Mapping and assessing pink-footed goose *Anser brachyrhynchus* usage of land beyond SPA boundaries in northwest England

A collaborative project between Natural England and Manchester Metropolitan University

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Final report

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1 Executive summary

- Introduction and objectives

The northwest of England, including Lancashire and Cumbria, represent internationally important areas for wintering pink-footed geese, providing habitat annually to at least 15% of the Iceland-Greenland biogeographic population. Geese begin arriving in the northwest in October and may move between Norfolk and other areas during the winter. During spring migration, the northwest may also represent a staging post, *en route* to reach Iceland by April. Population numbers of pink-footed geese have significantly increased in the UK in the last 30 years, with dramatic increased from 1985 onwards, representing population changes from under 100,000 geese to more than 350,000.

In Britain, pink-footed geese mainly feed on farmland, with diet changing as winter progresses, following an approximate of sequence of cereal grains from stubble fields in early autumn, roots and tubers in late autumn and finally moving on to grass shoots and growing cereal shoots before the return migration. Threats to pink-footed geese are mainly from legal and illegal hunting, disturbance from farmers, land management change and habitat loss. Pink-footed geese are among the bird species used to designate Special Protection Areas (SPAs) in the UK. Three such areas have been designated for pink-footed geese, among other species, in the northwest of England (Figure s1).

This project focuses on pink-footed geese *Anser brachyrhynchus* and the land used by this species across the borough of Fylde (to the east of Blackpool and north of Preston in Lancashire; Figure s1), most of which is outside the boundary of designated SPAs. A greater understanding of the extent of usage across this Local Planning Authority boundary will help to identify where data gaps exist or other reasons, such as a landscape feature, that may render certain areas unlikely to support significant numbers of birds. The project aims to support planning developments in a more structured and environmentally sensitive manner, specifically, the project aims to:

- assess existing availability and spatial scale of data on pink-footed goose in Fylde;
- provide initial GIS mapping and spatial analyses of available pink-footed goose distribution data;
- assess the extent of 'functionally linked land', that is, land used by this species beyond the designated sites;
- assess at a more detailed scale, field by field, the usage by this species with specific consideration of:
    - Areas known to be used by SSSI/SPA bird populations
    - Areas of suitable habitat currently not used but potentially suitable
    - Areas which are unlikely to be used/are unsuitable for use.

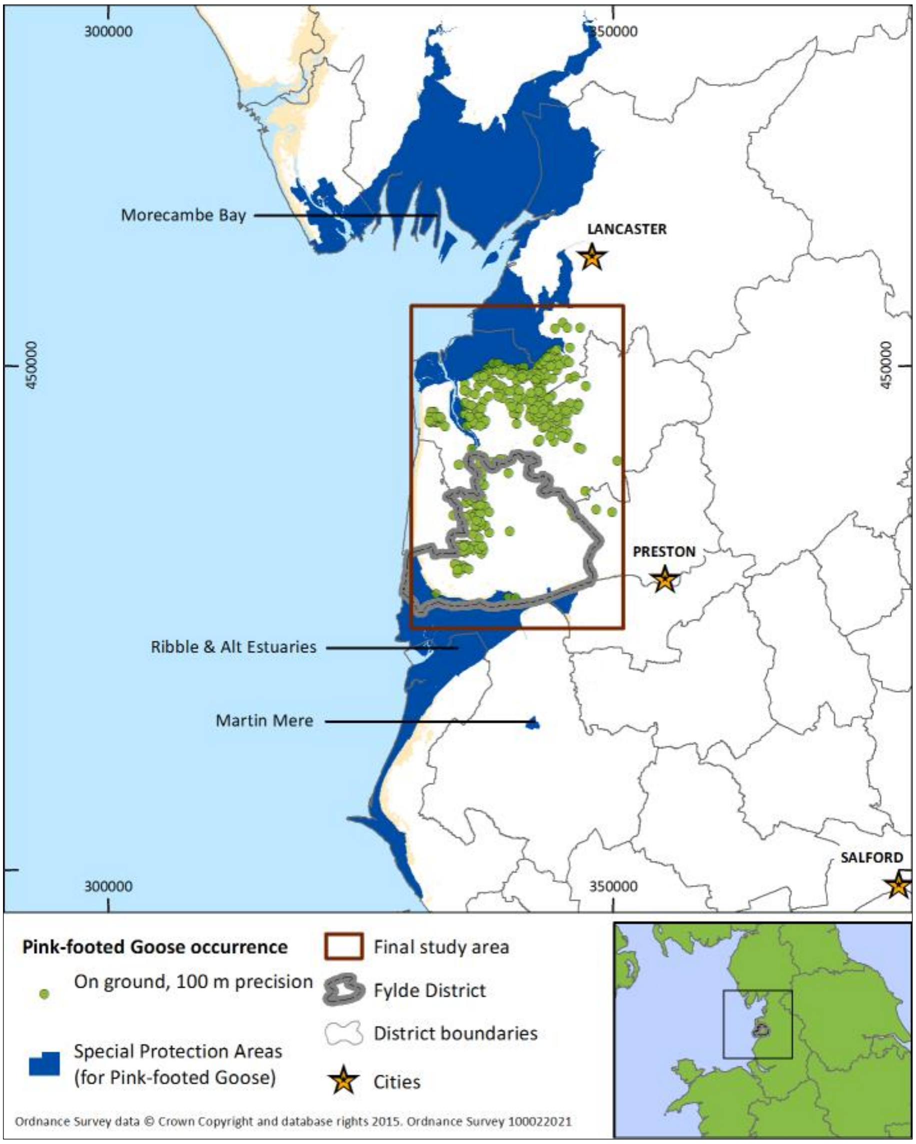

Figure s1. Location of SPAs and final set of pink-footed goose records within Fylde District.

- *Methods*

Two different statistical models were constructed (generalised linear model, generalised additive model) with recent pink-footed geese occurrence records and environmental variables thought to affect the species' habitat use. The models attempt to predict geese occurrence across Fylde based on current habitat use and results in a suitability value (probability of occurrence). A two stage modelling process was employed, with a second step to control for spatial autocorrelation. Spatial autocorrelation can be present when goose records occur in clumps, or when nearby values of environmental variables are more similar than those further apart.

Initially, occurrence records were obtained from Fylde Bird Club, Lancashire and Cheshire Fauna Society, BirdTrack and eBird and individuals. Unsuitable records were excluded, for example, where geese were recorded as in flight, where no count information was available or where group size < 10, where records were recorded with a precision > 100 m, or with dates prior to 2000. Only one record was used from each unique location.

Environmental variables with which to predict geese presence were chosen after a literature review of factors affecting habitat choice in pink-footed geese. Those initially included for consideration were: field size, visibility (based on size of open habitats known to be used by geese), distance from roosting sites, distance to coast, proportion of arable/grassland area, agricultural area within surrounding 25 ha, land cover category, slope, elevation, vegetation index (from satellite images), distance to major/minor roads/tracks, distance to landscape structures. These predictors were mapped at a resolution of 100 m (that is, values for each predictor are assigned to 100 x 100 m cells on a grid covering the study area). To assess the current accuracy of available habitat maps (CEH Land cover, 2007), current fields types (pasture, crops, etc.) were surveyed and compared to field types appearing on the habitat map. A final set of variables was chosen by excluding strongly correlated variables and favouring those with highest ecological value.

The resulting habitat suitability map was compared to an expert assessment of mapped areas of importance for pink-footed geese in Fylde between 1977 and 2009 provided by Derek Forshaw and members of Fylde Bird Club. The model was also compared to priority areas identified through a national project to map the distribution of feeding pink-footed geese in England.

Field visits were organized to assess the feasibility of incorporating information on crops over a similar temporal period to that of the occurrence records as well as interviewing farmers on their experience with pink-footed geese on their land. The visits also provided an opportunity to obtain additional occurrence records and implement the field survey (see above). Field visits were coordinated through Natural England, targeting farmers subscribing to the Environmental Stewardship Scheme. A questionnaire was administered personally to each farmer relating to crop rotation, occurrence of pink-footed geese on their land, damage caused by geese, avoidance mechanisms and hunting. Additionally, a map of the farm, created as part of the project, was used to mark fields with specific crops over a 5-year period.

A meeting was also set up with Fylde Bird Club committee to review pink-footed geese occurrence data received from them. Other issues raised by members of the bird club and discussed included:

- Existing Pink-footed goose counts in the region
- Creation of reserves in the Fylde area
- Disturbance factors for pink-footed geese, especially hunting and land use change through development (e.g., housing)
- Improving farmland management practices for farmland birds
- Presentation of project results at a club meeting

- Findings
Of a total 6289 records in the final data set, 321 remained after those without six figure grid references (representing a spatial precision of 100 m), exact spatial duplicates, and observations within 200 m of each other were removed. These locations represent the areas currently known to be used by Pink-Footed Geese in Fylde (Figure s1).
The final variables used in the model were proportion of agricultural area within surrounding 25 ha, elevation, distance to roost sites, and visibility index. Low accuracy between current field types and arable types in the habitat map (representing a conversion from arable to pasture between 2007 and the present) meant that arable and pasture types were combined into a single agricultural category. Although this prevents distinguishing between two important habitat types for pink-footed geese, information on land cover was maintained in the model using the proportion of agricultural area within the wider habitat matrix (that is, the surrounding 25 ha). Although remotely sensed data on vegetation was not included in this model, exploratory analyses showed that it could be used to distinguish field types, and would be worth exploring if pink-footed geese records over time were to be incorporated.

The field trips resulted in nine sightings of pink-footed geese (average flock size c.850) over four days, with an effort of approximately 100 km in 16 hours of observation (by car). Sightings were concentrated in east Fylde, coinciding with supplied occurrence records. Approximately 65% of non-urban 1 km squares within Fylde district were covered during the field trips. Four farmers were interviewed, showing a high degree of agreement among responses. All farmers knew and could recognise the pink-footed geese and also recognised the importance of the area for the geese. Importantly, the farmers concurred that geese did not represent a major factor in damaging crops and also were aware of temporal patterns in the geese's use of different field types. Farmers did not use bird scarers, but occasionally shot at geese to drive them off land. Hunting organized by farmers tends to be for game shooting (pheasant, partridge).

The final model parameters indicate that, in order of importance, pink-footed geese are more likely to be found at sites closer to roosting sites, where agricultural land represents a higher proportion of the surrounding habitat, in areas with lower elevations and with increasing visibility across the immediate habitat. The final model was divided into three regions, indicative of priority areas for pink-footed geese. The medium or 'no omission' category has the strongest precautionary approach and represents the minimum area that includes all the locations of known presence used in the model. The high or '5% omission' category corresponds to a threshold excluding 5% of the presence points (17 occurrence points) in the model[1]. Both higher regions coincide with the national 1 km grid of priority feeding sites (based on spatial occurrence and frequency of occurrence alone) and the expert assessment (Figure s2). Both medium and high priority areas represent suitable habitat for the species whereas low priority areas can be interpreted as having lower suitability or representing areas unlikely to be used. The model shows that areas used by the geese in 1970s are still used today. However, there are regions, especially those marked as areas of recent expansion for the geese that the model does not highlight within the high priority rating. These regions also correspond to areas with a lack of accurate occurrence data.

The model has shown important factors in habitat selection at field level, with similar results found in northern Europe; however, the model lacks information on movements or temporal habitat use patterns over the winter. Predictors incorporating threats (e.g., hunting, land use conversion, and disturbance) should also be explored. A collaborative approach to implement future work is feasible with the collaboration of Fylde Bird Club, and could provide a model of local cooperation to inform local decisions and improve data quality from local recorders.

[1] The model output provides a relative probability of occurrence (i.e. a value between 0 and 1, where 0 represents the lowest and 1 represents the highest habitat suitability for the species) for each 100 m grid cell within the study area. To convert this output to three priority regions, a threshold must be used to define each area, above which, model values are considered to belong to the corresponding region. The medium threshold represents the minimum model value at any known point of occurrence. Therefore, all the area within the medium region will include all known presence points. However, given that some presence points may represent records from areas where geese are observed very infrequently (a type of 'vagrant' record), and that inaccuracies likely still exist in the data, using a threshold that excludes the lowest 5% of model values at known occurrence points, aims to reduce the effect of such points on the model, and provides a mapped region of higher suitability.

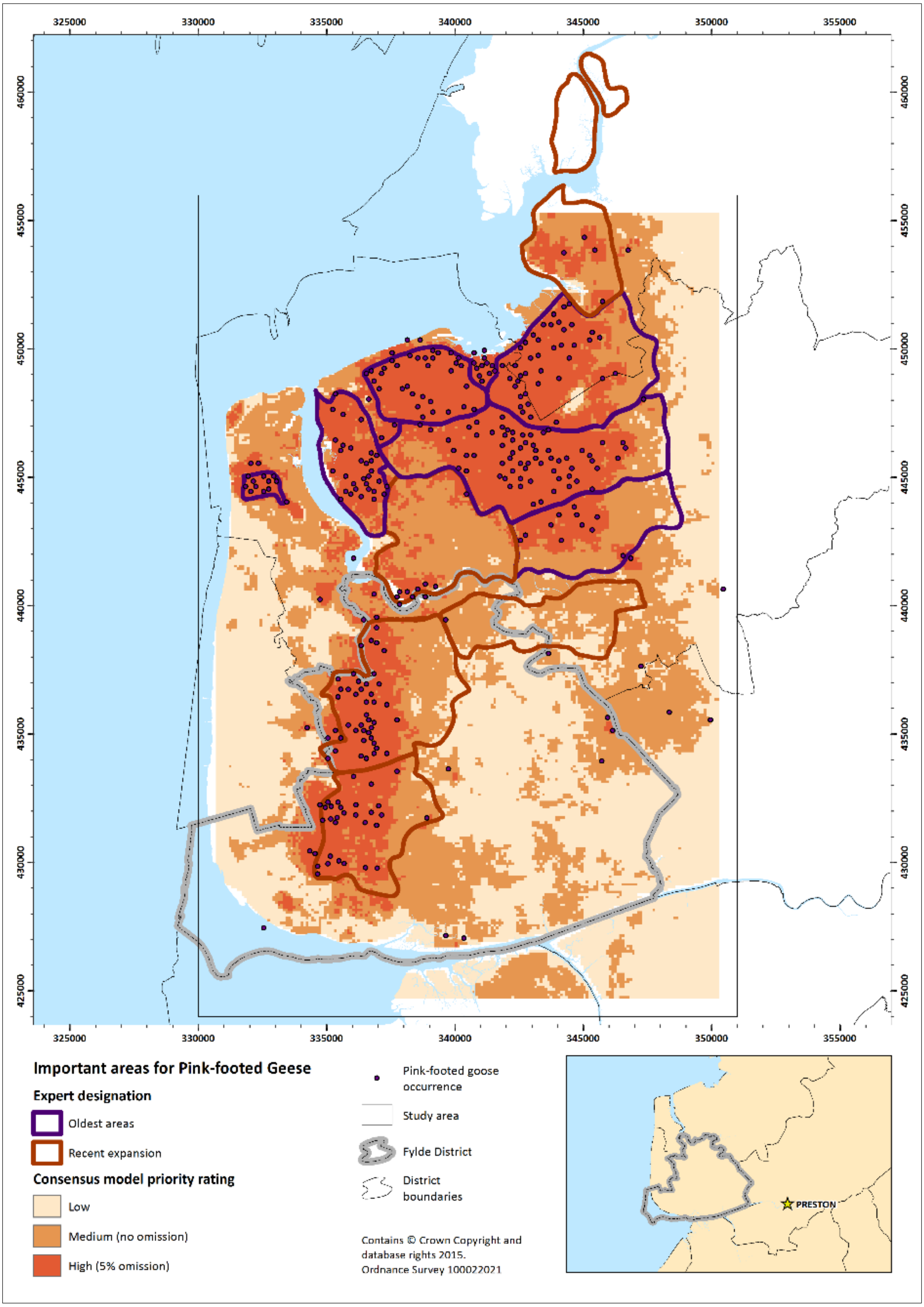

Figure s2. Expert-designated areas of importance for pink-footed geese compared to the model prediction.

2 Introduction

2.1 Distribution and habitat use of pink-footed geese in the northwest of England

The northwest of England, including Lancashire and Cumbria, represent internationally important areas for wintering pink-footed geese. Pink-footed geese have two distinct breeding populations with separate migration flyways. Those overwintering in Britain, including Lancashire, belong to the Iceland and Greenland breeding population, with at least 15% of this biogeographic population wintering in the northwest (Mitchell, 2015). Geese begin arriving in the United Kingdom around October, with some arriving directly to the northwest of England (Brides et al., 2013), and others moving south from an initial staging post in Scotland (Mitchell et al., 2004). Pink-footed geese in the northwest do not remain in this area for the whole season, part of the Lancashire population move between Lancashire and Norfolk during mid winter (Fox et al., 1994). During the spring migration, geese may pass northwards through Fylde, en route to reach Grampia and the Moray Firth, Scotland by mid March (Fox et al., 1994), to reach Iceland by April. Population numbers of pink-footed geese have significantly increased in the UK in the last 30 years, with dramatic increased from 1985 onwards, representing population changes from under 100,000 geese to more than 350,000 (Mitchell, 2015).

Pink-footed geese often roost on coastal flats, sandbanks, undisturbed water and sometimes heather moor (Cramp, 1977), with roosting sites around Fylde identified as the inter-tidal areas of the Ribble Estuary, the mouth of the river Alt, and Pilling sands at the mouth of the river Lune and Martin Mere (Forshaw, 1983). Roosting sites at inland, or dry sites, have also been identified at several fields in Lancashire, with important sites being Downholland Moss and Altcar Withins (Forshaw, 1983). When feeding, geese mainly remain within 5-10 of roosting sites, although they have been known to travel up to 30 km to feed (Mitchell et al., 2004). Field roosts in Lancashire may be used to reduce energy expenditure between feeding and roosting sites (Forshaw, 1983). A high site fidelity has been reported for pink-footed geese, both at feeding, roosting and breeding sites, with some seemingly suitable areas for feeding or breeding remaining unused for unknown reasons (Cramp, 1977; Forshaw, 1983; Fox et al., 1994).

In Britain, pink-footed geese mainly feed on farmland, with diet changing as winter progresses. A general pattern follows the following sequence, but is subject to variation and local differences: cereal grains from stubble fields (in possible conflict with shooting estates) in early autumn, roots and tubers (e.g. potatoes, carrots) in late autumn and grass shoots and growing cereal shoots in spring (Cramp, 1977). However, geese may be seen on pasture and cereal throughout the winter. In southwest Lancashire, Forshaw (1983) found that potato consumption was greatest in November and December, with root crops in general reaching maximum importance in January, and pasture increasing in importance from December to April. Geese disperse from the larger roosting groups into smaller feeding groups, often walking across a field slowly, while grazing (Cramp, 1977). Groups vary in size, from the low hundreds to several thousand for feeding and tens of thousands for roosting.

Threats to pink-footed geese are mainly from legal and illegal hunting, disturbance from farmers, land management change and habitat loss (BirdLife International, 2016). The increase in the species' use of agricultural land for feeding since the 1960s may be due to a reduction in natural habitats (Mitchell et al., 2004), although crops and pasture may represent more efficient energy sources for the species. It is unclear whether the species is a major factor in damaging crops with studies showing both limited damage and loss of yield due to geese (Mitchell et al., 2004). Pink-footed geese are hunted throughout their range but data for hunt bags in Britain are not known with accuracy. Frederiksen (2002) estimated an annual hunt bag of 25,000 and suggested that the activity is likely to exert a strong impact on the population dynamics of the species. In terms of conservation, pink-footed geese are among the bird species used to designate Special Protection Areas (SPAs) in the UK. Three such areas have been designated for pink-footed geese, among other species, in the northwest of England (see Table 1).

2.2 Methods for assessing habitat suitability

Predictive modelling is an increasingly important analytical tool with which ecologists are able to assess the influence of environmental variables, including habitat, on bird presence or abundance. Such models, applied to species distributions, typically extrapolate species occurrence data in time or space. A variety of methodological approaches exist, broadly grouped into statistical and machine learning techniques (Franklin, 2009). In the first group, methods include regression models (e.g. Generalized Linear Models, Generalised Linear Mixed Models, and Generalized Additive Models) and multivariate adaptive regression splines. The second group includes techniques such as decision trees (e.g., regression trees, random forests), artificial neural networks and maximum entropy (e.g. MaxEnt Phillips et al., 2006). Given the multiple techniques, one recent innovation has been to adopt an ensemble approach, employing a suite of commonly utilized SDM techniques to create a consensus model, that is, an averaged model from multiple methods, often weighted by an accuracy metric from each individual model. Regression models and MaxEnt remain among the most common techniques currently used (Franklin, 2009). MaxEnt has been increasingly used to model species distributions across disturbed landscapes to assess the impacts of habitat loss, fragmentation and degradation (Lu et al., 2012). Both MaxEnt and regression methods are capable of dealing with both continuous and categorical environmental variables simultaneously (Phillips et al., 2006). Recently, statistical techniques have been shown to produce very similar results to MaxEnt (Renner & Warton, 2013), and given their long-established use within ecology (Zuur et al., 2007; Hastie, 2009), much literature and multiple software packages (for example, within the R programming environment) permit the user a high degree of control and evaluation of the modelling process. Furthermore, these techniques have been used recently with encouraging results to model habitat suitability and effects of climate change on pink-footed goose (Wisz et al., 2008).

2.3 Objectives

This project focuses on pink-footed geese *Anser brachyrhynchus* and the land used by this species across the borough of Fylde, most of which is outside the boundary of designated SPAs. A greater understanding of the extent of usage across this Local Planning Authority boundary will help to identify where data gaps exist and whether they are attributed to lack of survey effort, or other reasons such as a landscape feature that may render certain areas unlikely to support significant numbers of birds.

This project will provide a more robust knowledge base that will enable Natural England and partners to support and plan developments in a more structured and environmentally sensitive manner, and provide a wider understanding to all stakeholders around the land usage by this species. Specifically, the project aims to

- review appropriate methodology for mapping bird species and their habitat associations and data requirements;
- assess existing availability and spatial scale of data on pink-footed goose in Fylde;
- provide initial GIS mapping and spatial analyses of available pink-footed goose distribution data;
- assess the extent of ‘functionally linked land’, that is, land used by this species beyond the designated sites;

- assess at a more detailed scale, field by field, the usage by this species with specific consideration of:
  - Areas known to be used by SSSI/SPA bird populations
  - Areas of suitable habitat currently not used but potentially suitable
  - Areas which are unlikely to be used/are unsuitable for use.

3 Methods

3.1 Study area

The areas of interest is the district borough of Fylde, situated to the east of Blackpool and north of Preston in Lancashire. Initially, given the paucity of records from the district itself, a wider study area was defined within the area used by pink-footed geese in the northwest, as determined by occurrence records. The initial idea was to train a model on a wider area, and then predict habitat suitability within Fylde. However, two factors changed this course of action, first, insufficient high quality records were obtained for the wider area, and, more importantly, after direct contact with Fylde Bird Club, a second batch of data was provided for Fylde district and north towards the Lune estuary. Subsequently, the study area was defined around Fylde and consists of the rectangle from lower left corner (330000, 424000) to upper right corner (351000, 456000) in projected coordinates of the British National Grid (Figure 3.1). Pink-footed goose is a qualifying species at three Special Protection Areas (SPA) near the study area, Morecambe Bay, Ribble and Alt Estuaries, and Martin Mere (Table 3.1, Figure 3.1), with internationally important numbers present in the region.

Table 3.1. SPAs within the wider study area with pink-footed goose as a qualifying species

SPA name	Percentage of wintering Eastern Greenland/Iceland/ UK population at designation[2]	Current 5 year maximum[2] (2009/10 – 2013/14)	Current 5 year average (2009/10 – 2013/14)[3]
Morecambe Bay	1.1%	36,382	19,174
Ribble & Alt Estuaries	10.6%	24,554	19,174
Martin Mere	11.5%	29,400	17,338

3.2 Occurrence records

Occurrence records were initially obtained from Fylde Bird Club, Lancashire, and Cheshire Fauna Society, two online bird occurrence record databases: BirdTrack (British Trust for Ornithology) and eBird (Cornell Laboratory for Ornithology). Records were checked, combined into a standardised spreadsheet with additional fields for coordinates of record centroid, spatial precision and activity status added. If spatial precision of records was not reported, it was inferred from the format of the records' coordinates (for instance, a record reported at tetrad level has a spatial precision of 2 km). Records from eBird were omitted given that only 136 records were from the northwest, they did not represent additional localities, they often represented historical sightings, and it was difficult to assign them an exact location and precision.

- Activity status

Records were grouped into five categories according to the activity reported or inferred from comments:

- Flight: birds recorded in flight, or comments to the effect of "birds flew NE", "skein of 400"
- Ground: either feeding birds, or reported as in fields.
- Roost: observed at roost
- Unknown: no information recorded about bird activity, or unclear from comments to which of the above categories the record belongs.
- Accidental: refers to birds reported as feral or injured, generally as single records or in very small numbers (< 10).

[2] http://jncc.defra.gov.uk/ (page-1982, page-1984, page-1985)
[3] WeBS http://app.bto.org/webs-reporting/. Affected by undercounts in 2010 and 2011.

- Exclusion of records

The following records were excluded (categories below are non-exclusive, that is, some records may be excluded for more than one reason). In order to maximise information on activity status among remaining records, where possible, records of unknown activity status were eliminated first.

- *Activity stated as Roosting, Flight, or Accidental (n = 517).*
  The study aims to predict suitable habitat within Fylde. This habitat will mainly correspond to feeding areas, given that the geese mainly feed inland and roost at coastal sites (REF). The main roosting site for pink-footed geese observed in Fylde corresponds to the Lune estuary (Forshaw, 1983). Most data sets were provided without records of birds in flight.

- *Activity unknown (n = 8730)*
  Given the lack of high resolution records, an attempt was made to include records with unknown activity. Unknown records were compared to feeding records in terms of spatial distribution and distribution of counts. A permutation test was used to compare spatial distribution. An average nearest neighbour distance between the unknown and feeding data sets was compared to the distribution of the same statistic for 999 random reassignments of the data set label (feeding or unknown). If the data sets have similar distribution, then the average nearest neighbour distance between the original datasets is expected to fall between the 5% and 95% percentile of the randomised distribution (with a significance level of 0.05). A Generalised Linear Model (GLM) was used to compare the distribution of counts between the feeding and unknown activity data sets. Count data was regressed against activity status (feeding or unknown) using a Poisson family GLM. If count distribution is similar in both data sets, then the coefficient of the feeding group should not be statistically different to the coefficient of the unknown group. Neither test showed that the unknown records were similarly distributed to the feeding records (permutation test: reference distance = 15209, $p < 0.001$; GLM: coefficient of unknown records = 0.39, $z = 151$, $p < 0.001$) and records with unknown status were discarded.

- *No count information (n = 2930)*

- *Counts ≤ 10 (n = 52)*
  Pink-footed geese usually feed in flocks of at least several hundred (Cramp, 1977), the median flock size for feeding records from the current data set was 330. Small counts may not be typical of geese behaviour, for example, many of the single observations were described as feral or injured were comments were available.

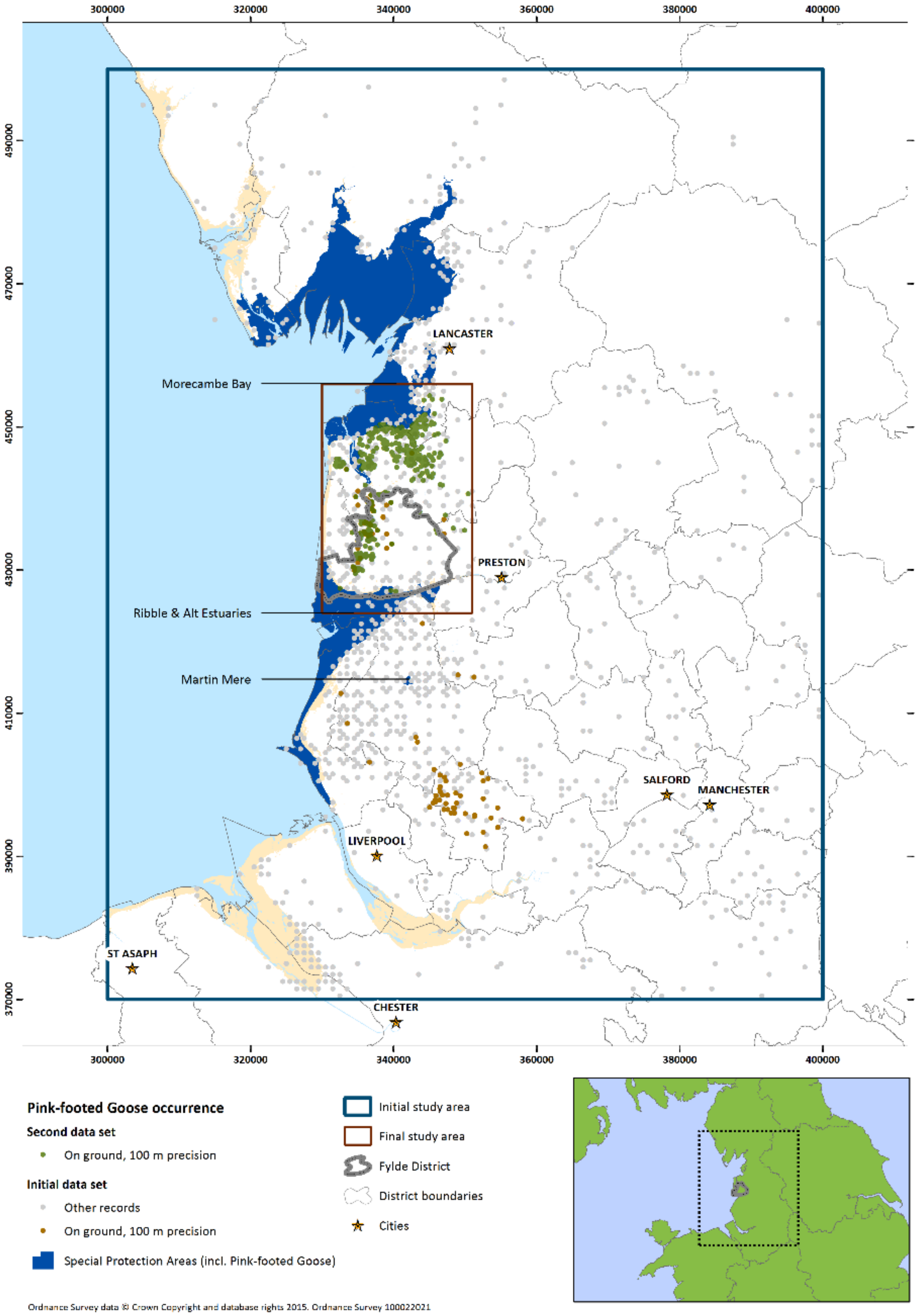

Figure 3.1 Location of SPAs and all pink-footed goose records received within Fylde District and wider study area.

- *Precision > 100 m (n = 9904)*
  Ideally, the model will only use records at a spatial precision of 100 m or less, to coincide with the resolution of the desired output. However, further methods might be possible to include records of precision between 100 and 2000 m.

- *Dated prior to 2000 (n = 6912)*
  Most records were post-2000, ideally, land-use data and records should coincide temporarily, but land-use data per year is not readily available (but see recommendations).

Spatial duplicates (n = 10,054)
The overwhelming majority of records represent spatial duplicates, often at different times (years or months). Temporal variation in habitat association of pink-footed geese was not part of this study, and therefore only single presence records were required per location. Furthermore, the unsystematic nature of the data collection would make using counts or frequency of records as a response variable difficult. Spatial duplicates do not necessarily correspond to areas with more abundance of geese, but may represent areas most visited by birdwatchers, for example, Martin Mere. Spatial filtering of data, by removing observations within a certain distance of each other, has been shown to improve model performance by counteracting the inflation of validation metrics such as AUC as a result of spatial autocorrelation of presence points (Boria et al., 2014; Radosavljevic & Anderson, 2014).

- Second data set
The above screening process left a small number of suitable records for a habitat model at field scale. A total of 10,687 records were supplied within the wider initial study area (Figure 3.1), however, for 82% of these records the activity of the geese at the time of observation (for example, feeding, in flight) was unrecorded. Of the remaining activities, 13% were recorded as on the ground or feeding (Table 3.2).

Table 3.2. Bird activity status by record origin

Source	Accidental	Flight	Ground	Roost	Unknown
BirdTrack	18	2	111	5	7745
Fylde Bird Club	11	293	138	0	984
Lancashire & Cheshire Fauna Society	0	66	1191	122	1
TOTAL	29	361	1440	127	8730

Only 7% of records were recorded at 100 m precision, adequate for habitat suitability models at field-level resolution. The majority of the remaining records were at 1000 m (67%) or 2000 m (15%) precision. Of these, 15 corresponded to records of less than five geese, which were eliminated to avoid using records from sick or feral geese. The remaining records spanned a period from 1989-2016, with the great majority of records from post 2000. Of the 326 ‘ground’ records at a precision of 100 m, 238 represent exact or near locality duplicates (that is, recorded at exactly the same site or within 100 m as another record) or records from before 2000, leaving just 88 unique locations. These locations are clustered around two areas, Fylde and St. Helens districts.

This situation led the project team to contact Fylde Bird Club directly and request corroboration of activity status of geese where this was unknown. However, after a meeting, a second batch of occurrence records was provided by the club, filtered by the club for feeding, in flight and spurious records. These records were subject to the same protocol as above, but without assigning activity status. These data make up the core data set for the habitat model. Additional records, complementing the second batch were obtained from field visits from this project (9 records); from Derek Forshaw (12 records); and a consultancy document on the Queensway development. The latter records were digitised from a high resolution map showing surveys during the 2014/15 period (TEP, 2015). All data are provided in

Appendix 6.

3.3 Predictors of habitat use

Predictors were chosen following a literature review of factors affecting habitat choice in pink-footed geese (Table 3.3) and according to data availability. A study to model future land-use effects on this species (Wisz et al., 2008) used five predictors: foraging categories –cropland, grassland (including salt marsh), non-foraging areas (including forest, urban areas, bare ground, among others); degree of habitat closure (distance from centre of field to nearest obstacles blocking view); distance from coast (proxy for roost sites); elevation; and spatial autocovariate. Other factors influencing choice of feeding habitat include proximity to sources of disturbance, e.g., roads, paths, structures (Forshaw, 1983; Gill, Sutherland, et al., 1996; Larsen & Madsen, 2000); hunting (Forshaw, 1983); type of crop, e.g., root crops, winter cereals (Forshaw, 1983; Gill, Watkinson, et al., 1996; Gill et al., 1997); condition of grassland (Vickery & Gill, 1999); site fidelity (Fox et al., 1994); month of the year; and climatic conditions (e.g., temperature), for example, a move from grassland to winter cereal as temperatures drop (Therkildsen & Madsen, 2000).

Table 3.3. Predictors considered for analysis within habitat suitability model. Those created as raster layers and trialled in models are noted with an asterisk (*)

Name (units)	Ecological relevance	Source	Method / Comments	License
Field size (m^2)	Factors such as line of sight, depend on field size, e.g., only fields of certain size will provide sufficient line of sight for geese to be able to see predators. Geese prefer a minimum field size of 6 ha and 500 m from trees (Kirby et al., 2000)	OS Master Map	Area of following polygons obtained by selecting - desgroup: 'General Surface'; make: 'Natural'; theme: 'Land'	OS PMSA License
		CEH Land cover 2007	Area of natural habitats	CEH License
Visibility index*	Safe feeding sites require visibility. Lidar data would include hedgerows, groups of trees, buildings etc., around fields. However, probably correlated to size of field.	CEH land cover 2007*	Habitat area as a proxy. See methods	CEH License
		Lidar Digital Surface Model (DSM) 2 m resolution	Average distance to nearest barrier in four directions. Alternatively, a coefficient of variation of surface model. However, Lidar coverage is incomplete	Open Government License
Distance from roosting sites (m)*	Pink-footed geese are known to feed at distances of 10 - 40 km from roosting sites (Mitchell et al., 2004; Wisz et al., 2008)	Roosting records from this study - Fylde Bird Club, Lancashire & Cheshire Fauna Society, and BTO BirdTrack.	Euclidean (straight line) distance calculated from principal roost sites. As provided by Fylde Bird Club (expert opinion)	FBC license.
Distance to coast (m)*	Pink-footed geese are known to roost in coastal areas (see above). However, they also roost in fields (Wisz et al., 2008) if conditions are suitable (e.g., moonlit nights, reduced presence of predators).	OS vector map (strategi)	Proxy for roosting sites. Calculated as distance from coastline.	OS Open Data License

Proportion of arable area*	Different agricultural practices are important for pink-footed geese feeding areas, such as pasture and arable (e.g., root crops and winter cereals) (Forshaw, 1983; Brides et al., 2013)	CEH Land cover 2007	Proportion or combined grassland / arable area within 100 m cell	CEH license
Proportion of improved grassland area*		CEH Land cover 2007		CEH license
Proportion of agricultural area in 500 m^2 (25 ha) surrounding area*	The type of land cover surrounding fields may also influence geese presence. e.g., geese may prefer to feed in areas surrounded by agricultural land, rather than areas surrounded by forest, or urban areas.	CEH Land cover 2007	Proportion of agricultural land (combined from grassland and arable land) within a 500 m cell centred on the 100 m cell centroid.	CEH license
Land cover category*	Three simplified categories: grassland, agricultural, unsuitable land cover (Wisz et al., 2013)	Reclassify from CEH Land cover	Combined grassland categories, arable, and all others together	CEH License
Slope (%, rise over run)*	Topographic features could influence sense of security (e.g., affect line of sight) and influence crop type or quality	OS Terrain 50 Digital Elevation Model	Calculated in R	OS Open Data License
Elevation above sea level (m)*	Elevation, as above, will influence ecosystem type		Aggregated to 100 m resolution in R.	
Normalized Difference Vegetation Index (NDVI)*	Can be classified to produce different vegetation cover classes, and could potentially differentiate between field types.	Landsat 8 (2015-16) Previous Landsat satellites (1980s to present)	Processed product. Could be used to evaluate temporal series of habitat suitability.	Landsat
Distance to nearest minor/major road (m)*	Disturbance factors could include roads and paths (Mitchell et al., 2004) (e.g., 100 km from road in Scotland), possibly more so from walkers, dogs, or cars stopping than major roads.	OS master map	Calculated in ArcGis	OS PMSA License
Distance to path/track (m)			Need to evaluate distinguishing paths from tracks and roads.	
Distance to structures (m) e.g., pylons, wind turbines	There is evidence that geese may avoid certain structures (Larsen & Madsen, 2000; Plonczkier & Simms, 2012).	OS master map	Check complete data availability	OS PMSA License

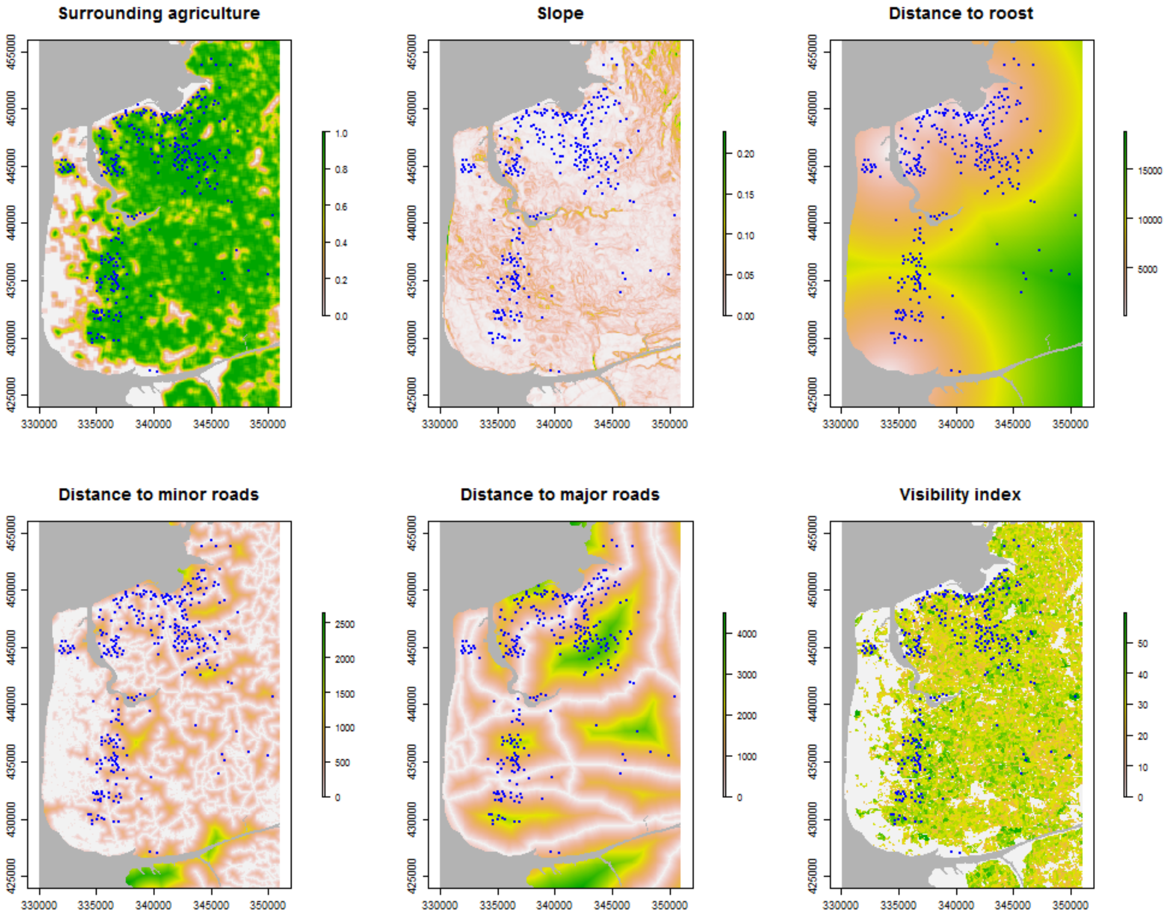

Figure 3.2. Predictors considered for inclusion in the model. Presence points are plotted in blue.

- Processing of predictors

Predictors were mapped as spatial raster layers at a resolution of 100 m (that is, cell size of 100 x 100 m) over the study area (Figure 3.2, Table 3.3), representing a suitable scale for field level analysis. Methods for creating the predictor layers are outlined above (Table 3.3), and where necessary, are complemented below.

The visibility index was based on the size of open, natural, and agricultural habitats, as known to be used by pink-footed geese. Despite OS Mastermap providing more up to date information on field boundaries, the CEH Landcover 2007 boundaries were used to calculate this index given that this spatial layer enables specific habitat types to be included. However, it is also recognised that the CEH Landcover map is sometimes subdivided for distinct agricultural uses where no physical boundary exists (Morton et al., 2011). Of the 19 Broad Habitat classes used by the land cover map, the following were selected:

- Arable and horticulture
- Fen marsh and swamp
- Improved grassland
- Neutral grassland
- Rough low-productivity grassland

The area of these within each 100 m cell of the raster layer was then calculated in R using raster package (Hijmans, 2014), and a cube root taken to reduce the effect of some very large open areas (e.g., moorland, saltmarsh). Cells without presence of any of the above habitats were assigned values of zero, effectively equating to zero visibility (e. g. urban areas and forests).

The main source for agricultural land cover information comes from the Centre for Ecology and Hydrology land cover data, created from satellite images from between 2005 and 2008 (Morton, 2015). Although the time period of the occurrence records does not coincide exactly with this time period, 66 % of the occurrence records used are from the period 2005-2010[4]. Pre-processed data at a finer temporal scale are not available for land cover (see recommendations). To assess the extent to which the 2007 land cover coincides with current land cover (2015-16), we surveyed fields along the routes travelled searching for pink-footed geese. Crop type in fields on both sides of the roads was surveyed and recorded as one of the following categories:

1. Winter cereal
2. Root crops (e.g., swede, carrot)
3. Pasture
4. Bare/ploughed ground
5. Stubble

Crop types were noted on specially prepared maps of every 5 km square of the study area outside urban areas, using field boundaries as shown by OS Mastermap (Appendix 5). Accuracy metrics (Sensitivity, Positive predictive power and overall accuracy) were calculated from the confusion matrix generated by overlaying the field survey data with the CEH land cover layer.

3.4 Habitat suitability model

A two-stage process was used to model the effect of environmental predictors on pink-footed goose presence. Given that true absences were not recorded, 5000 background absences were randomly created across the study area. Although other methods exist for the inclusion of pseudoabsences in species distribution models, such as choosing absences within a radius of the presence points (VanDerWal et al., 2009), random background absences are less problematic in statistical models such as GLM (). First, initial models were created using Generalised Linear Models (GLM) and Generalised Additive Models (GAM) with binomial error distribution and logit link. Logistic regression takes a binary response variable (presence or absence of geese) and a series of numeric or categorical predictors and provides a probability of occurrence or habitat suitability. GAMs were also evaluated, given that they allow non-linear relationships between the predictors and the response, which is common in ecological data (Zuur et al., 2009). Different combinations of predictors were trialled individually and in pairs in preliminary models, and a subset of predictors chosen, based on ecological value, minimising collinearity, and bearing in mind the limited number of samples. Collinearity was evaluated using scatterplots, spearman correlation coefficients and Variance Inflation Factors (Zuur et al., 2007). Models were then built with each combination of the subset of predictors and were evaluated using AIC. AIC is a measure of model fit, and penalises additional parameters, therefore preferring simpler models.

The initial model was tested for presence of spatial autocorrelation in the model residuals using a correlogram (Legendre & Legendre, 1998), and then an autocovariate was fitted as a further predictor to take into account the spatial structure. Although other methods exist for controlling for spatial autocorrelation (Dormann et al., 2007), many are not applicable to sampled data (as is the case without full absence data), or to regression methods such as GLM with non-normal distributions (e. g. binomial or logistic, poisson). An autocovariate can be calculated as a neighbourhood measure (e.g. Luoto et al., 2001) that attempts to counter the violation of independence in the response variable, in other words, that the pink-footed geese records show some spatial clustering. Neighbourhood measures are calculated by

[4] Data from the Lancashire Bird Atlas (White et al., 2013) only have date information given as 2007-2010, therefore occurrence data were classified in three temporal bands spanning the period 2000-2015.

applying a function (e.g., a sum or average) over a neighbourhood, or 'window' of adjoining cells, for example, a 3 x 3 window, which includes the central cell of interest and eight surrounding cells.

Autocovariates, or autologistic regression, have been used for similar species distribution models successfully (Syartinilia & Tsuyuki, 2008; Bardos et al., 2015), using either the original response variable (in case of complete sampling), or the fitted probabilities from a preliminary model (Augustin et al., 1996). However, a novel approach, suggested by Crase (2012), uses the model residuals to derive the autocovariate, therefore only using the variance unexplained by the predictors, and attempting to retain the effects of the predictors themselves in the final model. Given the sampled nature of this data set, the latter method was extended in this project to calculate an autocovariate from the residuals of the first stage model, using a focal window approach, with a neighbourhood area large enough to capture the background absences and create a complete raster layer to use later at the prediction stage. A neighbourhood mean of 9 x 9 and 15 x 15 were trialled and tested in the second stage model, and evaluated in the same way as the other predictors.

The predictors were evaluated again in the second stage model, using AIC to select the best models. The best model was validated visually using residual plots, and with explained deviance. An additional measure of fit, the average Area Under the Receiver Operating Curve (AUC), was calculated using 5-fold cross validation. Given the relatively small number of presence points, all the data were then used to create the final model. Data analysis was carried out in R (R Core Team, 2014), using packages raster, sp, rgdal, MuMin. Maps were created with ArcGis 10.3. The models were then used to predict the habitat suitability of the pink-footed geese across the study area. The best GLM and GAM models were averaged to obtain a consensus model.

- Expert evaluation

The model was evaluated using expert data, obtained from Derek Forshaw and members of Fylde Bird Club. The expert data consisted of mapped areas of importance for pink-footed geese in Fylde over the time period, 1977-2009, also providing an opportunity to evaluate the stability of the geese's use of land in the area. In this data set, 13 areas were designated as important to pink-footed geese and drawn onto 25 5-km^2 OS master map sheets (approximately 1:20,000), prepared for this project (as in Appendix 5 but without occurrence points). Additionally, the areas were classified as having been important at the start of the period (1980s), and those into which geese expanded in recent years (1990-2000s). The areas of highest habitat suitability, or probability of occurrence, from the model, were visually compared to those designated by experts. Finally, the model was also compared to the priority areas identified through a project to map the distribution of feeding pink-footed geese in England. Feeding areas were only based on occurrence data, incorporating a measure of peak count, count frequency and accuracy per 1 km cell (Brides et al., 2013).

3.5 Field visits

- Farmer interviews

Field visits were coordinated through Natural England, targeting farmers subscribing to the Environmental Stewardship Scheme. The visits aimed to assess the feasibility of incorporating information on crops over a similar temporal period to that of the occurrence records as well as interviewing farmers on their experience with pink-footed geese on their land (Appendix 1). A questionnaire was administered personally to each farmer, with open and closed questions relating to crop rotation, occurrence of pink-footed geese on their land, damage caused by geese, avoidance mechanisms and hunting. Additionally, a map of the farm, created as part of the project, was used to mark fields with specific crops (Appendix 2).

- Pink-footed geese observation

Surveys were conducted along minor roads in Fylde district, driving at suitable speeds to view geese but also bearing in mind the safety of other road users (approximately 30 - 40 miles per hour), with one observer looking for geese in fields on both sides of the road. When flocks or possible flocks were seen, a safe place to stop was found and identification of geese was verified, and flocks were counted and observed for between 5-10 minutes. Observations were carried out by Christian Devenish and Chris Harrison.

3.6 Collaboration

- Fylde Bird Club

A meeting was set up with Fylde Bird Club committee on 25/2/2016 with two main purposes, to review the data we had received from the club, and discuss opportunities for future collaboration (Appendix 3). After presenting the aims of the project, it became clear that data had not initially been provided for some areas in the wider Fylde region. Confusion may have resulted as to the exact area required; Fylde may refer to the administrative district itself, or the entire peninsula between the Ribble and the Lune. As a result of the meeting, Fylde Bird Club kindly sent a second data set with all records for Pink-Footed Geese, sorted by behaviour (in flight or on the ground). In terms of future collaboration, the members of the club were very willing to be involved in future projects, such as monitoring pink-footed geese to evaluate movements over the winter period on a monthly basis. Other issues raised by members of the bird club and discussed included:

- Existing Pink-footed goose counts in the region
- Creation of reserves in the Fylde area
- Disturbance factors for pink-footed geese, especially hunting and land use change through development (e.g., housing)
- Improving farmland management practices for farmland birds
- Presentation of project results at a club meeting

- Expert assessment of habitat suitability

Derek Forshaw has worked on pink-footed goose in Lancashire since 1970s, with research on habitat use (Forshaw, 1983) and on goose counts for Wildfowl & Wetlands Trust (WWT). After being contacted through this project, D. Forshaw kindly provided data from 1970s of pink-footed goose occurrences and his expert opinion on main feeding areas during the period of his initial study (1977/78 to 1981/2) and during latter goose counts (until 2009), enabling an evaluation to be made of the stability of feeding areas over time.

4 Findings

4.1 Summary of occurrence data

The final data set contained 6289 records, of which 789 contained six figure user supplied grid references, representing a spatial precision of 100 m. Of these, 15 corresponded to records of less than five geese, which were eliminated to avoid using records from sick or feral geese. The remaining records spanned a period from 1989-2016, with the great majority of records from post 2000 (Figure 4.1). Spatial filtering of records excluded 212 exact spatial duplicates and 241 observations within 200 m of each other.

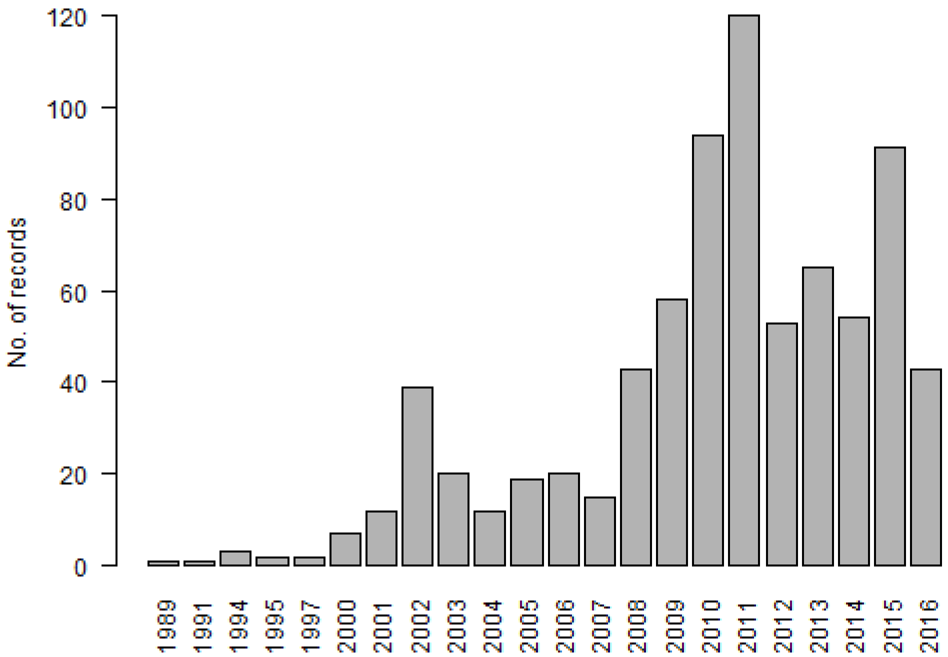

Figure 4.1. Number of pink-footed geese 'on the ground' records per year, for which spatial precision is 100 m.

The final presence records were reviewed with OS master map (Appendix 5), and checked according to the Broad Habitat type from CEH land cover (Table 4.1), some records still fell outside of suitable habitat for on ground records for pink-footed geese (e.g., in fields, saltmarsh, coastlines, according to literature). Although most of these records were eventually filtered through the above processes (Table 4.1), to avoid circularity in filtering records with the same data sources as the predictors, no further filtering was carried out.

Table 4.1. Land cover category of final pink-footed geese 'on the ground' records.

Approximate suitability	Broad habitat	No. of records	
		With spatial duplicates	Without spatial duplicates
High	Arable and horticulture	190	87
	Improved grassland	468	193
	Neutral grassland	15	5
	Rough low-productivity grassland	18	8
	Litoral sediment	51	14
	Supra-littoral sediment	8	4
	Dwarf shrub heath	2	2
	Freshwater	6	3
	Broad leaved, mixed and yew woodland	1	1
	Inland rock	1	1
Low	Built up areas and gardens	14	3
	Total	**774**	**321**

4.2 Predictor processing

- Temporal coincidence of land cover data

A total of 193 fields were surveyed over the four days of field trips (Figure 4.2, Table 4.2). Categories were combined into arable and pasture from both CEH land cover and our field survey to facilitate comparison. A conversion from arable to pasture was observed between CEH 2007 data and current land cover Table 4.2, reflected in low accuracy metrics for arable categories (Table 4.3). Conversely, most fields in pasture in 2007 were still in pasture during our survey.

Table 4.2. Confusion matrix for field based land cover and CEH land cover

		Field Survey (Current land cover)			
		Arable	Pasture	Other	**Totals**
CEH 2007 land cover (Morton, 2011)	Arable	23	28	0	51
	Pasture	17	122	0	139
	Other	0	3	0	3
	Totals	40	153	0	193

It should be noted that these metrics (apart from arable sensitivity) are affected by the unbalanced sample size between arable and pasture and the overall accuracy shown is likely to be an overestimate. The results, however, do not provide confidence in being able to separate between arable and grassland for geese records almost 10 years after the images were taken used to classify the CEH land cover layer, (that is, overall, 1 in 4 fields is misclassified with CEH land cover). Therefore, the arable and pasture field types were aggregated into a single agricultural category. This prevents distinguishing between two important field types in the feeding ecology of the pink-footed goose, furthermore, due to the dominance of agricultural fields over the Fylde area, the discriminating power of this predictor as a categorical indication of field type is greatly reduced, and so was dropped from analysis. However, the proportion of agricultural area within the wider habitat matrix was retained, thus maintaining information on land cover within the model.

Table 4.3. Accuracy metrics for CEH land cover predictor

Field type	Sensitivity (Producer's accuracy)	Positive predictive power (User's accuracy)	Overall accuracy
Arable	57.5%	45.1%	75.1%
Pasture	79.7%	87.8%	

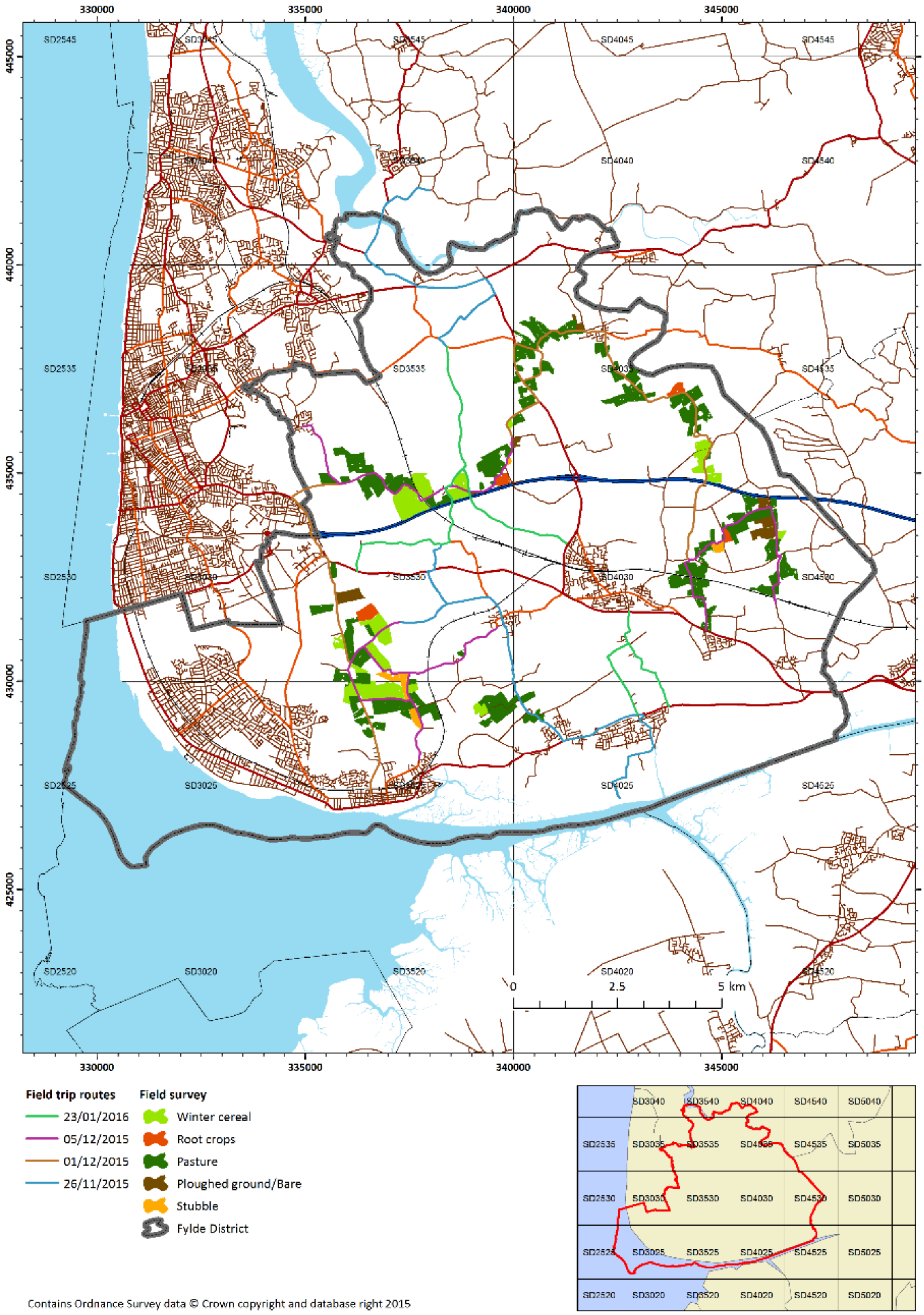

Figure 4.2. Location and types of fields surveyed during pilot field trips within Fylde district.

- Exploration of NDVI as a potential predictor of land cover

As an alternative to ready processed land cover maps, Normalized Difference Vegetation Index (NDVI), derived from Landsat images, is a potential proxy of vegetation cover. Landsat images have a 30 m resolution, and are suitable for the scale of this analysis. Problems with images, however, include excessive cloud cover, and an inability to calculate surface reflectance when the solar angle is too small, exacerbated during the winter. Averaged values from other images close to the required dates may be used to fill gaps, and partially overcome some of these problems (Baldi et al., 2008).

Two relatively cloudless Landsat images (< 30% cloud across the image) were available from the time of the field survey (30 September 2015, 20 January 2016). Average NDVI values were extracted for each field covered during the survey. For each date, field types had significantly different NDVI values (September: Kruskal Wallis $\chi2 = 3167.5$, df = 4, $p < 0.001$; January: $\chi2 = 1745.8$, df = 4, $p < 0.001$). However, there are also significant differences between periods, therefore, NDVI as a predictor would require temporal alignment to occurrence records (Figure 4.3). NDVI merits further exploration as a predictor of habitat use, especially through time series of satellite images, including as far back as 1980s.

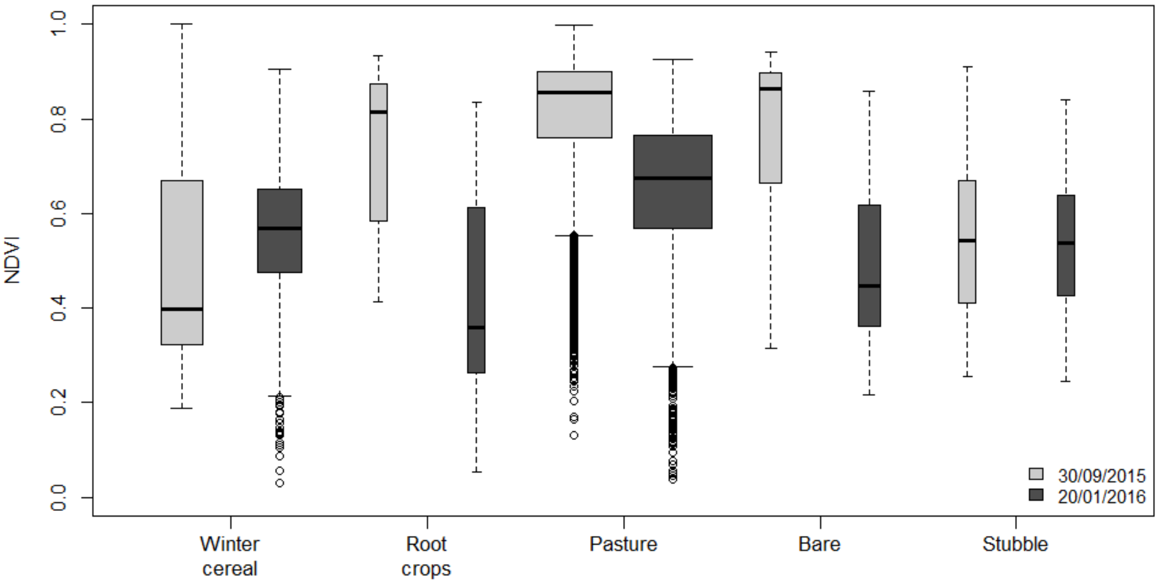

Figure 4.3. NDVI, derived from Landsat 8 images, across field types on two dates within two months of field survey dates. Differences are significant between field types. Width of boxes are proportional to sample size.

- Exploratory analysis with predictors

To maintain adequate statistical power from a model, the number of samples (312 in this case) should far outweigh the number of predictors, with rules of thumb giving proportions such as 40 times more samples than predictors (Franklin, 2009). Additionally, increasing model complexity makes interpretation increasingly difficult. Therefore, it is of interest to use the smallest number of predictors while allowing for useful predictor effects to be inferred. In exploratory models, incorporating predictors singly, or in pairs, distance to road were not found to be significant, and so were left out of the final model. Distance to coast was also left out, as distance to principal roost sites relates to a similar concept. Collinearity of predictors was also explored, and slope was eliminated due to being correlated to elevation, however, Variance Inflation Factors for all remaining predictors was less than 2.5 (Appendix 4), implying that multicollinearity between predictors was weak. A final selection of four predictors was chosen to build models, and incorporated into a model selection process using AIC, as described above. These were surrounding agriculture, elevation, distance to roost sites, visibility index (see Table 3.3).

4.3 Habitat suitability model

A weak, but significant ($p < 0.05$) spatial autocorrelation was found in both initial models which was virtually eliminated by including spatial terms, slightly more successfully in the GLM by means of the spatial autocovariate than with the smoothed coordinates in the GAM (Figure 4.4). Inclusion of the spatial terms did not diminish the effect of the other predictors. In the case of the GLM (Table 4.4), using the residuals, rather than the initial response variable or an initial prediction, to base the autocovariate on, has been shown to maintain the effects of the predictors (Crase et al., 2012), and this seems to be the case here. In the case of the GAM, the direction of the effects were also maintained, although the confidence intervals increased with the inclusion of the coordinates (Figure 4.5).

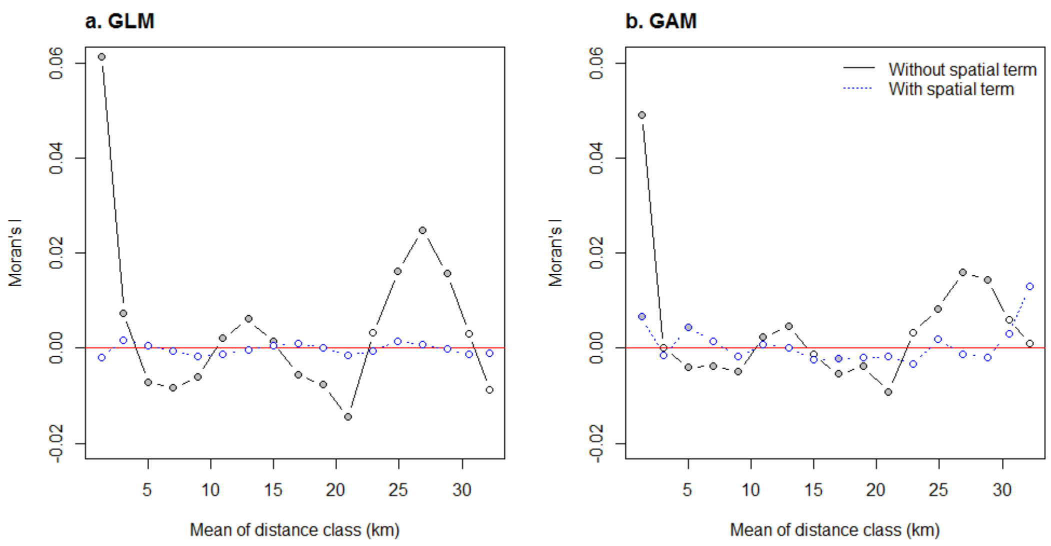

Figure 4.4. Moran's I of model residuals at 17 distance bands from a) GLM and b) GAM with and without a spatial autocovariate as an additional term. Filled points indicate significant autocorrelation a significance level of 0.05.

Model performance was satisfactory for both final models, with the GLM performing slightly better than the GAM under both evaluation methods. In terms of the receiver operating curve, 5-fold cross validation produced an average AUC of 0.937 and 0.878 for the GLM and GAM, respectively. Any value above 0.5 means that the model performs better than random predictions. Models with AUC in the range of 0.7-0.9 are considered to perform moderately, and above 0.9 are considered to perform highly (Franklin, 2009). Explained deviance, the amount of variation in the presence or absence of the pink-footed geese that is explained by the predictors, was 40.7% in the GLM and 31.3% in the final GAM. Inclusion of the GAM, however, is warranted, given that all the predictors, except for Elevation, showed a non-linear response to the presence or absence of the geese (Figure 4.5). The effective degrees of freedom, which can be interpreted as the degree of non-linearity in the response (with a value of 1 signifying a linear response, as in Elevation), increased in most predictors with the inclusion of the smoothed coordinates (Figure 4.5).

Table 4.4. Model coefficients and AIC weights for top five GLM models (intercept as fixed term, not shown)

	Standardised coefficients					Model evaluation				
	Surrounding agriculture	Elevation	Distance to roost	Visibility index	Spatial autoco-variate	Degrees of freedom	Log Likelihood	AIC_c	ΔAIC_c	Akaike weight
Without spatial term	2.855	-2.778	-4.064	2.046		5	-933.72	1877.45	0.00	1.00E+00
	4.105	-2.924	-3.982	NA		4	-945.94	1899.89	22.44	1.34E-05
	2.936	NA	-5.341	2.164		4	-948.87	1905.74	28.29	7.18E-07
	NA	-2.816	-3.706	3.544		4	-955.75	1919.50	42.06	7.37E-10
	4.232	NA	-5.317	NA		3	-962.60	1931.20	53.75	2.13E-12
With spatial term	2.825	-2.515	-4.190	2.448	3.852	6	-689.90	1391.82	0.00	9.99E-01
	2.924	NA	-5.280	2.487	3.959	5	-698.17	1406.36	14.54	6.97E-04
	4.295	-2.562	-4.023	NA	3.824	5	-703.58	1417.17	25.35	3.13E-06
	NA	-2.595	-3.760	3.794	3.942	5	-705.38	1420.77	28.95	5.17E-07
	4.389	NA	-5.126	NA	3.943	4	-712.30	1432.60	40.77	1.40E-09

In the GLM and GAM including spatial terms, the difference in AIC between the best and second best model was 22.44 and 8.91, respectively (Table 4.4; GAM table not shown). This difference is large enough to warrant using just each of the first models alone for the purposes of prediction, rather than using model averaging based on Akaike weights to produce averaged coefficients. To summarise the model parameters, in order of importance, pink-footed geese are more likely to be found at sites closer to roosting sites, where agricultural land represents a higher proportion of the surrounding habitat elements, with lower elevations and increasing visibility within habitat areas (, Figure 4.5).

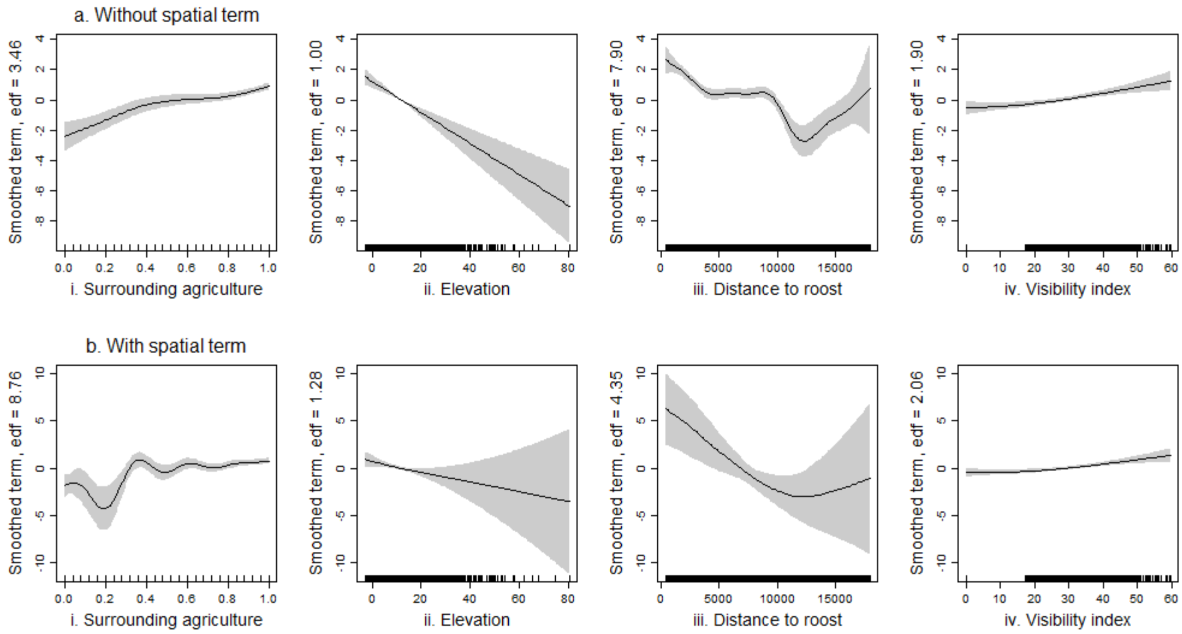

Figure 4.5. Response curves for predictors in GAM models a) without spatial term, and b) with spatial term. Effective degrees of freedom for each smooth term is shown on the x axis label.

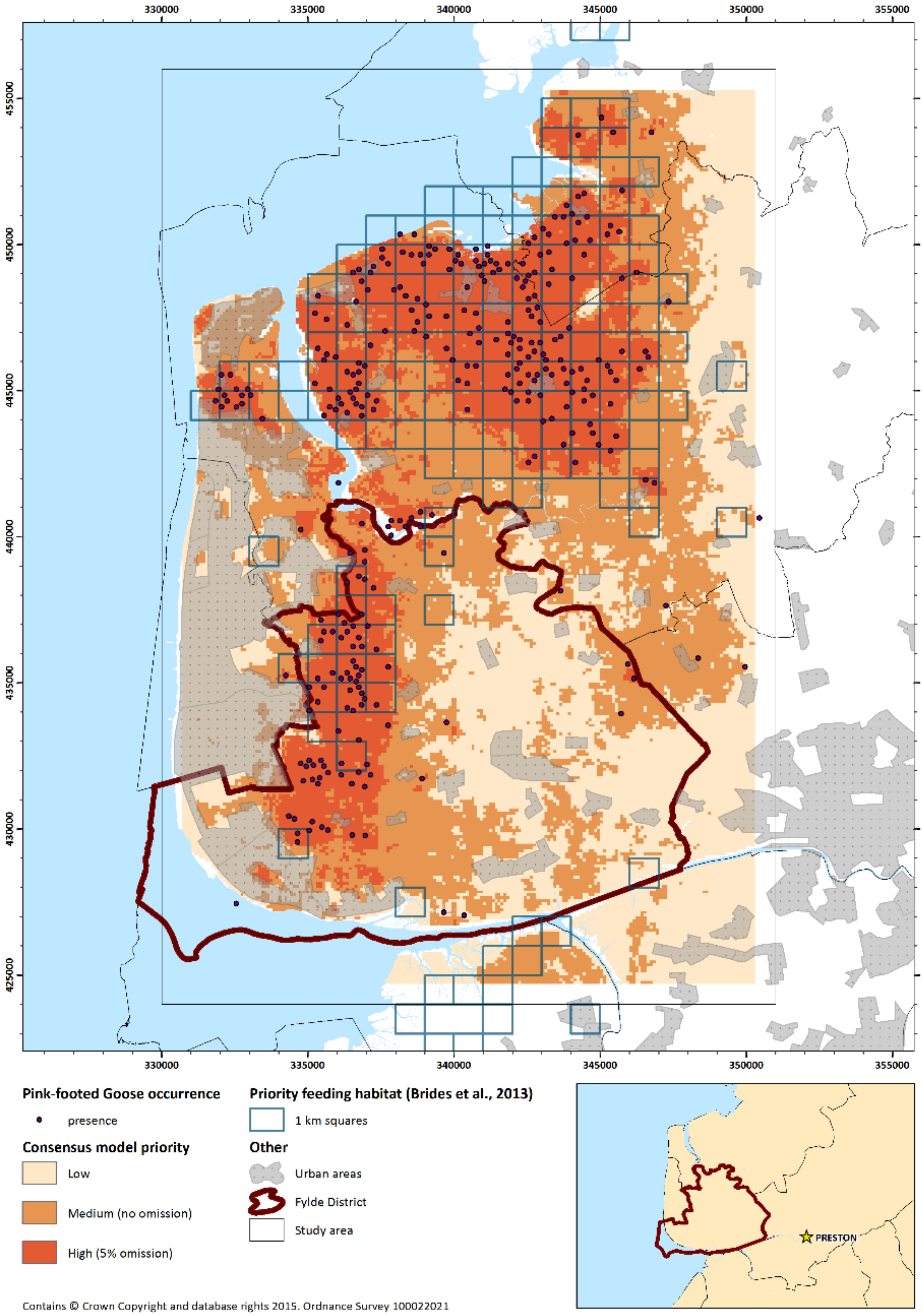

Figure 4.6. Habitat suitability model, divided into low, medium and high suitability, showing coincidence of nationally mapped feeding areas (Brides et al., 2013) in Fylde district.

The final consensus model (Figure 4.6), the average of the best GLM and GAM models, had good threshold-independent accuracy metrics with an AUC value of 0.93 and a strong and significant Pearson biserial correlation coefficient between observed values (presence/pseudoabsence) and prediction ($r = 0.53$, $p < 0.0001$). The consensus model was divided into three regions, indicative of priority areas for pink-footed geese. The medium or ‘no omission’ category has the strongest precautionary approach, and corresponds to areas equal to or above any value predicted for a presence point, that is, all presence points used in the model lie within this area. The high or ’5% omission’ category corresponds to a threshold below which only 5% of the presence points (17 occurrence points) are not included in the model. Both higher regions coincide with the national 1 km grid of priority feeding sites (Brides et al., 2013), based on spatial occurrence and frequency of occurrence alone. Anomalies are likely to be due to differences in data used, and the degree of filtering applied to data sources.

The model also coincides with most of the areas provided by Derek Forshaw, showing general boundaries of important feeding areas within Fylde and north towards the Lune estuary, based on the geese seen during his study period (1977-2009). The expert-designated areas (Figure 4.7) are broad, large areas that include specific preferred feeding fields that the geese use every year (D. Forshaw, pers. com). The model shows that areas used by the geese in 1970s are still used today. However, there are regions, especially those marked as areas of recent expansion for the geese that the model does not highlight within the high priority rating. These regions also correspond to areas with a lack of accurate occurrence data.

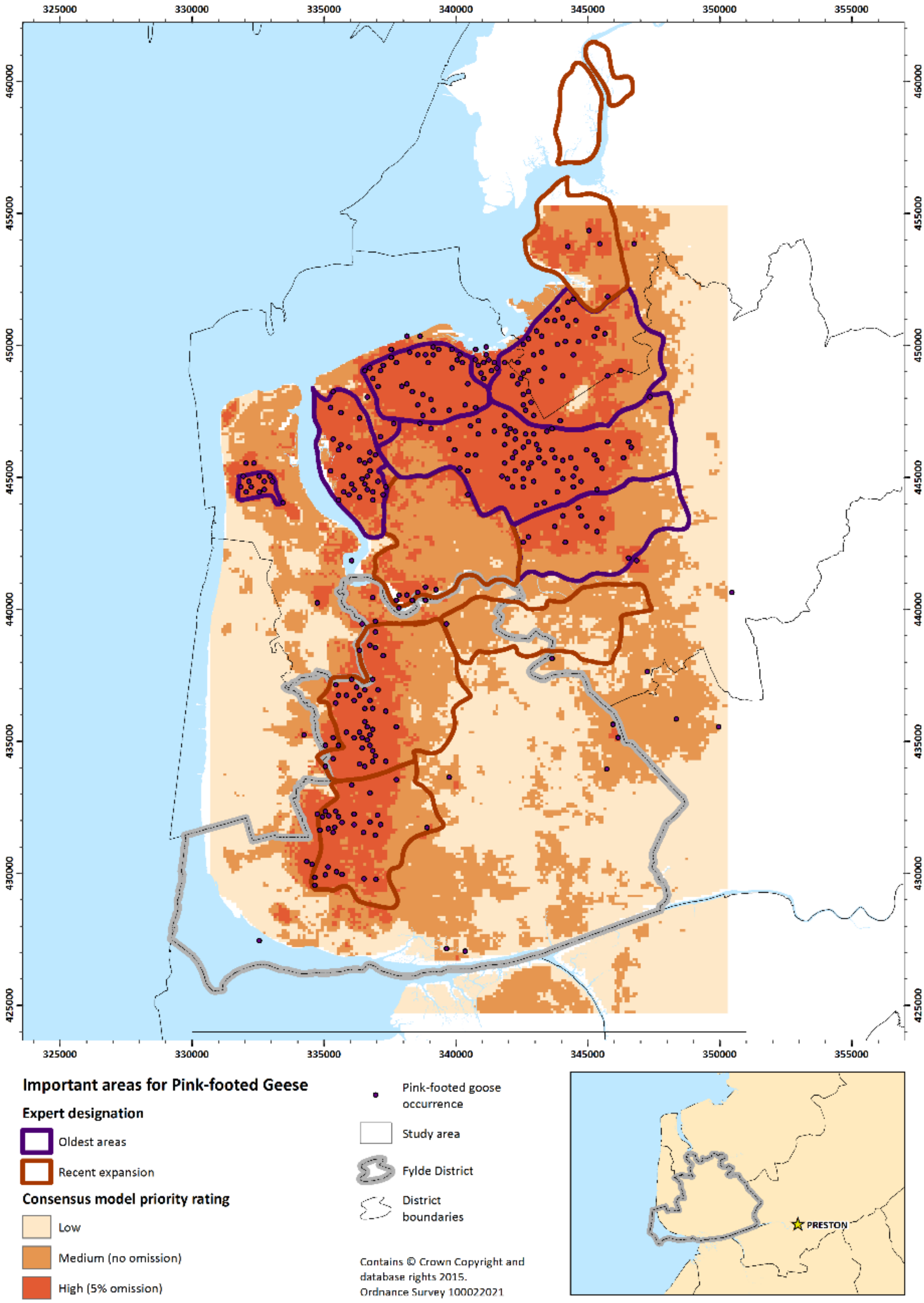

Figure 4.7. Expert-designated areas of importance for pink-footed geese compared to the model prediction.

4.4 Pilot field trips

A pilot to assess the feasibility of sighting geese and mapping habitat from car-based surveys was successful, in providing observations of geese and covering large areas of Fylde in relatively short time. However, the survey was biased towards roadside sites. The field trips were also invaluable in providing the researchers with the opportunity to talk to farmers and wildfowlers, and gauge the effort required for larger surveys. A summary of results follows:

- Nine sightings of pink-footed geese were recorded in four days of fieldwork, with an effort of 100 km in approximately 16 hours of observation (Figure 4.8, Table 4.5).
- Approximately 65% of non-urban 1 km squares covered in four days of field trips.
- Average flock size observed of c.850.
- Sightings concentrated in east of Fylde, coinciding with other occurrence records

Table 4.5. Location and numbers of pink-footed geese sighted during surveys: 26/11 – 05/12 2015.

Date	Time	Location (British National Grid)		Count	Field type	Behaviour notes
		X	Y			
26/11/2015	11:50	338910	431735	400	Winter cereal	Geese were alerted by car stopping, and continued walking/feeding after about 1 minute. Undisturbed by train passing close by.
01/12/2015	12:30	336519	429797	150	Winter cereal	Some geese splashing/washing in large pool of water in field.
01/12/2015	13.35	336506	431557	350	Root crop	Waterlogged field, crop height up to necks of geese.
01/12/2015	14:00	335560	434906	600	Winter cereal /Pasture	Near large pool of water (left as part of ESS). Disturbed by CD & CH walking along field margin. Drizzling.
05/12/2015	13:31	336969	429778	200	Winter cereal	Field with flooding, patches of water. Grazing and walking, about 100-150 m from road.
05/12/2015	15:44	345716	433948	50	Pasture, with muddy areas and puddles	Disturbed by car stopping about 100 m away.
23/1/2016	12:15	338837	446891	5000	Pasture	Loafing, not grazing, some standing, others sitting. Small groups flying in and others moving position.
23/1/2016	12:45	340775	447558	15	Pasture / harvest root crops	In field. About 10 m from clumps of trees.
23/1/2016	13:05	343819	451231	1000	Pasture	Grazing, field adjacent to sheep and dyke at Lune Estuary, near Pilling Sands.

Six farmers were selected for interview from those within the Higher Level Environmental Stewardship Scheme (Table 4.6), according to information supplied by Natural England. Of the six contacted for interview, four interviews were completed. Interviews lasted between 30 minutes and 1 hour. The main points are summarised below (Table 4.7).

Table 4.6. Farm visited for pilot interviews

Farm	Location	Date	Interviewee	ESS Reference No.
B & M Cornthwaite & Son	Poulton-Le-Fylde	26/11/2015	Tom Cornthwaite	AG00332425
Rigby, P	Preston	01/12/2015	Paul Rigby	AG00199628
RJ & D Loftus Farms	Preston	05/12/2015	John Loftus	AG00314774
D Fryars & Son	Poulton-Le-Fylde	23/1/2016	Robert Fryars	AG00369223

There was a high degree of agreement between the responses of all four farmers. All farmers knew and could recognise the pink-footed geese and also recognised the importance of the area for the geese. Importantly, the farmers concurred that geese did not represent a major factor in damaging crops (Table 4.7). With regard to mapping crop type over the last five years within each farmer's fields, this was not possible for all fields across all farms. Some farmers had in excess of 10 or 15 fields, and not all could provide yearly information of crop type for this time period. However, from some of these responses, it is clear that crop types change according to market forces (e.g., if grain for dairy farmers becomes cheaper to buy than produce, fields may change from arable to pasture); and crop rotation cycles. Apart from the 5-year arable cycle (Table 4.7), pasture may have a lifetime of between 10 and 15 years, after which it is either replanted or the field type is changed. This dynamic nature of field types concurs with results of the comparison between the field survey from this project and the CEH land cover map.

Table 4.7. Summary of farmer interview responses

Topic	Summary of answers
Occurrence of pink-footed geese	All farmers reported occurrence of pink-footed geese on their land. Most coincided with a temporal pattern of geese shifting from (root crops to) cereal to grass as winter progressed and temperatures dropped.
Damage by geese	Coincided that geese were not a major factor damaging crops (winter cereals recovered after grazing by geese, with additional fertiliser application in Spring). One farmer reported extensive damage to pasture one year (about 10 years ago).
Crop rotation	Three farmers used five year crop rotation, with potato for one year, then 4 years of winter cereal, some with a year of maize.
Hunting	Hunting occurred on most land, some organized shoots, others hired out land for shoots, but geese not main target of hunters (pheasant, mallard, partridge). One farmer reported shooting geese as a way to move them on.
Use of bird scarers	One farmer used bird scarer briefly, but had to stop due to complaints by neighbours. Scaring geese was not main concern, more for starlings.

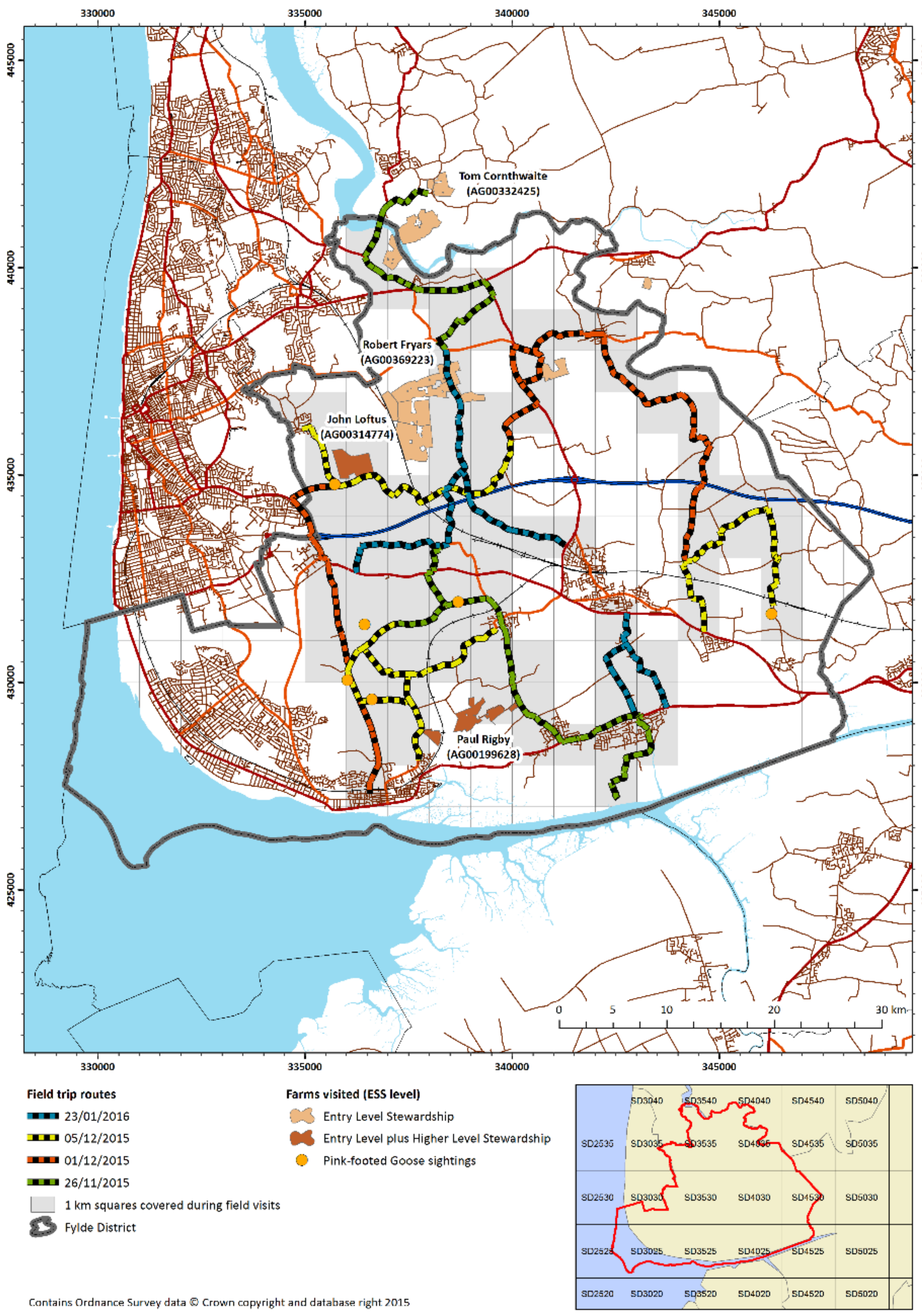

Figure 4.8. Location of farms visited, field trip routes and pink-footed goose sightings during pilot surveys (26/11/2015 to 23/1 2016).

5 Discussion

The process to construct the pink-footed geese distribution model represents an important first step in furthering knowledge of where and how geese use habitat in the Fylde area, with a view to informing planning decisions, and furthering biodiversity conservation. All steps in the process are important, including data acquisition, predictor selection, modelling methods, through to collaboration with local stakeholders.

The priority areas designated as medium and high (no omission and 5% omission errors, respectively) need be considered simultaneously with the quality of the presence points used in the model. If all the presence points correspond to sites which are regularly used by pink-footed geese and have a very high spatial accuracy, then the threshold for predicting priority areas should include all presence points used in the model. This is the approach taken in the first category. If some of the presence points are less accurate (e.g., some presence points employed are not in suitable habitats for pink-footed geese, Table 4.1), then a threshold can be set where a larger area of unfavourable predictions are omitted. However, without systematic sampling for presence values, it is difficult to assign quantitative quality metrics to the data. Given that the model is not a field level model, it should be taken as indicative of broad regions within the Fylde area containing important feeding sites for pink-footed geese. Furthermore, pinpointing priority fields implies a static picture at a given time and does not take into account the dynamic nature of the landscape (e.g., changing agricultural patterns) and the dynamic nature of geese movements and habitat use (e.g., population growth and expansion into new areas). As a planning approach, a model that identifies landscape scale characteristics of fields and other features that contribute to pink-footed geese's local wellbeing is recommended. The model produced here, as well as the suggestions for future work, contribute to this approach.

The model has shown important factors in habitat selection at field level such as distance to roosting sites, proportion of agricultural land in the surrounding area, and visibility, with similar results found in northern Europe (Wisz et al., 2008). However, the model lacks information on movements or temporal habitat use patterns over the winter. Movement dynamics take place a different scales, including movement between regions in the UK (WWT, 2015), for example, flocks moving between Norfolk and Lancashire more than once per season, and daily movement patterns within regions (Giroux & Patterson, 1995), related to food availability (Fox et al., 1994), among other reasons. Knowledge of both of these patterns will be important in building a model of field use in Fylde. Pink-footed goose use of the Fylde area has changed over time, with the most obvious change being the large increase in numbers since the 1980s (Mitchell, 2015). Undoubtedly, this increase has led to changes in habitat use within the region. For example, geese are reported to have expanded into previously unused areas of Fylde (D. Forshaw, Fylde Bird Club, pers. com) in recent years, and changed their use of overwintering and stopover sites within the UK (Fox et al., 1994, Fylde Bird Club, pers. com). There is also a need for finer scale habitat information, for example, there is evidence that geese respond to fine-scale differences in grass quality (Fox, 1993). Finer scale habitat data (e.g., from remote sensing) could be employed for this, as was used in a study on geese foraging employing aerial photography (Anderson et al., 2012). However, these data must also be matched with temporally coinciding occurrence records of geese, which would require intensive field work, unless a remotely sensed data could also be obtained for geese, for example, by satellite tagging.

Predictors that incorporate disturbance factors at a suitable resolution should also be explored. Two major disturbance factors for pink-footed geese in Fylde are hunting and land use conversion. Hunting in Fylde involves at least three types, wildfowler organisations, organised weekend shoots and farmers. Results from the small numbers of interviews with farmers suggested that geese were not a major factor in causing damage to crops in Fylde, a finding also reported nationally, despite local areas where damage had occurred (Patterson et al., 1989; Fox et al., 1994). Therefore, it is unlikely that shooting, as a method of moving birds from fields (as reported in this project) is a large disturbance factor. Organised weekend shoots focus more on pheasant and partridge, specially bred locally for the purpose. However, the influence of wildfowlers in taking geese as they come off the roosting sites may be more of a concern. A study comparing demographic data and Icelandic hunt bags found no evidence of mismatches in the data for pink-footed geese, as was the case with Greylag Geese *Anser anser* (Frederiksen et al., 2004). However, hunting does exert a strong influence on population dynamics in pink-footed geese, and the absence of national hunt bag information from Britain makes monitoring the effect of hunting, and implementing management strategies difficult (Frederiksen, 2002). Measuring land cover change was beyond the scope of this project, but exploratory analyses with NDVI do show promise as a feasible method to measure the influence of changing vegetation cover (and changing total extent of vegetation cover) on geese occurrence. The dynamic nature of changing crops, coupled with habitat loss through development, should be considered together in identifying important areas for Pink-foot Goose conservation.

Citizen science data has increasingly contributed to conservation studies and conservation management in recent years, in part, aided by greater capacity for sharing information with internet technologies (Wood et al., 2011; Cavalli et al., 2014). A valuable resource, especially in countries such as the UK and the USA, with strong bird watching traditions, are local recorders of biodiversity information, evidenced by the contribution of long-standing initiatives such Breeding Bird Surveys to establishing population trends in birds (e.g. Gregory et al., 2008). A collaborative approach to implement future work in Fylde is feasible, as established through contact with Fylde Bird Club, and could provide a model of local cooperation to inform local decisions, where local stakeholder participation from the outset strengthens outcomes. Although the pilot study produced records that corroborated the general pattern of goose occurrence records provided by Fylde Bird Club, the topography of Fylde may not lend itself to car-based studies alone. Therefore, a combination of data collecting techniques, including car and foot-based surveys, possibly in coordination with existing goose counts (organised by the WWT) could provide the kind of information needed to advance a model of habitat use. Outcomes from more detailed fieldwork, such as behavioural observations, could also inform mitigation measures. For example, simple counts of feeding time and food source could provide information on the seasonality and quantity of supplementary feeding programmes.

Although data were greatly enriched through the addition of the second data set received from Fylde Bird Club, improvements could still be made to the way data are recorded, especially in terms of encouraging at least six figure coordinates and behaviour to be noted with bird records. Through collaborative projects, where bird club members fully understand the value of their data and feel that they are actively participating in activities that will inform management, changes in practices of data recording may be more feasible.

A further advantage of Fylde as a study area is that baseline data on pink-footed geese exist (Forshaw, 1983) with which to compare contemporary/future data. Furthermore, Fylde Bird Club have a large database on other farmland birds, many subject to recent declines (Gregory et al., 2004). Combining information on farmland birds, of conservation interest, with Pink-foot Goose data, could provide opportunities to implement conservation measures for multiple species.

6 Proposal for future work

6.1 General findings

- Temporal patterns and trends

- Obtain field-based information on monthly habitat usage in Fylde over the winter. Compare to published data on changing patterns of crop use as the winter progresses.
- Trial methods using remote sensed images to evaluate changing crop use over same monthly periods.

- Disturbance and ecology

- Gather data on feeding ecology, especially, movement patterns and energetics, with a view to informing mitigation measures.
- Obtain data on disturbance by wildfowl hunting, e.g., do geese patterns change after the shooting season closes? What are popular hunting sites? Is there information on hunt bags from specific sites?
- What happens when geese are disturbed? Are there different responses depending on preference for feeding site? That is, can preferred feeding sites be identified by returning after disturbance?

- Modelling field importance

- Investigate further predictors at field level, especially remote sensed data and Lidar-based surface elevation models with a view to establishing vegetation condition and refining field level visibility, also, spatial information on paths, tracks, proximity to villages or pedestrian traffic.
- Evaluate schemes to take into account the landscape scale availability of suitable habitat (that is, field types) within Fylde at any given time, e.g., using a model to inform a series of dynamic set aside areas for geese near roosting sites (e.g., Giroux & Patterson, 1995), as part of a renewed Environmental Stewardship scheme.

- Local stakeholders

- Work closely with local recorders to obtain field based information on pink-footed geese and improve recording techniques.
- Involve local recorders in other project activities, such as outreach work (raising awareness of region's importance for geese) and obtaining information from wildfowlers or farmers.

- Wider impacts for biodiversity conservation

- Incorporate information from other species of conservation interest into priority areas, especially farmland birds and evaluate any congruence

6.2 Specific proposal

We strongly recommend that, to equip planners with the proper tools to assess the impacts of potential developments on pink-footed geese in the coming decades, further ecological and modelling work be done on the Fylde population. This work should have strong input from local recorders (especially Fylde Bird Club) from its inception and incorporate the above recommendations. We believe that due to the collaborative implementation and the methods involved, the project would be relevant to aiding planning decisions in other regions, and with other species. Ideally, the objectives would be the following. Given that funding may be limited, we propose two potential projects, one including the full three objectives, and one ‘stripped-back’ proposal that includes objectives 1 & 2 only.

Objective 1. To fully develop and validate a 'broad-brush' model of Pink-footed goose usage across Fylde that will inform planners as to the likelihood and scale of negative impacts of developments in different regions of Fylde. Models will be tested for longevity by examining the degree to which zones of high habitat usage by geese change over the decades.

Objective 2. To develop fine-scale models identifying characteristics of individual fields that determine high, medium or low usage by Pink-footed goose – thereby creating a 'likely importance score' for each field.

Objective 3. To undertake detailed ecological work on feeding, movements, response to disturbance at different times of the winter, to inform planners as to likely impacts of loss of individual sites for pink-footed goose. These data will aid planners in ascertaining exact roles of individual sites on local goose ecology, helping them to prescribe survey work on geese at the planning stage and mitigation measures, where appropriate.

Objective	Methods and outcomes	Partial project	Full project
1. Model of goose usage across Fylde	We will work closely with Fylde Bird Club members, and integrate data with those from other sources, to define fully the use of different areas by geese across years and different months of the winter periods. The robustness of models will be tested across decadal periods to determine the 'life expectancy' of the model, and what supplementary data are needed to update the model in the future to account for changes in goose usage.	Y	Y
2. Field-level models	This strand of work will draw on data from local recorders and targeted work by MMU ecologists to model the characteristics of fields used by geese. A first step is to generate robust and accurate field-based predictor variables describing fields. As land use, and especially crop/pasture type is dynamic in the area, then accurate ways of identifying field type for the model need to be developed. A large dataset of field usage at different times of the winter will be gathered within two subsections of the Fylde area. This will be a high usage area and a mid-level usage area as identified in Objective 1. The resulting model accounting for differences in fields used and those not used will not be spatially explicit – but will allow similar fields to be identified in other areas (based on their characteristics). This will from an evidence base for planners to identify field types that if developed, will have greatest likelihood of impacting goose ecology.	Y	Y
3. Detailed ecological work	This will involve around 90 person-days of fieldwork plus considerable input from targeted fieldwork by local recorders. We will also explore the use of multiple data-loggers	N	Y

Objective	Methods and outcomes	Partial project	Full project
	to track individual geese through the winter. The fieldwork will yield very detailed data on habitat use and how this changes through the winter. A key component will be the calculation of a proxy for ‘calorific intake’ and ‘ecological importance’ that each field contributes to the local goose population at different stages of the winter. In effect, it will attempt to find the actual effect of ‘losing’ individual fields to development on the geese.		

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9 Appendices

Appendix 1. Interview form used during field visits.

Questionnaire for farmers - Natural England / Manchester Metropolitan University
Pink-footed Geese habitat suitability

Manchester Metropolitan University

1. Name: ______________________________

2. Field use

-Please list how you have used the fields in the map over the last 5 years.

-Please include information on presence of pink-footed geese, use of bird scarers, and hunting for the most recent year

Field	Year	Crop / Use (e.g. potato, pasture, wheat, etc)	Notes	Have you observed Pink-footed geese in this field? (yes/no)	Do you use bird scarers in this field (yes / no)	Do people hunt in this field? (yes/no)
	2014					
	2014					
	2014					
	2014					

3. Crop rotation

3.1 Do you have fixed crop rotation cycles?

e.g. 5 year cycle for potatoes?

3.2 If yes, please give some examples. If not, please explain how crops/field use is decided:

4. Pink-footed geese

Please provide further details of any observations of Pink-footed geese.

4.1 Have you seen them roosting? 4.2 Where? 4.3 How many?

4.4 Have you seen them feeding? 4.5 Where? 4.6 What? 4.7 In groups of how many?

4.8 Do they cause damage to fields/crops? 4.9 How much? 4.10 Doing what?

4.11 Are they present only at certain times of the winter? 4.12 How would you describe their movemen

4.13 Are they present only in certain types of field? 4.14 Which ones? 4.15 In which months?

5. Hunting

5.1 Does hunting of Pink-footed Geese take place on your land? 5.2 Approximate bag size per month?

5.3 Do any hunting syndicates or wildfowler groups use your land for hunting?

5.4 Do you have any idea of approximate hunting bags per month?

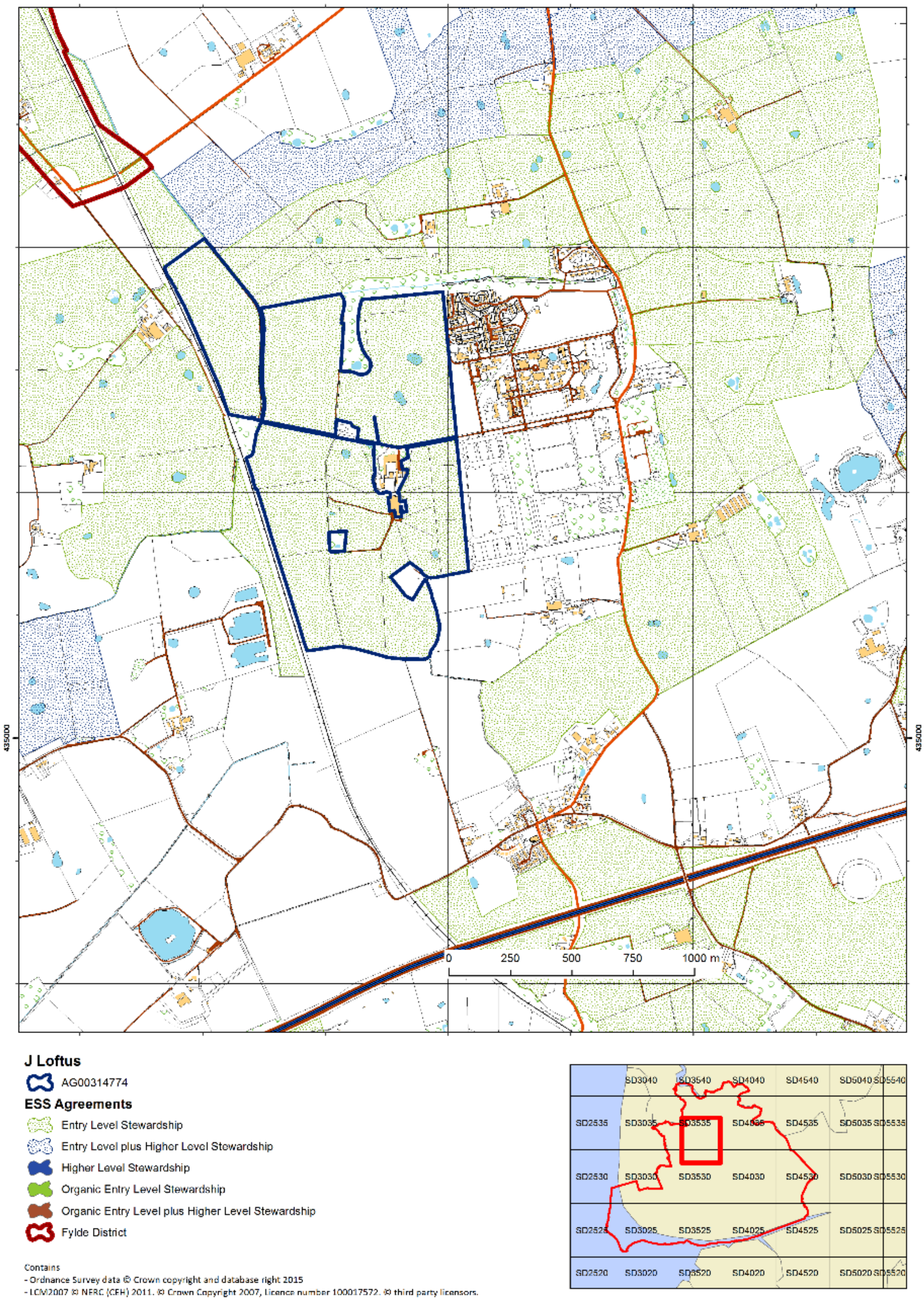
6. Bird scarers

6.1 Do you use bird scarers for any type of bird?

6.2 Is this use restricted to certain times of the year?

6.3 What kind of negative impacts of birds are you trying to prevent?

Appendix 2. Map of Loftus Farms, showing field boundaries.



Appendix 3. Participants at meeting between project and Fylde Bird Club

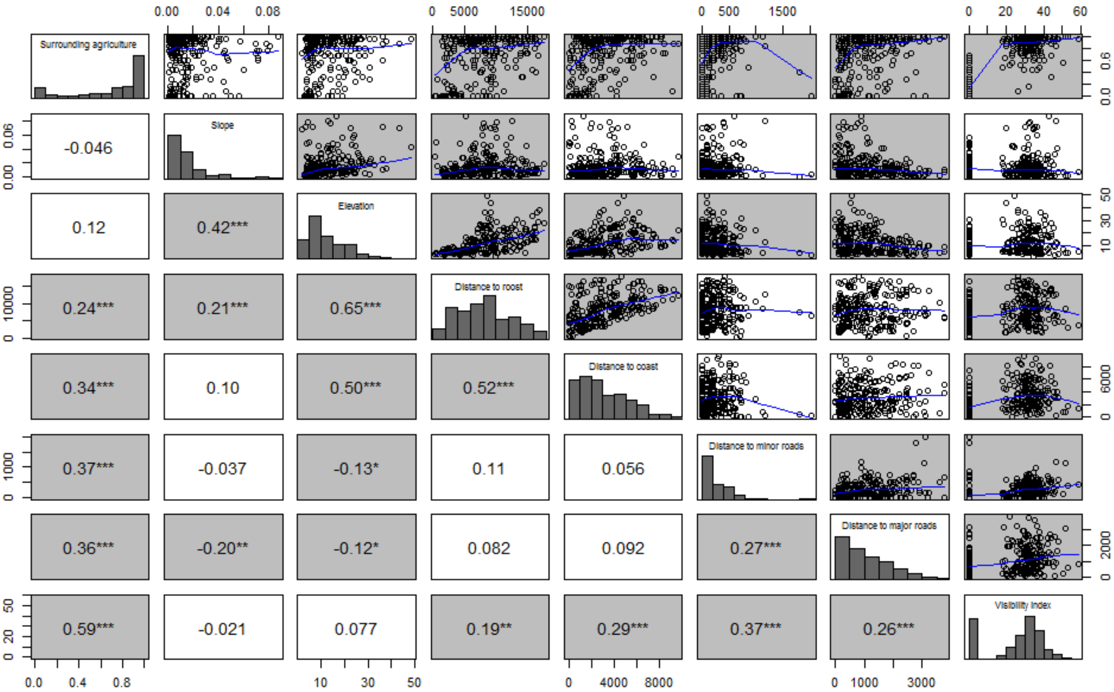
Fylde Bird Club

Paul Slade	Chairman
Paul Ellis	Secretary
Chris Batty	Database manager

MMU

Christian Devenish	Researcher
Stuart Marsden	Professor of Conservation Ecology
Chris Harrison	Researcher

Appendix 4. a) Correlations amongst predictor variables. Scatterplots with smoothers are shown in the upper diagonal, histograms of predictors on the diagonal, and spearman correlation coefficients are presented in the lower diagonal. Stars correspond to significance: *** p < 0.001; ** p < 0.01; * p < 0.05.



b) Variation Inflation Factor of predictors. Values below 5 are considered to imply a lack of multicollinearity.

Predictor	VIF
Surrounding agriculture	1.43
Visibility index	1.26
Slope	1.24
Elevation	1.73
Distance to roost	1.57
Distance to minor roads	1.16
Distance to major roads	1.23

See separate files for following appendices:

Appendix 5. Maps of study area showing presence points used in model. Point labels correspond to ID column in data base (Appendix 5).

Appendix 6. Data base of occurrence points provided by all sources for project.

Further information

Natural England evidence can be downloaded from our **Access to Evidence Catalogue**. For more information about Natural England and our work see **Gov.UK**. For any queries contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk** .

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