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An assessment of the numbers and distributions of wintering red-throated diver, little gull and common scoter in the Greater Wash

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Summary

The Birds Directive (Directive 2009/147/EC) requires member states to classify the most suitable territories for the conservation of rare and vulnerable species as Special Protection Areas (SPAs). To identify inshore areas that might be suitable for SPA classification 45 areas of search (AoS) were selected where potentially important numbers of these birds congregate outside the breeding season. The Greater Wash was one of these as it is known that seabirds and waterbirds use the Greater Wash area during winter. The existing SPAs fringing the Greater Wash area provide for a variety of bird features above mean low water. There is currently no marine provision for seabirds or sea duck. This report presents five seasons of aerial survey data (2002/03, 2004/05, 2005/06, 2006/07, 2007/08), using distance sampling methods and the mean of the highest counts from each winter to estimate numbers of birds in the Greater Wash. The resulting numbers of inshore wintering waterbirds using the Greater Wash were assessed against the UK SPA selection guideline thresholds (Stroud *et al* 2001). For species with numbers above the thresholds important aggregations were identified to inform a possible SPA boundary within the area of search.

Red-throated divers (*Gavia stellata),* were present within the Greater Wash in all surveys. The mean of peak population estimate taken over three winter seasons was 1,787 birds. Numbers of red-throated diver in the Greater Wash area therefore exceed 1% of the GB wintering population for red-throated divers (170 individuals), and the area is considered for SPA status under stage 1.1 of the UK SPA selection guidelines. Red-throated divers were distributed throughout the Greater Wash, the main concentrations being fairly mobile throughout the area both within and across years. The Greater Wash area supports 10% of the GB wintering population of red-throated diver and is the second most important site in the UK for this species after the Outer Thames Estuary.

Little gull (*Hydrocoloeus minutes*)*,* were present within the Greater Wash area of search in important numbers (2,153 individuals). This is the largest number of little gulls of any inshore area around Britain. The highest densities of little gull were concentrated in the area north-east of the Wash. Numbers of little gull recorded within the Greater Wash area of search showed high temporal variability with low numbers of birds recorded in some surveys. Such data are often difficult to analyse, therefore statistical advice was sought in producing a population estimate. There is no GB population estimate for little gull currently available, so little gull were assessed under stage 1.4 of the UK SPA selection guidelines.

Common scoter (*Melanitta nigra*), sometimes occurred in very small flocks of a few individuals and at other times in large flocks of >1,000 individuals. Standard distance sampling methods do not perform well when flock size ranges so widely, especially when the number of flocks recorded is relatively low, as was the case here. Consequently, data were pooled within seasons and a single population estimate for each season was produced, rather than several survey-specific estimates within each season as for other species. Each season-specific estimate had narrower confidence intervals compared with the survey-specific estimates, some of which had unacceptably large confidence intervals. A mean of these season-specific estimates was then calculated (mean = 3,517 individuals). This mean of the four season-specific common scoter estimates was less than 1% of the biogeographic wintering population for the species (5,500 birds), so common scoter did not meet the stage 1.2 threshold of the UK SPA selection guidelines.

The area of search within the Greater Wash did not hold sufficient numbers to support an assemblage (>20,000 waterfowl or seabirds) under Stage 1.3 of the UK SPA selection guidelines.

Contents

1 Introduction

In 1979, the European Commission adopted the European Council (EC) Directive on the conservation of wild birds, commonly known as the Birds Directive (Directive 2009/147/EC). It requires Member States to classify the "most suitable territories" in number and size as Special Protection Areas (SPAs) for species listed on Annex I of the Directive and regularly occurring migratory species.

The UK SPA selection guidelines for the identification of SPAs advise that sites should be identified in two stages (Stroud *et al* 2001). While Stage 1 identifies areas that are likely to qualify for SPA status, Stage 2 further considers these areas to select the most suitable areas in number and size for SPA classification.

Stage 1 of the Guidelines are:

1. Stage 1.1, an area is used regularly by 1% or more of the Great Britain (GB) population of a species listed in Annex I of the EC Birds Directive;
2. Stage 1.2, an area is used regularly by 1% or more of the biogeographic population of a regularly occurring migratory species, other than those listed in Annex I of the EC Birds Directive;
3. Stage 1.3, an area is used regularly by an assemblage of more than 20,000 waterbirds comprising at least two species;
4. Stage 1.4, where the application of stages 1.1-1.3 does not identify an adequate suite of areas, additional sites may be selected if they meet one or more of the Stage 2 guidelines.

In order to help identify inshore areas that might be suitable for SPA classification for waterbirds (mostly divers, grebes, and seaduck), 45 areas of search (AoS) were selected where potentially important numbers of these birds congregate outside the breeding season. The Greater Wash was one these areas of search as the existing literature indicated that large numbers of red-throated diver occurred there annually outside the breeding season.

Natural England (NE) advises the UK Government of the most suitable areas for classification as SPAs in UK territorial waters adjacent to England (within 12nm). The aim of this report is to provide NE with the evidence necessary to support its advice to the UK Government on the relative importance of the Greater Wash area in a UK context for inshore wintering waterbirds.

This report presents population estimates for waterbirds in the Greater Wash area of search during the winter period October to March, inclusive, based on aerial survey data collected during the period 2002 to 2008. The numbers of these species are assessed against the population thresholds advised in the UK SPA selection guidelines. Musgrove *et al* (2013) was used for UK population estimates and biogeographic population estimates were from Wetlands International, WPE5 (2015). Where species populations meet these thresholds in the area of search important aggregations are identified with a view to delineation of a possible SPA boundary. The Greater Wash area was also assessed at Stage 1.3 of the Guidelines to determine whether sufficient numbers were present to support an assemblage of >20,000 waterfowl or seabirds.

2 Methods

2.1 Greater Wash area of search

The Greater Wash, as defined herein, stretches from Bridlington Bay (East Yorkshire) in the north, to where the Norfolk coast meets the Suffolk coast in the south (Figure 1). Some gaps along the inshore boundary of the area of search are an artefact of a block based survey design (Figure A1, Appendix 3). Data were collected in a series of survey blocks and were not originally designed for the purpose of SPA identification.

The Wash is the largest estuarine system in the UK and comprises very extensive saltmarshes, major intertidal banks of sand and mud, shallow waters and deep channels such as the Lynn Deeps channel. It is fed by the rivers Witham, Welland, Nene and Great Ouse that drain much of the east midlands of England. Several SACs and SPAs have been designated within the Greater Wash area (Stroud *et al* 2001). The SACs classified within this area (The Wash and the North Norfolk Coast, Haisborough, Hammond and Winterton, Humber Estuary, Inner Dowsing, Race Bank and North Ridge) protect Annex I habitat types under the Habitats Directive (EC 2007; consolidated version 1.1) including sandbanks, mudflats and coastal lagoons (Figure 2). There are seven SPAs that have been classified in or adjacent to the Greater Wash area of search (Hornsea Mere, Humber Estuary, Gibraltar Point, The Wash, North Norfolk Coast, Great Yarmouth and North Denes and the Outer Thames Estuary (Figure 1). Of these, four (Humber Estuary, The Wash, North Norfolk Coast the Outer Thames Estuary SPAs) provide protection for some waterbirds species. The Wash SPA includes some estuarine areas that are below mean low water, however, with the exception of the Outer Thames Estuary, these are terrestrial SPA and mean low water is their seaward extent. The Outer Thames Estuary SPA, which is adjacent to the Greater Wash area of search, protects wintering red-throated diver under Article 4.1 of the Birds Directive.

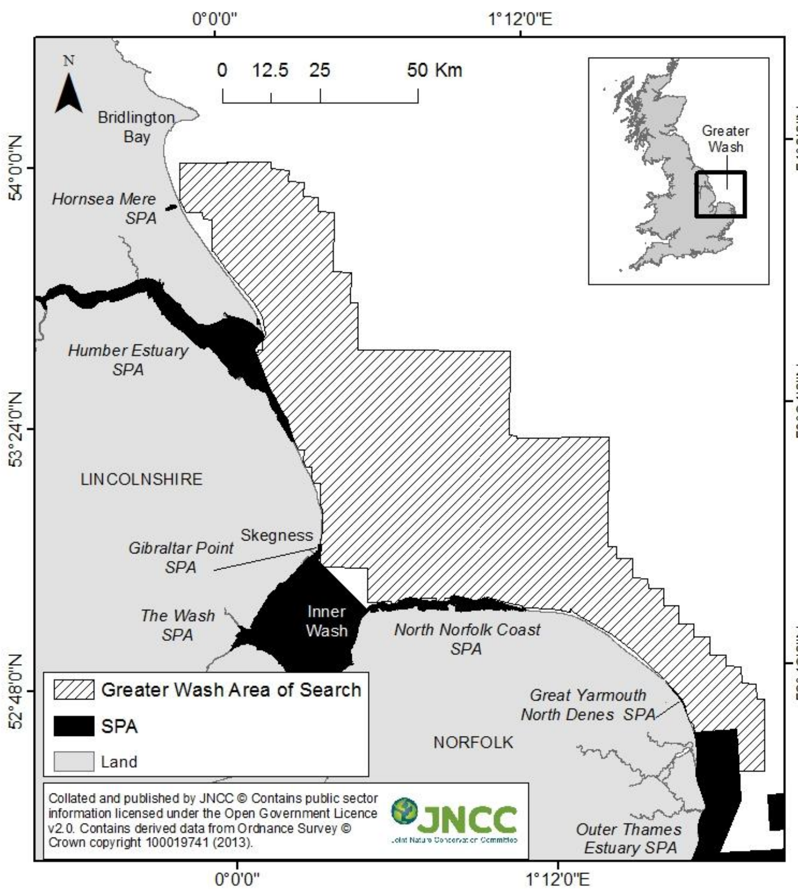

Figure 1. Map indicating the location of existing SPAs in relation to the Greater Wash area of search.

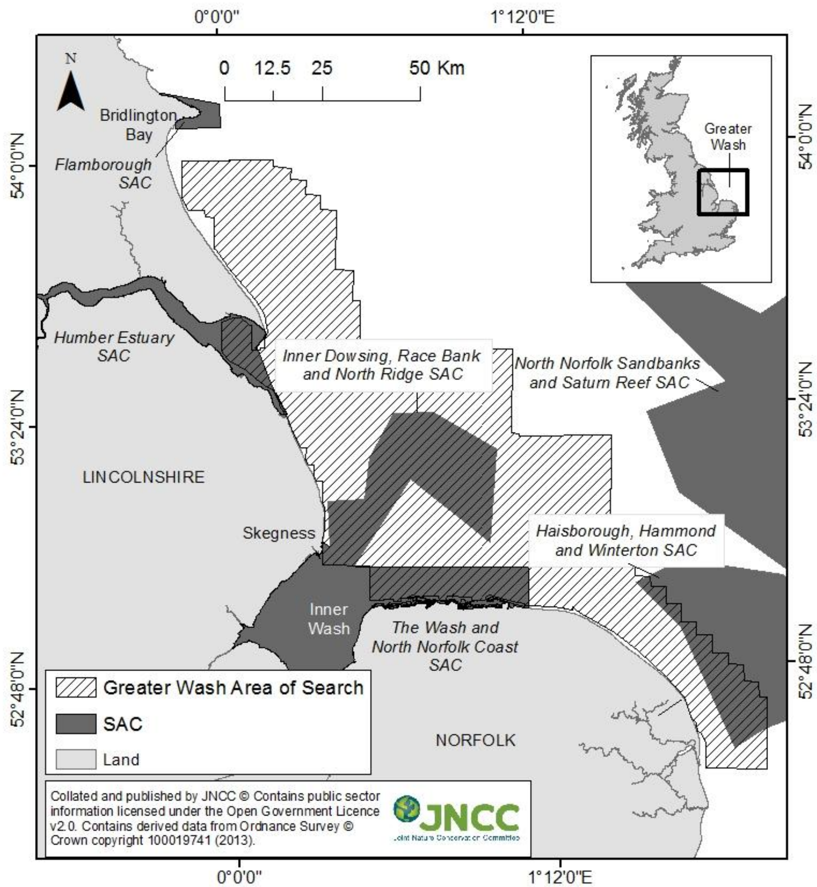

Figure 2. Map indicating the location of existing SACs in relation to the Greater Wash area of search.

2.2 Survey design

The Greater Wash area of search (AoS) was one of 45 inshore sites across the UK that were identified in 2000, as supporting potentially important numbers of inshore waterbirds outside the breeding season (Webb & Reid 2004). Existing data and literature were used to initially identify these areas of search.

Aerial survey is usually the preferred method for data collection to inform marine SPA classification for inshore wintering aggregations of waterbirds (Webb & Reid 2004; Camphuysen *et al* 2004). Aerial surveys allow large areas of water to be surveyed in a relatively short time period, thereby enabling repeat surveys to be undertaken. They generally provide more robust estimates of the numbers of wintering divers and seaduck than boat-based surveys, particularly where species are prone to disturbance by boats (Schwemmer *et al* 2011). However, species that aggregate very close to the coast are often missed by visual aerial surveys as the aircraft has to climb or turn as it approaches land. The seaward limit of the areas of search was defined by water depth, based on expert knowledge of the ecology of the target species. Where feasible, the areas of search extended to cover inshore waters up to 30-50m depth.

Aerial surveys of the Greater Wash were carried out over eight winter seasons (1988/89, 1989/90, 1991/92, 2002/03, 2004/05, 2005/06, 2006/07, and 2007/08). Surveys in the first three seasons were conducted using strip-transect methods, which provide total counts of birds using the area. Total counts underestimate the true numbers of birds, as birds further from the observer are more likely to be missed. The surveys from 1988/89, 1989/90, and 1991/92 were therefore excluded from further analysis as more recent better quality survey data were available. The other subsequent surveys deployed line-transect sampling techniques, and used distance analysis, to provide a corrected estimate of the total numbers of birds in the area. Distance analysis was conducted using the software *Distance* 6.0 (see section 2.4.1; Thomas *et al* 2010).

A number of repeat surveys (two to four) of the Greater Wash area of search were undertaken within each winter season. In some cases, one survey took a number of days to complete and although the dates were not always consecutive they were as close as possible given weather conditions and logistical constraints. This is not ideal as there is the potential for double-counting birds that have moved and changed their distribution within what is considered a single survey. Conversely, birds could have moved such that they avoid being counted on either survey, so there was no systematic bias towards under- or overestimating numbers. Table 1 shows the dates of each survey and the number of repeat surveys within a winter season. The spatial coverage of surveys within the area of search was not consistent; Figure A1 Appendix 3, show the transect lines for each of the surveys within the study area. The data and survey coverage were carefully assessed prior to analysis to ensure that only representative surveys were included. A survey was representative if it covered the main distribution of the bird population both spatially and temporally i.e. the survey should have sufficient spatial coverage of the area of search, considering individual species distributions and surveys within a season should sample across any seasonal variation in the numbers of birds present. Further detail is provided in the results section for each species.

Table 1. Dates for surveys undertaken in the Greater Wash area of search. In many cases one survey of the area was split over a number of dates, the dates that together make a single survey are shown in the table below.

Winter season	Survey	Date
2002/03	Feb-2003	13 Feb 2003
		14 Feb 2003
		17 Feb 2003
	Mar-2003	13 Mar 2003
		14 Mar 2003
2004/05	Oct-Nov 2004	31 Oct 2004
		03 Nov 2004
		11 Nov 2004
		19 Nov 2004
		17 Nov 2004
		20 Nov-2004
	Dec-2004	23 Nov 2004
		08 Dec 2004
		09 Dec 2004
	Jan-Feb 2005	26 Jan 2005
		01 Feb 2005
		02 Feb 2005
	Feb-Mar 2005	26 Feb 2005
		03 Mar 2005
		09 Mar 2005
		10 Mar 2005

Winter season	Survey	Date
2005/06	Nov-2005	07 Nov 2005
		09 Nov 2005
		15 Nov 2005
		18 Nov 2005
	Nov-Dec 2005	28 Nov 2005
		29 Nov 2005
		30 Nov 2005
		14 Nov 2005
	Jan-Feb 2006	12 Jan 2006
		18 Jan 2006
		19 Jan 2006
		02 Feb 2006
		11 Feb 2006
	Feb-Mar 2006	19 Feb 2006
		04 Mar 2006
		10 Mar 2006
		11 Mar 2006
		14 Mar 2006
		16 Mar 2006
2006/07	Jan-Feb 2007	16 Jan 2007
		01 Feb 2007
		02 Feb 2007
		17 Feb 2007
		19 Feb 2007
	Feb-Mar 2007	23 Feb 2007
		07 Mar 2007
2007/08	Nov-2007	15 Nov 2007
	Dec-2007	04 Dec 2007
		14 Dec 2007[1]
		30 Dec 2007[1]
	Feb- 2008	16 Feb 2008
	Feb-Mar 2008	28 Feb 2008
		30 Mar 2008[1]
		31 Mar 2008[1]

[1] Survey includes additional areas that were not part of the original AoS of the Greater Wash. Areas outside the original AoS were not included in the analysis.

2.3 Data Collection

A summary of data collection methods is presented here, but see Kahlert *et al* (2000) and Camphuysen *et al* (2004) for more detail on general survey methods. Data were collected along line transects to derive population estimates; distance sampling is described in more detail in the data analysis section below.

Surveys were carried out from a Partenavia PN68 aircraft flying at an altitude of 76m (250ft) and a speed of approximately 185kmh^{-1} (100 knots). The aircraft flew in a systematic pattern of line-transects, designed to repeatedly cross environmental gradients such as sea depth. In 2003, line transects were spaced 4km apart, but in subsequent surveys transects were spaced 2km apart to ensure better coverage. Following Kahlert *et al* (2000), this distance was chosen to maximise the detection of birds, or flocks of birds located between transects, while minimising the risk of double counting birds on neighbouring transects.

Two observers recorded numbers of birds (identified to species level where possible) and time of observation from either side of the aircraft. A Global Positioning System (GPS) recorded the location of the aircraft. All bird observations were allocated to one of four distance bands (A = 44-162m, B = 163-282m, C = 283-426m and D = 427-1000m) based on the perpendicular distance of the bird(s) from the aircraft track line. Data were collected to the nearest second, though an error margin of up to five seconds (which equates to a distance of approximately 250m) is possible between the exact location of the bird and the time at which it was recorded. Observers were unable to see birds directly below the aircraft so the closest distance band started 44m from the aircraft. Observers determined these distances using fixed angles of declination from the visual horizon, measured using a clinometer. For each bird, or flock of birds, the time at which it was perpendicular to the flight path of the aircraft was recorded. It was not always possible to assign birds to a species during aerial surveys, and in such cases birds were assigned to the lowest taxonomic level possible. The survey data analysed in this report were collected over five winter seasons from 2002/03 to 2007/08 between the months of October to March, inclusive.

2.4 Number of birds in the Greater Wash area of search

The UK SPA selection guideline thresholds are provided as a percentage (1%) of the national or biogeographic populations of a given species (Stroud *et al* 2001). The biogeographic population estimates used to assess regularly occurring migratory species, under Stage 1.2 of the UK SPA selection guidelines, are published in *Waterbird Population Estimates* WPE5 (Wetlands International, 2015). The Great Britain population estimates used to assess Annex 1 species, under Stage 1.1 of the UK SPA selection guidelines, are published in (Musgrove *et al* 2013).

To estimate the number of individuals within the Greater Wash area of search, a population estimate was determined for each species and survey[1], with the help of Distance Sampling. A peak count was then identified from these individual survey estimates within a winter season and an average of the peak counts from the five most recent winter seasons was calculated to produce the mean of peak population estimate for the area of search. The mean was taken over five seasons where the data were available. The mean of peak was assessed to determine if the numbers present exceeded the thresholds on a regular basis under the UK SPA Selection Guidelines (Stroud *et al* 2001).

Little gull is considered under stage 1.4 of the Guidelines as there is no GB population estimate currently available against which to assess it. It is nonetheless relevant to establish

[1] Or season for the pooled data analysis of common scoter, only one average estimate of the population for each season was produced.

the numbers of little gull that regularly occur to determine the relative importance of this area, and thereby identify the most important site/s for this Annex 1 species as required under the Birds Directive. It has been the long-standing practice amongst the statutory nature conservation bodies to require at least 50 individuals to be regularly present for the area to be considered for SSSI (Site of Special Scientific Interest) site selection and this has also applied to SPA site selection (Stroud *et al* 2001).

To assess whether the numbers of birds present in the area of search exceeded the Stage 1.3 threshold (>20,000 individuals) of the UK SPA selection guidelines, the size of the waterbird assemblage was calculated. The mean of peak population estimates produced for each individual species were summed to produce an assemblage total (Table 2).

2.4.1 Distance sampling

Distance sampling uses a detection function to model the decline in the probability of detecting an individual with increasing distance from the transect line. By assuming that the observer has seen all birds on the transect line closest to the aircraft, the numbers of undetected individuals can be estimated with help of the detection function, and the total number of individuals in the survey area - including missed individuals - can be estimated for each survey.

Distance sampling is widely used in ecology to estimate the numbers of animals in an area when it is not feasible to make a complete count (Buckland *et al* 2001). It has also been used in other parts of JNCC's marine SPA work (e.g. O'Brien *et al* 2012; O'Brien 2014). Distance analysis undertaken by WWT Consulting was applied using the R (R Core Team 2013) package 'Distance' (Miller 2013). The software Distance 6.0 was used by JNCC to analyse numbers of little gull and red-throated diver. See Thomas *et al* (2010) for more information on distance sampling methods.

When a sufficient number of observations were made in different distance bands, a detection function was chosen that provided the best fit to the data on the basis of minimising the Akaike Information Criterion (AIC). A half-normal or hazard-rate model with one or two adjustment terms, using the size-bias regression method of cluster size estimation, provided the best fit. Where possible, non-parametric bootstrapping, re-sampling transects as samples with replacements, was used to produce 95% confidence limits for abundance estimates (Buckland *et al* 2001).

On several of the surveys, conventional distance sampling methods could not be used to provide population estimates for little gull, as the numbers recorded were too low to allow a useful survey-specific detection function to be modelled. A single global detection function was created based on all little gull survey data for the Greater Wash (Figure 3). This improves the model for the detection function but does not bias the density estimate for individual surveys. Pooling data helps to overcome problems of small sample sizes, the global detection function was then used to estimate the number of little gulls that were present on each individual survey, based on the number of birds and the distance band in which they were recorded on that survey.

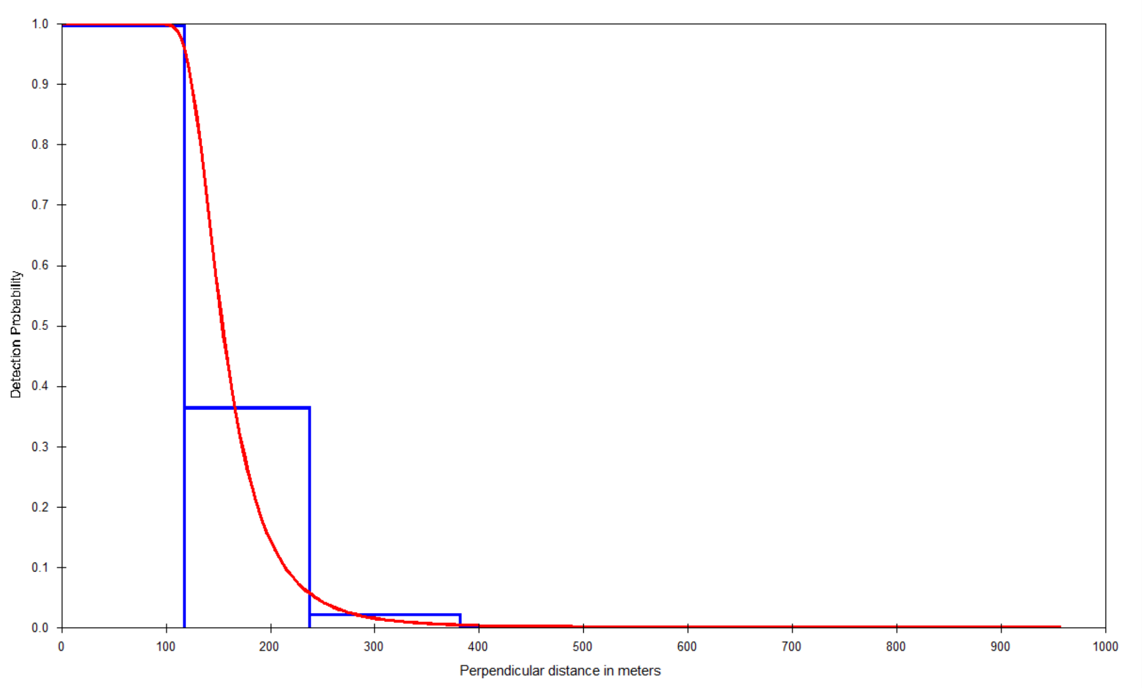

Figure 3. Global detection function (red line) fitted to little gull observations (blue histogram) from the Greater Wash. Perpendicular distance in metres = x axis, detection probability = y axis. This global detection function provides a reasonably good fit to the data; this was not the case for many of the surveys where few data were available. The Greater Wash histogram has data in Bands A, B and C presented separately.

There was considerable variation in the numbers of common scoter recorded during the surveys of the Greater Wash (15-3,217). Most of the surveys recorded few flocks consisting of relatively low numbers of common scoter, but some surveys (13 Feb 2003, 26 Feb 2005, and 4 Dec 2007) recorded very large flocks. In addition, the encounter rate variability was also very high based on the very low number of flocks seen per transect. This caused some problems in producing a reliable population estimate. The initial outputs from conventional Distance analysis techniques had a lot of variation around the mean, indicated by a very high percentage in component variance for cluster size, reflecting what could be seen in the raw numbers. To overcome these problems all flocks numbering more than 1,000 individuals were removed for the calculation of the Distance function, but re-added post-analysis as raw counts in order to generate total abundance estimates. However, the desired effect of reducing variability in cluster size and encounter rate was not accomplished; confidence intervals around the population estimates remained very wide, e.g. 5,533 (167-44,700) (Table 5). Common scoter data were combined from all surveys within the same season and a pooled detection function was generated for each winter season; this was used to calculate an average abundance estimate for the season with 95% confidence intervals. There is a strong chance that the same birds will be counted multiple times in multiple surveys, but that is counter-acted by the total effort (or line length) being the sum of the lengths of all replicate surveys within a season. This approach assumed that the largest flocks would be equally detectable over all distance bands. Pooling data within a season succeeded in reducing the confidence intervals and produced a more reliable population estimate than the standard procedure. However, as this effectively produces an average population estimate over the surveys of a given season, no survey specific results are available, and the average population estimate will be an underestimate compared with the mean of peak estimates, which were calculated as a standard for other species. A similar approach was used previously to produce a population estimate for common scoter in Carmarthen Bay (Buckland *et al* 2012; Burt 2010).

2.4.2 Regularity

An assessment was made of the regularity with which numbers of birds in excess of their 1% population thresholds occurred within the Greater Wash area of search. The UK SPA Selection Guidelines define regular occurrence as:

- the requisite number of birds is known to have occurred in two thirds of the seasons for which adequate data are available, the total number of seasons being not less than three; or
- the mean of the maxima of those seasons in which the site is internationally important, taken over at least five years, amounts to the required level.

Webb and Reid (2004) considered the most appropriate definition to use for inshore waterbird aggregations is two thirds of the seasons for which adequate data are available, the total number of seasons being not less than three. Using the mean of peak method for assessing regularity "...may be inappropriate in the marine environment, where transient aggregations of prey might lead to irregular occurrences of very large numbers of some inshore birds at a site."

Therefore this report, with reference to Webb and Reid (2004), considers that a population is regularly occurring if "the requisite number of birds is known to have occurred in two thirds of the seasons for which adequate data are available, the total number of seasons being not less than three".

However, there are circumstances in which the mean of peaks method would be more appropriate. For example where there is evidence that a site provides a severe weather refuge resulting in unusually high counts in one year.

2.5 Identifying important aggregations within the area of search

It was assumed that the areas supporting the highest densities of birds represented the most suitable areas to protect for those species. Where possible, a modelled density surface was produced on which a boundary could be drawn around the highest estimated densities for each species whose population estimate exceeded the relevant UK SPA Selection Guidelines thresholds.

2.5.1 Modelling bird densities

For each species, a mean density surface was produced that showed the distribution and estimated density within the Greater Wash area of search. Continuous density surfaces were generated for each individual survey using Kernel Density Estimation (KDE) applied to the raw bird observations. KDE smoothed the point density estimates into a surface of relative densities (Silverman 1998), displayed on a grid of 1km by 1km cells. The chosen bandwidth, in this case 3km, ensures the density estimate is produced from data collected on at least one and usually two transects. This retains sufficient detail in the bird distribution patterns to allow identification of areas of higher density without excessively smoothing and flattening out high density areas (O'Brien *et al* 2012).

The density surface was restricted to the area where data were collected, defined as the area within 1km of any line transects, to ensure it was not predicting densities over areas without survey data. In order to obtain density estimates from the KDE surfaces that accorded with the Distance corrected population estimates, the density values in all cells were rescaled to match the Distance estimate for each survey. In the case of common scoter, a mean density surface of all surveys (within a winter season) was created first before a pooled population estimate for the winter season (rather than a survey period) was used to re-scale the density surface.

Finally, a single mean modelled density surface for the area of search was created for each species by overlaying the KDE surfaces from all surveys (or seasons for common scoter) and calculating the mean density in each 1km x 1km cell.

All surveys were given equal weight, irrespective of survey month and year. The resulting mean density surface might be described as representing an average or typical indication of where birds regularly occur in higher numbers. However, because November and December were covered slightly less frequently than January and February, the average distribution might be biased towards the distributions at the beginning of the calendar years.

3 Results

3.1 Numbers of birds in the Greater Wash area of search

A population estimate for every species was produced for each representative survey. A survey was representative if it covered the main distribution of the bird population both spatially and temporally. These population estimates are presented in Table 2. From this table the mean of the peak population estimate, based on a minimum of three winter seasons was calculated for each species. The (mean of peak) numbers were then compared with the relevant 1% thresholds in the SPA Selection Guidelines to determine whether the Greater Wash qualified for SPA status for each species.

Red-throated diver occur in nationally important numbers (>1% of the GB population) in the Greater Wash and numbers of little gull here are the highest of the inshore areas of search around the UK, this area should therefore be considered for SPA status (Table 2).

The Greater Wash area of search did not support sufficient numbers to exceed the threshold for an assemblage (>20,000 waterfowl or seabirds) under Stage 1.3 of the UK SPA selection guidelines (Table 2).

Surveys in the seasons 2002/03, 2006/07 and 2007/08 had limited spatial coverage of the area of search (AoS) and may therefore underestimate the true numbers of birds present. The peak estimates that were used in the mean of peak calculation are indicated in the table. Some of the population estimates were unreliable indicated by wide confidence intervals, as a result of low counts of birds recorded during the survey. These are indicated by grey text in Table 2, and the raw counts are provided.

Table 2. Population estimates for species surveyed during WWT consulting aerial surveys between 2002 and 2008. Surveys marked with an asterix * had limited spatial coverage of the area of search and may therefore underestimate the true numbers of birds present. Numbers in **bold** text indicate the peak estimates that were used in the mean of peak calculation. Grey text indicates wide confidence intervals around the population estimates (raw counts in brackets).

season	2002/03*	2004/05				2005/06				2006/07*		2007/08*			**MoP**	1% GB	**1% SPA guideline**
species	Feb/ Mar	Oct/ Nov	Dec	Jan/ Feb	Feb/ Mar	Nov	Nov/ Dec	Jan/ Feb	Feb/ Mar	Jan/ Feb	Feb/ Mar	Nov	Dec	Feb/ Mar			
black-headed gull	**59**	151	**461**	230	(83) 351	161	(83) **412**	75	352	0	**77**	0	(5)**21**	0	206	22,000	22,000
great cormorant	**0**	**51**	26	42	(1)4	17	**94**	34	34	(1)3	(4)**17**	8	**42**	0	41	350	1,200
common gull	**17**	81	**759**	596	(106) 631	175	187	313	**1,084**	**1,473**	585	182	25	**183**	703	7,000	17,250
common guillemot	**0**	0	**0**	0	0	0	0	0	**0**	0	(1)**4**	0	0	**0**	1	-	20,000
common scoter	**3,150**		**7,686**				**889**						**2,341**		3,517	1,000	5,500
common eider	**0**	(5)21	0	**47**	(5)21	0	(2)10	0	(3)**13**	0	**303**	**67**	0	0	86	600	10,300
northern fulmar	**59**	55	257	**556**	320	248	**633**	127	413	171	**173**	**68**	30	58	298	-	20,000
great black-backed gull	(1)**8**	388	**632**	358	34	29	**301**	138	30	**222**	9	8	**42**	(1)4	241	760	4,350
great crested grebe	**0**	0	0	0	(1)**4**	0	**0**	0	0	**0**	0	0	0	(1)**4**	2	190	3,500
great northern diver	**0**	0	**43**	0	0	0	0	(1)**4**	(1)4	**8**	0	0	**0**	0	11	25	25
northern gannet	**0**	**305**	30	17	55	**736**	35	95	(48)255	74	**259**	(2)4	**8**	(2)8	262	-	9,700
herring gull	**50**	**658**	424	106	13	17	241	276	**640**	556	**563**	34	**59**	34	394	7,300	22,000
black-legged kittiwake	**372**	**986**	931	692	417	**1,411**	856	338	405	435	**450**	**362**	88	183	716	-	66,000
lesser black-backed gull	(1)8	(1)4	**244**	25	21	**46**	45	26	(1)4	**30**	9	**13**	0	(1)4	68	1,200	5,500
little gull		**2,645**	884	45	0	**1,660**	280	169	23	0	8	**653**	112	8	**2,153**	-	50
puffin	**0**	**0**	0	0	0	**0**	0	0	0	0	(1)4	**0**	0	0	1	-	135,000
razorbill	**0**	**0**	0	0	0	**0**	0	0	0	0	(1)4	**0**	0	0	1	-	13,800
red-throated diver	608 **1,431**	787	1,490	1,149	**1,525**	754	750	2,026	**2,405**						**1,787**	170	170
red-breasted merganser	**0**	(1)4	0	(5)**21**	0	0	(2)**10**	0	0	0	0	8	(7)**30**	25	12	84	1,700
shag	(1)**8**	0	0	(1)**4**	0	**0**	0	0	0	0	0	0	0	(1)**4**	3	1,100	2,000
velvet scoter	**0**	**0**	0	0	0	0	0	(3)**13**	0	0	0	**0**	0	0	3	25	4,500
shag/ cormorant	(1)**8**	9	0	**25**	(1)4	(1)4	(1)5	(1)4	**13**	(2)**8**	0	**0**	0	0	11	-	-
large gull sp.	**53**	**207**	180	65	198	72	122	80	**224**	74	**86**	17	(11)**46**	30	123	-	-

season	2002/03*	2004/05				2005/06				2006/07*		2007/08*			**MoP**	1% GB	**1% SPA guideline**
species	Feb/ Mar	Oct/ Nov	Dec	Jan/ Feb	Feb/ Mar	Nov	Nov/ Dec	Jan/ Feb	Feb/ Mar	Jan/ Feb	Feb/ Mar	Nov	Dec	Feb/ Mar			
black-backed gull sp.	**59**	435	**528**	140	59	55	**185**	162	21	**250**	55	29	(65) **274**	(1)4	259	-	-
grey gull spp.	**262**	817	**1,635**	768	566	254	**478**	474	436	**876**	294	**119**	84	0	674	-	-
duck sp.	**0**	0	(300) **323**	(3)13	0	(3)13	(45) **223**	(3)13	0	0	**0**	**0**	0	0	109	-	-
small gull sp.	**0**	0	**286**	139	47	415	**951**	55	157	175	**205**	**224**	(7)30	201	333	-	-
gull sp.	**180**	678	**896**	406	579	264	241	290	**541**	**442**	164	**207**	42	109	453	-	-
grebe sp.	**0**	0	(1)4	0	(7)**30**	0	(5)**25**	0	(3)13	0	**0**	0	0	(3)**13**	14	-	-
auk sp.	**528**	**10,248**	6,426	5,099	3,835	**3,623**	3,589	3,173	1,758	**4,192**	3,207	1,431	639	**1,495**	4,017	-	-
Assemblage															16,497	**(<20,000)**	

3.1.1 Red-throated diver

Red throated divers were observed in all surveys of the Greater Wash between the winter seasons of 2002/03 and 2007/08. There were generally higher numbers present in the surveys undertaken during January to March, reflecting the period when peak numbers of birds occur in Britain (O'Brien *et al* 2008). A large proportion (81%) of diver observations were recorded as 'unidentified diver'. It was noted in Cranswick *et al* (2003) that many of these unidentified divers were thought to be red-throated diver but only those positively identified were recorded to species level. Of the positively identified divers, all were red-throated divers, apart from 12 great northern divers. Consequently, analyses were performed on combined red-throated and unidentified diver records, the latter being assumed to be red-throated divers; the small amount of error (4.7%) relating to other diver species among the unidentified divers was deemed acceptable. The proportion of 4.7% of great northern divers among the unidentified divers suggests that this species could exceed its default population threshold of 50 individuals on a regular basis in the Greater Wash area of search. However, better data with positive identification of this species would be required to justify considering it as a feature of interest in the possible SPA. The population estimates for each survey are presented in Table 3 below. The spatial coverage varied considerably between surveys (Figure A1, Appendix 3) and therefore some surveys that covered only a small part of the area of search were considered unrepresentative of the true numbers and distribution of red throated divers within the Greater Wash area of search. Unrepresentative surveys (2006/07 and 2007/08) are identified by grey text in Table 3 and were excluded from the analysis. Survey coverage in 2003 did not extend to the northern and southern areas of the Greater Wash area of search these surveys were retained in the analysis but it is likely they may underestimate numbers of red-throated diver within the Greater Wash area of search. Numbers of red throated diver in the Greater Wash area of search exceeded 1% of the GB wintering population estimate (170 individuals) in all surveys. Red-throated divers can therefore be considered to be regularly present with numbers exceeding the relevant threshold in the Greater Wash, and it can be considered further for classification. The mean of peak (1,787) exceeds the 1% threshold based on three winter seasons (Table 2).

Table 3. Population estimates for red-throated diver in the Greater Wash area of search. A number of surveys were disregarded at this stage as there was low confidence in the population estimate; these are indicated by grey text in the table. **Bold** text indicates the estimate used to calculate the mean of peak. CI indicates confidence intervals; n indicates the total number of individuals recorded during each survey period while Obs. refers to the number of clusters that were input to the analysis.

	Survey	Estimate	%CV	Lower CI	Upper CI	n	Obs.
2002/2003	Feb 2003	608	24.4	336	945	39	35
	Mar 2003	**1,431**	31.4	787	2,462	147	85
2004/2005	Oct/Nov 2004	787	24.7	569	1,149	131	121
	Dec 2004	1,490	17	982	2,041	145	129
	Jan/Feb 2005	1,149	20.9	723	1,600	126	120
	Feb/Mar 2005	**1,525**	18.3	1,052	1,968	226	198
2005/2006	Nov 2005	754	21.1	470	1,139	83	79
	Nov/Dec 2005	750	22.1	484	1,064	85	77
	Jan/Feb 2006	2,026	20.2	1,226	2,959	274	181
	Feb/Mar 2006	**2,405**	15.1	1,877	3,308	348	268

2006/2007	Jan/Feb 2007	Unrepresentative of red-throated diver distribution, excluded from the analysis					
	Feb/Mar 2007	Unrepresentative of red-throated diver distribution, excluded from the analysis					
2007/2008	Nov 2007	Unrepresentative of red-throated diver distribution, excluded from the analysis					
	Dec 2007	Unrepresentative of red-throated diver distribution, excluded from the analysis					
	Feb 2008	Unrepresentative of red-throated diver distribution, excluded from the analysis					
	Feb/Mar 2008	Unrepresentative of red-throated diver distribution, excluded from the analysis					
Population estimate (mean of peak)		**1,787**	-	-	-	-	

3.1.2 Little gull

Little gulls are difficult to distinguish from other small gull species on aerial surveys so many little gulls may have been recorded as 'small gull species'. Little gulls were certainly under recorded on some aerial surveys but it is impossible to estimate the proportion of birds recorded as 'small gull species' that were actually little gulls. The true numbers of little gull within the survey area may have been at least double that recorded (Cranswick, *pers. comm.*). Only birds identified to species as little gulls were included in the analyses, so the population estimates presented may underestimate the true numbers of birds.

There was a strong seasonal pattern evident in the data with high numbers of little gull recorded at the start of the winter period (Oct/Nov/Dec) and fewer birds present at the end of the winter period (Jan/Feb/Mar).

Survey data were available for five winter seasons (2002/03 - 2007/08) however observers were not specifically requested to record little gull in the 2002/03 surveys, and these surveys were not included in the analysis. The spatial coverage of the surveys in 2006/07 and 2007/08 was insufficient to provide a representative estimate of the numbers and distribution of little gull within the Greater Wash area of search. In addition, surveys in the 2006/07 season were undertaken between January and March, but not in November or December, when peak numbers of little gull were recorded in other years. These seasons were therefore excluded from the analysis. Representative population estimates were only available for two seasons (2004/05 and 2005/06).

There is currently no GB population threshold against which to assess whether little gull exceeds the UK SPA selection guidelines (Musgrove *et al* 2013) so a default threshold of 50 birds was applied (Stroud *et al* 2001). Of the seven surveys on which little gulls were observed in 2004/05 and 2005/06, only one population estimate was less than 50 birds. The mean of peak population estimate for little gull within the Greater Wash based on two seasons data was 2,153 individuals. Application of the SPA guidelines to little gull is discussed further in section 4.

Table 4. Population estimates for little gull in the Greater Wash area of search. A number of surveys were disregarded at this stage as there was low confidence in the population estimate; these are indicated by grey text in the table. **Bold** text indicates the estimate used to calculate the mean of peak. CI indicates confidence intervals; n indicates the total number of individuals recorded during each survey period while Obs. refers to the number of clusters that were input to the analysis.

Season	Survey	Estimate	%CV	Lower CI	Upper CI	n	Obs.
2002/2003	Feb 2003	-	-	-	-	-	-
	Mar 2003	-	-	-	-	-	-
2004/2005	**Oct/Nov 2004**	**2,645**		1,845	3,791	330	250
	Dec 2004	884		536	1,458	95	82
	Jan/Feb 2005	45		17	118	5	5
	Feb/Mar 2005	0		0	0	0	0
2005/2006	**Nov 2005**	**1,660**		1,059	2,604	222	153
	Nov/Dec 2005	280		169	464	33	26
	Jan/Feb 2006	169		38	760	11	5
	Feb/Mar 2006	23		4	120	3	1
2006/2007	Jan/Feb 2007	0		0	0	0	0
	Feb/Mar 2007	8		2	44	1	1
2007/2008	Nov 2007	653		371	1,151	86	63
	Dec 2007	112		31	401	15	13
	Feb 2008	0		0	0	0	0
	Feb/Mar 2008	8		1	43	1	1
Population estimate (mean of peak)		**2,153**	-	-	-	-	-

3.1.3 Common scoter

The spatial coverage of the surveys in the 2002/03 and 2007/08 winter seasons were not complete and did not cover the northern and southern parts of the area of search. However, these surveys did include the area where the main aggregations of common scoter occurred on the other surveys and were therefore included in the analysis.

As explained above in section 2.4.1, most of the flocks of common scoters recorded in the Greater Wash comprised low numbers of birds, but a few very large flocks were recorded. This resulted in a very high percentage in the component variance for cluster size in the distance analysis, and the encounter rate variance was also very high due to the very low number of flocks seen per transect. Consequently, it is difficult to determine any seasonal trends, but higher numbers of birds were generally recorded in the middle of the winter (December–January), with lower numbers in early and late season.

The population estimates and confidence intervals for common scoter derived using conventional methods, i.e. determining a population estimate for each survey are presented in Table 5. Clearly, the confidence intervals around these estimates are unacceptably large and the estimates are not reliable.

The population estimates based on data that were pooled to provide an average population estimate within each season are presented in Table 6. The range of the confidence intervals are still wide, but some improvement i.e. a narrower range can be seen compared to the survey specific estimates of common scoter from Table 5. It is important to remember that these pooled estimates provide an average population over the winter season, rather than the standard approach that uses the peak survey estimate from each season in calculating the mean of peak. It is recommended, that these pooled estimates are used for common scoter in the Greater Wash area of search. This is a more conservative approach given the uncertainty around the estimate, as the population estimate is based on the average rather than the peak population for each season.

Based on the pooled population estimates, numbers of common scoters in the Greater Wash area of search only exceeded 1% of the biogeographical wintering population estimate (5,500 individuals) in one winter season (2004/2005), common scoter is therefore not regularly present in sufficient numbers to be considered further for classification in the Greater Wash. The population estimate (3,517 individuals) does not exceed the 1% threshold based on data from four winter seasons (Table 2).

Table 5. Survey-specific population estimates for common scoter in the Greater Wash area of search. A number of surveys were disregarded at this stage due to insufficient spatial or temporal coverage; these are indicated by grey text in the table. **Bold** text indicates the estimate used to calculate the mean of peak. CI indicates confidence intervals; n indicates the total number of individuals recorded during each survey period while Obs. refers to the number of observations that were input to the analysis, i.e. each recorded sighting which could be an individual or a flock of birds. Note the large confidence intervals.

	Survey	Estimate	Lower CI	Upper CI	N	Obs.
2002/2003	**Feb 2003**	**4,763**	426	24,970	2,042	6
	Mar 2003	451	122	1,655	170	9
2004/2005	Oct/Nov 2004	4,781	1,283	17,820	1,141	30
	Dec 2004	**11,470**	2,803	46,928	3,217	28
	Jan/Feb 2005	3,436	388	30,405	2,105	10
	Feb/Mar 2005	5,533	167	44,700	3,109	8
2005/2006	Nov 2005	155	10	2,297	50	2
	Nov/Dec 2005	978	143	6,712	205	8
	Jan/Feb 2006	**1,819**	321	10,292	450	2
	Feb/Mar 2006	1,108	52	23,612	1,275	6
2006/2007	Jan/Feb 2007	Unrepresentative				
	Feb/Mar 2007	Unrepresentative				
2007/2008	Nov 2007	26	7	100	15	4
	Dec 2007	**2,087**	6	1,319	2,028	4
	Feb 2008	1,126	498	2,546	1,000	7
	Feb/Mar 2008	0	0	0	0	0
Population estimate		**6,107**	-	-	-	

Table 6. Pooled winter population estimates for common scoter in the Greater Wash area of search. Two surveys were disregarded at this stage due to insufficient spatial or temporal coverage; these are indicated by grey text in the table. **Bold** text indicates the estimate used to calculate the population estimate. CI indicates confidence intervals and n indicates the total number of flocks recorded during each survey period.

	Estimate	Lower CI	Upper CI	n
2002/2003	3,150	354	7,690	15
2004/2005	7,686	2,032	11,750	75
2005/2006	889	198	3,985	18
2006/2007	unrepresentative			
2007/2008	2,341	88	1,325	13
Population estimate	**3,517**	-	-	-

3.2 Distribution and densities of birds in the Greater Wash area of search

3.2.1 Red-throated diver

Red-throated divers were observed throughout the whole survey area (Figure 4). However, higher densities of birds were recorded close inshore, particularly in the area outside The Wash SPA, north of the Humber Estuary and along the eastern part of North Norfolk Coast (Figure 5). High numbers of red-throated diver were recorded in the south of the area where it abuts the Outer Thames Estuary area of search; this aggregation was also identified by previous analysis of waterbirds in the Outer Thames estuary, which were made part of the Outer Thames Estuary SPA in 2010. The surveys undertaken in 2007/08 were not included in the red-throated diver analysis as they provide insufficient spatial coverage of red-throated diver distribution within the Greater Wash area of search.

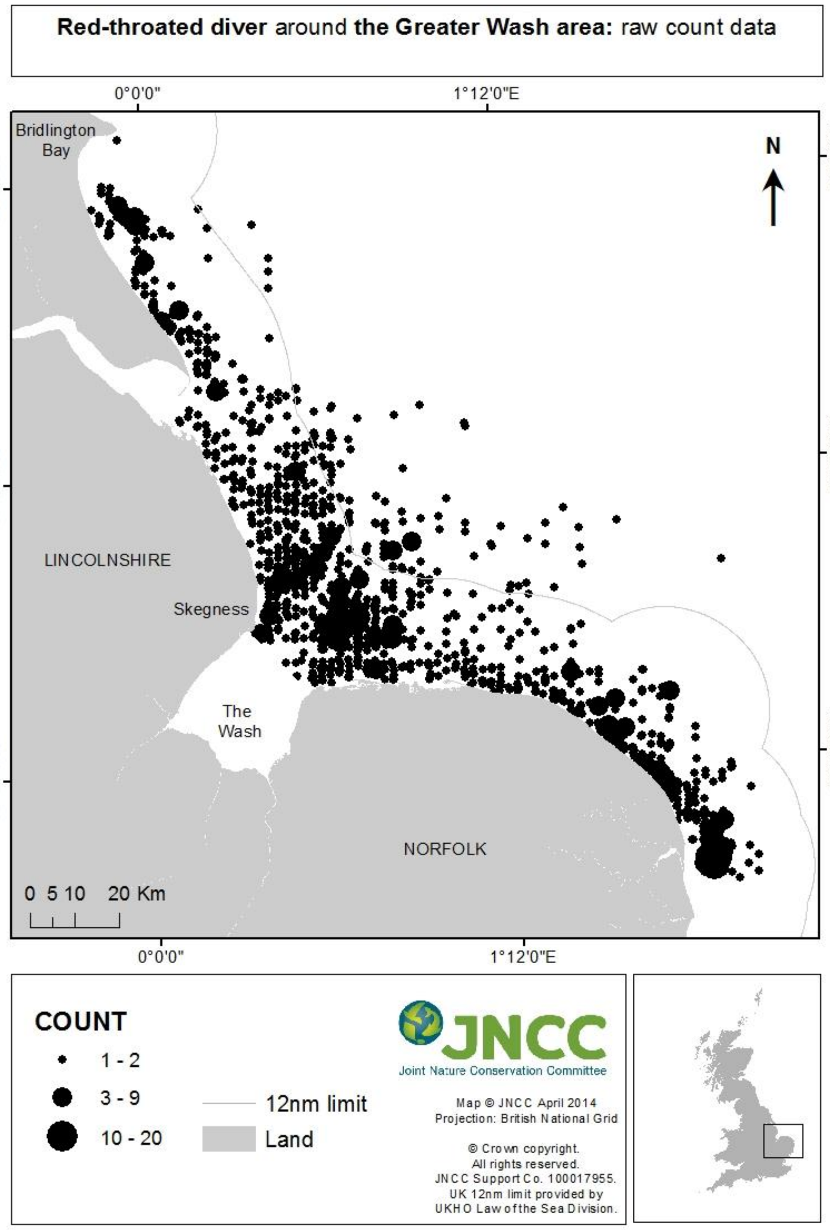

Figure 4. Raw count data of red-throated divers recorded during aerial surveys in the Greater Wash AoS (2002/03, 2004/05, 2005/06).

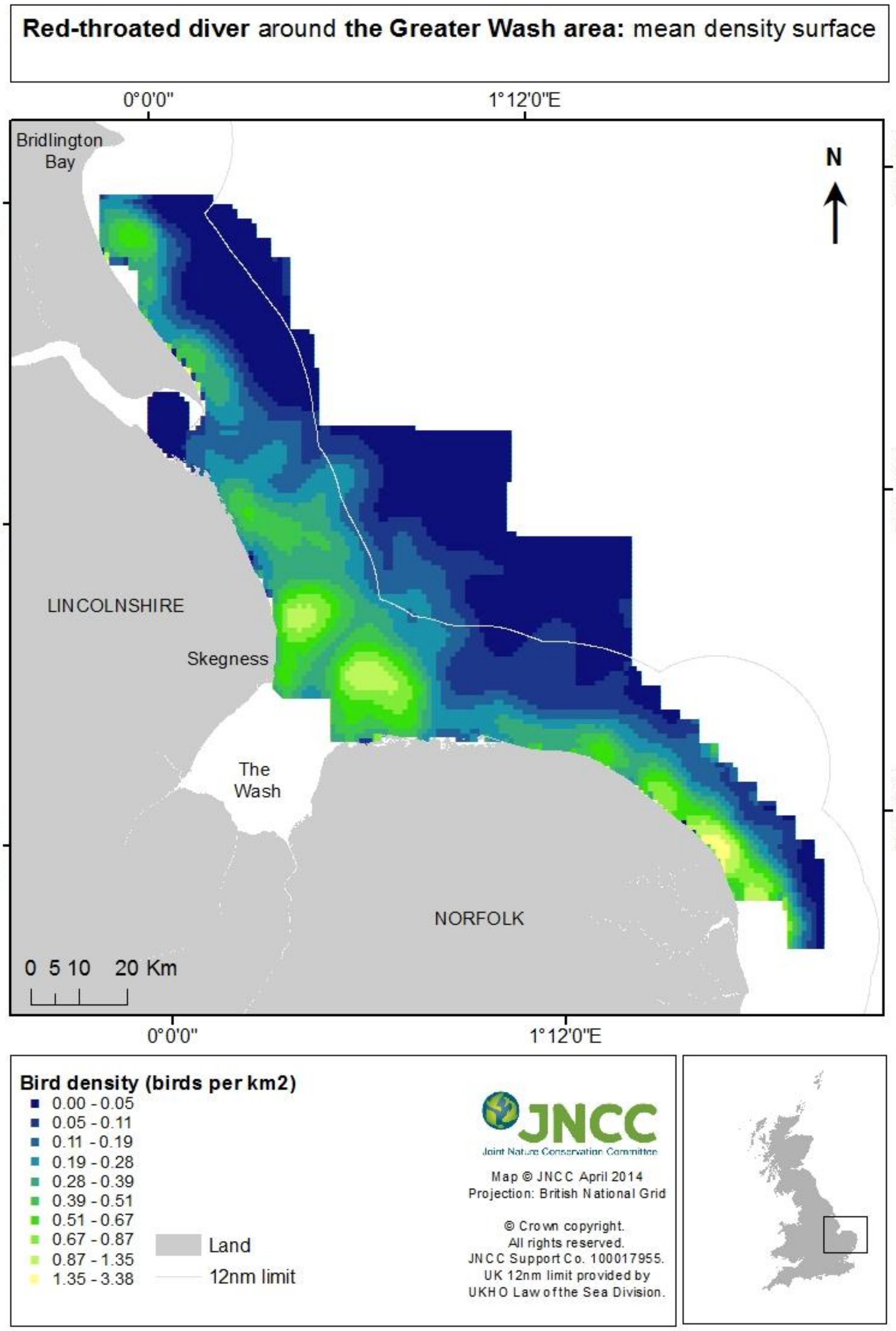

Figure 5. Estimated mean density surface of red-throated divers recorded during WWT Consulting aerial surveys within the Greater Wash AoS (2002/03, 2004/05, 2005/06).

3.2.2 Little gull

Observations of little gulls were concentrated in the area outside The Wash SPA and extending north towards the Humber Estuary, although lower numbers of birds were also recorded off the eastern Norfolk coast (Figure 6). Few observations of little gull were recorded in the 2007/08 season, and these surveys were not included in the analysis as they did not cover the main distributions of little gull in the Greater Wash area of search. Most little gull were found to be present just outside the Wash SPA (Figure 7), in addition to these, smaller high density areas were found at the margins of the area of search off the east Norfolk coast.

These distribution maps suggest the full offshore extent of little gull distribution may not have been captured by these surveys. Higher density aggregations occurred along the seaward boundary of the area of search off the eastern part of the Norfolk coast and it seems likely that the full northern extent of the aggregation north of The Wash SPA has not been captured. Surveys were undertaken in these areas (Figure A1, Appendix 3) but only in one winter season, and few little gull observations were recorded (0-1).

Only two seasons of data with sufficient spatial and temporal coverage of the Greater Wash area of search were available for little gull. To better understand how frequently higher density areas of little gull occurred across surveys, a ‘hotspot’ analysis is presented in Figure 8. Maximum curvature analysis (Appendix 1) identified a threshold density of 0.0757 birds per km^2 for little gull. This density was applied to each survey-specific density surface, such that each cell on the surface with a density equal to or greater than 0.0757 birds per km^2 was given a score of 1 (hotspot ‘present’) and cells with a density less than this were given a score of 0 (hotspot ‘absent’). The survey-specific density surfaces were then overlaid and summed, so that each cell on this surface had a count of the number of times a hotspot was ‘present’ (and exceeded the required threshold) in that cell.

The result of this analysis (figure 8) demonstrates that the main aggregation north of The Wash was consistently used by little gull across the survey where they were recorded. Away from this main hotspot, little gull exceeded the threshold density less consistently, only in one to three surveys.

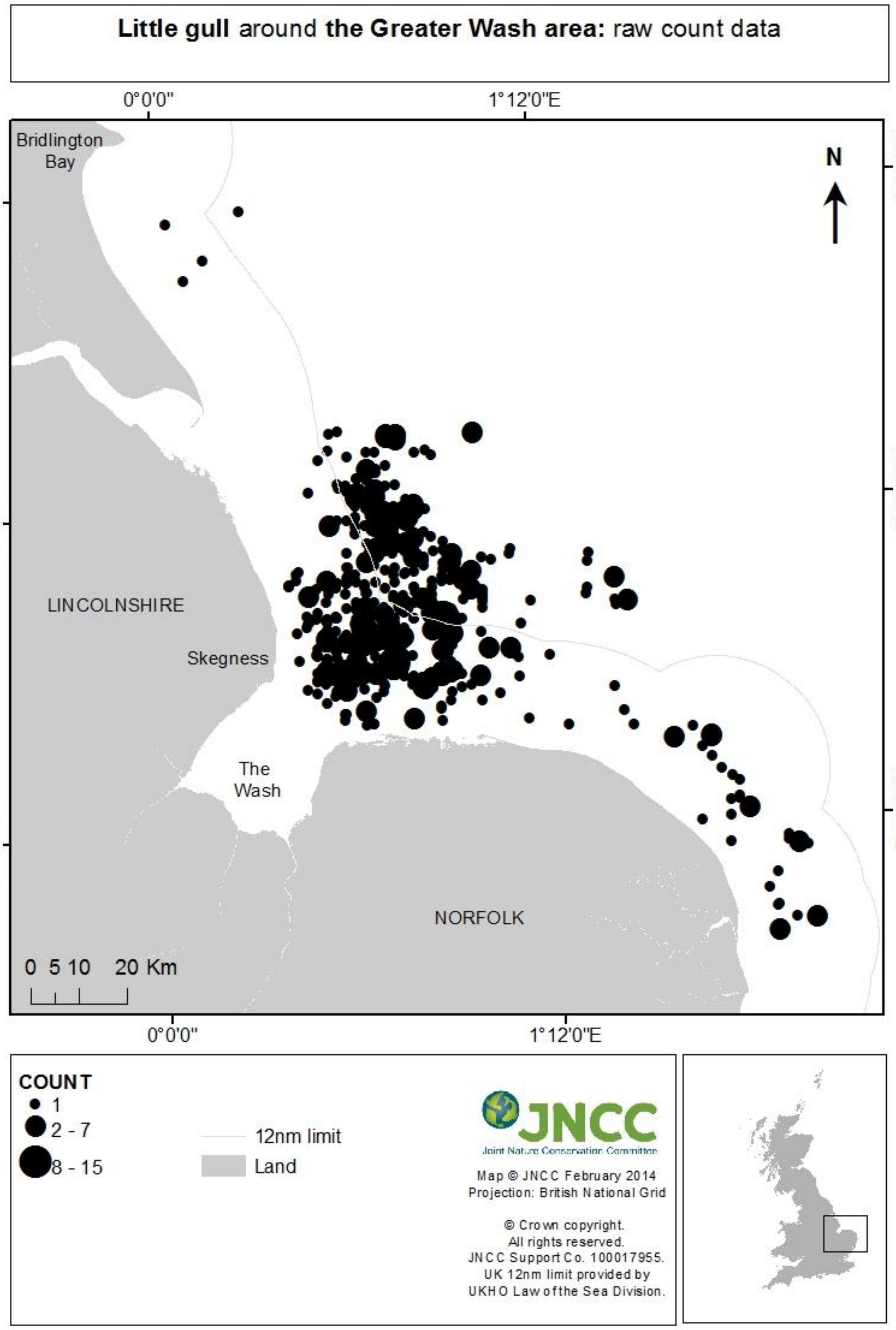

Figure 6. Raw count data of little gull recorded during WWT Consulting aerial surveys within the Greater Wash AoS (2004/05, 2005/06).

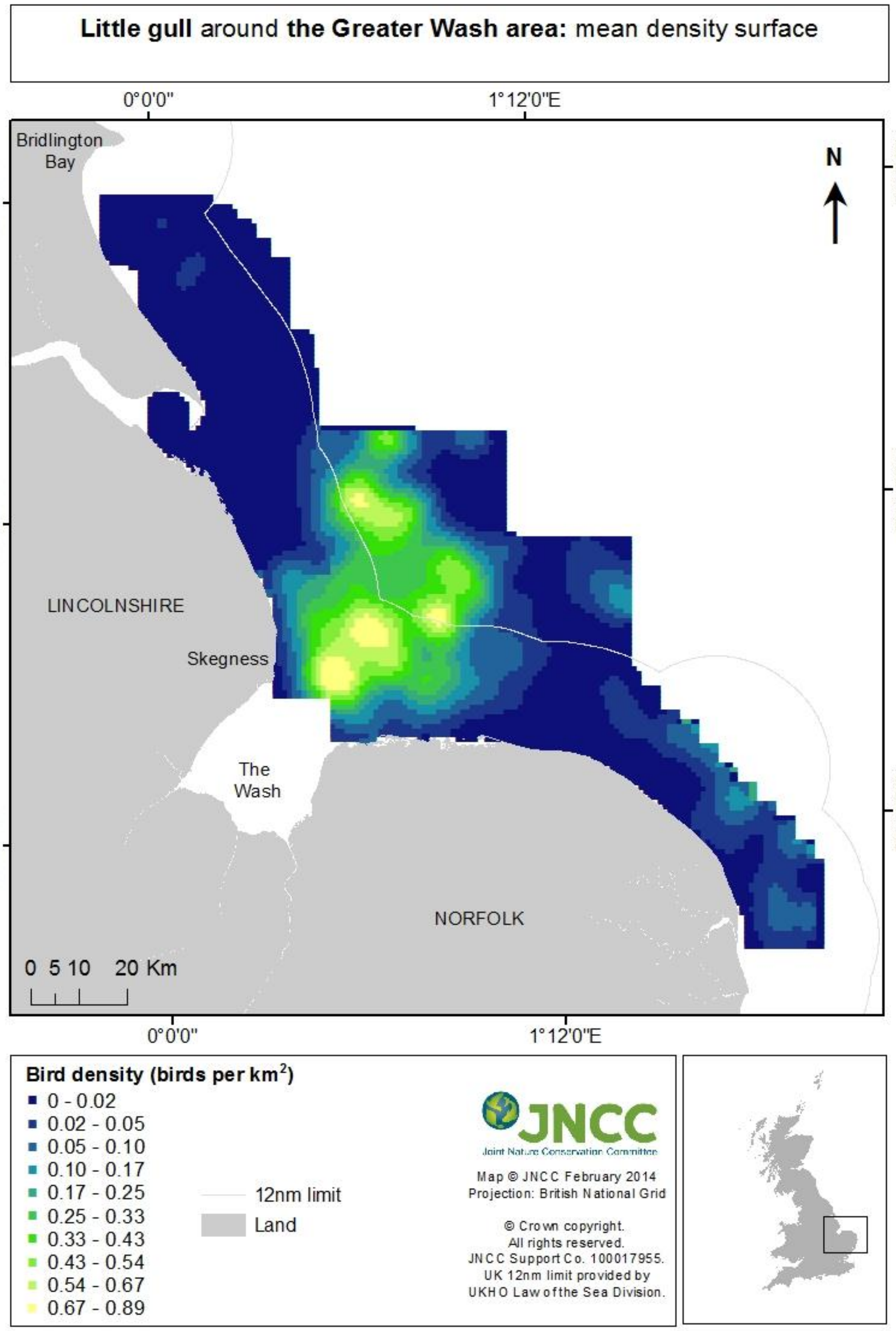

Figure 7. Estimated mean density surface of little gull recorded from aerial surveys within the Greater Wash AoS (2004/05, 2005/06).

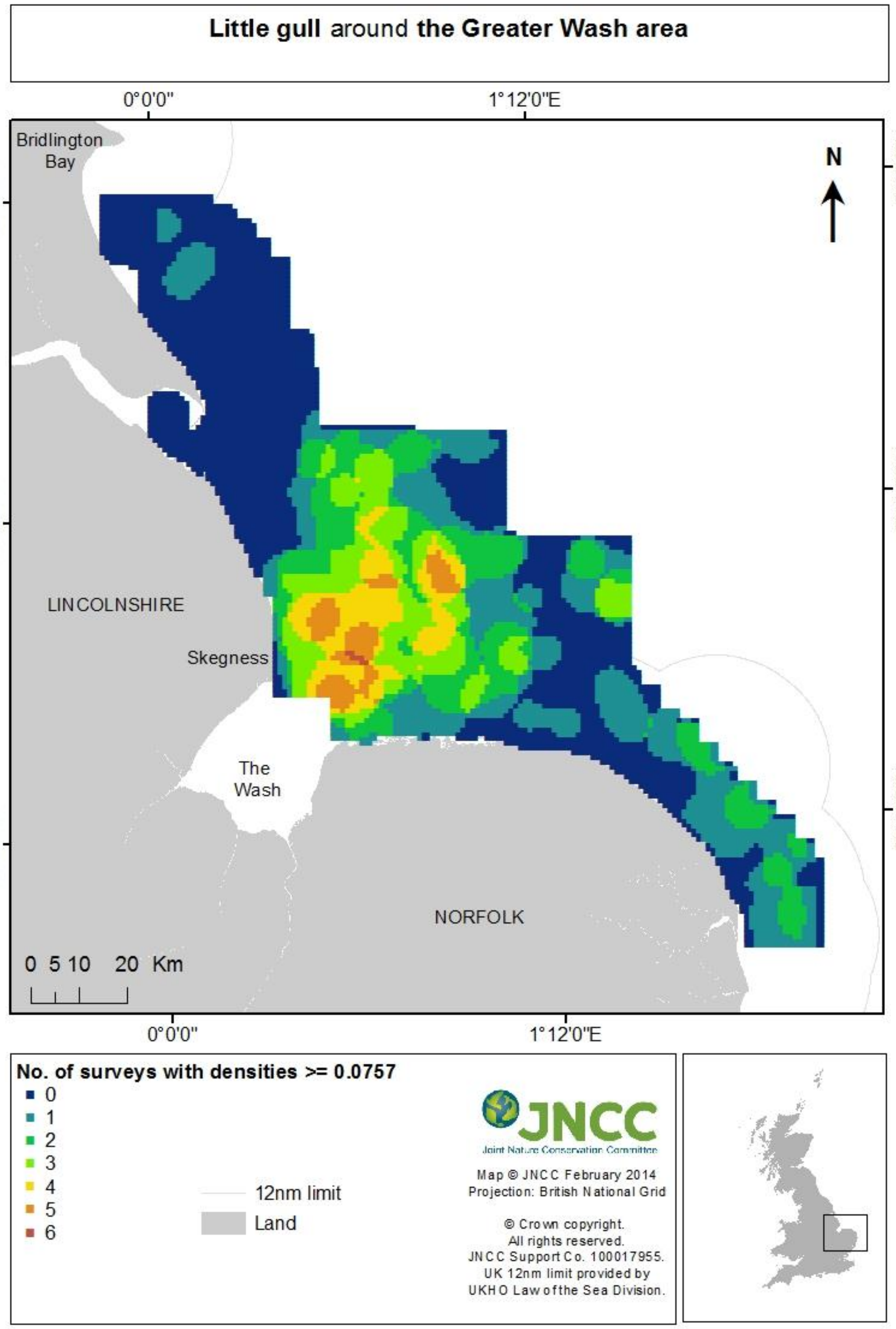

Figure 8. The number of surveys on which little gull densities met or exceeded the maximum curvature density threshold (0.0757 birds per km^2) in the Greater Wash AoS.

3.2.3 Common Scoter

There is a cluster of common scoter observations just east of The Wash SPA, and again, but in lower numbers, near Skegness (Figure 9). Common scoters were observed in highest densities in the area outside The Wash SPA and along the North Norfolk Coast SPA. Common scoters were also recorded close inshore in the north and south of the area of search.

The mean density surface for common scoter was produced from the mean of four KDE surfaces that were re-scaled based on the season-specific population estimates (Figure 10). Higher density areas are present off Skegness and at the opposite side of the Wash off the west Norfolk coast.

The North Norfolk Coast SPA protects wintering common scoter. The distribution maps below clearly indicate that birds regularly utilise areas beyond the boundary of The Wash SPA. It is possible that the birds recorded here could be part of an aggregation that is already protected within the North Norfolk Coast SPA.

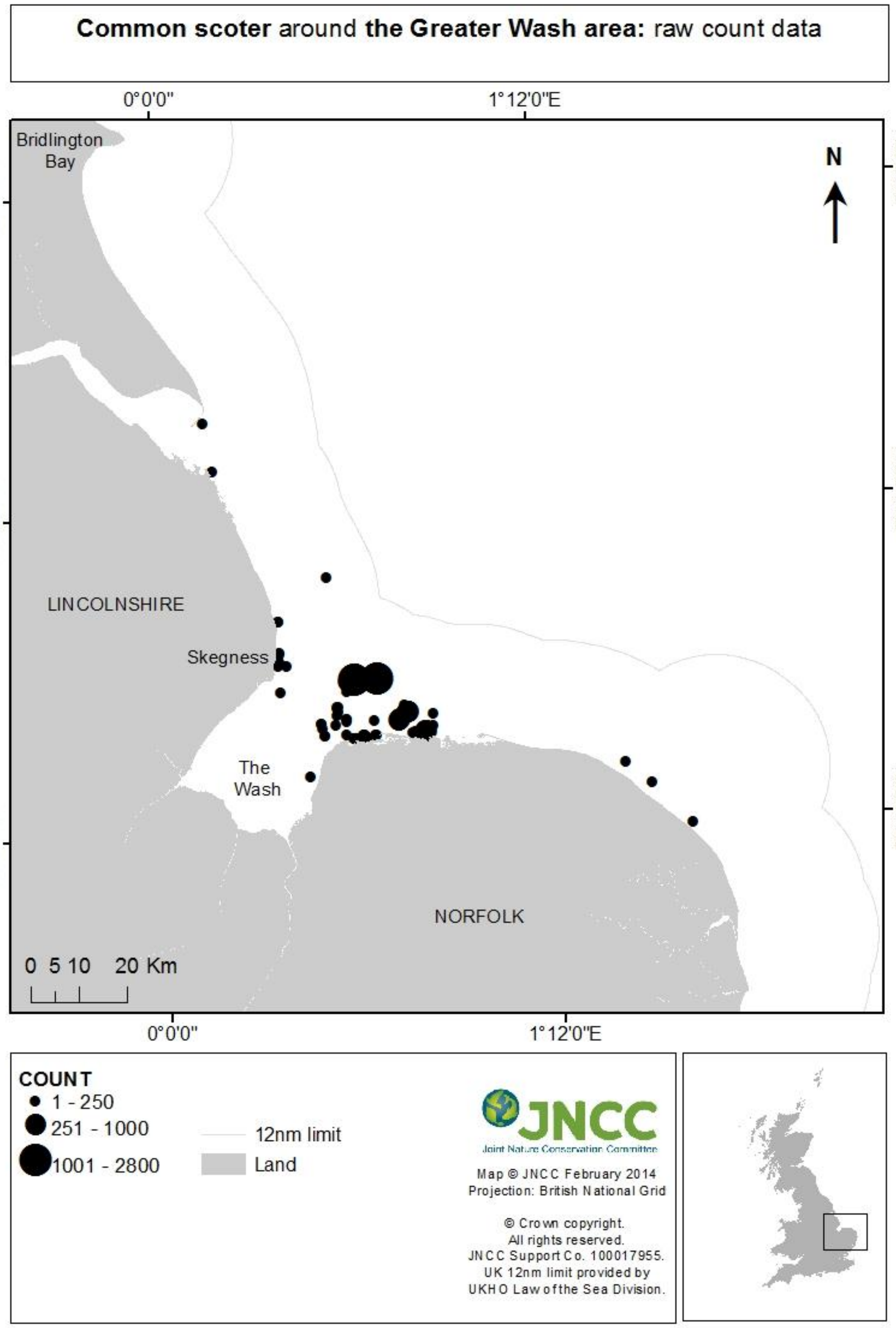

Figure 9. Raw count data of common scoter recorded during WWT Consulting aerial surveys within the Greater Wash AoS (2002/03, 2004/05, 2005/06, 2007/08).

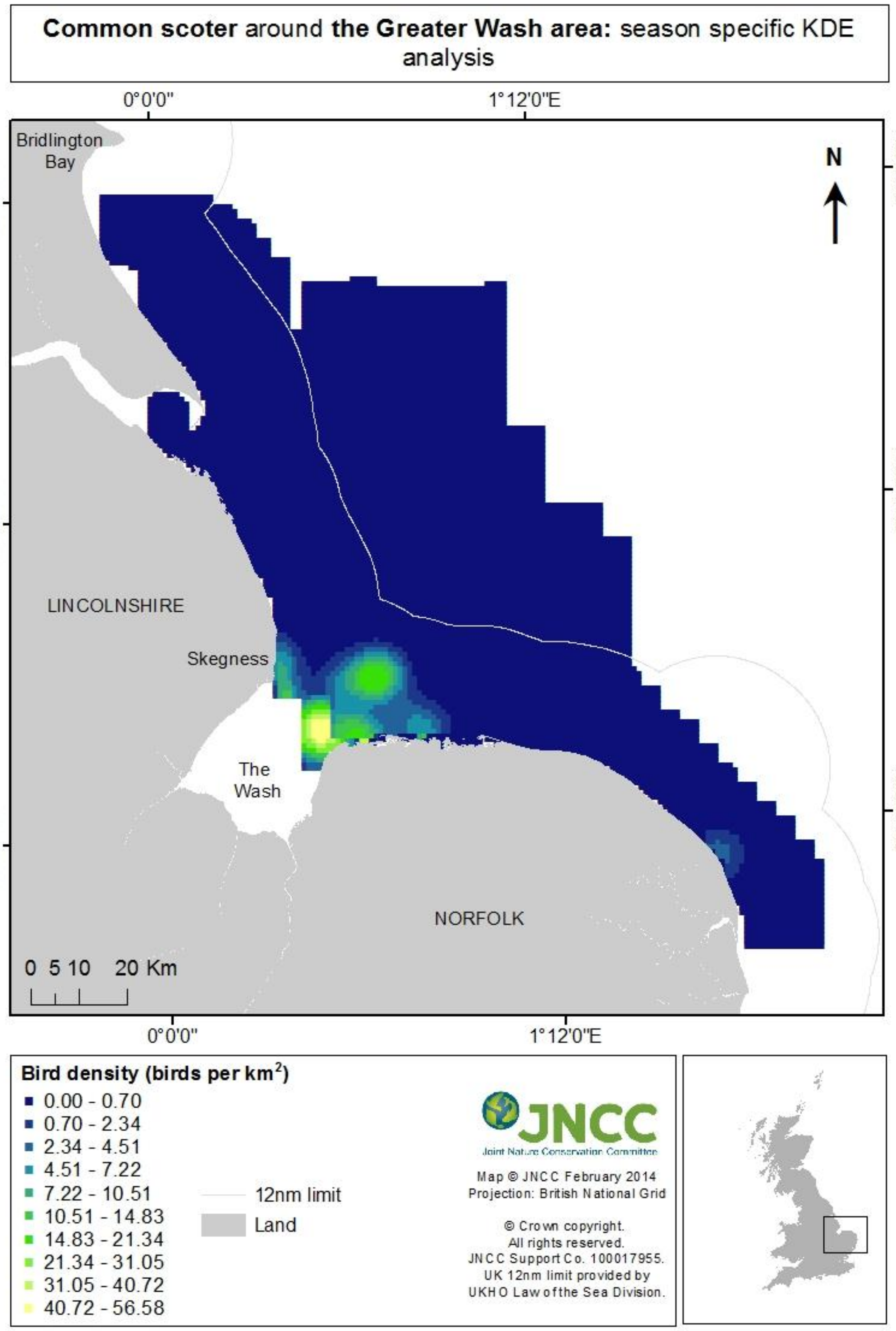

Figure 10. Estimated mean density surface of common scoter from aerial surveys within the Greater Wash AoS (2002/03, 2004/05, 2005/06, 2007/08). This map was derived from an analysis that pooled all data recorded in a winter season. Subsequently a density surface was produced for each season (resulting in four seasonal density surfaces), and a mean density surface produced from these.

4 Discussion

The Greater Wash survey area supports an estimated 1,787 red-throated divers during the winter season. This greatly exceeds the 1% SPA qualification threshold of 170 birds by application of the SPA selection guidelines during all years of data collection. Of the inshore areas of search surveyed around the UK the Greater Wash supports the second highest number of red-throated diver, after The Outer Thames Estuary SPA (O'Brien *et al* 2008). As qualifying numbers of red-throated divers were regularly present in the area of search, further analysis was undertaken to determine a seaward boundary. This analysis is presented in Appendix 1.

Little gull numbers are often underestimated in aerial surveys as they are difficult to identify. However, the aerial survey data that are currently available for little gull wintering around the UK in inshore areas indicate that the Greater Wash area of search supports the highest numbers, an estimated 2,153 birds (MoP estimate, 2004/05, 2005/06). The area north-east of The Wash SPA in particular, is an important area for the little gull. There is currently no GB population threshold against which to assess whether little gull numbers here exceed the UK SPA Selection Guidelines threshold (Musgrove *et al* 2013). If there is no population estimate available against which to assess a species' SPA qualification status then it is considered at Stage 1.4 of the UK SPA Selection Guidelines. The mean of peak for little gull was 2,153, based on two years of data; and areas of relatively higher density within the area of search were delineated using maximum curvature (Mel'nikov 1995); this analysis is presented in Appendix 1. Three years of data are suggested under the SPA guidelines in order to demonstrate regularity of occurrence. Table 4 demonstrates that little gull were present in numbers that exceed the default 50 individuals in two of the four surveys in 2007/08. The surveys in this season had limited coverage of the area of search and of the main area of little gull distribution. They may underestimate the true numbers of little gull present and were therefore not included into the mean of peak calculation. They do, however, support the case that little gull are regularly occurring within the site as a whole.

It was not possible to provide a reliable estimate of the wintering population of common scoter in the Greater Wash area of search based on the estimates from individual surveys. There were large confidence intervals around these estimates due to the variability in the encounter rate of flocks of common scoter between transects and the presence of few very large flocks of birds. Using the estimates based on individual surveys is not recommended; instead data from within seasons were pooled to produce a more reliable population estimate with reduced confidence intervals. Based on this pooled population estimate (3,517 individuals) common scoter numbers do not exceed 1% of the biogeographic population (5,500 individuals) and therefore do not meet Stage 1.2 of the UK SPA Selection Guidelines. The population estimate from this pooled data is lower than those calculated as a standard for other species because it produces an average (rather than a peak) estimate for each winter season.

Observations of a flock of common scoter by Cranswick *et al* (2003) off the northwest Norfolk coastline from land based observations suggests that it is possible that they are located close inshore and could have been missed or underestimated from aerial survey data. Nevertheless, aerial surveys are considered to be the best technique for collecting data on common scoter as land-based counts will not be able to detect flocks further away from the coast and boat-based surveys will cause individuals to take off – both resulting into underestimates of the actual population sizes. The distribution of common scoter has been analysed using these standard inshore methods (O'Brien *et al* 2012) as applied at other areas of search around the UK, this problem of close inshore distribution has not been evident at other areas of search. However, other species that are known to be distributed close inshore have been assessed using both systematic shore based count data and aerial survey data at other areas of search.

Common scoter might still be considered at Stage 1.4 of the SPA Selection Guidelines as a listed feature in any future SPA in the Greater Wash, so further analyses aimed at identifying a boundary around the most important concentrations were undertaken; these are presented in Appendix 1.

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Appendix 1 - Delineating important aggregations of red-throated diver, little gull and common scoter within the Greater Wash survey area

Identifying the most suitable areas at sea for SPA classification presents particular challenges as physical features or habitat boundaries are rarely visible and are not readily detectable without time-consuming and costly data collection and analysis. Identifying boundaries for important areas at sea therefore is usually based on the dispersion of the birds themselves.

Maximum curvature was used to delineate areas of high bird density on the mean modelled density surface. Maximum curvature identifies the point of greatest change in a curve in the relationship between two values (Mel'nikov 1995). It is a relatively objective, and repeatable, method to identify a threshold density for determining the important parts of aggregated species' distributions. Areas (1km x 1km grid cells in these analyses) hosting densities above the threshold density may be deemed as important and used to define a boundary to the important parts of the distribution (O'Brien *et al* 2012).

Application of maximum curvature follows a stepwise procedure. Large areas of a density surface might have no observations of a particular species, i.e. zero density. These areas were excluded from the analysis because the threshold density identified by maximum curvature analysis is sensitive to the size of the area considered (Webb *et al* 2009). These areas were excluded using the software *Geospatial Modelling Environment* (Beyer 2012) to draw one or more minimum convex polygons (MCPs) around the raw observations. These MCPs were then over-laid on the mean modelled density surface and any cells with a zero density within the MCPs were excluded from the maximum curvature analysis. The remaining grid cells were then ranked from high to low based on bird density. The relationship between the cumulative number of birds and cumulative area is not linear but curved, increasing rapidly at first as high density areas are selected and then increasing more slowly as larger areas are required to capture the same number of birds in low density areas. Maximum curvature identifies the point of greatest change in the relationship between the cumulative modelled number of birds and the cumulative area that supports that number of birds (see Cannone (2004) and Holt and Mantua (2009) for examples of the application of maximum curvature elsewhere in ecology). The point of maximum curvature is used as the threshold density to inform boundary placement as this represents the point of optimal trade-off between the 'gain' (increased numbers of birds) and the 'cost' (increased area within a boundary), see O'Brien *et al* (2012) for more details. It was determined by fitting a statistical model, either exponential, or double exponential (depending on which best fitted the observed data) to best fit the relationship between cumulative usage against cumulative area supporting that usage. Maximum curvature analysis has been used extensively in JNCC's marine SPA work (e.g. O'Brien *et al* 2012; O'Brien *et al* 2014). It should be noted that this procedure is applied to determine a seaward boundary only; the landward boundary will be determined by Natural England, the landward boundaries presented herein were clipped to mean high water mark.

In this way species specific maximum curvature boundaries were identified. Usually each species-specific boundary, of all species exceeding their qualifying population thresholds within an area of search, were then overlaid and combined to produce a composite boundary that followed the maximum extent of the species-specific boundaries. In this case, only the boundary of red-throated diver was used to determine the boundary. The two years of data available for little gull distributions were investigated for their potential to be used for the determination of a boundary, e.g. in combination with other collaborative evidence. However, it was decided that in this case, and based on all available data, such a boundary would be

based on too limited data, given that little gull shows a particularly variable distribution from year to year in the area. Hence for this species the conclusion was reached that although there is overall a good case for this species to be suggested for protection under 1.4 of the UK SPA selection guidelines (see Discussion section above), the evidence about where the most important aggregations of little gull occur is not consistent enough to allow an unequivocal boundary. The boundary was drawn following accepted protocol described by Webb and Reid (2004). Lines of latitude and longitude were followed to the nearest 10 seconds, such that the boundary was always a minimum of 250m from any cell with a predicted density greater than the threshold density; 250m was the maximum potential error incurred when recording the location of any bird observed during aerial survey and represents a precautionary approach to ensuring all high density areas are captured within the boundary (Webb & Reid 2004).
In delineating boundaries, a trade-off is required between boundary complexity and the amount of area included that is below the usage threshold identified by maximum curvature. Further consideration will be necessary to finalise the exact boundary shape and level of complexity deemed appropriate for any actual SPA boundary.

The Greater Wash area of search is adjacent to and abuts the Outer Thames Estuary area of search. There is a small area of overlap (<3km) in the areas surveyed for each area of search, however the survey data that contributed to the population estimates within each were separate. In 2010, the Outer Thames Estuary SPA was classified for red-throated diver. Its boundary was drawn to incorporate an aggregation of red-throated diver that extended into the Greater Wash area of search; it therefore overlaps a part of the Greater Wash area of search.

A boundary delineating important aggregations of red-throated diver is also required within the Greater Wash area of search. To avoid double counting of red-throated divers in the overlap area, the area of the Outer Thames Estuary SPA was removed from the density surfaces of red-throated diver for the Greater Wash. This was done before running maximum curvature analysis, as maximum curvature identifies the threshold density above which important aggregations are delineated.

The high bird density areas defined by the maximum curvature threshold density for red-throated diver and little gull are presented in Figures A1 and A2 respectively. The threshold density for red-throated diver was 0.1665 birds per km^2 and for little gull 0.0757 birds per km^2. A simplified boundary was then drawn around the maximum curvature for red-throated diver following the boundary drawing procedure described above to produce the possible SPA boundary shown in Figures A1-A3 below.

Numbers of common scoter in the Greater Wash did not meet stage 1.2 of the UK SPA selection guidelines. Therefore, they have not been used to produce the possible SPA boundary presented in this report. However, they might still be considered at Stage 1.4 of the SPA Selection Guidelines as a listed feature in any future SPA in the Greater Wash and maximum curvature analysis was applied to delineate important aggregations of common scoter (1.6773 birds per km^2) as presented below (figure A3).

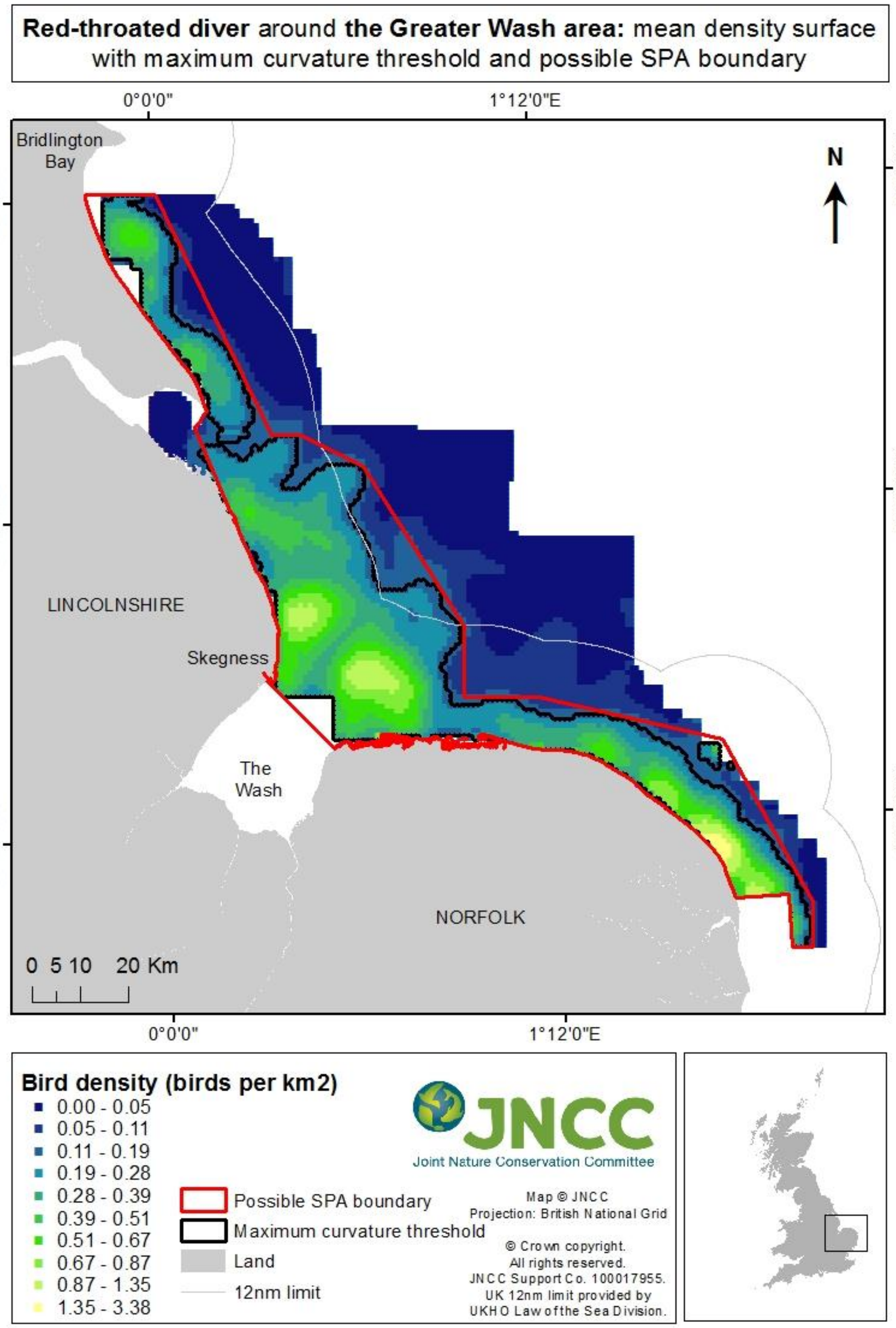


Figure A1. Estimated mean density surface for red-throated diver with the threshold densities delineated, as identified by maximum curvature (0.1665 birds per km^2) and the composite possible SPA boundary.

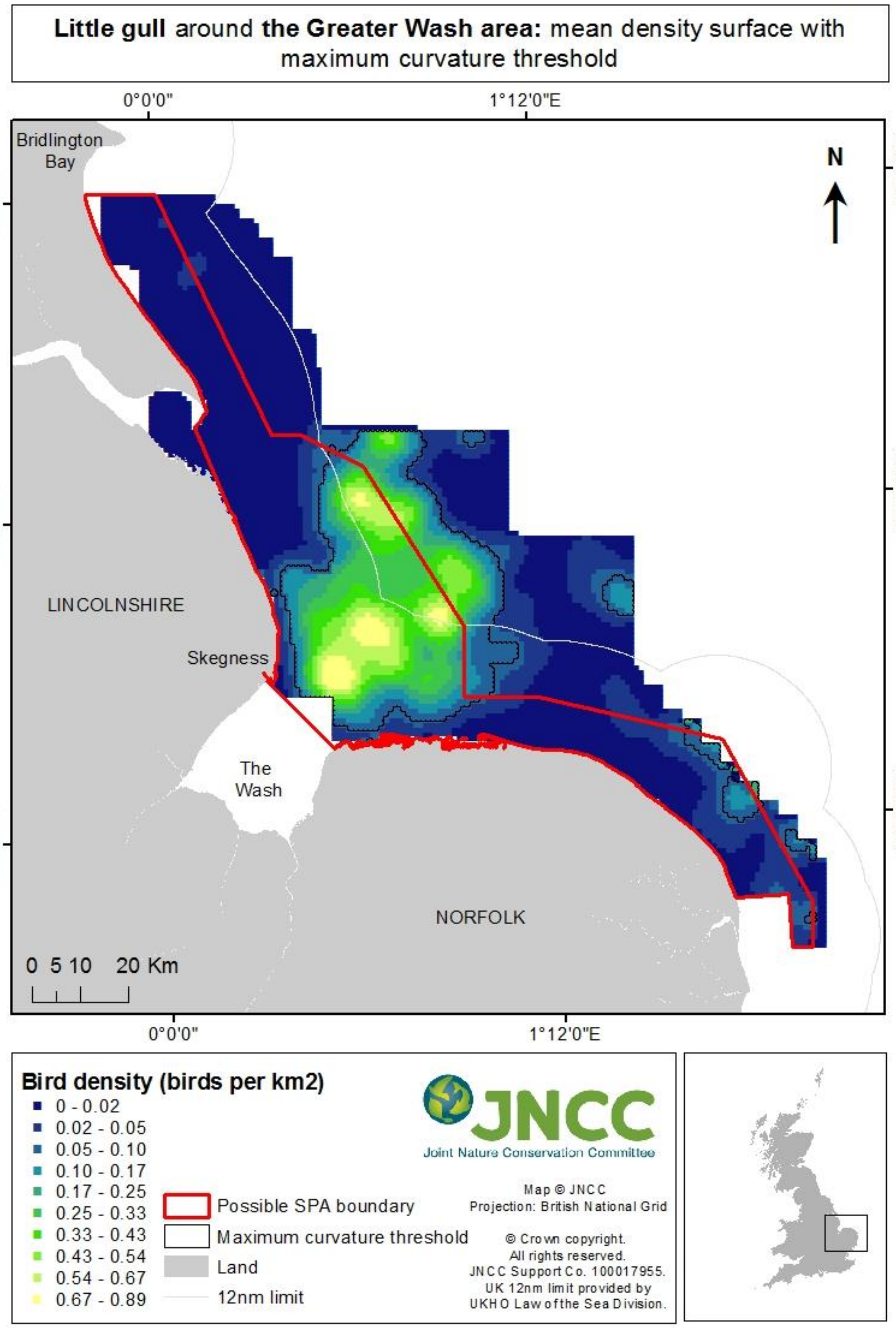


Figure A2. Estimated mean density surface for little gull with the threshold densities delineated, as identified by maximum curvature (0.0757 birds per km^2) and the composite possible SPA boundary.

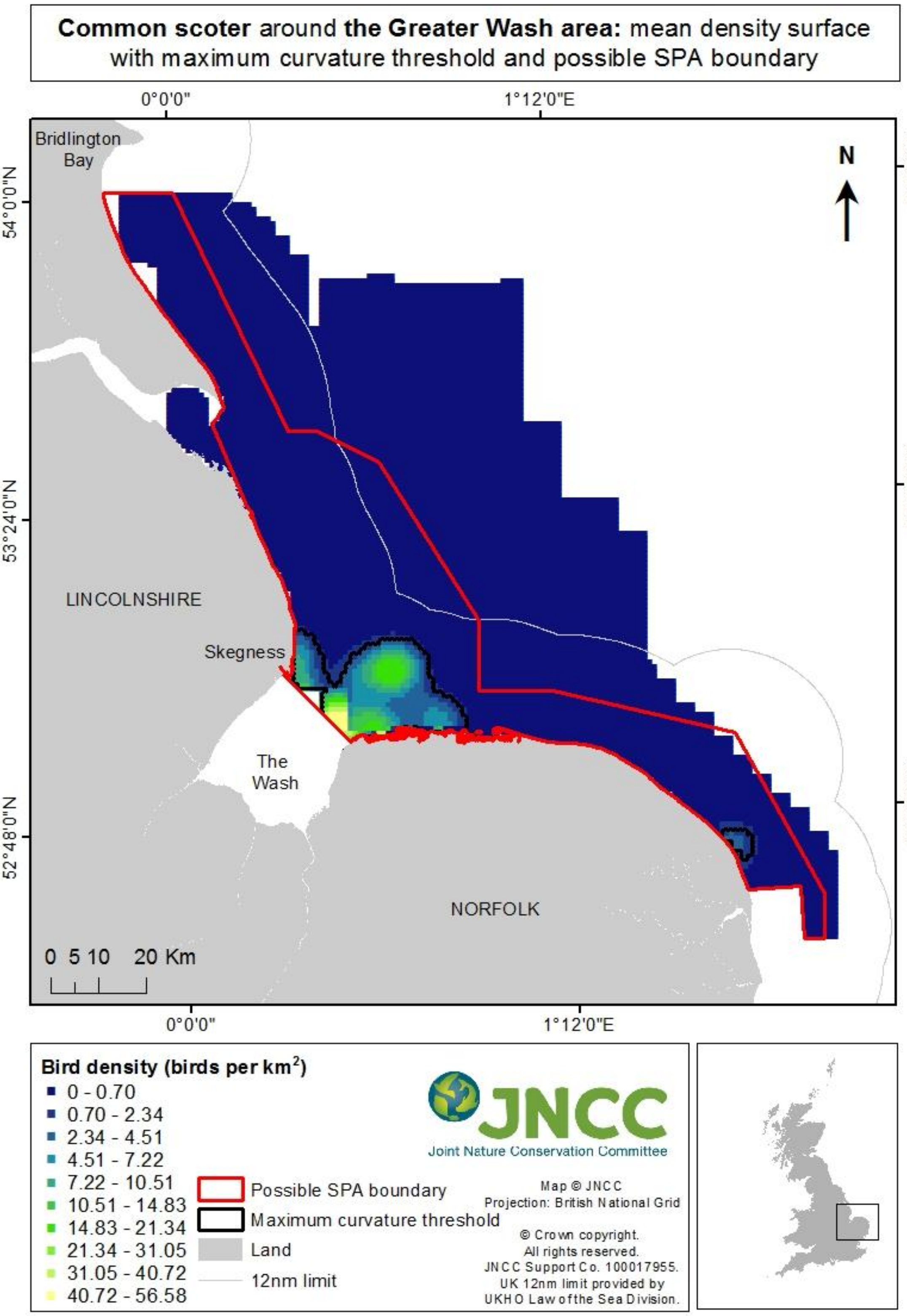


Figure A3. Estimated mean density surface for common scoter (season specific data) with the threshold densities (1.6773 birds per km^2) delineated, as identified by maximum curvature and the composite possible SPA boundary.

Estimating numbers of birds within a possible SPA boundary

Distance sampling methods provide the most reliable assessment of the numbers of birds within an area, but this method can generate biased estimates if the same data are used to estimate a population estimate for an area of search, and then used again to reassess the numbers of birds in a part of the area of search (S. Buckland & E. Rexstad, pers. comm.). Therefore, in order to estimate population sizes within a boundary, the modelled density surfaces generated for each individual survey were used.

For each density surface i.e. each survey, the densities of all cells that had their centre point within the boundary were summed. This provided a population estimate within the boundary for that survey. The mean of peak population estimates within the boundary were calculated from these surveys and are presented in Table A1 below.

The population estimates for the AoS and the possible SPA boundary present similar numbers as the distribution of red-throated diver in particular occur throughout much of the area of search.

Within the possible SPA boundary, the number of red-throated diver present exceeded the relevant threshold in all three seasons for which data were available. Red-throated divers are therefore regularly occurring within this boundary and may be considered further for SPA classification under Stage 1.1 of the SPA Guidelines.

The numbers of little gull within the possible SPA boundary for the Greater Wash indicate that this is an important area for this species. The numbers estimated to occur here are higher than those found within any of the other inshore areas of search around the UK. As only two seasons of data were available it is not possible to assess whether these numbers are regularly occurring. However, based on the data that is currently available little gull could be considered further for SPA classification within this site.

Table A1. Population estimates within the Greater Wash possible SPA boundary and area of search for red-throated diver and little gull.

Survey date	year	species	Sum within draft SPA boundary	peak	MoP draft SPA boundary	MoP within area of search
2003 Feb	2002/03	RTD	543			
2003 Mar	2002/03	RTD	**1,381**	**1,381**		
2004 Oct & Nov	2004/05	RTD	672			
2004 Dec	2004/05	RTD	**1,361**	**1,361**		
2005 Jan & Feb	2004/05	RTD	964			
2005 Feb & Mar	2004/05	RTD	1,301			
2005 Nov	2005/06	RTD	602			
2005 Nov & Dec	2005/06	RTD	607			
2006 Jan & Feb	2005/06	RTD	1,669			
2006 Feb & Mar	2005/06	RTD	**1,910**	**1,910**		
					1,551	**1,787**
2004 Oct & Nov	2004/05	LG	**1,530**	**1,530**		
2004 Dec	2004/05	LG	757			
2005 Jan & Feb	2004/05	LG	28			
2005 Feb & Mar	2004/05	LG	0			
2005 Nov	2005/06	LG	**1,533**	**1,533**		
2005 Nov & Dec	2005/06	LG	152			
2006 Jan & Feb	2005/06	LG	149			
2006 Feb & Mar	2005/06	LG	21			
					1,532	**2,153**

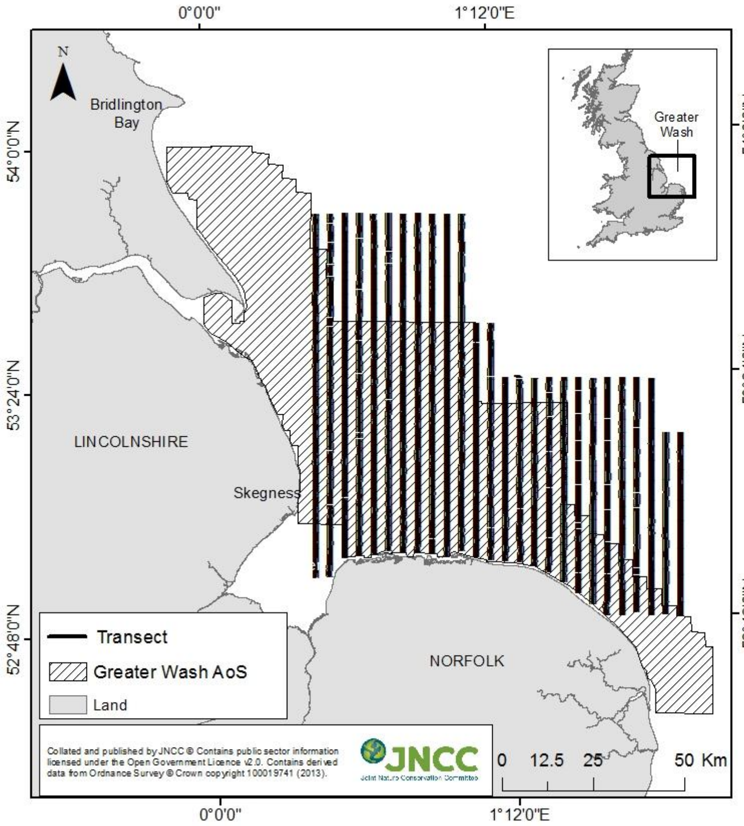
Appendix 2 – Summary tables

Table A2. Total number (raw counts) of birds and flocks (represented in brackets) counted in the Greater Wash AoS during survey periods from February 2003 to March 2008. Numbers represent the total sample counts of all birds recorded strip-transect aerial surveys (2002/03) and line transect aerial surveys (2004/05 to 2007/08).

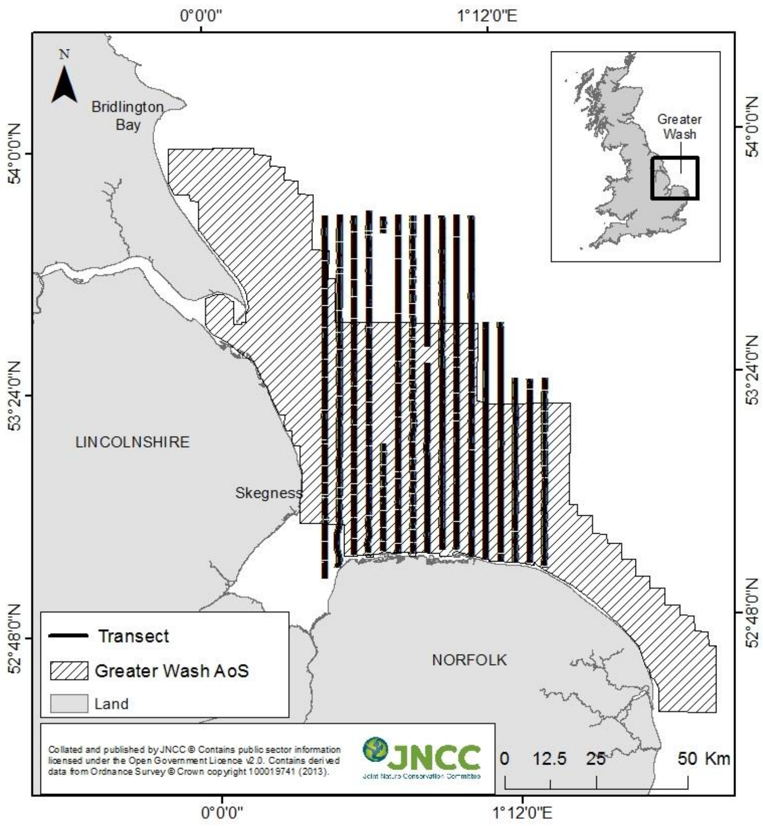
Period of surveys	Common scoter	Velvet scoter	Red-throated diver	Great northern diver	Unidentified diver
Winter season 2002/03					
Feb 2003	2,041 (6)	0	14 (10)	0	25 (25)
Mar 2003	170 (9)	0	39 (28)	0	108 (57)
Winter season 2004/05					
Oct/Nov 2004	1,141 (30)	0	33 (32)	0	98 (89)
Dec 2004	3,217 (28)	0	32 (28)	10 (7)	113 (101)
Jan/Feb 2005	2,105 (10)	0	20 (20)	0	106 (100)
Feb/Mar 2005	3,109 (8)	0	7 (7)	0	220 (192)
Winter season 2005/06					
Nov 2005	50 (2)	0	0	0	83 (79)
Nov/Dec 2005	205 (8)	0	9 (9)	0	76 (68)
Jan/Feb 2006	450 (2)	3 (2)	32 (23)	1 (1)	242 (158)
Feb/Mar 2006	1,275 (6)	0	68 (53)	1 (1)	280 (215)
Winter season 2006/07					
Jan/Feb 2007	2,867 (4)	0	35 (30)	2 (2)	147 (116)
Feb/Mar 2007	41 (3)	0	40 (32)		54 (38)
Winter season 2007/08					
Nov 2007	15 (4)	0	80 (53)	0	536 (55)
Dec 2007	2,028 (4)	0	15 (13)	0	21 (18)[2]
Feb 2008	1,000 (7)	0	35 (34)	0	78 (73)[2]
Feb/Mar 2008	0	0	33 (28)	0	15 (13)[2]

[2] Survey period includes additional survey blocks that were not part of the original AoS of the Greater Wash. Raw number of birds presented here are from survey block GW 4 only.

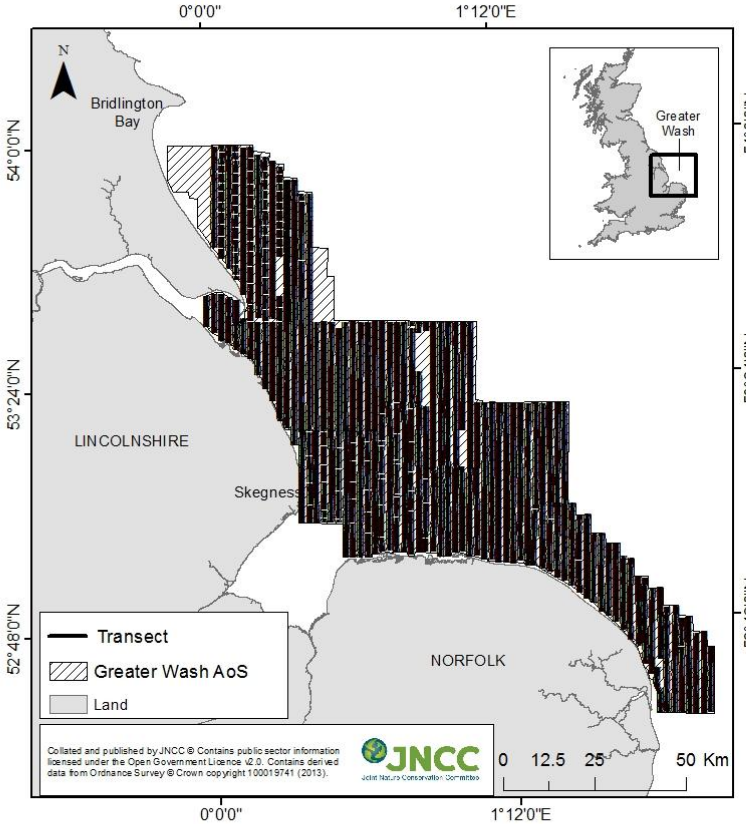
Appendix 3 – survey effort within the Greater Wash area of search



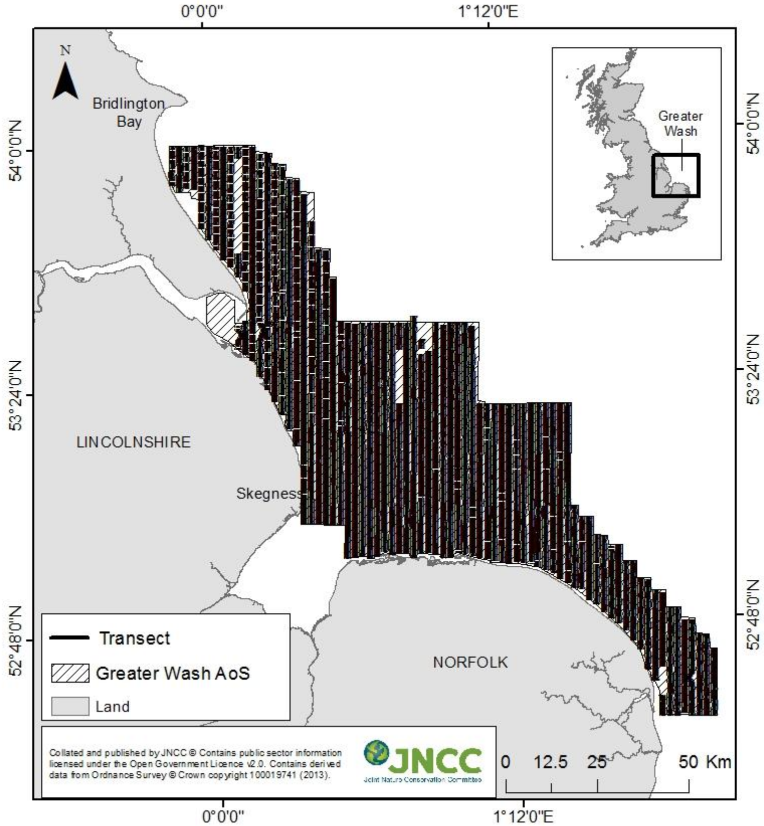
a) Winter season 2002/03 - Feb



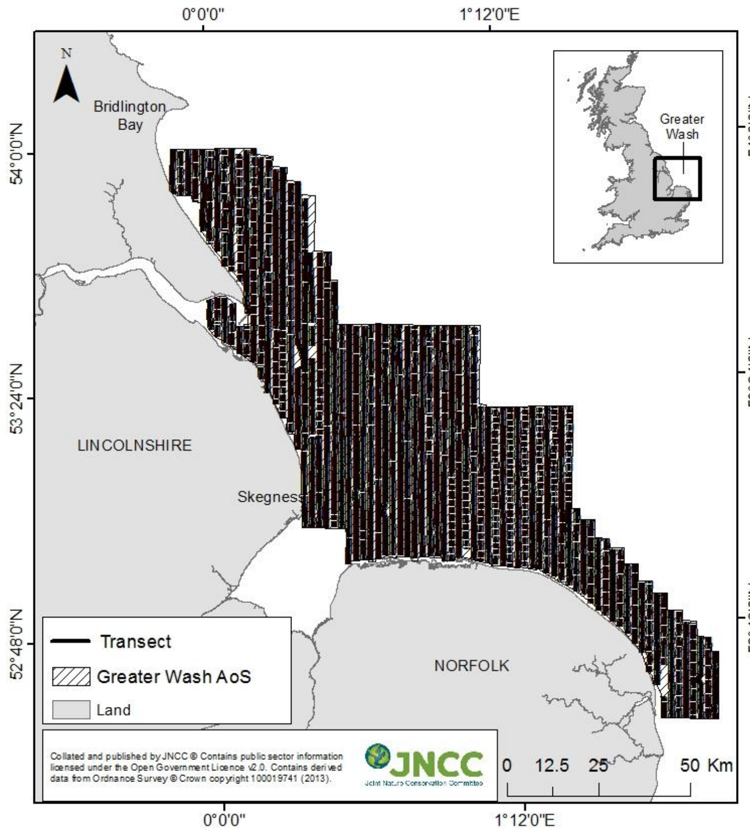
b) Winter season 2002/03 - Mar



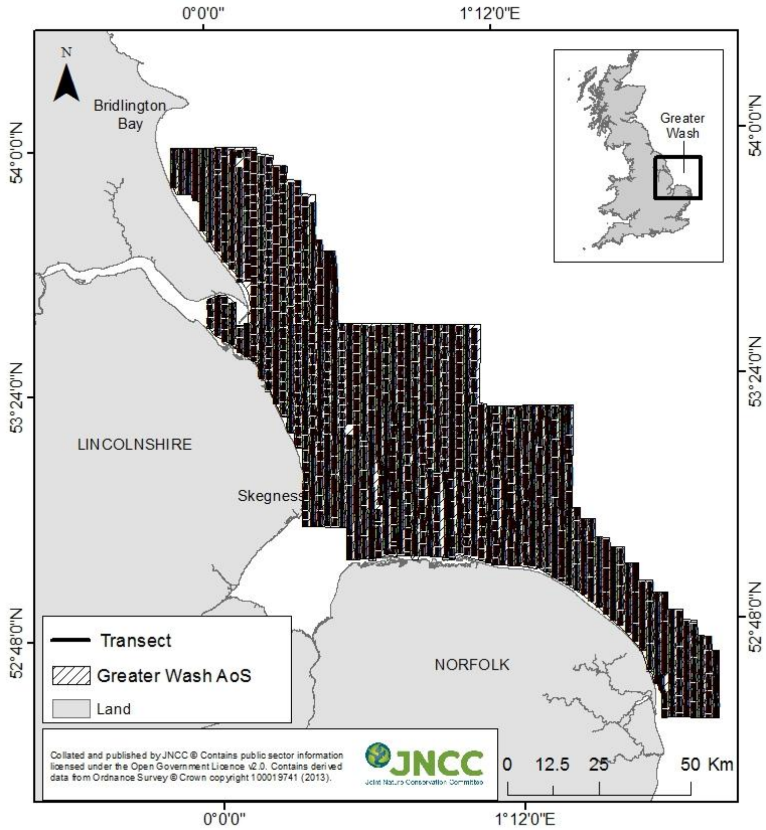
c) Winter season 2004/05 – Oct/Nov



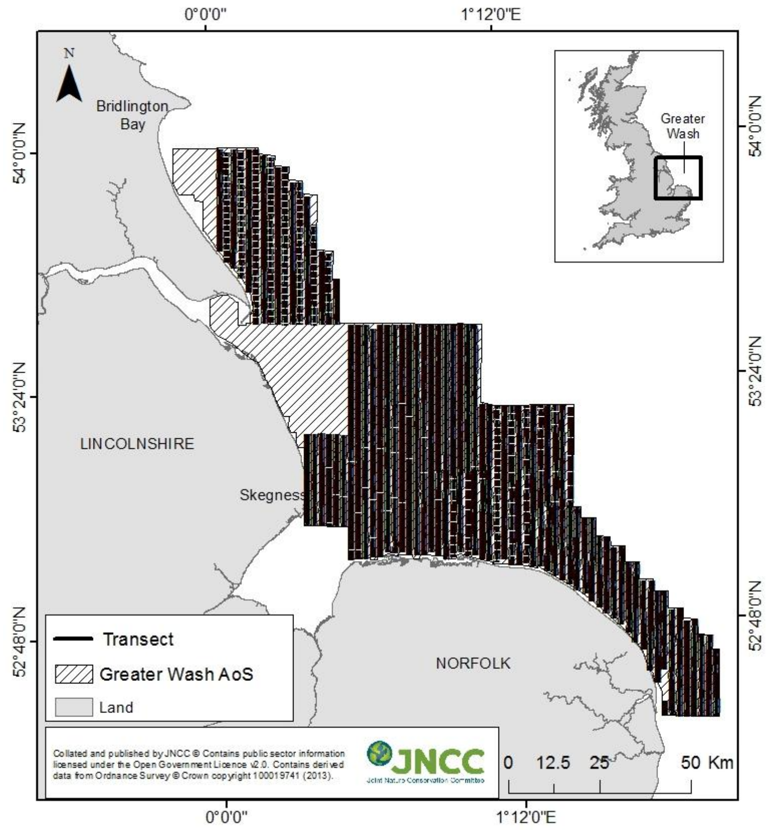
d) Winter season 2004/05 – Nov/Dec



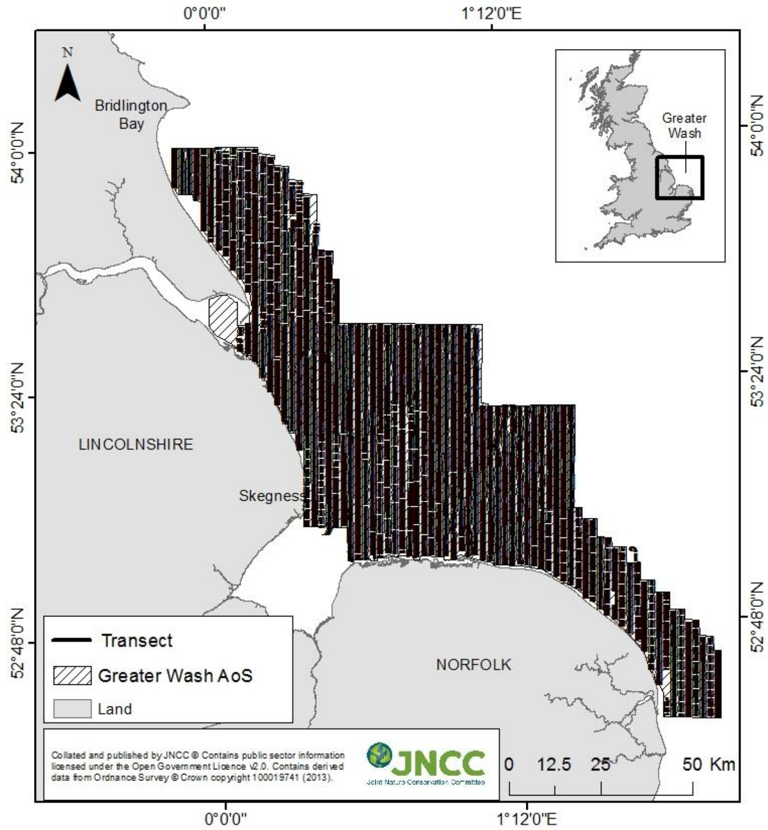
e) Winter season 2004/05 – Jan/Feb



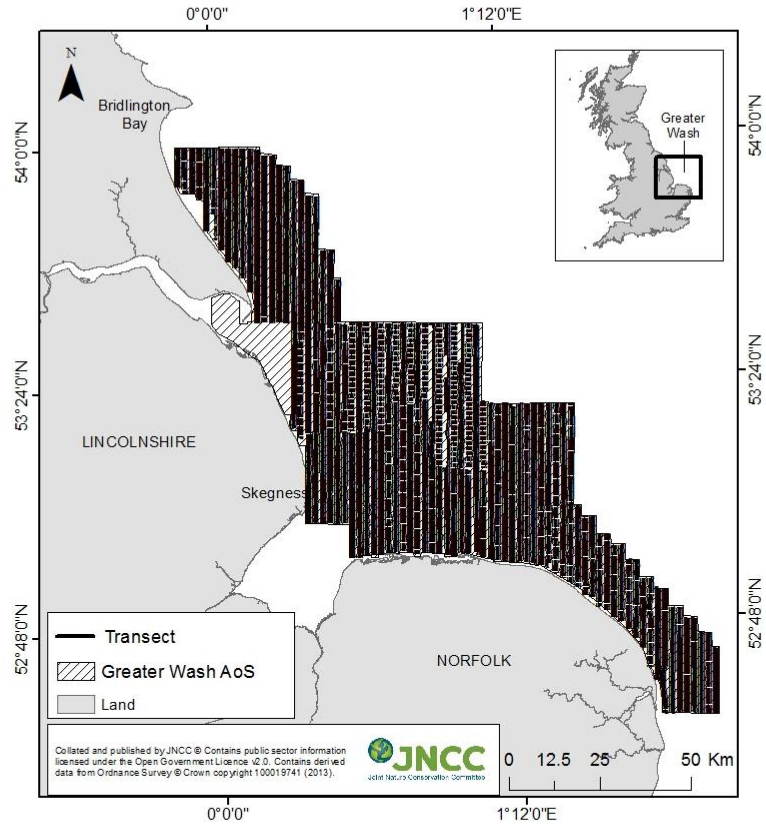
f) Winter season 2004/05 – Feb/Mar



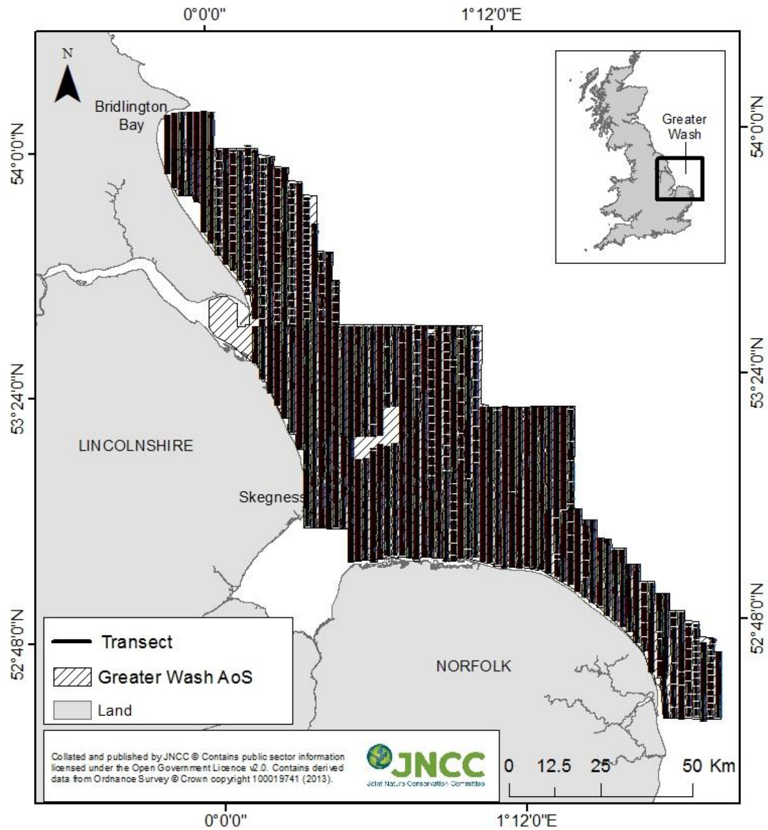
g) Winter season 2005/06 - Nov



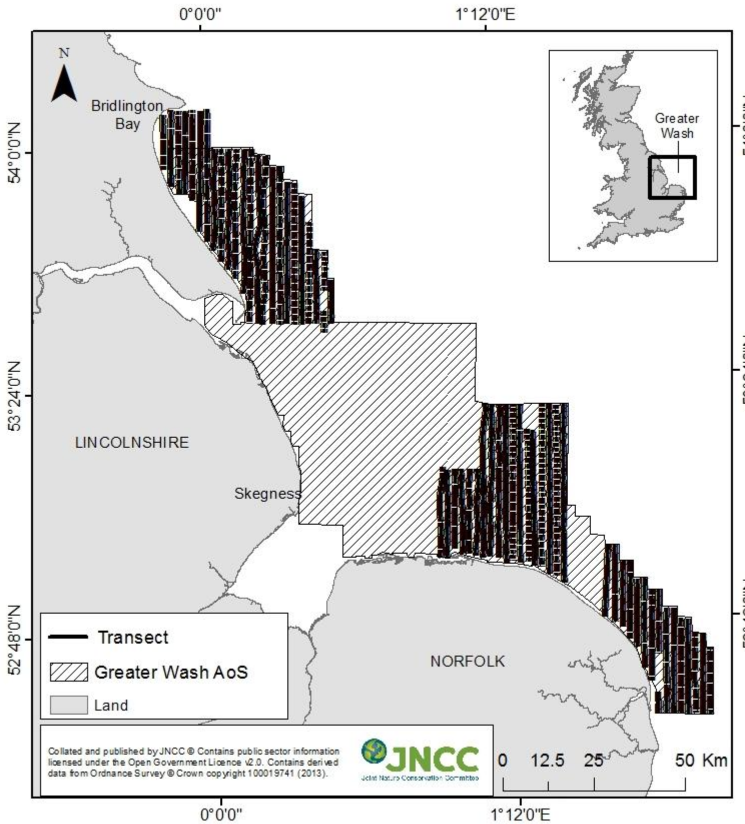
h) Winter season 2005/06 – Nov/Dec



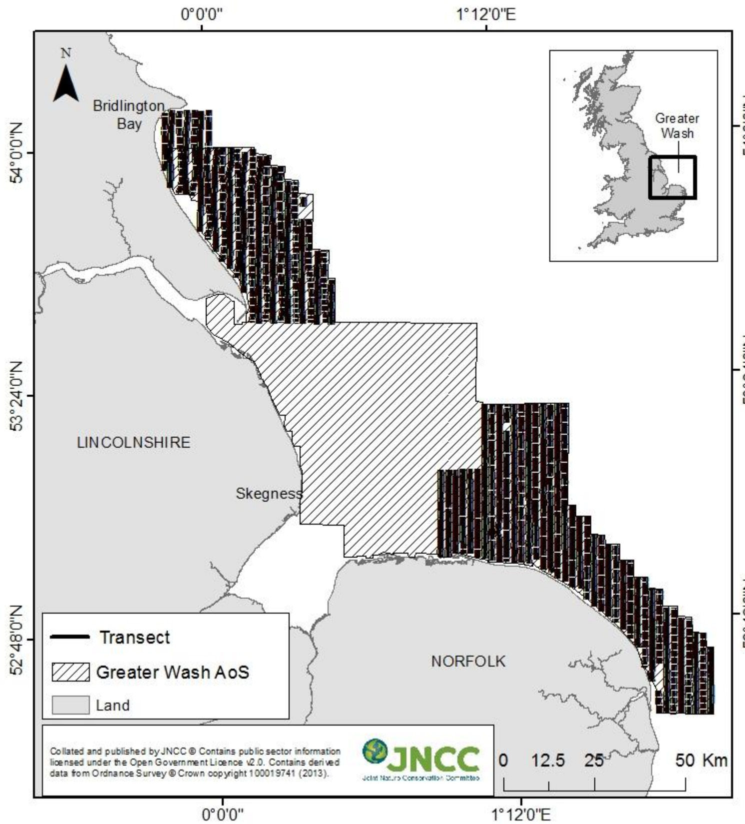
i) Winter season 2005/06 – Jan/Feb



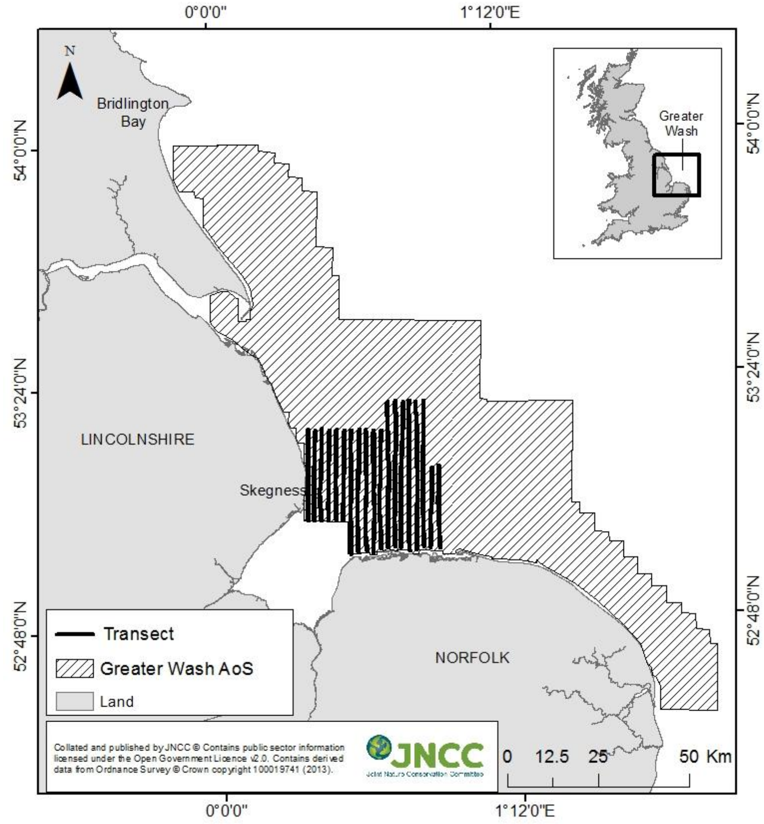
j) Winter season 2005/06 – Feb/Mar



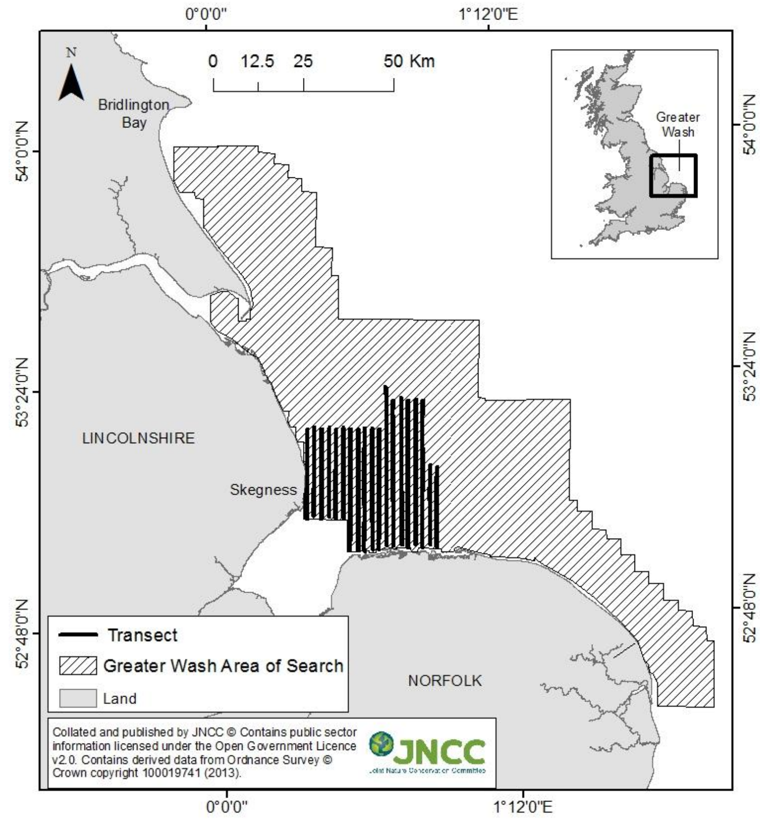
k) Winter season 2006/07 – Jan/Feb



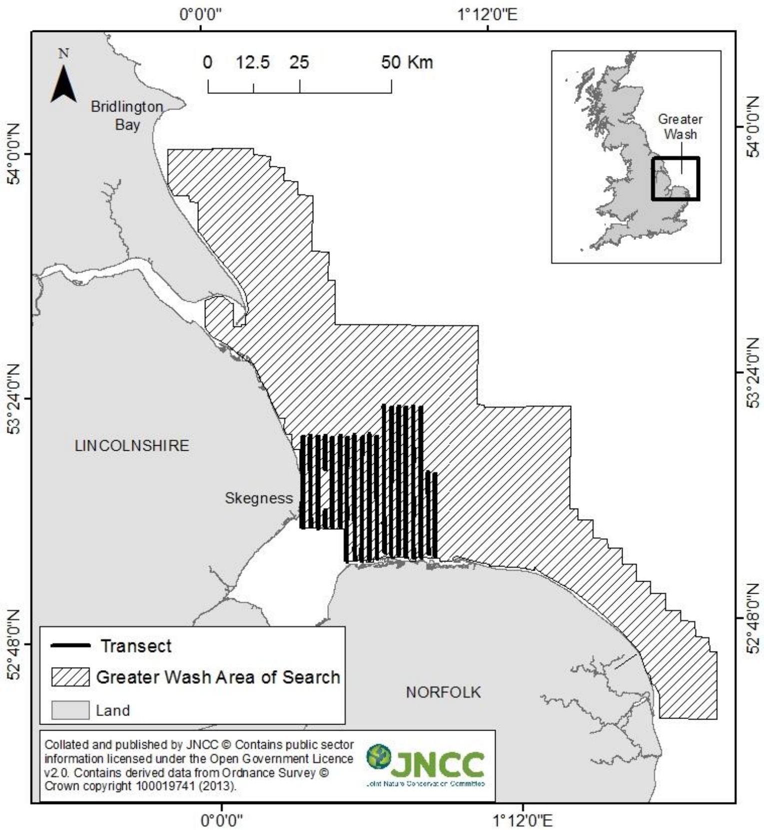
l) Winter season 2006/07 – Feb/Mar



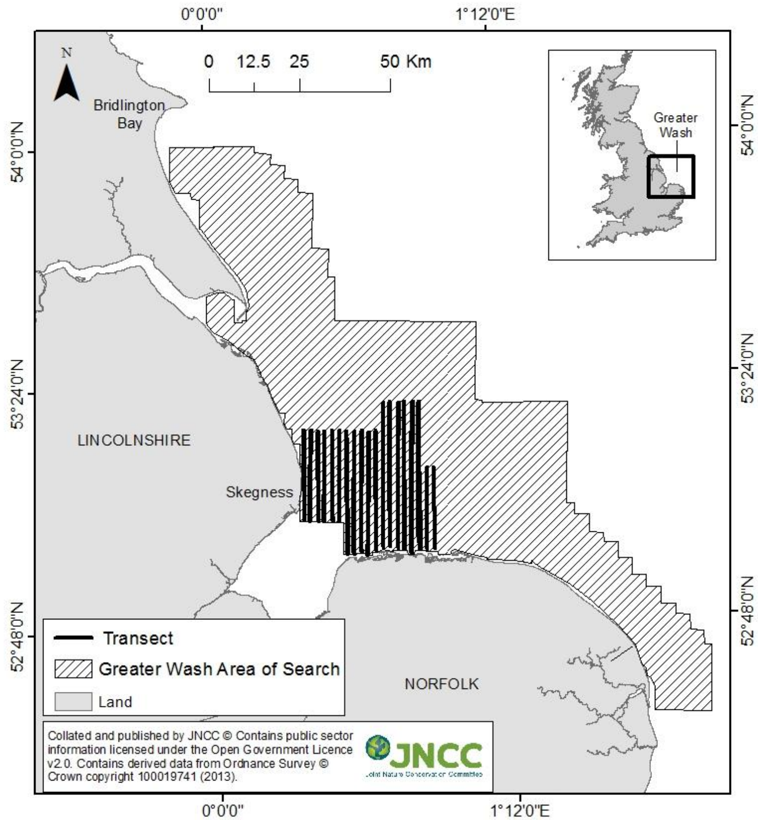
m) Winter season 2007/08 - Nov



n) Winter season 2007/08 - Dec



o) Winter season 2007/08 – Feb



p) Winter season 2007/08 – Mar

Figure A1. Spatial coverage of the aerial surveys in relation to the Greater Wash area of search for each of the winter seasons.