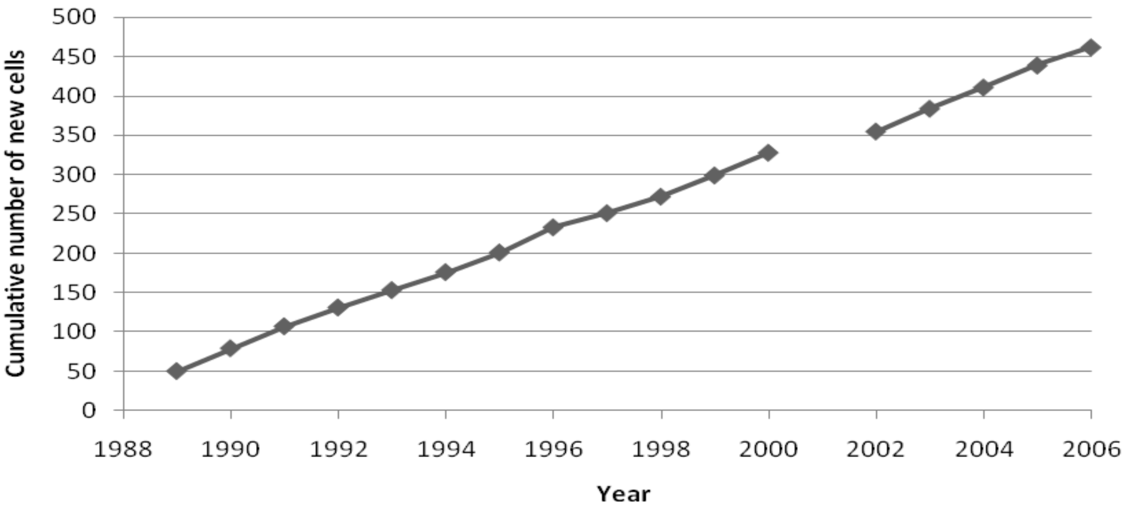


Figure 6: Cumulative total number of 500m cells in which stone curlew nests have been observed since 1988.

Temporal stability in the spatial distribution of stone curlew nests:

If stone curlews tend to try use the same places in which to nest each year (but not necessarily the same birds in the same place), then in our analyses the same 500m grid cells will tend to be occupied each year (in addition to extra nest sites as the population has grown over the past 20 years). This would mean that the distribution of distances to the housing and roads would tend to be very similar each year and correlations between stone curlew presence or abundance and the extent of nearby housing or roads would be very similar data each year and inevitably give similar results. Consequently analyses which involved using all of the years' data together, yet treating each observation separately, care is necessary in interpreting the statistical significance of results which treat all of the observations as statistically independent.

To assess the strength of temporal correlation in stone curlew spatial distribution between successive years, we calculated the proportion of the 500m gird cells occupied by one or more stone curlew nest in one year that were also occupied the next year (Figure 7). The median value of this measure of temporal-spatial auto-correlation was only 0.45, but it has tended to increase over the 20 years and 92% of cells with stone curlews in 2005 also had them in 2006. The observed increase in stone curlew population totals, at least in terms of observed nests (Figure 5), may have reduced the choice of suitable remaining unoccupied territories, thus increasing the observed tendency for more cells to be occupied in consecutive years. Any reduction in general rate of rotation of major crop types might also increase the spatial stability of occupied nest sites (i.e. grid squares).

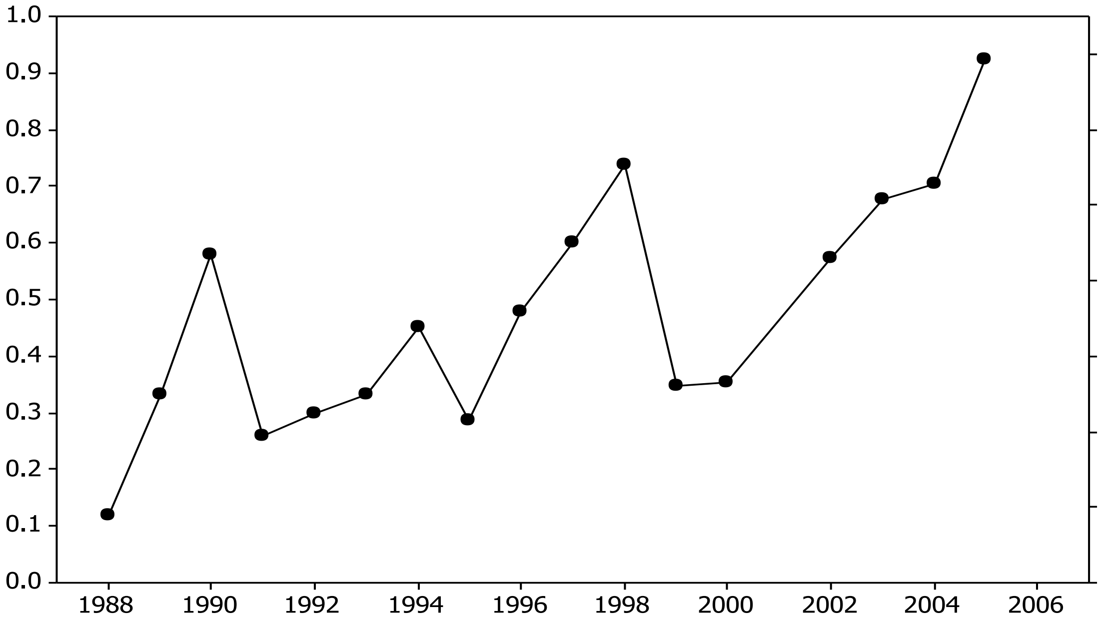


Figure 7: Proportion of the 500m grid cells occupied by one or more stone curlew nests in a year which are also occupied in the following year for each year 1988-2005

Thus there is considerable turnover and change in the precise areas which are used for nest each year, which indicates that the individual years' data do provide useful extra information to support any apparent observed relationship between stone curlew nests and distance to nearest settlement.

Housing patterns

Housing Stock

When comparing the whole districts within and surrounding the study area, Breckland District consistently has the second greatest housing stock after Kings Lynn and West Norfolk throughout the period 1981 to 2004. Breckland District increased from approximately 36,000 homes in 1981 to approximately 53,000 in 2004 (Figure 8).

Figure 8 also shows that between 1981 and 2004 the housing stock of all of the five districts increased, with Breckland District increasing by the greatest amount, approximately 17,000 homes, which equates to an average annual increase of 1.6%. Forest Heath had the smallest housing stock between the five districts, with approximately 19,000 homes in 1981 increasing by 5,000 to approximately 24,000 in 2004, an average annual increase of 1.0%.

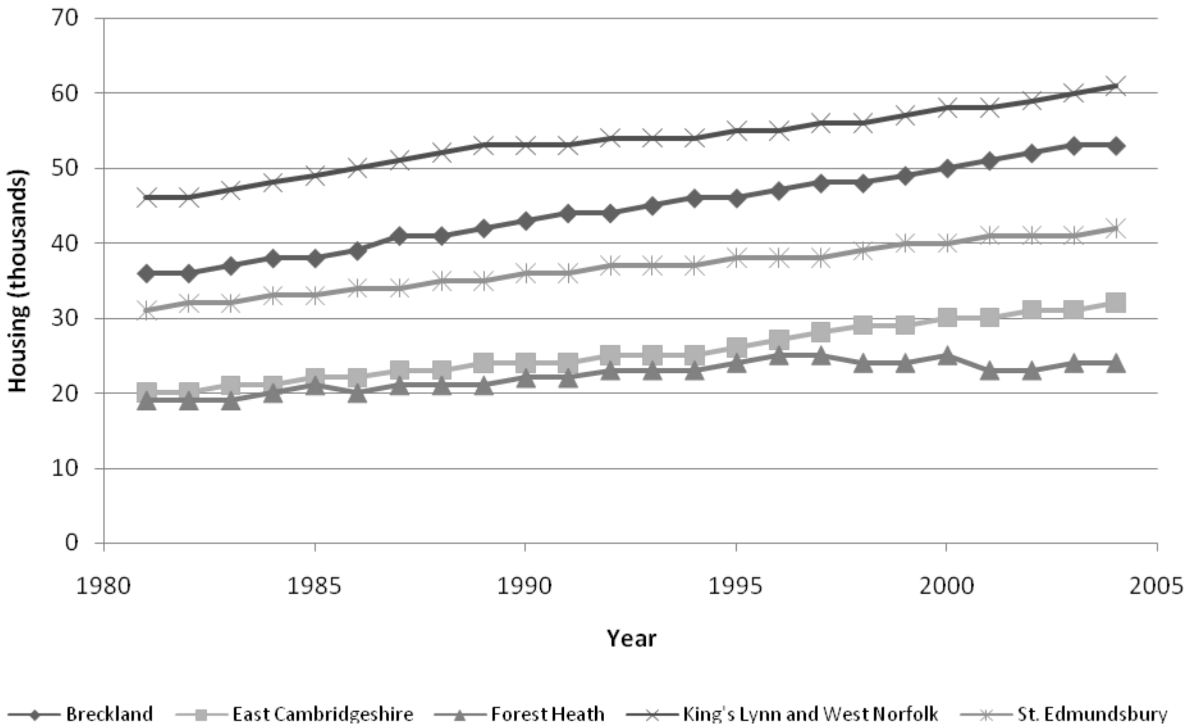
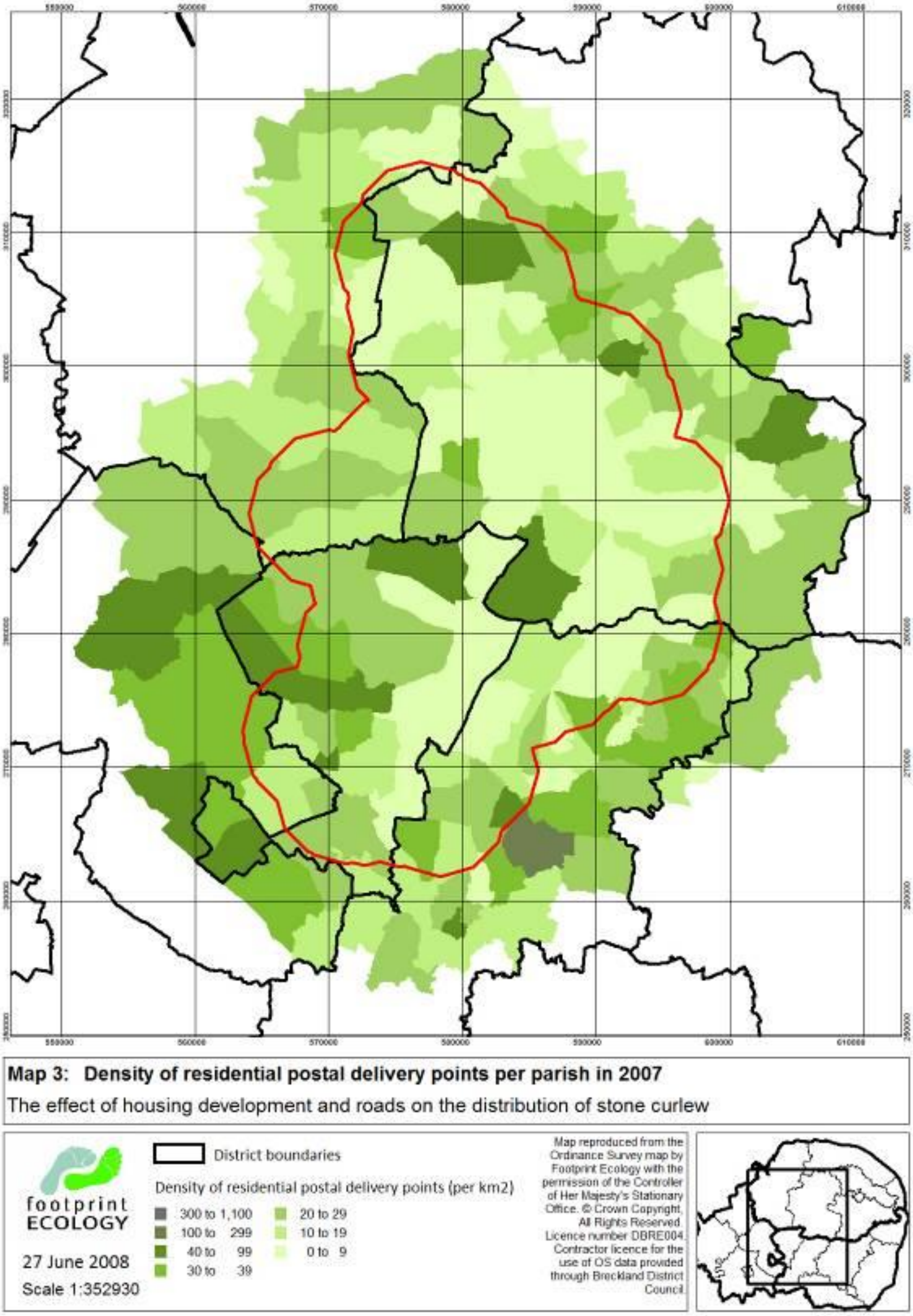


Figure 8: Housing stock for the five districts within and surrounding the study area. (Source: Department for Communities and Local Government).

The specific spatial distribution of the current housing stock is shown in Map 3 which plots the density of residential postal delivery points (i.e. housing units), in 2007 for each parish in and around the study area. It shows that parishes to the east of the study area around the Norfolk – Suffolk – Cambridgeshire border have the greatest housing density, especially Mildenhall. Other parishes outside this region that had high housing density include Thetford, Brandon, Swaffham and Watton. The lowest housing densities, with the exception of the area around Thetford, are currently in the centre of our study area.



Map 3: Density of residential postal delivery points per parish in 2007

The effect of housing development and roads on the distribution of stone curlew

Housing completions

Figure 9 shows the annual number of new houses completed from 1988 to 2007 for each of the districts within and around the study area as a whole. Across districts the annual number of housing completions has remained relatively constant with no signifiacnt trends for the period 1988 to 2007. As described above, the Breckland District housing stock has increased by the greatest amount and this is reflected in Figure 9. Breckland District often had the greatest number of annual housing completions compared to the other districts, with values ranging from just under 400 homes to over 1,100 per year. Conversley Forest Heath has often had the fewest number of housing completions, with values ranging from approximately 450 completions per year to under 100 completions per year.

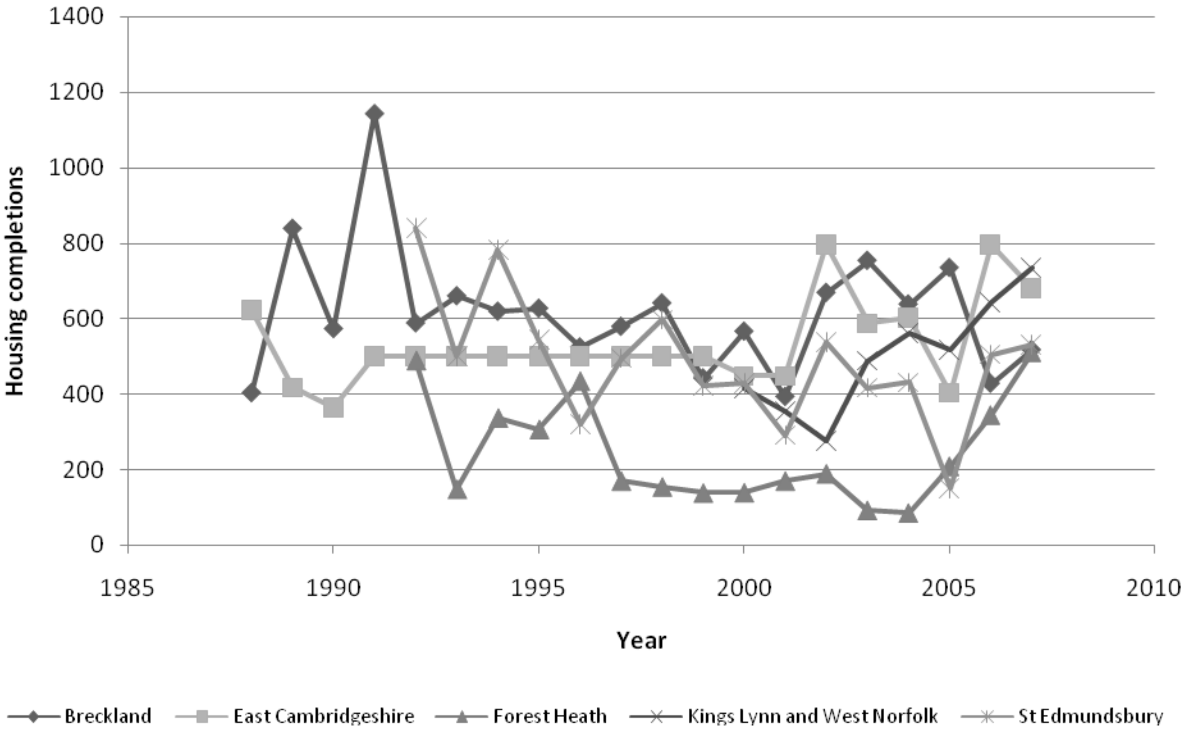
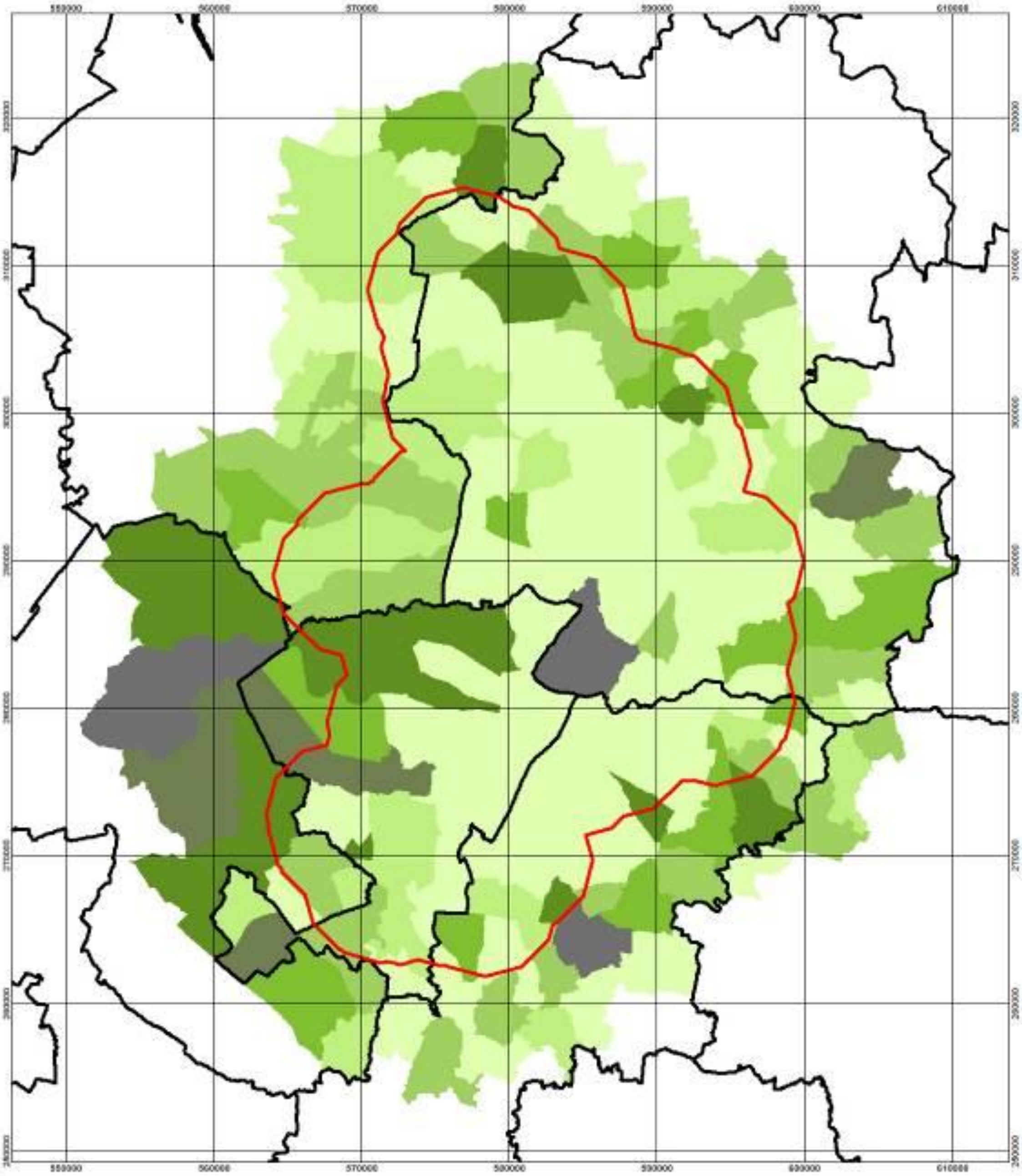


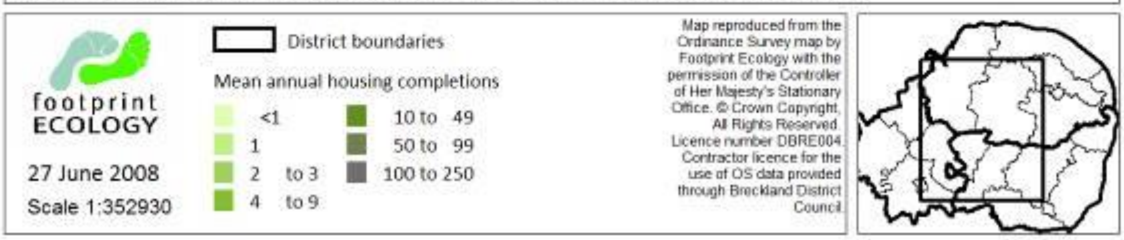
Figure 9: Housing completions for the five districts within or surrounding the study area.

To demonstrate these housing completions spatially, Map 4 shows the average annual number of housing completions on a parish basis. It shows that within the study area there are a number of parishes with housing completions exceeding 40 per year, which include Watton, Swaffham, Attleborough, Mildenhall, Brandon, with Thetford exceeding 130 housing completions per year.



Map 4: Mean annual housing completions in each parish within and surrounding the study area

The effect of housing development and roads on the distribution of stone curlew



Stone curlew nest density in relation to distance to nearest "settlement"

New housing has consistently occurred within and surrounding the study area, over the period 1988 to 2006. The amount of housing varies to a lesser or greater extent between and within the different districts.

Whether or not the spatial distribution of stone curlew nests is related to the distribution of development was explored by looking at the density of stone curlew nests in areas at different distances away from any "settlements" such as towns and villages. Stone curlew nest density in each 500m distance band was measured by dividing the total number of nests found on arable land of suitable soil type in that distance band by the total area (in km^2) of such land.

Figure 10 show that, up to 2.5 km away from settlements, the average density of stone curlew nests per year on arable land of suitable soil type increases with distance from any settlements. This would therefore suggest that stone curlew show avoidance of towns and villages, up to 2.5 km away. The area of suitable habitat type in each distance class decreases with distance, such that there is only about 10 km^2 which is 2.5 – 4.0 km away from any settlement, compared to 84 km^2 which is within 500m of the nearest settlement (Figure 10).

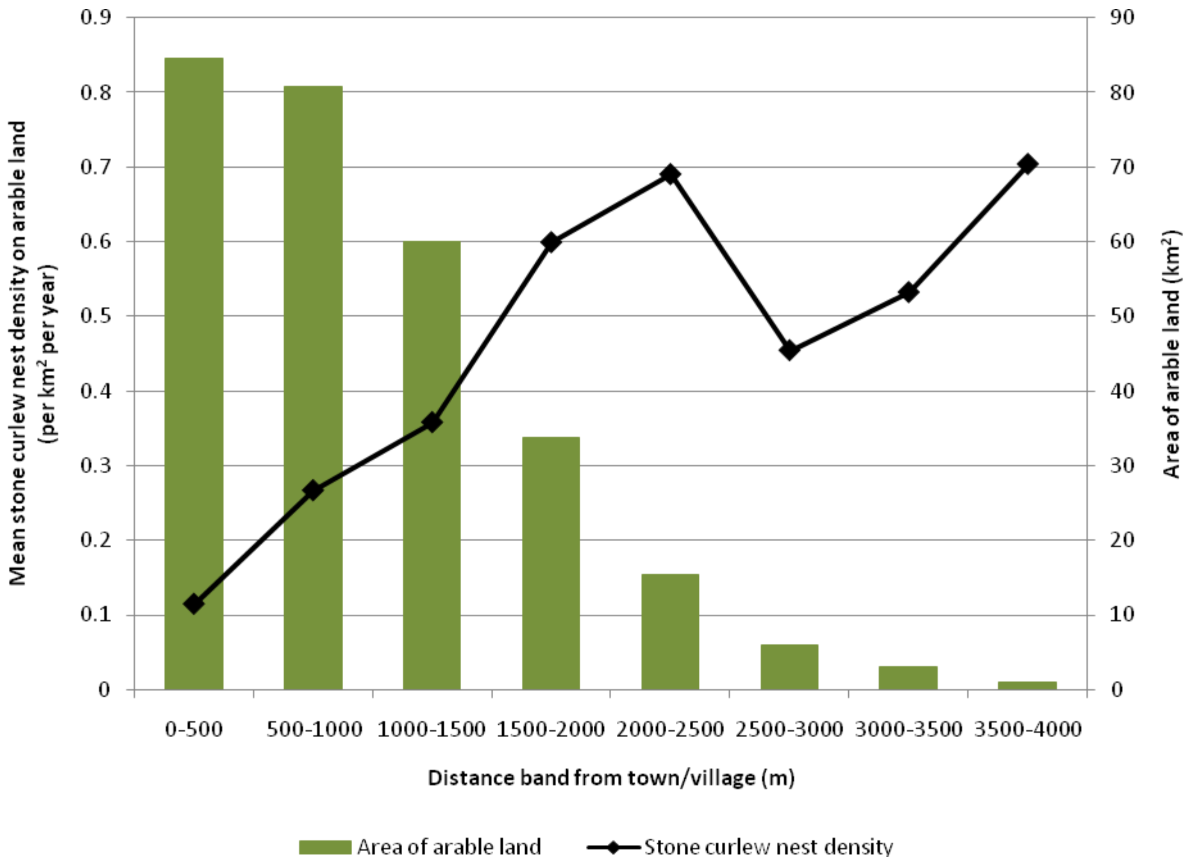


Figure 10: Average density of stone curlew nests on arable land (1988-2006) and the area of arable land available at different distance bands away from towns and villages.

This pattern was observed over all years of the study, as shown in Figure 11. It shows that for groups of 4 or 5 years, the average mean nest density of stone curlews on arable land consistently shows a positive relationship with distance from settlements. Through time, as the number of nests has increased (Figure 2), the nest density has almost always increased at each distance band (Figure 11).

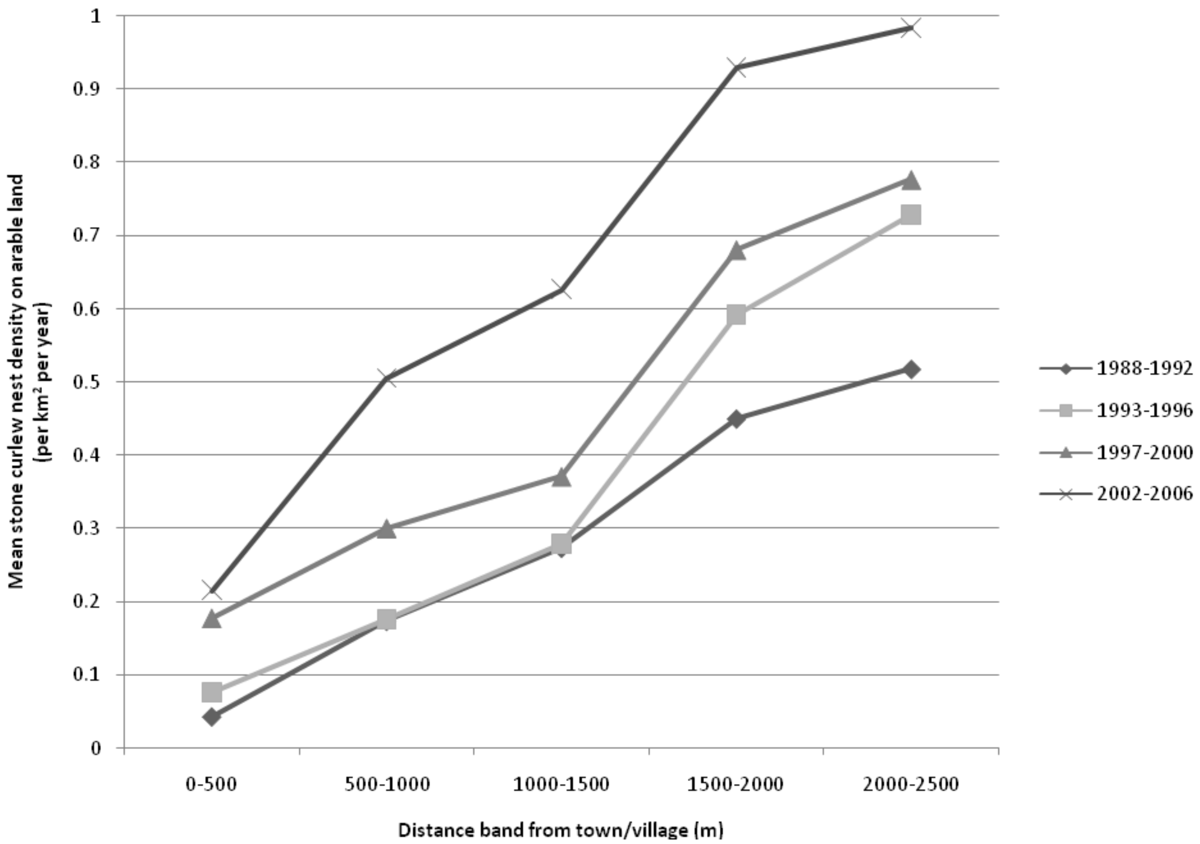


Figure 11: Stone curlew nest density in the first 2.5 km from towns and villages, grouped by runs of 4 or 5 years.

Similar analyses were conducted for SSSIs and semi-natural grassland (Figure 12). They show that there is some avoidance of housing, with a positive relationship between nest density and distance from settlements up to 1.5 km, however this relationship is not clear. This may be due to the variability in precise habitat type and quality observed between different fragments of SSSI and semi-natural grassland.

This is why we have concentrated most of our statistical analyses on stone curlew nests on arable land of suitable soil type.

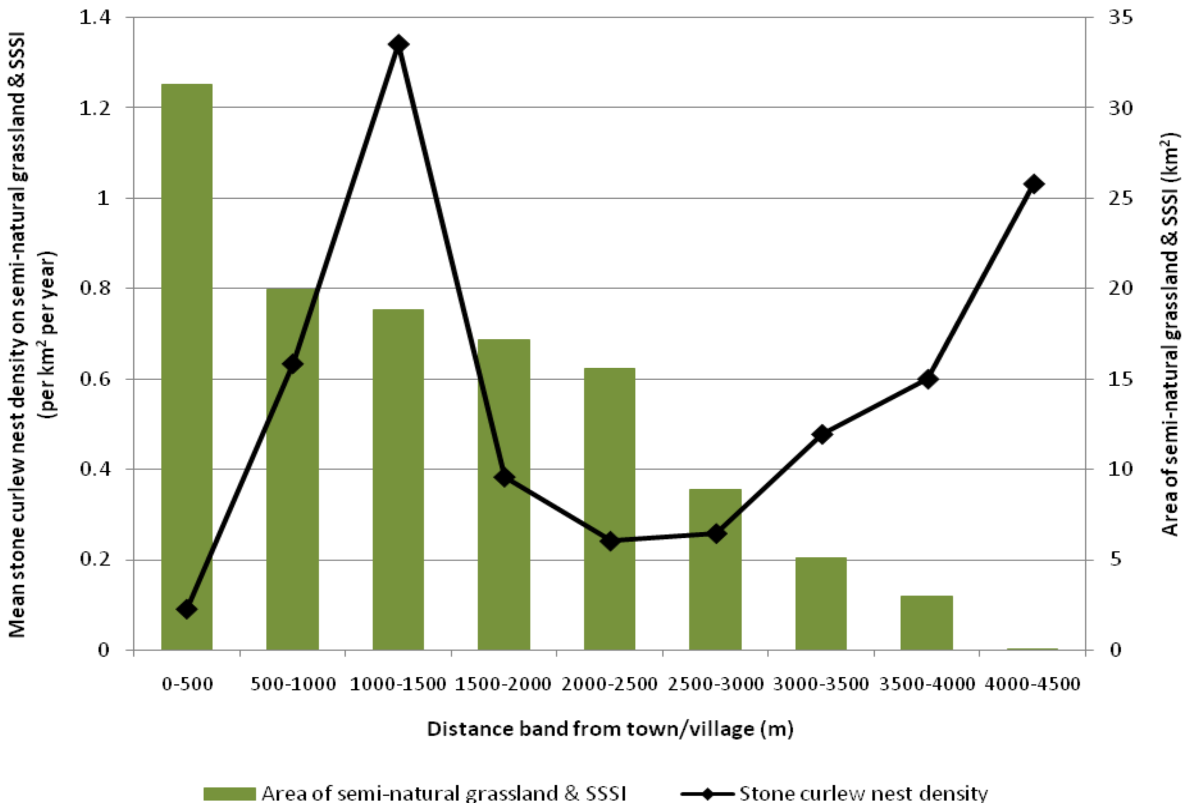


Figure 12: Density of stone curlew nests on semi-natural grassland and SSSI, and the area of semi-natural grassland and SSSI available at different distance bands from any settlement.

Statistical test of stone curlew nest density association with distance from settlement

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 the whole study area in a year, 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 numbers in 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.

The Chi-square tests for each individual year were all statistically significant (under the null model of no relationship all single-year test probability p were < 0.001; Table 1). In fact, within every single year from 1988 to 2006, the stone curlew nest density (per ha of suitable arable land) was lower on land within 0-500m of the nearest settlement than on land either 500-1000m, 1500-2000m or 2000-2500m from the nearest settlement (Table 2). Annual nest densities on arable land 500-1000m from settlements were lower than densities on land at the 1500-2000m and 2000-2500m in 14 of the 18 years over the period 1988-2006 (Table 2). This consistency across the whole study period provides strong long-term evidence of some negative impacts or association of housing on stone curlews densities on arable land.

Table 1: Area (km²) and percentage of suitable arable land in each band of distance to the nearest "settlement", together with the observed percentage of the total number (N) of stone curlew nests on suitable arable land each year occurring within each distance band; *p* denotes Chi-square test probability assessing differences from expected in observed nest numbers per distance band.

	Total nests (N)	Distance to nearest settlement" <500	500-1000	1000-1500	1500-2000	2000-2500	2500-4000	test *p*
Area (km²)		84.59	80.74	59.99	33.77	15.44	10.06	
%Area		29.7	28.4	21.1	11.9	5.4	3.5	
1988	62	4.8	27.4	22.6	22.6	14.5	8.1	<0.001
1989	63	4.8	28.6	20.6	28.6	12.7	4.8	<0.001
1990	57	5.3	21.1	36.8	22.8	5.3	8.8	<0.001
1991	70	7.1	20.0	24.3	25.7	15.7	7.1	<0.001
1992	53	7.5	17.0	32.1	24.5	17.0	1.9	<0.001
1993	71	8.5	14.1	26.8	31.0	15.5	4.2	<0.001
1994	67	7.5	16.4	23.9	23.9	23.9	4.5	<0.001
1995	73	9.6	31.5	16.4	24.7	12.3	5.5	<0.001
1996	81	9.9	16.0	24.7	29.6	11.1	8.6	<0.001
1997	90	13.3	20.0	22.2	30.0	10.0	4.4	<0.001
1998	90	16.7	23.3	13.3	28.9	14.4	3.3	<0.001
1999	103	16.5	25.2	19.4	21.4	10.7	6.8	<0.001
2000	122	13.1	26.2	30.3	13.9	12.3	4.1	<0.001
2002	116	8.6	30.2	27.6	19.8	8.6	5.2	<0.001
2003	124	13.7	34.7	20.2	15.3	9.7	6.5	<0.001
2004	152	11.2	25.0	32.9	19.7	7.9	3.3	<0.001
2005	167	13.8	23.4	24.6	26.3	8.4	3.6	<0.001
2006	193	12.4	25.4	20.7	21.2	14.5	5.7	<0.001

Table 2: Annual density (per km²) of stone curlew nests on suitable arable land within each band of distance to the nearest "settlement

	Total nests (N)	Distance to nearest settlement" <500	500-1000	1000-1500	1500-2000	2000-2500	>2500
1988	62	0.04	0.21	0.23	0.41	0.58	0.50
1989	63	0.04	0.22	0.22	0.53	0.52	0.30
1990	57	0.04	0.15	0.35	0.38	0.19	0.50
1991	70	0.06	0.17	0.28	0.53	0.71	0.50
1992	53	0.05	0.11	0.28	0.38	0.58	0.10
1993	71	0.07	0.12	0.32	0.65	0.71	0.30
1994	67	0.06	0.14	0.27	0.47	1.04	0.30
1995	73	0.08	0.28	0.20	0.53	0.58	0.40
1996	81	0.09	0.16	0.33	0.71	0.58	0.70
1997	90	0.14	0.22	0.33	0.80	0.58	0.40
1998	90	0.18	0.26	0.20	0.77	0.84	0.30
1999	103	0.20	0.32	0.33	0.65	0.71	0.70
2000	122	0.19	0.40	0.62	0.50	0.97	0.50
2002	116	0.12	0.43	0.53	0.68	0.65	0.60
2003	124	0.20	0.53	0.42	0.56	0.78	0.79
2004	152	0.20	0.47	0.83	0.89	0.78	0.50
2005	167	0.27	0.48	0.68	1.30	0.91	0.60
2006	193	0.28	0.61	0.67	1.21	1.81	1.09

Trends in proportion of nests close to settlements

Over the study period 1998-2006, annual stone curlews numbers on arable land have tended to increase from always less than 80 prior to 1996 to always over 140 since 2004 (Figure 5). With increasing population size, it is perhaps expected that there may be more competition for territories, which may result in individuals choosing to nest nearer to settlements. Figure 13 shows the how the proportion of all stone curlew on suitable arable land within a year which are nesting within 500m or within 500-1000m of any "settlement" has steadily increased over the past two decades. The proportion within 500m has increased from around 5% in the late 80s to 11-14% since 2003; this is still much less than the 30% expected from the proportion of all suitable arable land in the study region which is within 500m of the nearest settlement (Table 1).

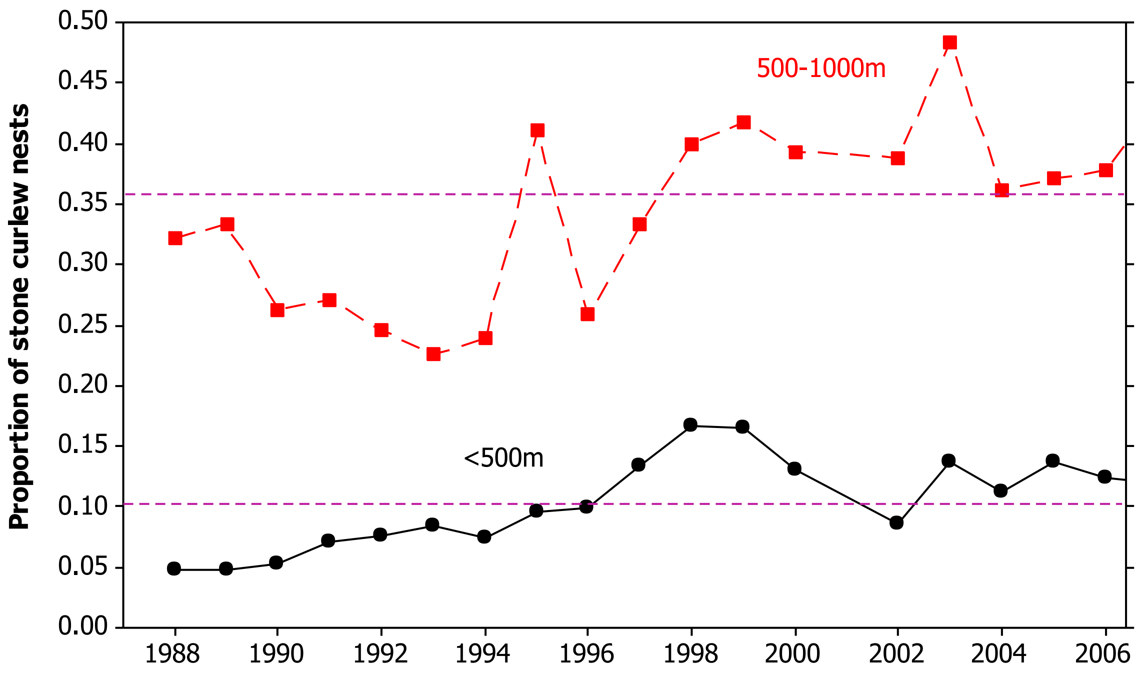


Figure 13 Trends over the period 1988-2006 in the proportion of all stone curlews on suitable arable land in a year which occur on land within 500m (black) or within 500-1000m (red) of the nearest "settlement"

Spatial spread of stone curlews in relation to distance from nearest settlement

Most statistical analyses of the inter-relationship between the distribution of a species (in this case stone curlew) and some environmental features (in this case nearby housing or road/road traffic levels) assume the data observations are independent. One important type of lack of statistical independence can be spatial, whereby all of the 500m cells in the study region which are at large distances from any settlement (or road traffic) occur in just one or two parts of the region, which may, by chance, have other features which make them relatively attractive (or unattractive) as nest sites for stone curlews.

To assess this, for each year, we determined the number of 5km national grid cells in the study area containing one or more 500m cells with stone curlews at each distance band to any settlement (Table 3). For each year, there are almost always at least 3, and often more than 10, separate 5km cells in the region with stone curlew present at any particular distance band up to 2500m. The low numbers for the <500m band are largely due to very few 500m cells so close to settlements having any stone curlews.

This simple form of spatial analysis gives us some confidence that the results are not largely or partly due to spurious spatial patch inter-correlations between stone curlew habitat quality and housing distribution. We have, of course, already tried to overcome this problem by restricting our analyses to those areas considered to be suitable nesting habitat for stone curlews, namely arable land or semi-natural grassland and SSSI on suitable soil types.

Table 3: Number of 5km square grid cells containing one or more 500m cells with stone curlews at each distance band to any settlement

Year	Distance of stone curlew location from nearest settlement							Total
	<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	>3000m	
1988	3	8	6	7	4	3	1	32
1989	2	11	7	10	4	1	1	36
1990	3	6	8	5	2	1	1	26
1991	3	11	8	9	3	2	1	37
1992	3	5	8	7	3	0	1	27
1993	4	7	8	12	3	1	1	36
1994	3	6	10	11	4	2	1	37
1995	5	12	7	8	4	1	1	38
1996	4	10	8	12	4	1	2	41
1997	6	10	10	10	4	1	1	42
1998	7	11	10	9	5	1	1	44
1999	8	14	11	10	5	2	1	51
2000	8	14	13	7	7	1	2	52
2002	7	13	11	7	5	1	1	45
2003	9	15	11	8	6	1	2	52
2004	10	16	16	8	3	1	2	56
2005	9	16	10	11	5	2	2	55
2006	11	14	15	12	7	1	2	62
Mean	5.8	11.1	9.8	9.1	4.3	1.3	1.3	43

Assessing distance from settlements over which nest density is reduced

In Table 1 above, we have already shown that there are statistically differences in nest density in relation to distance from the nearest settlement and furthermore, in Table 2 that the nest density was lowest in the 0-500m distance band for every year over the period 1988-2006. 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.

This was assessed by repeating the Chi-square tests comparing the observed number of nests with the expected number in each distance band, where the expected is based on the proportion of all suitable arable land in that distance band. In these additional tests, again for each year separately, the analysis was repeated initially using all data, then excluding those areas (and their nests) within 500m of any settlement, then excluding all areas (and nests) within 1000m, then 1500m and finally 2000m of the nearest settlement (Table 4). The highest distance band at which there are still statistically detectable (i.e. Chi-square test $p < 0.05$) differences in nest density between this and higher distance bands suggests the maximum distance at which we can detect an effect (or association) of housing with nest density.

Table 4: Annual density (per km^2) of stone curlew nests on suitable arable land within each band of distance to the nearest "settlement; together with maximum distance band for which there are statistically significant Chi-square test p values for differences in nest density between it and higher distance bands (p value for each test given in brackets)

Area (km^2)	Total nests (N)	Distance to nearest settlement" <500	500-1000	1000-1500	1500-2000	>2000	Max distance (m) showing significant difference (p<0.05) in nest density
		84.59	80.74	59.99	33.77	25.51	
1988	62	0.04 (.001)	0.21 (.019)	0.23 (.061)	0.41 (.456)	0.55	1000
1989	63	0.04 (.001)	0.22 (.014)	0.22 (.035)	0.53 (.579)	0.43	1500
1990	57	0.04 (.001)	0.15 (.054)	0.35 (.900)	0.38 (.658)	0.31	500
1991	70	0.06 (.001)	0.17 (.001)	0.28 (.046)	0.53 (.635)	0.63	1500
1992	53	0.05 (.001)	0.11 (.001)	0.28 (.614)	0.38 (.966)	0.39	1000
1993	71	0.07 (.001)	0.12 (.001)	0.32 (.055)	0.65 (.616)	0.55	1000
1994	67	0.06 (.001)	0.14 (.001)	0.27 (.007)	0.47 (.171)	0.74	1500
1995	73	0.08 (.001)	0.28 (.016)	0.20 (.013)	0.53 (.902)	0.51	1500
1996	81	0.09 (.001)	0.16 (.001)	0.33 (.029)	0.71 (.698)	0.63	1500
1997	90	0.14 (.001)	0.22 (.001)	0.33 (.009)	0.80 (.179)	0.51	1500
1998	90	0.18 (.001)	0.26 (.001)	0.20 (.001)	0.77 (.518)	0.63	1500
1999	103	0.20 (.001)	0.32 (.008)	0.33 (.030)	0.65 (.802)	0.71	1500
2000	122	0.19 (.001)	0.40 (.081)	0.62 (.397)	0.50 (.176)	0.78	500
2002	116	0.12 (.001)	0.43 (.343)	0.53 (.554)	0.68 (.800)	0.63	500
2003	124	0.20 (.001)	0.53 (.206)	0.42 (.102)	0.56 (.298)	0.78	500
2004	152	0.20 (.001)	0.47 (.023)	0.83 (.625)	0.89 (.342)	0.67	1000
2005	167	0.27 (.001)	0.48 (.001)	0.68 (.008)	1.30 (.057)	0.78	1500
2006	193	0.28 (.001)	0.61 (.001)	0.67 (.001)	1.21 (.302)	1.53	1500

In 10 of the 18 years, statistically significant lower nest densities were detectable for areas within 1000-1500m of the nearest settlement (compared to areas even further from any settlement). In four other years the maximum distance with detectable reduction was 500-1000m and in the remaining four years, significant differences were only detectable for the area up to 500m from the nearest settlement.

These analyses suggest that new housing developments (i.e. non-infilling) may need to be at least 1500m from any stone curlew habitat on arable land to avoid potential impact on stone curlew nesting densities and rates.

Roads

Roads within the study area

Map 5 shows all A-roads within the study area and highlights the two that are trunk roads (the A11 and the A14). The A11 passes through the southern part of the study area by-passing Thetford while the A14 passes through the south-west corner. The traffic flows on the trunk sections of these roads were acquired and show considerable variation between different sections of the A11 and A14.

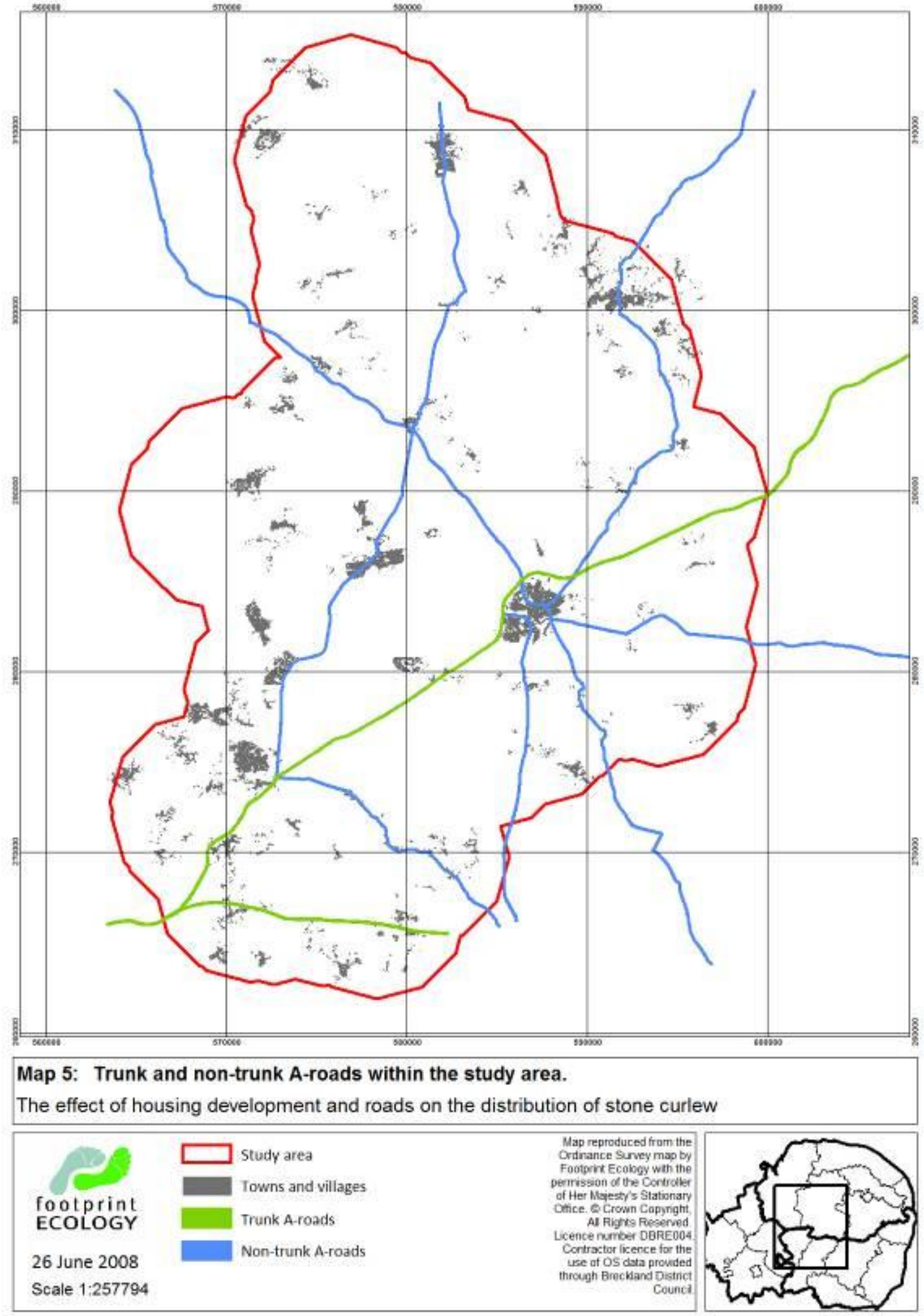
The mean total daily traffic flow increases from March to August, across all of the different sections, as shown in Table 5. The busiest road section within the study area is the A14 between the junctions with the A11 and the A1302, and the daily flow in one direction is between 19,327 vehicles in March to 22,224 vehicles in July. The section of trunk road within the study area which has the lowest traffic flows is the section of the A11 between the A1075 and the A134, and the daily flow in one direction is between 11,343 vehicles in March to 13,162 vehicles in August.

The non-trunk A-roads radiate out from Thetford and Mildenhall to other settlements, such as Bury St Edmunds, Diss, Swaffham and Watton (Map 5). No data was available for the flows of traffic on these non-trunk roads.

Table 5: Mean total unidirectional daily traffic flow of each section of trunk road within the study area, for the months of March to August.

Road	Section	March	April	May	June	July	August	*Mean*
A11	**A1075 to A134**	11,343	11,813	12,034	12,466	12,651	13,162	*12,245*
A11	**A1075 to A47**	15,781	15,472	15,619	16,280	16,010	16,755	*15,986*
A11	**A1101 to A134**	11,409	12,021	12,014	12,490	12,848	13,040	*12,304*
A11	**A1101 to A14**	17,765	18,774	18,933	19,510	19,867	20,253	*19,184*
A11	**A134 to A1075**	11,394	11,833	12,035	12,481	12,671	13,043	*12,243*
A11	**A134 to A1101**	11,524	12,151	12,247	12,705	12,991	13,384	*12,500*
A11	**A134 to A134**	14,021	14,882	14,992	15,547	15,872	16,166	*15,247*
A11	**A134 to A134**	14,047	14,873	15,027	15,603	15,757	16,300	*15,268*
A11	**A14 to A1101**	18,192	19,133	19,252	19,689	20,263	20,714	*19,540*
A11	**A47 to A1075**	15,770	16,103	16,313	16,962	16,667	17,631	*16,574*
A14	**A11 to A1302**	20,812	21,007	21,442	22,094	22,224	22,074	*21,609*
A14	**A11 to A142**	*	*	*	*	*	*	
A14	**A1302 to A11**	19,327	20,815	21,467	22,114	22,103	22,088	*21,319*
A14	**A142 to A11**	15,596	15,875	16,129	16,822	16,630	16,823	*16,313*
	Mean	16,745	17,487	17,739	18,341	18,494	18,880	
	Total	234,428	244,816	248,351	256,771	258,913	264,316	

*Data inconclusive – Unexplained errors found in raw data acquired from TRADS.



Map 5: Trunk and non-trunk A-roads within the study area.
The effect of housing development and roads on the distribution of stone curlew

Figure 14 shows the mean daily traffic flow during daylight and darkness hours within the study area through time. It demonstrates that, unsurprisingly, traffic flows are heavier during daylight hours. It also shows that between 2003 and 2007 there are no significant trends, and between years average traffic flows have remained relatively constant. Within years, as the traffic increases during the spring and summer (Table 5) and the number of daylight hours extend, the volume of traffic observed from March to June during daylight hours increases, while that in darkness hours decreases. After mid-summer from June to August, the reverse is true as the number of darkness hours starts to increase again (Figure 14).

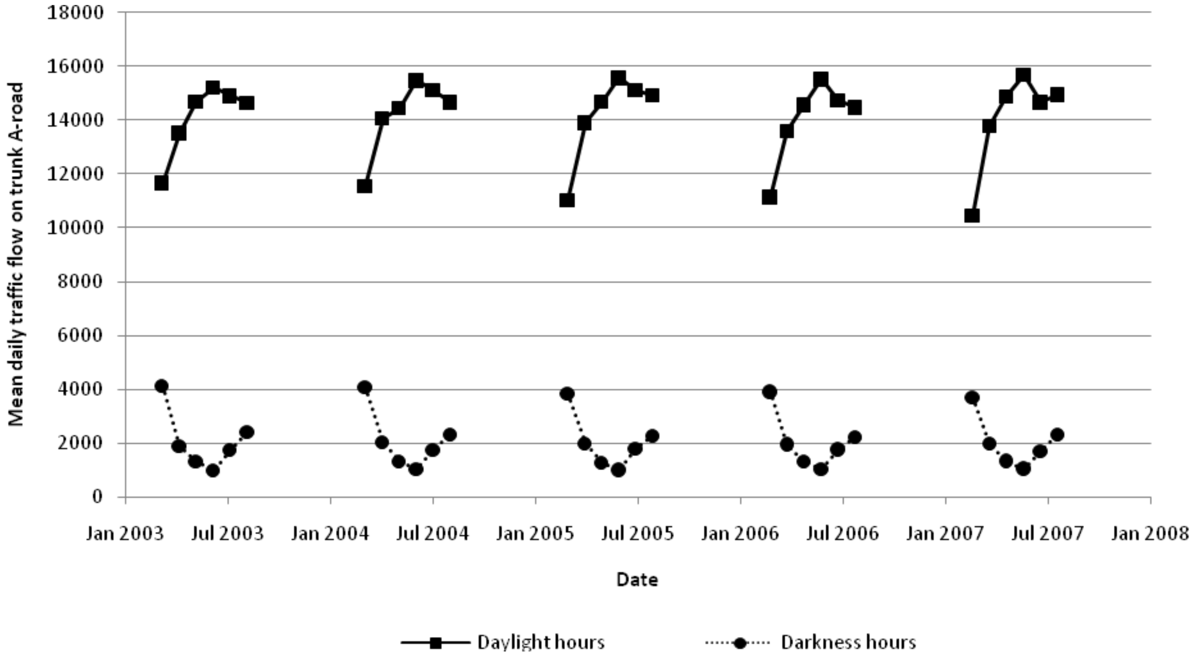


Figure 14: Mean daily unidirectional traffic flow on trunk roads within the study area during daylight and darkness hours.

Avoidance of roads

There is an extensive road network system within the study area, with a number of A-roads and two trunk A-roads present. As described in the Introduction, stone curlew have previously been shown in Breckland and Wessex to avoid roads when choosing a nesting location, with there being a positive relationship up to 3 km between the density of stone curlew nests and the distance from a motorway or trunk road (Day 2003). These analyses were repeated for the Breckland region for this study to include the most recent stone curlew nest data.

Figure 15 shows the stone curlew nest density on arable habitat within different distance bands from trunk A-roads. It shows that as the distance from the trunk road increases up to 3 km, the nest density increases, while the area of available habitat in each distance band remains relatively similar. This suggests that roads have a significant impact on stone curlew nesting behaviour and tend to avoid nesting near to roads.

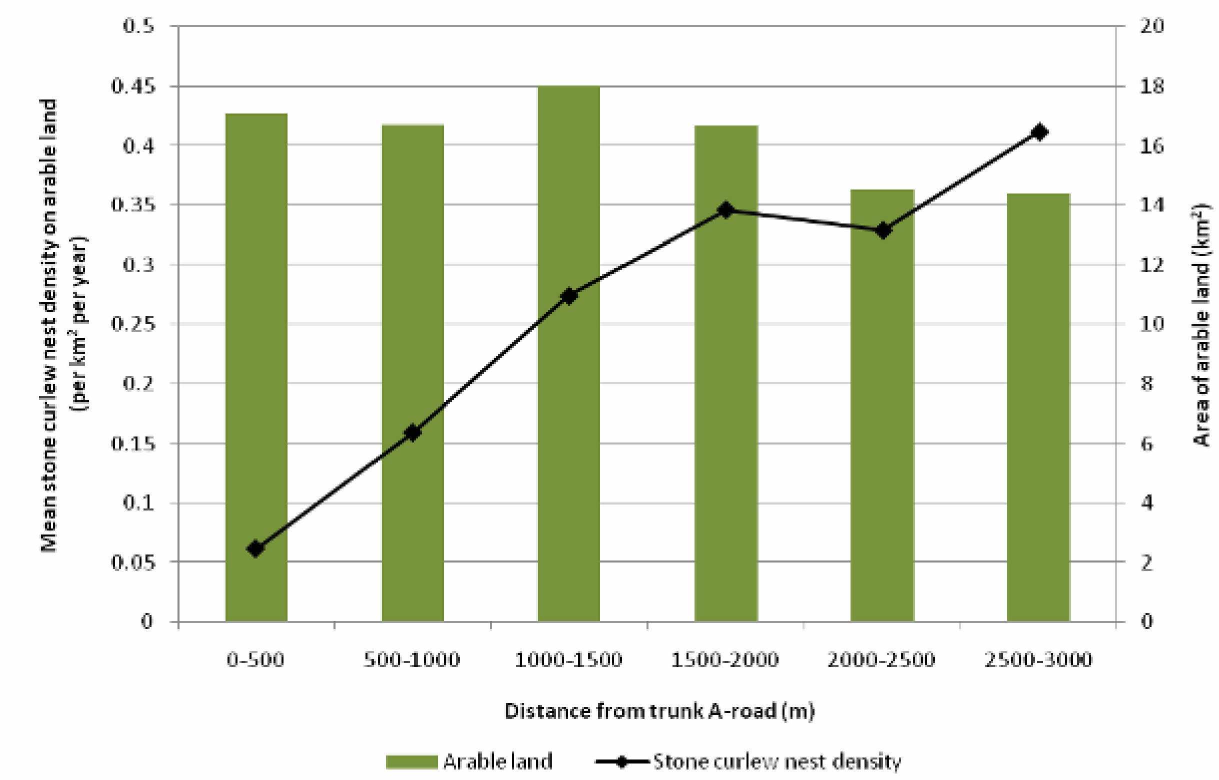


Figure 15 Mean stone curlew nest density on arable land and the area of arable habitat available at different distance bands away from trunk A-roads.

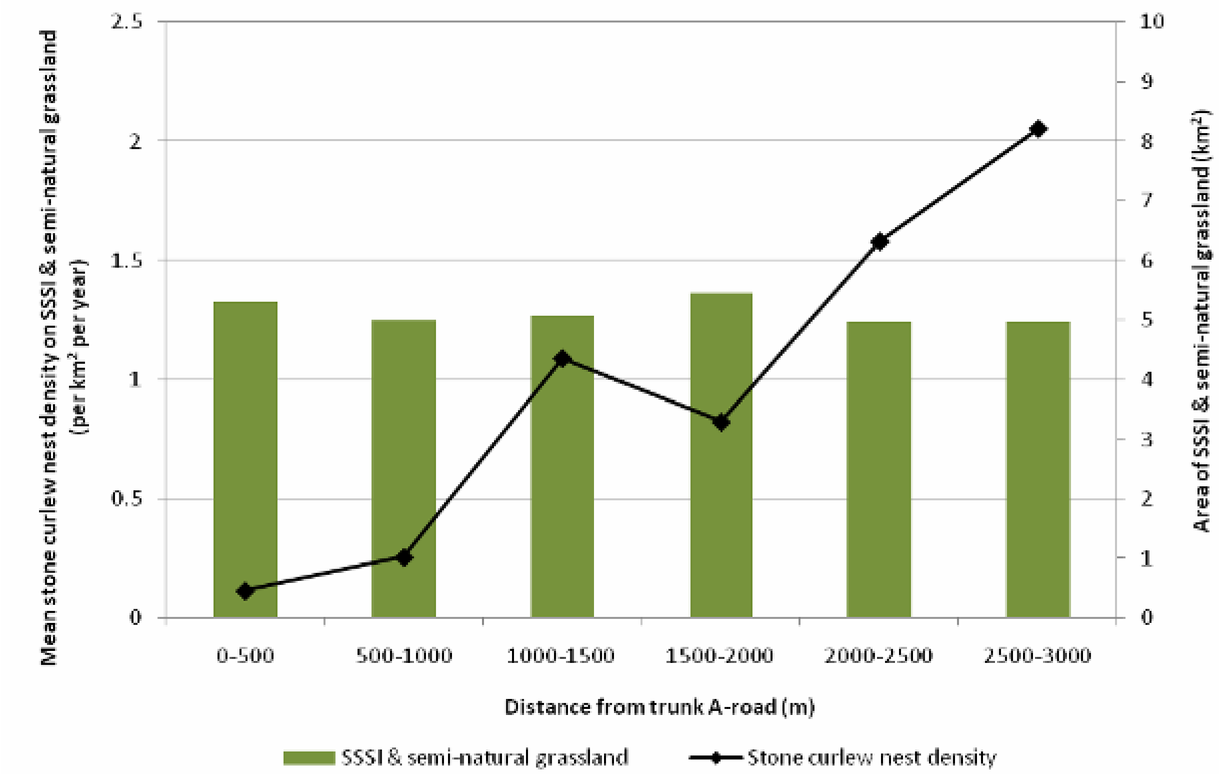


Figure 16 Mean stone curlew nest density on SSSI and semi-natural grassland and the area of SSSI and semi-natural grassland habitat available at different distance bands away from trunk A-roads.

Figure 16 shows a similar positive relationship between the distance, up to 3 km, away from a trunk A-road and stone curlew nest density on areas of SSSI and semi-natural grassland. This indicates that stone curlews nesting on SSSIs and on semi-natural grassland also avoid nesting close to a trunk road. Notice that average nest densities achieved on this habitat are far greater than those on arable land, both overall and at each distance band from trunk A-roads, although the total area of SSSI and semi-natural grassland within each distance band (about 5km^2) is only about one-third as much as that of arable land (14-18 km^2) within the study area (Figure 15 and Figure 16).

For comparison, similar analyses were conducted for non-trunk A-roads. Figure 17 shows that there is some avoidance of non-trunk A-roads within the first 500 m of the road, with lower nest density, while further from such roads nest density is higher but remains relatively level at around 0.4 to 0.5 nests per km^2 per year. This therefore suggests that avoidance of non-trunk A-roads by stone curlews nesting on arable habitat is not as great, and occurs over a much shorter distance, as that on trunk A-roads. Figure 18 show the same for nests found on SSSI and semi-natural grassland. It does not show any clear avoidance of roads, although the density of nests is greater in the 500 to 1000 m band, compared to the 0 to 500 m band. Average nest density is actually lower in such areas further from trunk A-roads; this may be due to various non-measured factors and management differences affecting the relative quality of the habitat for stone curlews in these SSSI and semi-natural grasslands and partly due to chance as smaller areas of this habitat type occur at larger distances from non-trunk A roads.

Figure 19 shows similar information on arable habitat for individual roads within the study area. It shows that in the majority of cases the same positive relationship between stone curlew nest density and distance from a road is observed. In the cases where it is not, the area of available habitat is often low and therefore average densities are based on few nests and thus more susceptible to stochastic variation due to having one or a few more or less nests.

When comparing the A11, a trunk road, and the A1065, a non-trunk road, both with similar areas of habitat available within similar distance bands, they both show nesting avoidance of the road, but the densities are far greater around the A1065 than the A11, and the avoidance only is observed in the nearest 500m for the A1065 while it is observed up to 3 km for the A11. While there are a number of other factors which influence the choice of nest location by stone curlew, such as the surrounding habitat quality, settlements and field size, the A11, which is likely to have heavier traffic, appears to have a greater impact upon the spatial distribution of stone curlew nests than the A1065, which is likely to have lighter traffic.

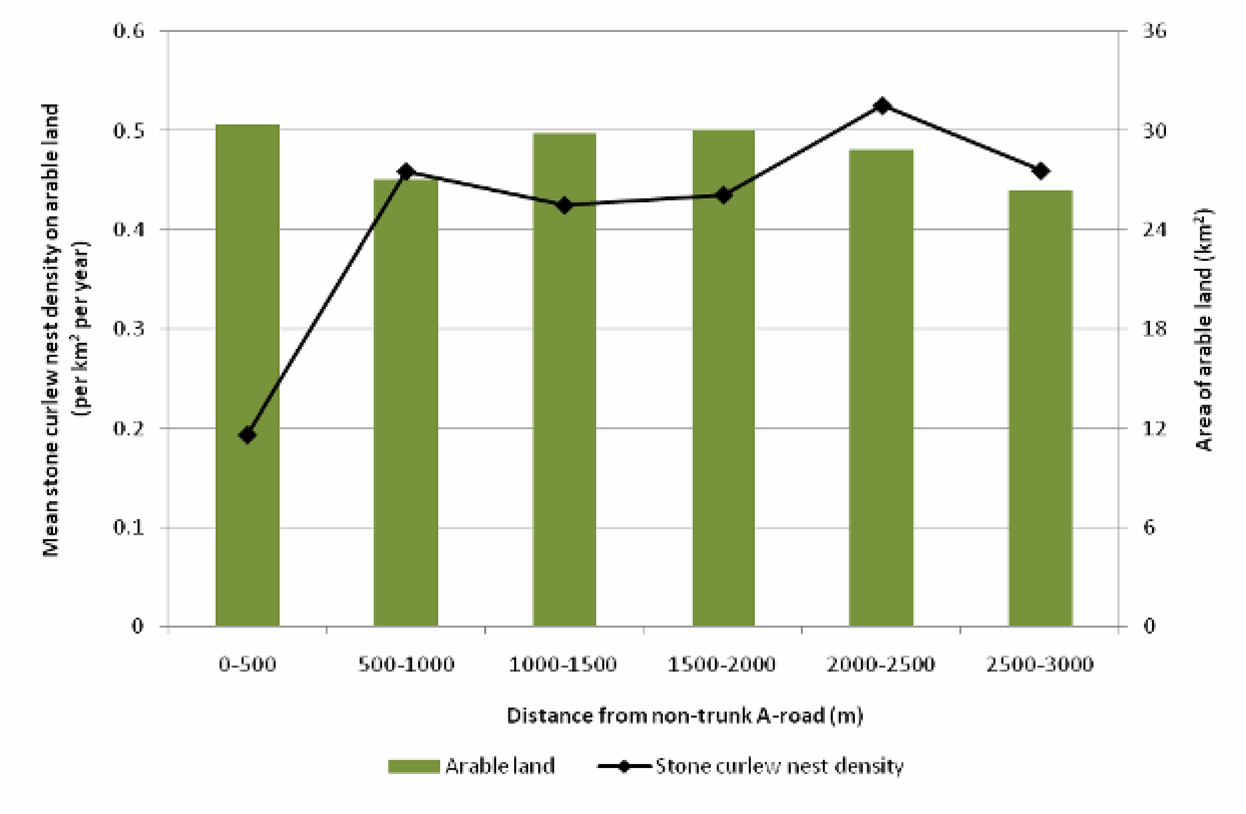


Figure 17 Mean stone curlew nest density on arable land and the area of arable habitat available at different distance bands away from non-trunk A-roads.

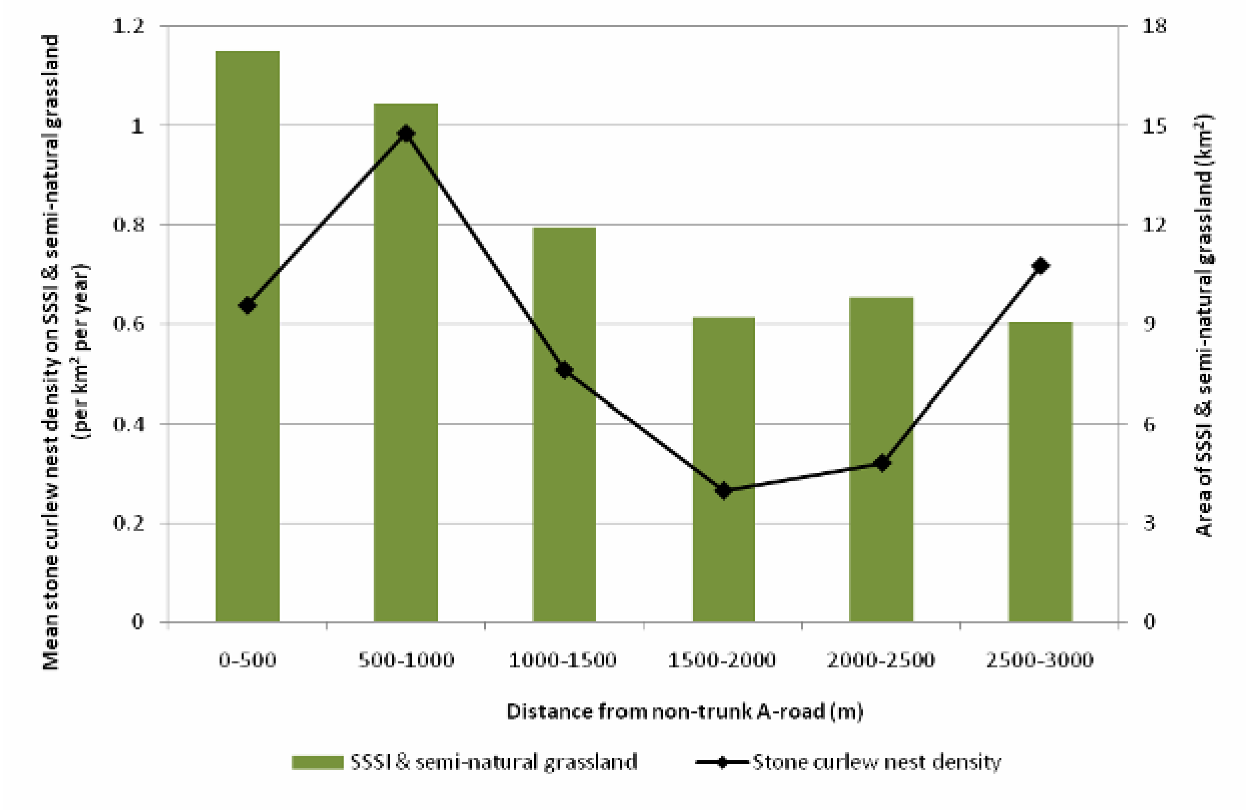


Figure 18 Mean stone curlew nest density on SSSI and semi-natural grassland and the area of SSSI and semi-natural grassland habitat available at different distance bands away from non-trunk A-roads.

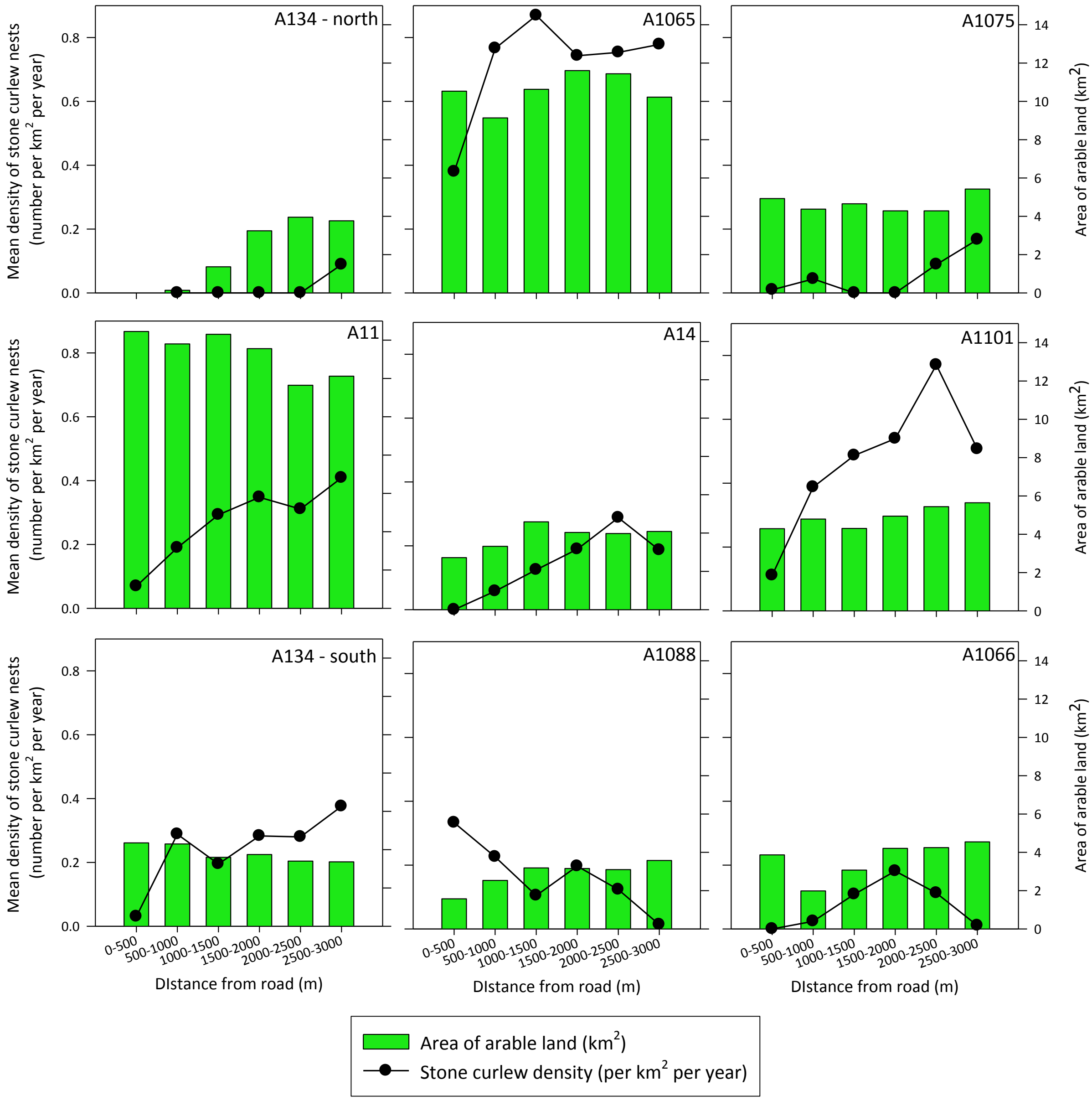


Figure 19: Mean density of stone curlew nests on arable land, and the area of arable land available, at different distance bands away from individual roads within the study area.

Assessing distance from Trunk roads over which nest density is reduced

As a means of assessing the distance over which trunk roads and their traffic appears to have a negative impact on stone curlew nest density, we calculated Chi-square tests comparing the observed number of nests with the expected number in each distance band up to 3000m. The expected number for any distance band is based on the proportion of all suitable arable land within 3000m of a Trunk road which is in that distance band. For example if there are 100 nests on all arable land within 3000m and 17% of the total area is within 500m of a Trunk road, then, if there is no effect of trunk roads on nest density, we would expect on average, 17 nests to occur on the arable land within 500m. Because relatively smaller areas within the study region were close (i.e. within 3000m) of a Trunk road compared to the areas within 3000m of any "settlement", the overall numbers of nests involved for each year were relatively small for the requirements of the Chi-square tests. Therefore, the Chi-square tests were carried on the overall nest numbers in each distance band in each of four periods (Table 6).

Table 6 (a) Average density (per km^2) and total numbers of stone curlew nests per period on suitable arable land within each band of distance to the nearest Trunk road; (b) maximum distance band for which there are statistically significant Chi-square test p values for differences in nest density between distance bands (that band and higher)

Distance to Trunk road (m)	Area (km^2	(a) mean nest density [and total nests] per period				
		1988-92	1993-96	1997-2000	2002-06	Overall 1988-2006
<500	17.12	0.08 [7]	0.07 [5]	0.04 [3]	0.05 [4]	0.06 [19]
500-1000	16.73	0.11 [9]	0.16 [11]	0.13 [9]	0.23 [19]	0.16 [59]
1000-1500	18.04	0.21 [19]	0.21 [15]	0.29 [21]	0.38 [34]	0.27 [92]
1500-2000	16.68	0.34 [28]	0.27 [18]	0.31 [21]	0.44 [37]	0.34 [108]
2000-2500	14.52	0.28 [20]	0.33 [19]	0.21 [12]	0.48 [35]	0.33 [91]
2500-3000	14.43	0.40 [29]	0.31 [18]	0.38 [22]	0.53 [38]	0.42 (114)
		(b) Chi-square test *p* value				
Minimum distance band involved in test		1988-92	1993-96	1997-2000	2002-06	Overall 1988-2006
<500		<0.001	0.018	<0.001	<0.001	<0.001
500-1000		0.003	0.308	0.066	0.030	<0.001
1000-1500		0.147	0.562	0.386	0.538	0.016
1500-2000		0.424	0.831	0.224	0.758	0.184
2000-2500		0.191	0.884	0.083	0.706	0.099
Max distance (m) showing significant difference (p<0.05) in nest density		1000	500	500	1000	1500

The tests initially used all data, then excluding those areas (and their nests) within 500m of any settlement, then excluding all areas on all arable land (and nests) within 1000m, then 1500m and finally 2000m of the nearest settlement (Table 6). The highest distance band at which there are still statistically detectable (i.e. Chi-square test p < 0.05) differences in nest density between this and higher distance bands suggests the maximum distance at which we can detect an effect (or association) of Trunk roads on nest density.

In all four periods, the nest density on arable land within 500m of a Trunk road is statistically (all p < 0.001) lower than densities at greater distances. Over the first (1988-1992) and last (2002-2006) periods, there was also statistically significant differences between nest densities on land in the 500-1000m band relative to those at greater distances from trunk roads. With all years' data combined, the total nest numbers involved are sufficient for effects to be detectable up to 1500m (Table 6).

Overall, this suggests that there is a negative relationship and potential negative impact of trunk roads on stone curlew nest density up to a distance of at least 1000m, and maybe up to 1500m.

Assessing distance from non-trunk A- roads over which nest density is reduced

A similar analysis of nest density in relation to distance from non-trunk A-roads was carried out When the data from all years were combined, the Chi-square tests showed no significance differences in nest density between distance bands after the 0-500m data had been excluded.

Thus, there appears to be a negative impact of the presence of non-trunk A-roads on stone curlew nest density up to a distance of 500m (Table 7).

The pattern of results was less consistent than that for trunk roads in that nest density varied more erratically with distance and density both increasing and decreasing with increasing distance band within any one four or five year period. However, in each of the four periods, the average nest density was lower on the arable land within 500m of a non-trunk A-road than on land in every greater distance band (Table 7). When the data from all years were combined, the Chi-square tests showed no significant differences in nest density between distance bands after the 0-500m data had been excluded.

Thus, there appears to be a negative impact of the presence of non-trunk A-roads on stone curlew nest density up to a distance of 500m

Table 7: (a) Average density (per km^2) and total numbers of stone curlew nests per period on suitable arable land within each band of distance to the nearest non-trunk A road; (b) maximum distance band for which there are statistically significant Chi-square test p values for differences in nest density between distance bands (that band and higher)

Distance to non-trunk A-road (m)	Area (km^2	(a) mean nest density [and total nests] per period				
		1988-92	1993-96	1997-2000	2002-06	Overall 1988-2006
<500	17.12	0.09 [13]	0.14 [17]	0.22 [27]	0.32 [49]	0.19 [106]
500-1000	16.73	0.30 [41]	0.24 [26]	0.42 [46]	0.82 [111]	0.46 [224]
1000-1500	18.04	0.29 [44]	0.33 [39]	0.38 [46]	0.67 [100]	0.43 [229]
1500-2000	16.68	0.19 [29]	0.40 [48]	0.42 [50]	0.72 [109]	0.44 [236]
2000-2500	14.52	0.29 [42]	0.35 [40]	0.62 [72]	0.83 [120]	0.53 [274]
2500-3000	14.43	0.39 [52]	0.41 [43]	0.54 [57]	0.51 [67]	0.46 (219)

	(b) Chi-square test *p* value				
Minimum distance band involved in test	1988-92	1993-96	1997-2000	2002-06	Overall 1988-2006
<500	<0.001	0.001	<0.001	<0.001	<0.001
500-1000	0.044	0.216	0.045	0.010	0.133
1000-1500	0.020	0.690	0.032	0.012	0.070
1500-2000	0.007	0.722	0.087	0.005	0.088
2000-2500	0.142	0.459	0.418	0.001	0.139
Max distance (m) showing significant difference (p<0.05) in nest densities and density is lower than for all higher bands	500	500	1500	500	500

Relationships of nest density with weighted housing/road density variables

Rank correlations

As a first exploratory step to assess the strength of relationship and help assess the distance over which housing may influence stone curlew nests, we calculated, for each year, the rank correlation between nest density per 500m cell and the level of nearby housing based on the weighted Normal kernel variables with values of the standard deviation (S) varied from 250m, in steps of 250m, up to 2000m (Table 8). Spearman rank correlations based on ranked nest and housing values were used to avoid problems of non-linearity in the relationship and determining appropriate transformations of variables and to avoid over-dominating influence of a few very high values of housing levels. There are many tied (i.e. equal) values for nest density, but this approach enables us to quickly assess the pattern in strength of correlation in relation to choice of standard deviation (S). The correlations are all statistically significant (all $p < 0.001$ ignoring adjustment for ties); the correlations are low because of the vast majority of cells had no nests.

The correlations do change to some extent with S, but the values of S which give the high rank correlations each year seems to change, from anywhere between 250 and 1000m prior to 1996, to 1750 or 2000m from 1998 onwards (with the exception of 2006, Table 8).

Table 8 Spearman rank correlations between stone curlew nest density per 500m cell and level of nearby housing based on weighted Normal kernel with standard deviation of S metres (S = 250, 500, ... , 2000m); highest two correlations each year highlighted in bold

	S = Normal kernel SD							
	250	500	750	1000	1250	1500	1750	2000
1988	-0.094	**-0.104**	**-0.108**	-0.102	-0.098	-0.097	-0.097	-0.096
1989	**-0.123**	**-0.119**	-0.110	-0.102	-0.096	-0.091	-0.087	-0.081
1990	-0.111	-0.120	**-0.133**	**-0.137**	-0.131	-0.122	-0.115	-0.109
1991	-0.109	-0.122	**-0.128**	**-0.129**	-0.127	-0.123	-0.118	-0.114
1992	-0.077	-0.093	**-0.105**	**-0.104**	-0.100	-0.097	-0.096	-0.096
1993	-0.115	-0.121	**-0.128**	**-0.130**	-0.125	-0.121	-0.118	-0.116
1994	**-0.093**	**-0.093**	-0.089	-0.089	-0.091	-0.091	-0.091	-0.091
1995	**-0.092**	**-0.091**	-0.085	-0.082	-0.079	-0.080	-0.082	-0.084
1996	-0.090	-0.101	-0.111	**-0.119**	**-0.119**	-0.115	-0.110	-0.103
1997	**-0.117**	**-0.114**	-0.112	-0.113	**-0.114**	-0.112	-0.110	-0.108
1998	-0.110	-0.116	-0.122	-0.126	-0.130	-0.132	**-0.133**	**-0.133**
1999	-0.095	-0.112	-0.123	-0.128	-0.127	-0.127	**-0.129**	**-0.129**
2000	-0.098	-0.116	-0.133	-0.143	-0.150	-0.157	**-0.162**	**-0.164**
2002	-0.066	-0.087	-0.110	-0.126	-0.137	-0.142	**-0.144**	**-0.143**
2003	-0.095	-0.108	-0.130	-0.144	-0.153	-0.161	**-0.167**	**-0.170**
2004	-0.089	-0.110	-0.125	-0.133	-0.141	-0.147	**-0.151**	**-0.155**
2005	-0.102	-0.122	-0.143	-0.161	-0.174	-0.181	**-0.186**	**-0.189**
2006	-0.114	-0.137	-0.161	-0.175	**-0.181**	**-0.180**	-0.175	-0.169
Average	-0.099	-0.110	-0.120	-0.125	-0.126	-0.126	-0.126	-0.125

A similar type of analysis was used to assess the pattern of rank correlations between nest density per 500m cell and the five road/traffic variables (Table 9). Because the traffic variables were based on traffic data for 2002 onwards, the correlations were restricted to nest densities in each year from 2002 to 2006, and then averaged across years. The rank correlations for every road/traffic variable were always lower than the correlations for the housing variable at all values of standard deviation (S).

Average correlations (across years) with the non-trunk A-road variables were highest when S was equal to 1750 or 2000m, but average correlations never exceeded 0.023 (Table 9).

Table 9 Spearman rank correlations between stone curlew nest density per 500m cell and variables (a)-(e) measuring levels of nearby roads and traffic based on weighted Normal kernel with standard deviation of S metres (S = 250, 500, ... , 2000m); highest two correlations each year highlighted in bold; average correlations over the period 2002-2006

	S = Normal kernel SD							
	250	500	750	1000	1250	1500	1750	2000
(a) Non-trunk A-roads								
2002	-0.021	-0.006	0.014	0.024	0.032	0.036	**0.039**	**0.037**
2003	-0.010	**-0.023**	**-0.016**	-0.002	0.001	0.002	0.005	0.004
2004	**-0.013**	**-0.023**	-0.003	0.005	0.004	0.007	0.007	0.006
2005	-0.026	-0.005	0.006	0.018	**0.030**	0.026	0.029	**0.032**
2006	-0.008	-0.012	0.011	0.018	0.029	0.031	**0.033**	**0.032**
Average	-0.016	-0.014	0.002	0.013	0.019	0.020	**0.023**	**0.022**
(b) Trunk roads								
2002	-0.061	-0.049	-0.066	**-0.077**	**-0.072**	-0.067	-0.069	-0.062
2003	-0.062	-0.071	-0.066	**-0.077**	-0.066	-0.068	**-0.073**	-0.072
2004	-0.078	**-0.086**	**-0.081**	-0.074	-0.075	-0.074	-0.071	-0.072
2005	**-0.068**	**-0.074**	-0.064	-0.056	-0.053	-0.049	-0.058	-0.055
2006	**-0.049**	**-0.049**	-0.048	-0.037	-0.028	-0.033	-0.039	-0.032
Average	-0.064	**-0.066**	**-0.065**	-0.064	-0.059	-0.058	-0.062	-0.059
(c) Daylight traffic								
2002	-0.061	-0.049	-0.067	**-0.077**	**-0.073**	-0.069	-0.069	-0.061
2003	-0.062	-0.071	-0.067	**-0.077**	-0.067	-0.069	**-0.073**	-0.071
2004	-0.078	**-0.086**	**-0.081**	-0.074	-0.076	-0.075	-0.070	-0.071
2005	**-0.068**	**-0.074**	-0.064	-0.056	-0.054	-0.050	-0.058	-0.054
2006	**-0.049**	**-0.049**	**-0.049**	-0.037	-0.029	-0.034	-0.038	-0.031
Average	-0.064	**-0.066**	**-0.066**	-0.064	-0.060	-0.059	-0.062	-0.058
(d) Night traffic								
2002	-0.061	-0.049	-0.067	**-0.077**	**-0.073**	-0.068	-0.068	-0.060
2003	-0.062	-0.071	-0.066	**-0.077**	-0.067	-0.068	**-0.072**	-0.071
2004	-0.078	**-0.086**	**-0.081**	-0.074	-0.076	-0.075	-0.070	-0.070
2005	**-0.068**	**-0.074**	-0.064	-0.056	-0.054	-0.050	-0.058	-0.053
2006	**-0.049**	**-0.049**	**-0.049**	-0.037	-0.029	-0.033	-0.038	-0.030
Average	-0.064	**-0.066**	**-0.065**	-0.064	-0.060	-0.059	-0.061	-0.057
(e) Total daily traffic								
2002	-0.061	-0.049	-0.067	**-0.077**	**-0.073**	-0.069	-0.069	-0.061
2003	-0.062	-0.071	-0.067	**-0.077**	-0.067	-0.069	**-0.073**	-0.071
2004	-0.078	**-0.086**	**-0.081**	-0.074	-0.076	-0.075	-0.070	-0.071
2005	**-0.068**	**-0.074**	-0.064	-0.056	-0.054	-0.050	-0.058	-0.054
2006	**-0.049**	**-0.049**	-0.049	-0.037	-0.029	-0.034	-0.038	-0.031
Average	-0.064	**-0.066**	**-0.066**	-0.064	-0.060	-0.059	-0.062	-0.058

In contrast, average correlations with the Trunk road variables were highest when S was in the range 250-1000m, peaking at S=500m (or 750m) with average correlations of 0.066; however the differences were small across the whole range of S from 250-2000m.

Correlations of nest density with the traffic flow variables at any specific value of S were almost identical for daylight traffic, night traffic and total daily traffic (correlations differed by no more than 0.001). On examination, this was found to occur because the daylight, night and daily total traffic variables at any particular values of S are themselves almost perfectly correlated with rank correlations all >0.999 (Figure 20).

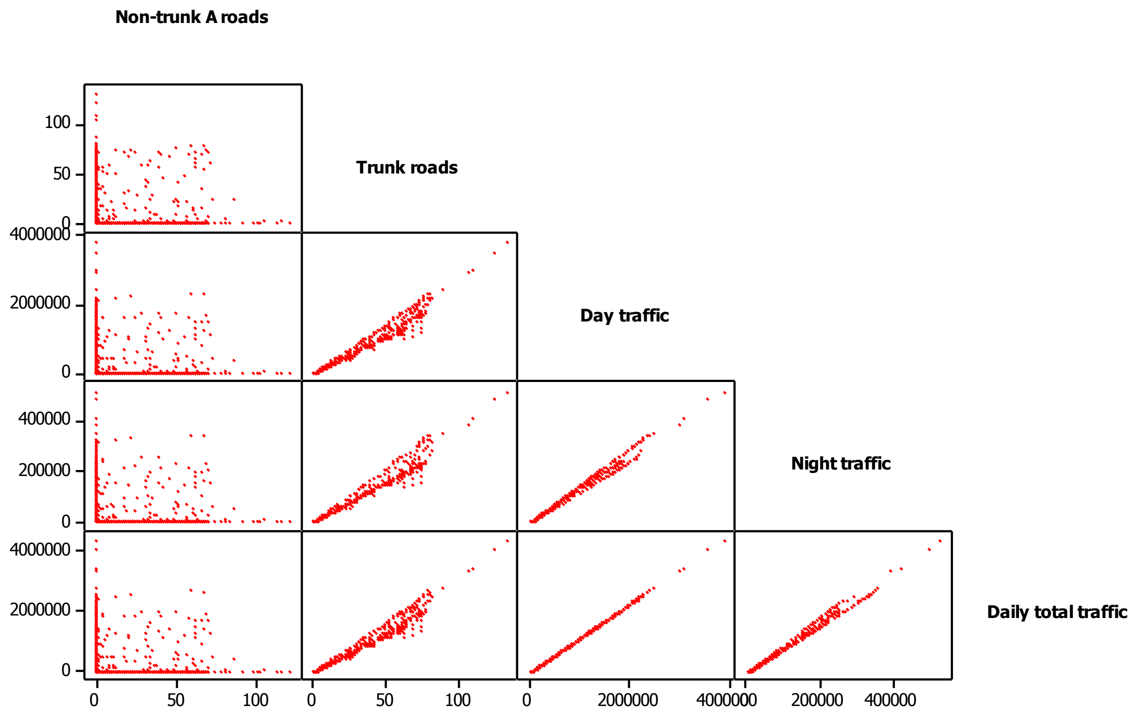


Figure 20 Plots of each pair of road and traffic variables when standard deviation S = 750m (n=2142 cells)

This means, unfortunately, that it will be impossible to differentiate between the effects of daylight and night-time traffic on the distribution of stone curlew nests.

Therefore, in the remainder of analyses in this study, we restricted our analysis of traffic flow effects to the daily total traffic flow variable, recognising that we could have obtained statistical equivalent and almost identical model relationships if we had used either the daylight or night traffic flow variable instead.

Furthermore, because the traffic flow data and derived variables were based only on traffic flow for sections of the A11 and A14 trunk roads, the traffic flow variables were also very highly correlated with the weighted Normal kernel of the presence of Trunk roads variable at all values of standard deviation S (all rank correlations >0.991); including the 750m version shown in Figure 21.

In retrospect, the daily mean traffic flow along sections of Trunk roads only varied from 12243 to 21609 (Table 5), which is a low coefficient of variation relative to the decrease in traffic variable values with the distance of 500m cells from trunk roads. This explains why the (trunk road) traffic variables are so highly correlated with the equivalent variable based solely on distance to 50m cells with a trunk road passing through (regardless of the traffic level).

Consequently the rank correlations between stone curlew nest density per 500m cell and weighted normal kernel of the presence of trunk roads are almost the same (within 0.002) as the correlations with the weighted normal kernel variables based on the actual traffic levels on each section of these trunk roads.

Thus it is difficult with the available information to differentiate the effects of the presence of nearby trunk roads from the actual level of traffic on them.

However, as already noted, the average rank correlations between nest density and the weighted normal kernel variable of nearby non-trunk A-roads are considerably lower at all values of S than those based on the presence or traffic levels of trunk roads. One obvious explanation for this is the increased level of traffic on the trunk roads (although it could potentially also be due to differences in physical characteristics of trunk roads).

The correlations between the weighted normal kernel variables measuring the amount of nearby housing and the nearby trunk roads traffic are low (all less than 0.2; see examples in Figure 21). This indicates that amongst all of the 500m grid cells on arable land on suitable soil type within the study region, the amount of nearby housing is largely unrelated to the amount of trunk roads traffic. Thus in the statistical models it should be possible to separate their separate effects.

All 2142 of the 500m cells on suitable arable land were grouped according to their level of the weighted normal kernel variables for nearby housing and daily total traffic, both using S=750m, and the average nest density per 500m cell in each group calculated (Table 10). Both nest density and housing were average values over the period 2002-2006 as this coincides with the period over which traffic levels were available. It can be seen that when the daily traffic variable was zero (77% of all 500m cells), average nest density declined consistent with increasing values of the housing variable, from 0.151 (nest per 500m cell) when housing value was <3000, to 0.039 when housing variable was >27000 (Table 10). Furthermore, when the housing variable had low values (<3000), then average nest density decreased as the daily traffic variable increased, from 0.151 nests per 500m cell at daily traffic variable values of zero to 0.012 when dally traffic variable was >130000 (Table 10). Nest density also declined consistently with increasing daily traffic amongst all cells housing variables values in the next higher class 3001-7000.

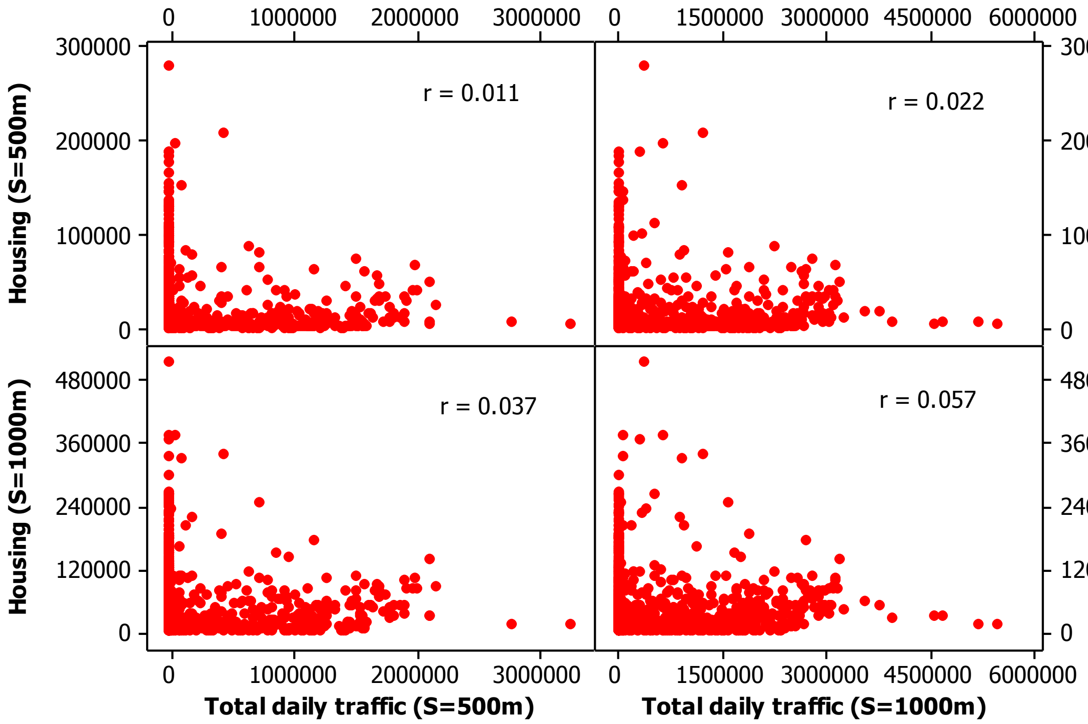


Figure 21 Relationship between total daily trunk road traffic variable and housing variable based on weighted normal kernel with S = 500m or 1000m (n = 2142 cells)

Table 10 Average stone curlew nest density per 500m cell classified by the weighted normal kernel variables (both using S=750m) for housing and daily total traffic; nest density and housing are average values for 2002-2006 (number of cells in brackets)

		Daily traffic				
		0	1-35000	350001-130000	130000-4400000	Overall
Housing	0-3000	0.151 (276)	0.087 (37)	0.052 (42)	0.012 (34)	0.122 (389)
	3001-7000	0.118 (363)	0.109 (35)	0.082 (34)	0.008 (26)	0.108 (458)
	7001-13000	0.074 (377)	0.008 (25)	0.032 (19)	0.000 (21)	0.065 (442)
	13001-27000	0.039 (333)	0.062 (26)	0.012 (33)	0.000 (30)	0.036 (422)
	27001-396000	0.031 (306)	0.005 (41)	0.006 (34)	0.000 (50)	0.023 (431)
	Overall	0.081 (1655)	0.055 (164)	0.038 (162)	0.004 (161)	0.070 (2142)

Fitted models of relationships

The generalised linear models (GLM) were fitted to the combined 500m grid cell data for all years over the period 1988-2006 (excluding 2001). In each case, GLM were fitted using one housing variable (X_H) and one weighted normal kernel road/traffic variable (X_R) measuring "nearby" extent of either A-roads, Trunk roads or average daily traffic levels on the trunk roads). Models were fitted repeatedly using all possible combinations of SD (250, 500, ..., 2000m) for the housing and S for the road/traffic variable, giving a total of 8 x 8 x 3 = 192 models). Because the model residual mean deviance was never greater than one, it was considered to be unnecessary to adjust for overdispersion. A Poisson model was assumed using a pre-fixed mean deviance of one for determination of the standard errors of the model parameters (see methods for further details).

The models were fitted to the whole dataset in two main forms:

Model form M1: (one observation per 500m cell):

$$\log_e N_i = \log_e A_i + \alpha + \beta_H\ X_{Hi}\ + \beta_R X_{Ri}$$

N_i = sum of nest numbers over whole period in 500m cell *i*
A_i = area (in hectares) of arable land on suitable soil type in cell *i*
X_{Hi} = average value of the housing variable for cell *i* over the whole period
X_{Ri} = value of the road/traffic variable for cell *i*.

Model form M2: (one observation per 500m cell per year):

$$\log_e N_{iy} = \log_e A_i + \alpha_y + \beta_H\ X_{Hi}\ + \beta_R X_{Ri}$$

N_{iy} = number of nests in 500m cell *i* in year in year *y* (*y* = 1988,..., 2006)
A_i = area (in hectares) of arable land on suitable soil type in cell *i*
X_{Hiu} = value of the housing variable for cell *i* in year *y*
X_{Ri} = value of the road/traffic variable for cell *i*
α_y = factor representing average nest density in year y

The two forms of model, M1 and M2, gave very similar estimates of the parameters β_H and β_R and similar results on the relative model accuracy of different choices of SD for the housing and selected road/traffic variables.

Initial results showed that the model fits (in both M1 and M2 form) were always considerably better, at all values of S, when the housing variable was used in its square root form (i.e. $\sqrt{X_H}$). When the housing variable was used in untransformed form, the best fit was obtained with a S of 750m for the housing variable and S of 1000m for the daily traffic variable and gave a maximum log likelihood ratio Chi-square (-2LogLR) value for model M2 of 953.7. However, simply by using the square root of the housing variable, the model fits, as measured by the -2LogLR statistic, increased for every model and S, reaching a maximum of 1098.0 when housing variable S was 1000m and the traffic variable S was 1000m.

The square root of the housing variable was therefore used in all further models and analyses. The relative strength of fits of models using different road/traffic variables and the optimum S are summarised in Table 11.

At all values of S, the presence of ‘nearby’ A-roads was less strongly related to nest density than the presence of ‘nearby’ Trunk roads (in all cases after allowing for the effect of housing). Models involving the amount of traffic on the trunk roads were slightly better than those based on just the presence of the Trunk roads, at all values of the S for the road/traffic variable and for all S for the housing variable (Table 11).

The weighted normal kernel S for the housing variable which, when combined with the daily traffic variable, gave the best relationship with nest density was always 1000m. However, the model fit (as measured by -2logLR) was almost as good for models with the next higher or lower tested values of the housing S. For example, with a S of 1000m for the daily traffic variable, model fits (-2logLR) for housing SD of 750m, 1000m and 1250m were 1079.1, 1098.0 and 1089.0 respectively.

The best two-variable predictive model therefore involved the housing variable with a kernel S of 1000m and the daily traffic variable with a kernel S of 1000m.

Preliminary analyses had shown a relative small but significant effect on nest density of the presence of non-trunk A-roads within 500m (Table 7). Therefore, we assessed whether the predictive model M2 could be improved by adding the variable representing local extent of non-trunk A-roads at each choice of kernel S in turn. A statistically significant partial effect (p<0.001) and overall model improvement (Chi-square (-2logLR) increased from 1098.0 to 1114.2) was obtained by adding the A-road variable with a S of 250m. Significant negative effects of A-roads were also obtained using a S of 500m (p=0.033), but not at any greater S value.

Table 11 Summary of GLM model M2 fits to nest density per year over the period 1988- 2006 in relation to the values of weighted normal variables for (square root of) average housing during the period and either presence of A-roads, presence of Trunk roads or average daily traffic; table shows optimum S for housing (top) and the maximum model fit likelihood ratio Chi-square (-2logLR, bottom) at each road/traffic variable S value. Overall optimal model highlighted in bold.

	SD for road/traffic variable							
	250	500	750	1000	1250	1500	1750	2000
A roads	1250 915.0	1250 904.9	1250 903.2	1250 910.0	1500 921.0	1500 933.4	1500 943.6	1500 948.3
Trunk roads	1250 1022.2	1000 1055.4	1000 1074.4	1000 1081.0	1000 1079.5	1000 1074.6	1000 1068.6	1000 1060.2
Daily traffic	1000 1029.5	1000 1068.4	1000 1090.0	**1000** **1098.0**	1000 1097.5	1000 1093.0	1000 1086.7	1000 1076.6

The best predictive model for stone curlew nest density on suitable arable land within each 500m cell therefore involves the weighted normal kernel variables for the housing (square root, $\sqrt{X_{H1000}}$) with S=1000m, daily traffic with S=1000m (X_{T1000}) and presence of A-roads with SD=250m (X_{AR250}). The estimates of this model’s parameters and their standard errors (given in brackets) are:

$$\log_e N_{iy} = \log_e A_i + \alpha_y - \underset{(0.00127)}{0.01002} \sqrt{X_{H1000i}} - \underset{(0.0000001089)}{0.0000008232}\, X_{T1000i} - \underset{(0.00589)}{0.01335}\, X_{AR250i}$$

where, for example, for the last study year (y=2006), α_y = -3.596.

The effect on model parameters, their standard errors and statistical significance, of potential lack of statistical independence of the nest observations in different years at the same 500m cells was assessed. Specifically, the optimum model was re-fitted using each of a range of assumed inter-year error correlation structures using the Generalised Estimating Equations (GEE) procedure in the SPSS statistics package, treating 500m cells as 'subjects' and years as a repeated measures (within-subject) factor. The fits of the assumed model error structures were compared using the quasi-likelihood information criteria (QIC, lower is better fit).

On assuming a first-order auto-regressive correlation structure between years, the average correlation between model residuals for nest density in successive years at the same 500m cell was only 0.23. Based on minimising QIC, the best fitting model was one assuming independent observations between years within each 500m cell. This is not particularly surprising given the high annual turnover and change in which 500m cells have any nests that was discussed near the start of the Results (see Figure 7).

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Predictions of the effects of growth in Thetford and traffic increases

The above best predictive model equation can be used to obtain predictions of relative nest densities on suitable arable land within each of the 2142 500m grid cells in the study region. This was done for the latest study year of 2006 using the current levels and spatial distribution of housing in 2006 in each 50m grid cell and hence using the values of the housing variable for 2006 based on a S value of 1000m. This described the "current" situation and predicted 193 stone curlew nests within the study area.

The predictions can then be re-run by adding in any proposed additional housing in the study area. The additional housing will increase the area of houses/buildings in some 50m grid cells, which will lead to increases in the housing variable values for some 500m cells, which will lead to decreases in the predicted stone curlew nest number and density in those 500m cells.

By summing the predicted number of nests on suitable arable land across all 500m cells in the study region based on both current and future housing levels, the proportional reduction in predicted total nests can be used to estimate the potential impact of the proposed increase in housing/buildings on stone curlew nesting numbers.

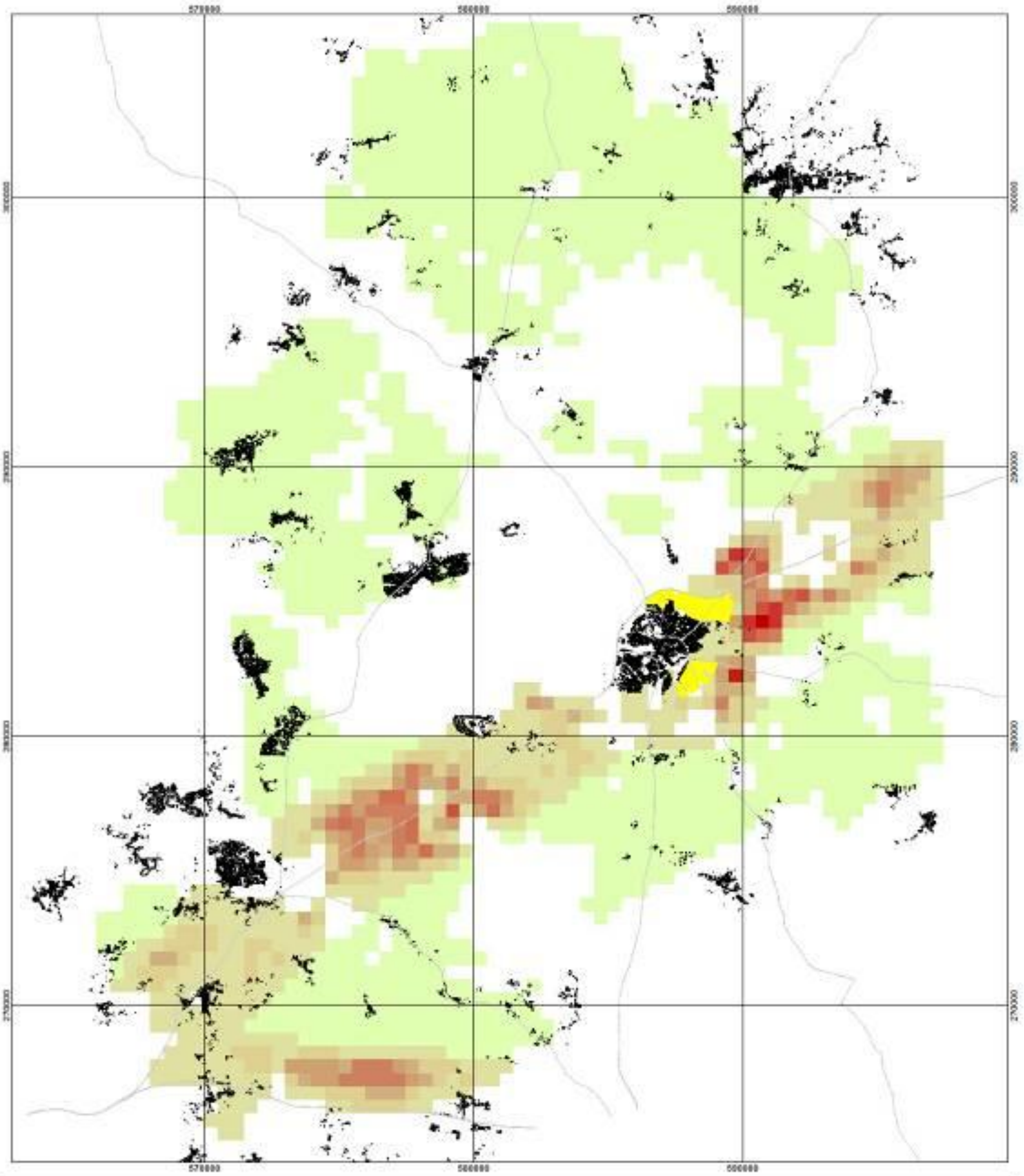
We derived six predictions, involving different housing and road traffic scenarios. We considered the effect of extensions to the north and south of Thetford and we also considered the effect of increasing traffic (by 35%). These predictions are summarised in Table 12. If both the north and south extensions were to go ahead, in combination with an increase in traffic of 35%, we would predict that there would be 5.6 fewer stone curlew nests, a reduction in the number of nests of 2.9%.

Stone curlews tend to be at very low densities across the study area. In order to take into account any spatial variation in density we also took the actual data for each cell, summarised as the mean number of stone curlew per 500m cell for the period 2002-2006. We then applied the predicted effect of housing and traffic (from the model equation above) to this actual data. Using this actual data we predict that the effect of the north and south extensions, in combination with an increase in traffic, would result in a reduction in the number of stone curlew nests of 3.2%.

Table 12: Predictions of the number (and % reduction) of stone curlew nests per annum within the study area under different housing and traffic scenarios

Traffic increase	*current*	*A Current and Thetford North Extension*	*B Current and Thetford South Extension*	*C Current and Thetford North and South Extensions*
Using model predictions				
a) none	193.1	192.3 (0.4)	192.7 (0.2)	192.0 (0.6)
b) high (35%)		187.8 (2.7)	188.0 (2.6)	187.5 (2.9)
Using actual data (mean no. stone curlew nests per square for period 02-06)				
c) none	150.4			148.6 (1.2)
d) high (35%)	150.4			145.6 (3.2)

These results for the scenarios in table 12 are mapped in Maps 6 to 9. Maps 6 and 7 illustrate scenarios aC and bC (in table 12), and Maps 8 and 9 illustrate scenarios cC and dC respectively.



Map 6: Decline in the predicted number of stone curlew nests - Housing and road traffic

The effect of housing development and roads on the distribution of stone curlew

footprint ECOLOGY

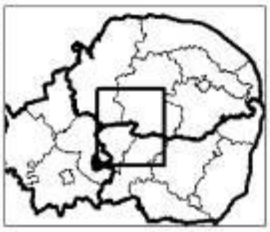
1 August 2008

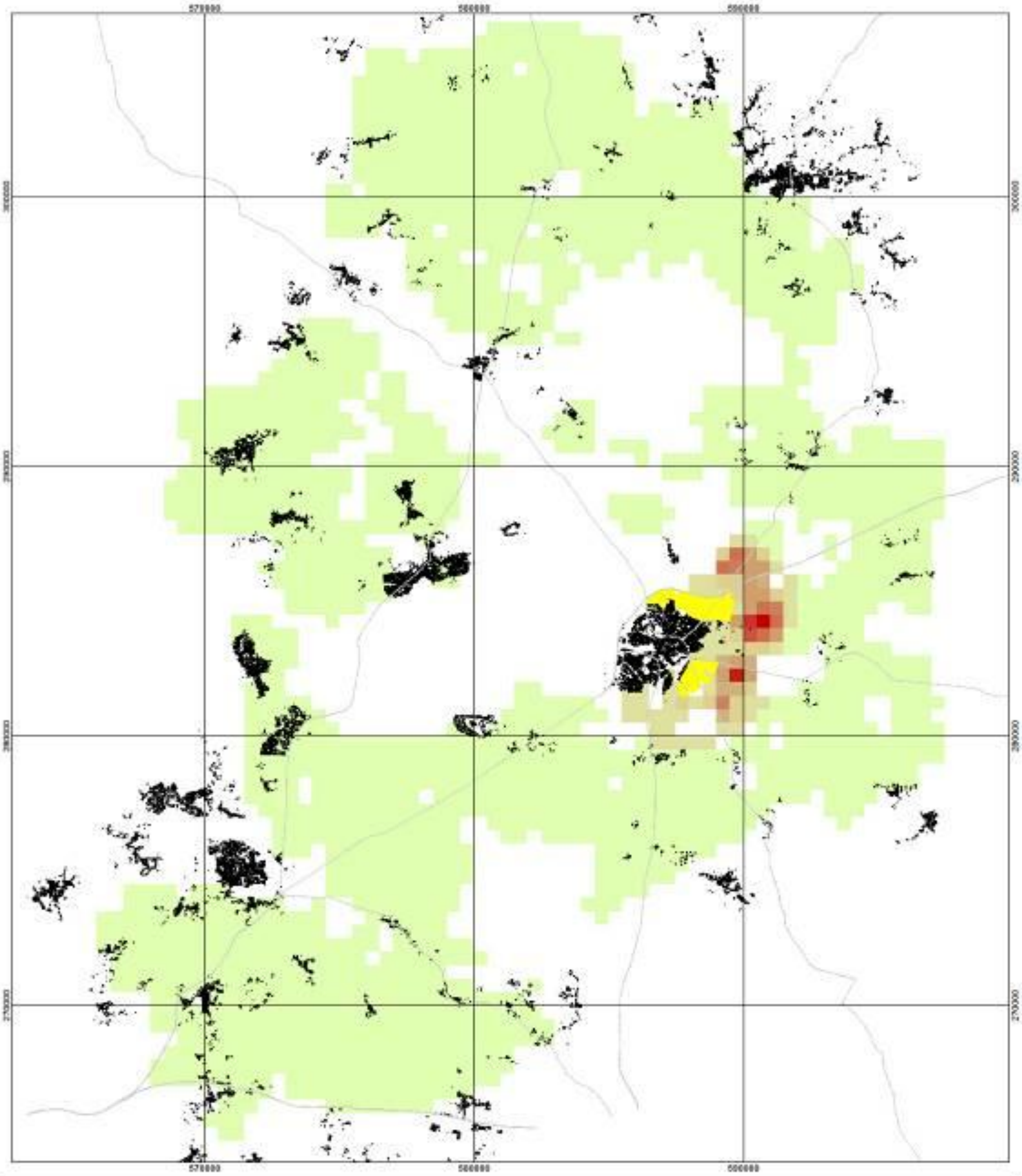
Scale 1:193347

Tested housing developments

Decline in the predicted number of stone curlew nests

0.0585 to 0.0648	0.0195 to 0.026
0.052 to 0.0585	0.013 to 0.0195
0.0455 to 0.052	0.0065 to 0.013
0.039 to 0.0455	0 to 0.0065
0.0325 to 0.039	0 to 0
0.026 to 0.0325	





Map 7: Decline in the predicted number of stone curlew nests - Housing only

The effect of housing development and roads on the distribution of stone curlew

footprint ECOLOGY

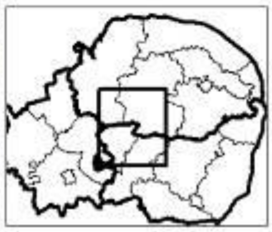
1 August 2008

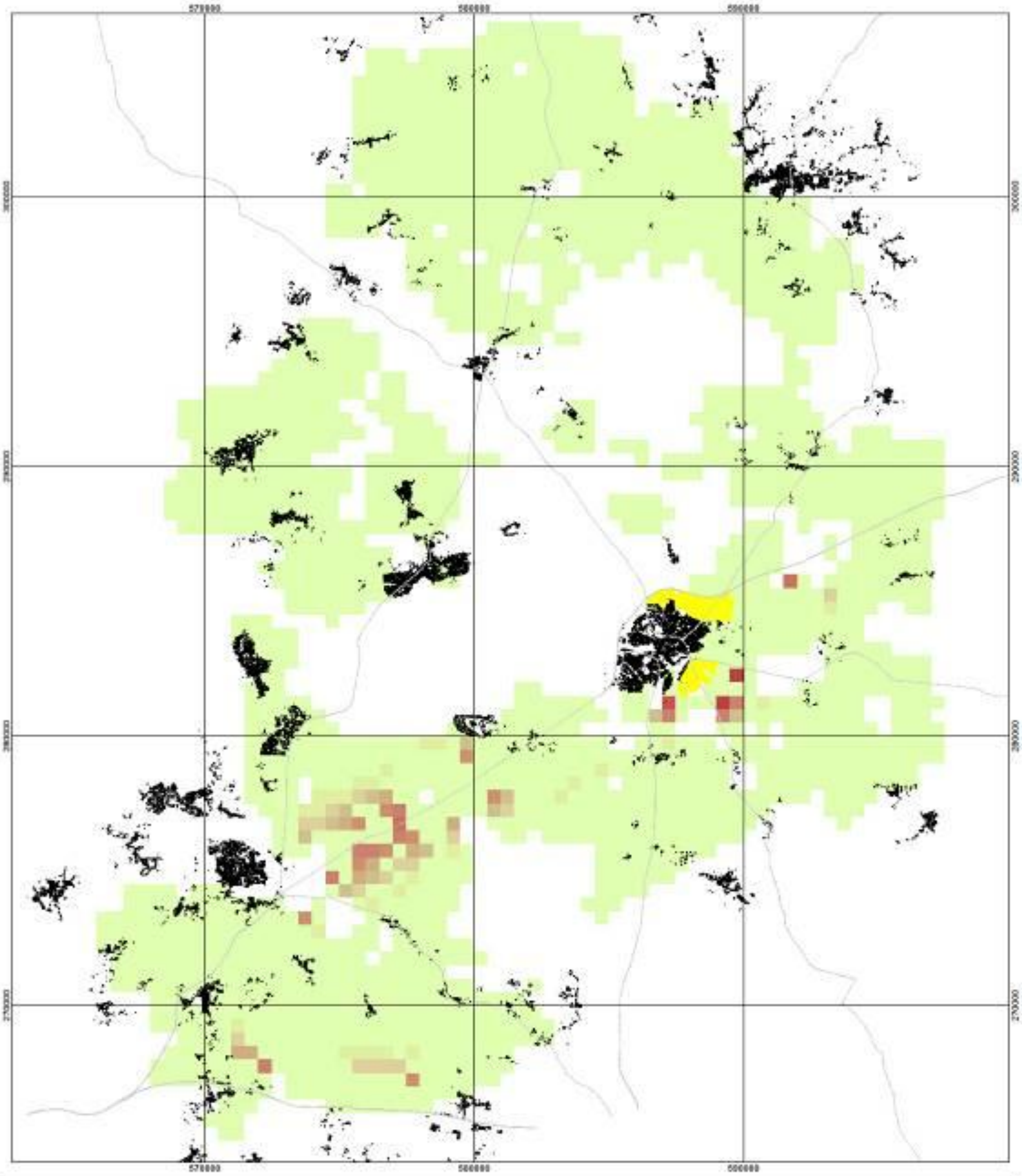
Scale 1:193347

Tested housing developments

Decline in the predicted number of stone curlew nests

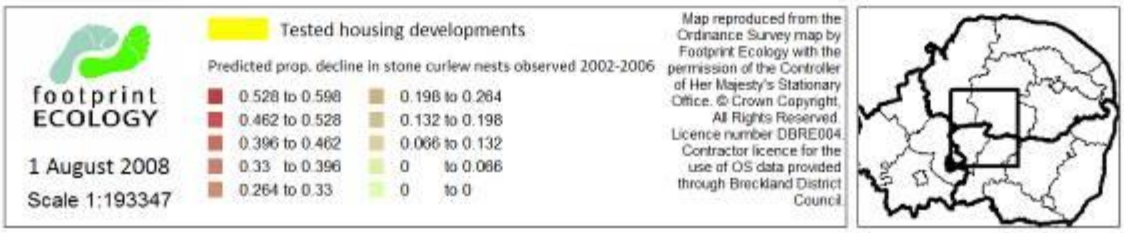
0.0585 to 0.0648	0.0195 to 0.026
0.052 to 0.0585	0.013 to 0.0195
0.0455 to 0.052	0.0065 to 0.013
0.039 to 0.0455	0 to 0.0065
0.0325 to 0.039	0 to 0
0.026 to 0.0325	

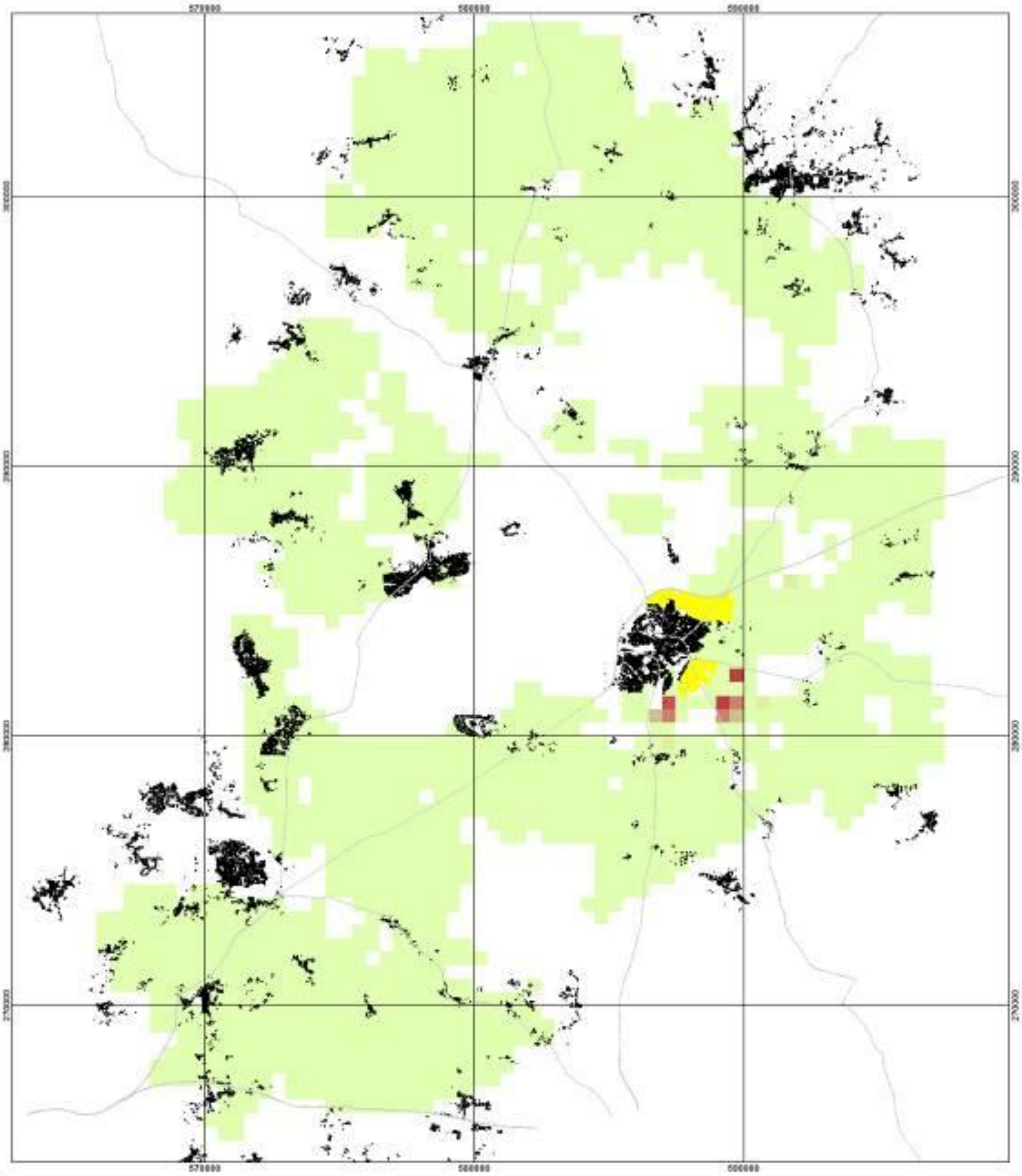




Map 8: Predicted proportional decline in stone curlew nests 2002-2006 - Housing and roads

The effect of housing development and roads on the distribution of stone curlew





Map 9: Predicted proportional decline in stone curlew nests 2002-2006 - Housing only

The effect of housing development and roads on the distribution of stone curlew

footprint ECOLOGY

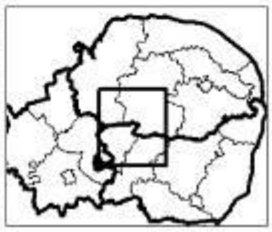
1 August 2008

Scale 1:193347

Tested housing developments

Predicted prop. decline in stone curlew nests observed 2002-2006

0.528 to 0.598	0.198 to 0.264
0.462 to 0.528	0.132 to 0.198
0.396 to 0.462	0.066 to 0.132
0.33 to 0.396	0 to 0.066
0.264 to 0.33	0 to 0



Consequences for Spatial Planning

The predictions show that there will be impacts on stone curlews from new housing and from increases in road traffic. The impact for stone curlew of the new housing extensions at Thetford and the traffic increases will spread over a considerable area of land, an area that includes Breckland SPA and also agricultural land suitable for nesting outside the SPA boundary. These results have implications for any Habitats Regulations Assessment of future development in Breckland.

Any avoidance of areas close to housing or roads may result in increased competition for territories or birds choosing not to breed as suitable habitat is unavailable. The extent to which housing or roads directly affects stone curlew population size remains unclear.

One complication in interpreting these results is that the stone curlew data we use for each year is the number of nests and we do not consider breeding success in relation to housing. We assume that the number of nests is a surrogate for the number of nesting stone curlews. 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 due to nest failure rates, with more nests expected where nest failure rates are higher. As a consequence it may be that if fewer nests are found in a given area (such as close to housing) this may be as a result of better nesting success rather than actual avoidance of housing.

In a study of woodlarks in Dorset (Mallord et al., 2006) found that the birds avoided establishing territories in areas with high levels of human disturbance, and therefore the density of territories in such areas was low. There was no negative effect on breeding success, in fact Mallord *et al.* found that breeding success was density-dependent: where territory density was low, breeding success was higher, and therefore where disturbance levels were high, woodlarks fledged more chicks. This effect partially compensated for the avoidance of suitable habitat due to human disturbance. This example highlights the importance of understanding variations in breeding success in order to fully understand the extent to which population size might be compromised.

Given the clear and highly significant lower density of nests close to both housing and roads we consider it unlikely that variation in breeding success may be an underlying factor. We suggest further work exploring breeding success in relation to housing would be useful, but in the absence of this understanding the work in this report would suggest a clear impact of new housing and roads, enough to trigger the precautionary principle and suggest that an adverse affect on the SPA is possible.

We use our model to predict the number of nests per year were the Thetofrd extensions to take place. The actual reduction in the number of nests per annum that the models predict are quite small. This is because we only make predictions for birds nesting on arable land, our scenarios only test extensions to Thetford (i.e. a limited part of a very large study area), and because stone curlews occur at very low densities on arable land.

Our focus has been on arable land because this habitat is likely to be more even in quality across the study area (and also across the period of study) and is likely to be less susceptible to a range of unmeasured factors (such as grazing levels) influencing habitat quality for nesting stone curlews. As Figure 12 shows, the pattern of avoidance of housing for this habitat is less clear. We could apply our model across all habitats, using the actual distribution of stone curlews and assuming the proportional decrease to be the same in all habitats. We have chosen not to take this approach as we believe caution is warranted. By focusing on arable land we hope we have in part controlled for variation in habitat quality and we have shown that there is an avoidance of both roads and housing. We see no reason why birds nesting in semi-natural habitats may not also show a similar avoidance, but it is not necessarily the case that the scale of avoidance is identical.

We have deliberately included all suitable arable land within our analyses, rather than limit ourselves to arable land within the SPA. The stone curlews are clearly highly mobile between years and birds nesting just outside the SPA in one year may well be nesting within the SPA in subsequent years. The Brecks represent a discrete part of the country and it is arguable that the stone curlew population here is discrete. The need to conserve and protect Annex I species is also not restricted to SPAs alone. The last sentence of Article 4(4) of the Birds Directive makes it clear that outside of SPAs, the Member States must: "…*strive to avoid pollution or deterioration of habitats* [of Annex I and migratory species protected under Article 4]."

In summary, the consequences of this work are:

- New housing development may need to be at least 1500m, and potentially 2000m from any arable land suitable for stone curlews for there to be no effect on stone curlew distribution
- There is a negative impact of trunk roads on stone curlew nest density on arable land up to a distance of at least 1000m, and maybe up to 2000m.
- There is a negative impact of the presence of non-trunk A-roads on stone curlew nest density on arable land up to a distance of 500m.
- There is no reason to suggest that similar avoidance of roads and housing does not occur on semi-natural habitats, but we err from highlighting specific distances.

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