BTO Research Report No. 693

Assessing habitat use of Herring Gulls in the Morecambe Bay SPA using GPS tracking devices

Authors

Chris B. Thaxter, Gary Clewley, Lee Barber, Greg J. Conway, Nigel A. Clark, Emily S. Scragg and Niall H.K. Burton

British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK

Report of work carried out by the British Trust for Ornithology
on behalf of Natural England

May 2017

The British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU
Registered Charity No. 216652

British Trust for Ornithology

Assessing habitat use of Herring Gulls in the Morecambe Bay SPA using GPS tracking devices

BTO Research Report No. 693

Chris B. Thaxter, Gary Clewley, Lee Barber, Greg J. Conway, Nigel A. Clark, Emily S. Scragg and Niall H.K. Burton

Published in May 2017 by the British Trust for Ornithology
The Nunnery, Thetford, Norfolk, IP24 2PU, UK

ISBN 978-1-908581-82-2

CONTENTS

Page No.

LIST OF TABLES

Page No.

Page No.

LIST OF FIGURES

Page No.

Page No.

LIST OF APPENDICES

Page No.

EXECUTIVE SUMMARY

1. Numbers of coastal Herring Gull populations have reduced markedly in recent years. The breeding gull colony of the South Walney and Piel Channel Flats Site of Special Scientific Interest (SSSI), within the Morecambe Bay and Duddon Estuary potential Special Protection Area (pSPA), is of national and international importance for its numbers of Herring Gull *Larus argentatus* and Lesser Black-backed Gull *Larus fuscus*. In recent years, however, the populations of both species at the site have declined significantly, and while this is considered to be largely a consequence of changes in the breeding colony itself, dependencies on habitats away from the colony may also play a role both in the observed decline and in the efficacy of proposed population recovery measures.

2. To date, although we know that Herring Gulls are largely resident within the UK after breeding, for instance through ringing records, we have little detailed knowledge of habitat use. A key resource for this species could be mussel bed areas, for which there are several in the local Morecambe Bay area. Data on the movements of Herring Gulls have also been gathered for this site using GPS telemetry, giving a year-round perspective of movements of adult birds from the pSPA.

3. We investigated the movements of 24 adult breeding Herring Gulls from the South Walney colony in pre-breeding, breeding, post-breeding and winter periods from the 2014 breeding season through to the 2015 post-breeding season. Delineation of these periods was based on colony-wide estimated mean hatching, fledging and laying dates. After GPS data were downloaded and cleaned, a Hidden Markov Modelling approach was used to identify three 'states' of activity: (1) resting stationary, (2) commuting, and (3) other foraging and resting behaviours, based on the turning angle and step length between consecutive GPS points. Given the variation in sampling rates inherent in this dataset, we investigated two sampling rates: (i) 10 minute and (ii) 60 minute, with the former providing a more refined picture of activity but potentially biased to times when GPS devices could sustain such rates. By contrast, the 60-minute dataset gave likely greater error in defining behavioural states but allowed assessment of habitat use through pre-breeding and post-breeding periods. During the winter, GPS rates could often sustain only one or two fixes per day, hence a dataset filtered to 18 hours (1080 minutes) was used to identify resting and commuting location based on step-length alone.

4. To assess usage of areas of interest, spatial area utilisation distributions were computed using the activity states of resting and foraging, excluding commuting. Kernel density estimation (KDE) was used to identify core (50% KDE) and total (95% KDE) foraging/roosting areas. The overlaps of these distributions with mussel bed areas and constituent SSSI components of the SPA were then calculated for each bird and the total population. Similarly, we also assessed the time budgets of each bird and the time spent in these areas split by behavioural states through the year.

5. A wide variation in habitat use was recorded among birds. Birds remained within the northwest region across the year, travelling no further south than the Mersey Estuary, and with some individuals making substantive use of the colony area even through the non-breeding period. Birds frequented intertidal mudflats, as well as terrestrial habitat such as fields, gravel workings, rubbish dumps and freshwater bodies. Some use of urban areas was seen, although the nearby Barrow-in-Furness was not extensively used. Mussel bed areas were also used, with some clear patterns in the foraging distributions indicating regular movements of the population to certain patches. Areas near to the colony were used most frequently. Birds made most use of the South Walney and Piel Channel Flats SSSI, which encompassed the breeding colony, but some use of other SSSIs within the SPA (with the exception of Roudsea Woods & Marshes SSSI) was also recorded. Substantial individual variation was apparent in the use of mussel beds. Based on mean values across individual birds, up to 11.6% of the 95% KDEs for individual birds overlapped with mussel beds, while up to 4.5% of time budgets were spent in this habitat (varying by period of the year). The largest overlaps with mussel beds were seen during breeding. Herring Gulls

spent 50-60% of their time away from the colony during breeding and over 70% at other times of the year. Temporal overlaps with mussel bed areas, based on time spent engaged in foraging/resting behaviours, were up to 9.5% of birds' time spent away from the colony (Appendix 1).

6. Data from GPS telemetry provide a valuable resource to investigate the importance of particular habitats to species. The data collected here for Herring Gulls clearly indicate some use of local mussel beds throughout the year. The analyses carried out here are a useful first step in assessing the relative use of habitat; however, although indications are strong, it is not possible at present to firmly conclude whether mussel bed habitats were positively selected by Herring Gulls above other habitats in the region. Therefore, to further our understanding, more formal statistical assessment of the relative use of these habitats in relation to others should be conducted. For example, the use of resource-selection functions to determine habitat linkages would be a next logical step in the analyses of these data.

1. INTRODUCTION

The breeding gull colony of the South Walney and Piel Channel Flats Site of Special Scientific Interest (SSSI), within the Morecambe Bay and Duddon Estuary potential Special Protection Area (pSPA), is of national and international importance for its numbers of Herring Gull *Larus argentatus* and Lesser Black-backed Gull *Larus fuscus*. In recent years, however, the populations of both species at the site have declined significantly, with the population of Herring Gull having declined from 20,000 individuals in the breeding season in the early 1990s to 3,192 individuals between 2011 and 2015 (Current five-year peak mean, Natural England 2016). While this is considered to be largely a consequence of changes in the breeding colony itself, dependencies on habitats away from the colony are unknown and may also play a role both in the observed decline and in the efficacy of proposed population recovery measures.

Information on the use of other areas away from the colony, both during the breeding season and non-breeding seasons, is thus vital to understand potential constraints on the colony.

Data gathered through recent tracking studies of both species at the South Walney colony led by the British Trust for Ornithology on behalf of the Department of Energy and Climate Change (DECC) (and overseen by Hartley Anderson) have the potential to inform on area usage, but require analysis.

1.1 Project Aims

This report provides an assessment of the data gathered by the BTO as part of their work on behalf of DECC that aims to inform Natural England's understanding of the dependencies of Herring Gull on the Morecambe Bay and Duddon Estuary pSPA and its component SSSIs, both during the breeding season and non-breeding seasons.

1.2 Objectives

Specifically, analyses aim to provide:

- An assessment of home ranges for the breeding period and non-breeding periods, as defined by individuals' association with the breeding colony (see Thaxter *et al.* 2015a, 2016b, in prep), and as feasible, separately also for the pre-breeding, incubation/chick-rearing and post-breeding periods.
- Assessment of the spatial overlap between these ranges and the pSPA and its component SSSIs ;
- Assessment of the spatial overlap between these ranges and mussel beds;
- Complementary assessment of the proportion of time spent by birds outside of the colony within the pSPA and its component SSSIs;
- Complementary assessment of the proportion of time spent by birds outside of the colony in mussel beds.

2. METHODS

2.1 Focal Species

The Herring Gull (the UK sub-species of which is *L. argentatus argenteus*) is a qualifying feature of three breeding colony SPAs in England, eight in Scotland and one in Northern Ireland (SPA Review: Stroud *et al*. 2001; SNH SPA extensions). There has also been much research into this species' breeding biology and ecology over a number of decades (e.g. Tinbergen 1953; Chabrzyk & Coulson 1976; Davis & Quinn 1997; Kim & Monaghan 2006). Tracking studies with this species are also now underway at various locations (e.g. Steinen *et al*. 2016), but few results are yet in the public domain. Hence limited data are available concerning foraging movements. During the non-breeding season, the extent of migration varies between and within populations. Data from ringing suggest that British Herring Gulls disperse from their breeding colonies, but generally do not make long distance migrations, although some birds do leave the country, and Britain also experiences an influx of Herring Gulls breeding elsewhere in Europe during the winter months (Wernham *et al*. 2002)

2.2 Field Site

The movements of Herring Gulls were studied at a mixed colony of Lesser Black-backed Gulls and Herring Gulls at South Walney, Cumbria (54°40'N, 3°14'W). South Walney forms the southern tip of Walney Island, a shingle island lying at the end of the Furness Peninsula. The Herring Gull is a feature of the South Walney and Piel Channel Flats SSSI, a component part of the Morecambe Bay SPA. The SPA also supports breeding terns and internationally and nationally important populations of wintering waterbirds. The South Walney Herring Gull colony reduced in size from 10,129 AONs in 1998-2002 (Mitchell *et al.* 2004) to 1,743 AONs in 2012 (JNCC 2014).

2.3 Capture and Attachment Methods

A total of 24 tags were deployed on adult breeding Herring Gulls during the 2014 breeding season, between 16 May 2014 and 3 June 2014. Birds were captured at nests during incubation using wire mesh traps (Thaxter *et al*. 2015b), and after catching a GPS tag (PathTrack Ltd – see below) was attached using a cross-over wing harness (see Thaxter *et al*. 2014a, 2014b). The harness used was the same style but varied in construction to provide samples of birds tagged using a permanent (n = 9) and non-permanent ('weak-link') harness (n = 15), hence allowing the harness to drop off after a certain amount of time; the latter was a trial of three different types of fixtures designed to last on average two years, so as to minimise impact on the birds. The principal behind the weak link is that once it gives, the harness becomes completely free. To enable this to happen, the weak link point in the harness was where the knot sits in the tracheal pit (see Thaxter *et al.* 2014a for wing harness design details). Once the harness was made the only difference to fitting is that two knots are needed to secure the tag rather than one under the standard permanent design.

Birds were kept captive for a maximum of 45 minutes, during which time biometric measurements were taken, and the tag was attached. All tagged birds were also fitted with individually inscribed colour-rings to allow for subsequent re-sightings. After tagging, birds were released and resumed normal incubating behaviour after a period of time away from the nest area.

2.4 The GPS System

2.4.1 GPS devices

To study the movements of Herring Gulls, we used Nanofix GPS devices from PathTrack Ltd, weighing 14 g (52 X 22 X 14 mm). The total weight (device plus harness) was no more than 16.1 g (< 3% body mass, mean weight of adults captured: 974±137 g, range: 730-1410 g, n = 66). The devices included solar cells and a radio transceiver thus having similar functionality to those University of Amsterdam devices used on Lesser Black-backed Gulls. One-way remote UHF data communication allowed data to be downloaded remotely to a field-based base station. Periodic downloads from the base station were then made to a laptop to recover the data for further processing. The undersides of the PathTrack tags, fitted to Herring Gulls, were sufficiently smooth and level not to require any epoxy resin. However, some of the tags had exposed connectors on the upper surface which may have affected the weather proofing of the device and sat slightly proud (no more than ca. 1 mm). These connectors were coated with epoxy resin before attachment. GPS xy position for these tags has an error of up to 20 m in good conditions (G. Brodin, PathTrack Pers. Comm.)

2.4.2 Sampling schedules

Two sampling schedules were uploaded to the devices prior to deployment. During a pre-determined 'breeding season' (March-August) fixes were taken continuously either every five or ten minutes; the initial expected functionality was not fully known, therefore these two different rates were used. The GPS operational mode chosen was 'solar assisted', whereby as the battery voltage decreases, the sampling rate drops dynamically through steps of ten minutes, preserving battery power. This allowed the most sustainable rate to be achieved. When the device was recharged it reverted to the desired sampling interval as soon as the battery voltage sufficiently recovered. The UHF communication frequency (download rate from the GPS devices to the base station) was set at 30 minutes. For a pre-determined 'non-breeding season' (ca. September to February), a second schedule was pre-programmed for the devices before deployment. A GPS sampling rate of 30 minute was chosen, solar assisted (see above), and the communication frequency with the base station was set to 60 minutes.

2.5 Defining periods of the year

We investigated the movements of Herring Gulls across the year from the 2014 breeding season to the end of the 2015 breeding season (Tables 2.1 and 2.2). We defined four periods: (i) pre-breeding, (ii) breeding, (iii) post-breeding and (iv) winter. The breeding period was defined using a combination of estimated hatching dates from the monitoring of nests of tagged birds, together with estimated incubation and chick-rearing periods (Robinson 2005). We used the mean incubation (28-30 days) and chick-rearing periods (35-40 days) for Herring Gulls to extrapolate forwards and backwards from the estimated hatching dates of eggs to estimate laying dates and fledging dates – see also Thaxter *et al.* (2015b) where the same approach was used for Lesser Black-backed Gulls.

First egg hatching dates in 2014 were estimated from site visits to the colony on 3 June 2014, 10 June 2014 and 25 June 2014, and thus were approximate, given that the first eggs of clutches may have hatched at any time between checks. As checks later in the season were restricted due to the need to minimise disturbance, overall hatching dates are likely slightly biased towards the peak hatching period. Across birds, estimated hatching dates ranged from 5 June 2014 to 15 June 2014, with a mean of 10 June 2014. Estimated egg laying dates were therefore 8 May 2014 to 16 May 2014 with a mean of 12 May 2014 and fledging dates were: 10 July 2014 to 25 July 2014 with a mean of 17 July 2014. Based on these mean dates, the 2014 breeding period was thus defined as 12 May 2014 to 17 July 2014 (although, it should be noted that tags were only deployed from 16 May 2014).

After breeding gulls are known to make progressively longer trips away from the colony, having lost any constraint of central place foraging, but still returning to the colony, prior to their final winter departure (e.g. for Lesser Black-backed Gulls, Klaassen *et al*. 2012). This pattern was also seen to an extent in Herring Gulls, therefore, we used bird-specific information to determine two additional periods of 'post-breeding' and 'winter'. Data were available for 11 birds for the subsequent 2014/15 winter (Table 2.1). Defining the end of the start of the winter period, however, was not straight-forward, as for Herring Gulls all birds frequented areas that were also used during the breeding season. There was also considerable individual variation in behaviour and breeding status. Therefore, it was not appropriate to define a colony-specific winter period as done above for the other periods. Therefore, we subjectively defined the start of winter using relationships between individual trip durations (periods from departure and re-arrival at the colony) and for those birds which returned to the breeding colony in 2015. A clear increase in time spent away from the colony, even if locally, was a clear indication that the winter period had begun. The difference between this winter date and the end of the breeding season above was then termed the 'post-breeding' period. For most birds, attendance was still recorded at the colony during the winter, with some smaller trips at this time, but then followed by further long winter absences. With this methodology, the start of the 2014/15 winter period was identified as a mean of 31 August 2014 (range, 26 July 2014 to 13 September 2014) and the end of winter (and start of the pre-breeding 2015 period) was identified as a mean of 21 February 2015 (range, 2 February 2015 to 15 March 2015).

During 2015, monitoring of nests was more problematic, with the colony suffering a wide-scale breeding failure due to mammalian predation. Therefore, we used the same laying date of 12 May as used in 2014 to define the start of the 2015 breeding period. All data after 23 June 2015 – when there was significant failure across the colony – were treated as 'post-breeding'. The same rationale as described above was then used to define the end of the 2015 post-breeding period and start of the subsequent winter.

Table 2.1 Defined bird-specific winter periods.

Individual	Start winter	End winter	Duration (days)
12646	11/09/2014	17/02/2015	159
12648*	08/07/2014*	12/02/2015	30*
12649	26/07/2014	04/03/2015	221
12653	12/09/2014	14/02/2015	155
12657	12/09/2014	12/02/2015	153
12658	03/09/2014	15/03/2015	193
12661	12/09/2014	03/02/2015	144
12670*	13/08/2014	19/03/2015*	71*
12674	13/09/2014	07/02/2015	147
12675	27/08/2014	02/02/2015	159
12676	30/08/2014	12/03/2015	194

* birds and periods affected by data gaps (see Table 2.2 for more details)

Table 2.2 Periods of data acquisition for each Herring Gull tagged at South Walney, from deployment to last data gathered, split by period investigated; note different sampling rates were used between March and August and between September and February (see text).

					Days of data per period					
			Total days		2014			2015		
Tag	Deployment	Last data	Actual	Potential	Breeding	Post-breeding	Winter	Pre-breeding	Breeding	Post-breeding
12646	01/06/2014	25/08/2015	451	451	46	56	159	84	42	64
12647	01/06/2014	12/09/2014	103	103	46	57				
12648*	16/05/2014	26/07/2015	247*	436	53*		30*	89	42	33
12649	02/06/2014	06/07/2015	399	399	45	9	221	69	42	13
12651	18/05/2014	29/07/2014	72	72	60	12				
12652	16/05/2014	19/05/2014	3	3	3					
12653	03/06/2014	30/08/2015	453	453	44	57	155	87	42	68
12654	17/05/2014	18/05/2014	1	1	1					
12657	01/06/2014	16/06/2015	380	380	46	57	153	89	35	
12658	03/06/2014	02/10/2015	486	486	44	48	193	58	42	101
12659	03/06/2014	11/09/2014	100	100	44	56				
12661	17/05/2014	30/08/2015	470	470	61	57	144	98	42	68
12662	17/05/2014	13/09/2014	119	119	61	58				
12665	01/06/2014	19/06/2014	18	18	18					
12666	02/06/2014	03/06/2014	1	1	1					
12669	02/06/2014	07/08/2014	66	66	45	21				
12670*	20/05/2014	12/08/2015	302*	449	58	27	71*	54*	42	50
12672	17/05/2014	02/07/2014	46	46	46					
12673	17/05/2014	03/07/2014	47	47	47					
12674	02/06/2014	13/07/2015	406	406	45	58	147	94	42	20
12675	03/06/2014	05/08/2015	428	428	44	41	159	99	42	43
12676	01/06/2014	31/08/2015	457	457	46	44	194	61	42	70
12678	02/06/2014	13/09/2014	103	103	45	58				
12680	02/06/2014	04/09/2014	94	94	45	49				

* Bird with tag 12648: data gap between 08/07/2014 and 13/01/2015; bird with tag 12670: data gap between 23/10/2014 and 19/03/2015. For these birds, stars denote periods when GPS information was not obtained, while the potential data that could have been obtained is also shown.

2.6 Data manipulation

Time-stamped GPS data were downloaded from the base station and processed in specially designed software, and then exported as text files for further manipulation in R 3.2.2 (R Core Team 2016). Data were then split into the periods identified above (i.e. 2014 breeding, 2014 post-breeding, 2014/15 winter, 2015 pre-breeding, 2015 breeding and 2015 post-breeding).

2.6.1 Sub-sampling data

A flat rate of sampling was specified in breeding and winter periods (see above). However, as the GPS sampling rate was solar-driven, the target sampling rates were frequently not achieved (see above). The resultant dataset was therefore a mixture of different sampling rates obtained across birds, periods and years. Considering the spatial data in its 'raw' form therefore risked potential biases of sampling to times when solar charging was highest (e.g. sunny daytime conditions when day length was longest). Therefore, we first considered whether data could be 'filtered' to a standard rate, subsampling periods of more frequent sampling, to remove such bias.

Between March and August, many tags could sustain at least a 10, 20 or 30 minute rate, but sometimes the sampling dropped to as low as a 60 minute rate. Therefore, we first considered (i) a 60 minute filtered rate. However, we also considered (ii) a 10 minute rate, removing all other data when such a rate was not achievable (note a five minute rate was also specified for some birds but was rarely sustainable for long periods).

Between September and February, although a target rate of 30 minutes was specified, often tags were restricted to sampling at a rate of (iii) 18 hours and we thus used this rate for the 'winter' period.

As the pre-breeding period for 2015 included a portion of February for most birds, at a time when tags could still only sustain an 18 hour rate in some cases, we also applied a filtering of 18 hours to this pre-breeding season dataset. The differing GPS sampling resolutions, although adding complexity, provide slightly alternative perspectives of the data (maximising its usage), and each has strengths and weaknesses. These are as follows:

- *Fine-scale 10 minute resolution*: most refined identification of foraging locations (see below) and most accurate general representation of space use. However, (depending on the bird and period) the data may not be fully representative of the period concerned, and/or may be biased to particular times within the period when the rate of GPS sampling was sustainable. For some birds (e.g. three birds during the 2014 breeding period) a 10 minute rate was not possible at all, hence sample sizes may also be reduced.
- *Mid-scale 60 minute resolution*: less refined identification of foraging locations (greater potential error on the delineation of activities), but for all periods except winter 2014/15 and pre-breeding 2015, provides a more complete unbiased temporal coverage of the period.
- *Wide-scale 1080 minute (18 hour) resolution*: used for the winter period and also for the 2015 pre-breeding period (see above). Least accuracy regarding defining behaviour of birds (see below), and coarse resolution gives far fewer data points to compute the kernel. However, coverage across the periods is unbiased to any particular time.

2.6.2 Indicative quality of filtered data

The spans of data also varied considerably between birds, reflecting the amount of data downloaded for each tag. The numbers of GPS fixes obtained per period are shown in Table 2.4 below, split also by the number of fixes available in the three rates of filtering applied. The filtered sample sizes therefore reflect

both data that could be downloaded per bird (minimum of 1 day for two birds – see Table 2.2 above), and the rates that were sustained by individual tags within each period. Although results are produced for all birds, we place caveats on those from birds for which only limited data were available using the following logic, based on (1) the amount of data that was collected on a given rate, and (2) the amount of data that could have been collected should that individual bird have been tracked for the entire period of interest. Under these criteria, the weighting given to data for individual birds reflected both the tag functionality to collect data at the desired rate, *and* the potential for data to have been lost, for example due to tag malfunction, the bird not being encountered again (leaving the area) or bird death. The weighting given was therefore calculated on a percentage basis of the proportion of data points at the filtered rate that were obtained from the potential for a given period. Given the fact it is easier to achieve a filtered rate of 60 minutes and 1080 minutes than 10 minutes, the latter rate being more battery-hungry, a different percentage category weighting was applied for the 10 minute filtered data (0-5%, 5-10%, 10-15%, 15-20%, 20-30% and 30%+), compared to the other two coarser rates (0-20%, 20-40%, 40-60%, 60-80%, 80-100%) – see Table 2.3 below.

Table 2.3 Upper and lower bounds of filtered GPS fixes falling within percentage categories, used in turn to indicate the quality of data for 10 minute, 60 minute and 1080 minute filtering rates, for each Herring Gull tagged at South Walney – see methods above for details. For periods where the potential data that could have been collected were dependent upon individual bird-specific dates, the lower and upper bounds are presented as means across all birds with data available.

			2014		2015			
		Category	Breeding	Post-breeding	Winter	Pre-breeding	Breeding	Post-breeding
10 min	Very low	0-5%	0-317	0-324	-	0-577	0-302	0-380
	Low	5-10%	317-634	324-645	-	577-1155	302-605	380-760
	Low-	10-15%	634-950	645-972	-	1155-1732	605-907	760-1140
	Medium	15-20%	950-1267	972-1296	-	1732-2309	907-1210	1140-1520
	High	20-30%	1267-1900	1296-1944	-	2309-3464	1210-1814	1520-2280
	Very high	30%	1900+	1944+	-	3464+	1814+	2280+
60 min	Very-low	0-20%	0-211	0-216	-	0-385	0-202	0-253
	Low	20-40%	211-422	216-432	-	385-770	202-403	253-507
	Low-	40-60%	422-634	432-648	-	770-1155	403-605	507-760
	Medium	60-80%	634-849	648-864	-	1155-1539	605-806	760-1014
	High	80%+	849+	864+	-	1539+	806+	1014+
1080 min	Very-low	0-20%	-	-	0-40	0-21	-	-
	Low	20-40%	-	-	40-80	21-43	-	-
	Low-	40-60%	-	-	80-118	43-64	-	-
	Medium	60-80%	-	-	118-158	64-86	-	-
	High	80%+	-	-	158+	86+	-	-

For the 2014 breeding period, calculations were based on a minimum period of 44 days from the date that the last bird was tagged until the mean fledging date (see Table 2.3). For the 2015 breeding period of 2015, calculations were based on a 42 days from mean colony laying date to date of colony failure. All other periods were dependent on individual defined periods for the start and end of the winter period, so calculations were based on potential data that could be gathered based on these individual periods. Thus: 9-58 days for the 2014 post-breeding period, 30-221 days for the 2014/15 winter, 54-99 days for the 2015 pre-breeding period and 13-101 days for the 2015 post-breeding period. Although there was considerable variation in the extent of data between birds in given periods, ultimately a sensible coding of weighting categories for samples sizes of GPS fixes was sought, for which the above approach was deemed adequate.

Note also that for the winter period, two birds had greatly reduced numbers of days tracking due to logger malfunction, thus we adjusted their quality to 'low-medium' to reflect this lack of data.

Table 2.4 Number of fixes from each Herring Gull tagged at South Walney between tag deployment and 2 October 2015, split by raw data, and the number of points filtered to a coarser rate for spatial analyses at different resolutions used in the study. Colour of the cells indicates the subjectively-assessed reliability of the sample size feeding into the analysis for each bird and period – see methods and Table 2.3 for details of this assessment. 'Br' = breeding; 'Po-Br' = post-breeding; 'Pr-Br' = pre-breeding; 'Wi' = winter.

	Filtered data																	
Rate	10					60					1080		Raw data					
Year	2014		2015			2014		2015			2014	2015	2014		2015			
Bird / phase	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Wi	PrBr	Br	PoBr	Wi	Br	PoBr	PrBr
12646	156	9	0	3118	0	1021	1213	906	1498	814	196	118	2175	2172	1374	2507	5884	1613
12647	2828	1226				1032	1402						4501	4409				
12648	1630		2880	2752	1063	1246		911	785	2187	41	124	4090		441	4163	3673	4895
12649	6	0	59	0	0	988	263	859	276	366	254	95	2062	577	2362	1890	501	695
12651	98	0				1347	328						2468	760				
12652	0					74							113					
12653	2696	6116	3487	5638	423	979	1391	908	1625	1645	188	122	4664	8216	2516	5310	8659	4689
12654	109					18							221					
12657	5355	5033	4070		2373	1031	1389	747		1803	204	124	8594	6715	2634	5049		6823
12658	3686	6787	0	874	0	992	1182	897	2387	672	212	83	4819	6915	1763	1581	5341	1052
12659	0	118				986	1372						1864	2850				
12661	6738	8007	4398	8965	825	1365	1380	911	1628	2315	192	136	9021	12167	3433	6417	13075	6072
12662	2714	3654				1370	1391						5076	5603				
12665	2024					434							2318					
12666	0					24							72					
12669	2156	160				1010	550						3808	1665				
12670	0	0	0	0	0	1111	693	110	428	6	90	67	1933	1389	1867	216	696	99
12672	2019					1090							4211					
12673	1186					1105							3627					
12674	4238	3739	3015	1555	0	1008	1421	910	479	1654	191	131	5146	5854	2183	4244	2214	3057
12675	3267	4435	1705	2080	107	991	1026	875	971	1142	210	138	5448	6353	2832	3612	4262	3489
12676	570	685	0	239	0	1034	1096	679	1508	674	237	84	3519	3941	1678	2027	4755	2060
12678	1043	38				997	1015						3758	3162				
12680	4270	6097				1002	1203						4942	6583				

For interpretation of maps and eventual summary tables, the data indicted as 'high' quality and above are taken as having highest confidence and consequently indicative of the period of interest. 'Low-medium' and 'medium' quality data deserve some greater caution but are nonetheless here treated as indicative of the period of interest. Confidence in 'low' and 'very low' quality data was lowest, and hence more caution is needed with respect to these results. Note 'low' and 'very low' quality data were excluded from final spatial and temporal assessments (Tables 3.10 and Table 3.17 respectively). The colouration of Table 2.4 is also carried through to the spatial and temporal overlap tables in results.

2.7 Data analysis

2.7.1 Space use

Hidden Markov model

To be able to better appraise habitat use, we first analysed the data to separate commuting flight behaviour between roosting and foraging sites from resting and foraging behaviour. We used two approaches to do this: (i) a very simple assessment of the step lengths between consecutive regularised GPS points to obtain a potential cut-off point to delineate resting and foraging from commuting, and (ii) a Hidden Markov Model (HMM) specified as a three-state model (R package: moveHMM, Michelot *et al.* 2015), based on speed and turning angles of regularised GPS points. We also ran a three-state Hidden Markov Model to identify potential resting, foraging and commuting behaviours. Models were fitted across all birds for both specified periods as well as for all periods together. Input parameters were specified for the HMM as follows for:

1. Stationary resting / foraging (small step length, high turning angle);
2. Commuting (larger step length, concentrated turning angle);
3. 'Other' behaviours including foraging and slow drift on the sea (small-medium step length, concentrated angle with high variation).

We carried out separate HMMs for the 10 minute and 60 minute filtered datasets (see above) specifying slightly different starting parameters for step lengths and turning angles. For the 10 minute filtered dataset (see above), we specified the following parameters in the R code:

Respective model parameters were as follows (behaviours i to iii respectively):

```
>Mean.step <- c(0.01, 2, 0.5)                  # Mean step length
>Sigma0 <- c(0.01, 0.5, 0.25)                  # Standard deviation of step length
>angleMean0 <- c(-0.002, -0.001, 0.005)        # Von Mises distribution for mean angle
                                                (radians)
>kappa0 <- c(1, 20, 10)                        # Concentration around mean (high value =
                                                high concentration, straighter movements)
```

For the HMM based on the 60 minute filtered dataset, starting parameters were specified as follows (behaviours i to iii respectively):

```
>Mean.step <- c(0.05, 4, 2)
>Sigma0 <- c(0.02, 2, 1)
>angleMean0 <- c(-0.002, -0.001, 0.005)
>kappa0 <- c(1, 20, 10)
```

Activity based on step length distribution alone

A HMM was also tested for the winter period with data filtered to 18 hours (1080 minutes). However, the HMM provided no meaningful delineation of behaviours due to the coarseness of the sampling rate, therefore to characterise area usage in this period we used the upper quartile of the distribution of step length alone; this approach provided an adequate means of removing GPS locations where birds were travelling at a faster average speed, most likely commuting. This approach was also used as an alternative filtering rate for the 2015 pre-breeding period, as for part of this period (within February), solar-charging of the tag was only sufficient to match that of the winter period. Hence for pre-breeding, the 1080 rate provided a better total period coverage, but at a much coarser GPS sampling rate.

We conducted further tests using the datasets filtered to 10 minutes and 60 minutes for the 2014 breeding period, to examine the usefulness of the 'step length' approach and accuracy when compared to the primary HMM approach. The upper quartile of the step length distribution, for data filtered to a 60 minute sampling rate, was given as 1.8 km (i.e. an overall ground speed of 1.8 km/h). The delineation of points assigned to each category using the IQR was: 5664/16725, i.e. 33% time in flight commuting, which seemed reasonable. Hence, the upper quartile approach was deemed suitable for examining behaviour in the winter period in this study.

Home range analysis

To assess home range area of Herring Gulls and in turn assess area overlap with the mussel beds, SPA and component SSSIs, we computed time-invariant utilisation distributions using Kernel Density Estimation (KDE) (Worton 1989). These analyses were performed on a subset of the data that excluded commuting behaviours, as defined by procedures outlined above. Therefore for analyses based on 10 minute and 60 minute filtered rates, data assigned to states 1 and 3 were combined and those data assigned to state 2 was excluded. For the 2014/15 winter period and 2015 pre-breeding period, where analyses used data filtered to the 1080 minute rate, data assigned to the commuting state identified through the inter-quartile range method were excluded.

In estimating the smoothing parameter, we conducted initial tests of the Least Squares Cross Validation (LSCV) approach, which provided no suitable convergence for this dataset. The default 'href' option greatly over-smoothed the spatial distribution. Therefore, following Wade *et al.* (2014) and Thaxter *et al.* (2015a, 2015b, in prep.), we examined a range of smoothing parameters (200-600 m) and grid resolutions (50-400 m). The most suitable smoothing parameter identified for the 10 minute resolution dataset was 200 m or 300 m whereas a slightly larger smoothing parameter was required for the 60 minute resolution data (h = 300) and 1080 minute resolution data (h = 400), with a grid resolution of 100 m. The chosen spatial distributions were bivariate normal and 'time invariant' static methods. We also tested time variant methods that also include smoothing parameters in the temporal dimension (e.g. Keating and Cherry 2009) and Brownian Bridge methods, however, these methods also carried a degree of subjectivity in selecting parameters and offered no apparent perceived improvement in overall distribution given the increased complexity of the algorithms. Therefore, for simplicity here we selected time invariant methods for characterising area use. The 50%, 75% and 95% KDEs of the utilisation distribution were taken to represent the core, middle, and total areas, respectively – although in line with other studies (e.g. Soanes *et al.* 2013), here we present overlaps using the core and total area usage for simplicity. For each individual, we then calculated the total area of the 95% and 50% KDEs and the percentage overlap of KDEs with these areas was then calculated. All GIS and kernel analyses were conducted using 3.2.2 (R Core Team 2016).

Mussel bed areas and protected sites

Defined mussel bed areas (two shapefiles provided by Natural England) and the SPA (and component SSSIs) are shown in Figure 2.1 below. Two different shapefiles were used in this assessment to indicate likely mussel bed locations, both relating to extent of rocky skear habitat, most of which, but not exclusively, is taken to be dominated by mussels but may also include other hard substrate biotopes such as stony reefs. The first shapefile ('shapefile 1', shown in Fig. 2.1) relates specifically to areas surveyed recently in 2015 on behalf of Natural England as part of an intertidal hard substrate/rock survey (Antill & Pérez-Domínguez 2016); an additional historic, less-refined shapefile for the whole of Morecambe Bay (from a North Western Inshore Fisheries and Conservation Authority survey in 2011) is also considered.

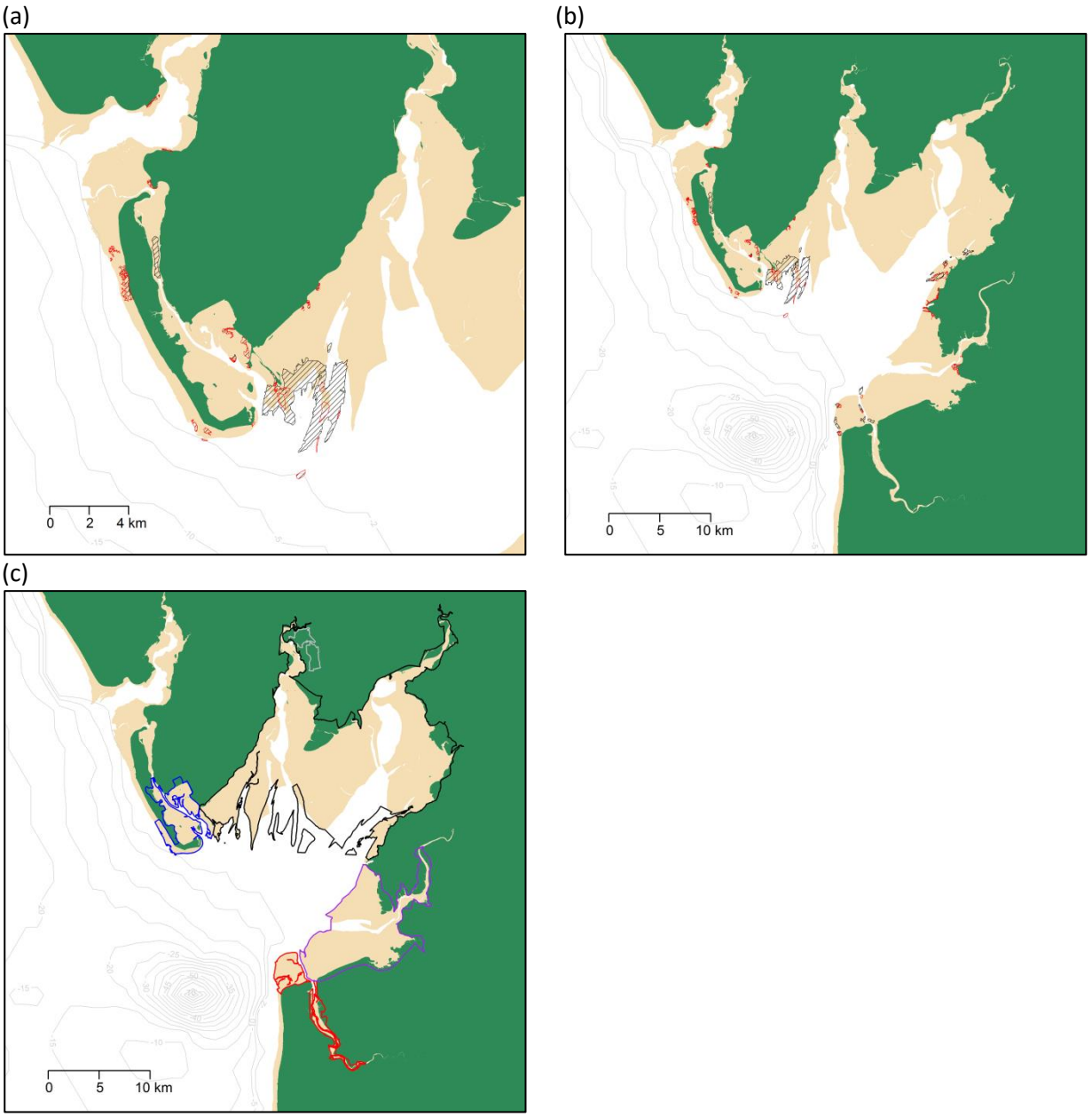


Figure 2.1 Location of the mussel bed areas, shown at two spatial extents (a) around the local South Walney breeding colony and (b) the total within the Morecambe Bay SPA area; red hashed = recent 2015 Natural England survey, 'mussel bed shapefile 1', black hashed = wider temporal survey and historic general information, 'mussel bed shapefile 2', see text for details; (c) SSSIs: Blue = South Walney and Piel Channel Flats SSSI, Black = Morecambe Bay SSSI, grey = Roudsea Wood and Mosses SSSI, black = Morecambe Bay SSSI and purple = Lune Estuary.

Assessment of overlaps

The percentage overlap of 95% (total use) and 50% (core use) KDEs was assessed in relation to the shapefiles above for mussel bed areas and SPAs and constituent SSSIs. Analysis was conducted for individual bird kernels as well as total 'all-bird' kernels. Sample sizes varied between birds and for each bird by period, as well as by the filtering rates used. Results were therefore tabulated and coloured by sample sizes of number of fixes (as indicated in Table 2.2). This categorisation of points enabled a more straightforward assessment of overlaps in relation to the (subjective) degree of confidence we have in the results.

2.7.2 Temporal use

For each bird, the total time spent in the mussel bed areas and other areas of interest was assessed. The time spent in these areas was quantified and is presented in relation to the total time that the bird was tracked in a given period. Specifically, to obtain the time spent in these areas, we used consecutive GPS points and linearly interpolated points to identify date-time stamped information on entry and exit points from GIS shapefiles (essentially identifying points in polygons for the interpolated dataset), and to allow subsequent time budget calculations. This analysis was conducted on the same dataset used for calculating utilisation distributions from the HMM. Hence the data were also regularised prior to analysis. Further, for simplicity, we present the temporal overlaps for birds based on the 60 minute resolution dataset for all periods except winter, and the 1080 minute resolution dataset for winter. For the 60 minute resolution data, points were interpolated to 10 seconds and for the 1080 minute resolution data, 60 seconds; these choices were based on computation time as a compromise of temporal resolution of the initial data and the number of interpolated points generated in programs. By using the HMM dataset, we were able to quantify the total time spent by each bird in each area split by either resting/foraging and commuting.

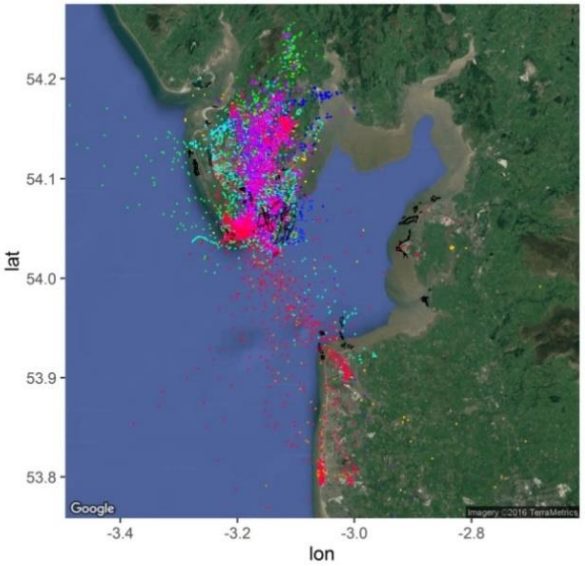
We also provide two versions of the temporal overlap analysis for within the breeding season whilst birds were considered central-place foragers: (1) using all locations including those at the colony and (2) excluding periods when birds were at the colony (see Appendix 1). The latter better emphasises foraging areas and provide a more refined assessment of key areas that were important to birds at given times of year, and consequently use of mussel beds and protected areas.

3. RESULTS

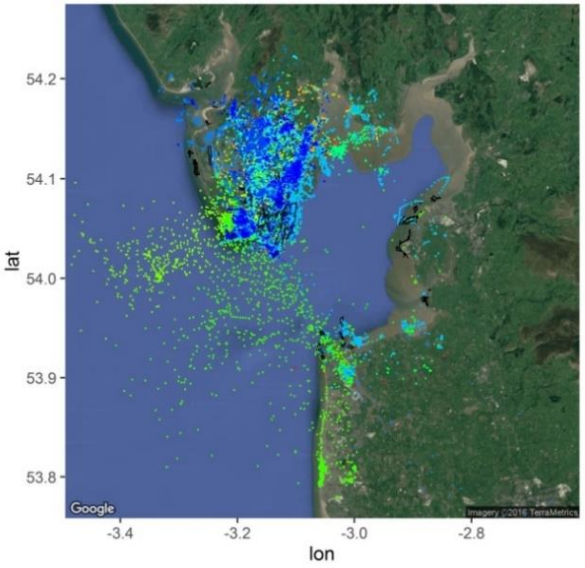
3.1 Data overview

Initial plots of the data are shown in Figs 3.1 and 3.2. Review of the data showed individual patterns in habitat use across the year and variations in the level of interaction that birds had with the mussel beds and protected areas. Birds mainly frequented terrestrial or intertidal areas, with only two birds going substantially offshore during the overall study period (excluding commuting periods across Morecambe Bay). The nearby mussel beds were frequently used. Several tracks were recorded to areas near to the colony, including mussel beds immediately to the south and east of the colony, as well as to the larger area of mussel bed to the east.

(a) 2014 breeding (n = 24 birds)



(b) 2014 post-breeding (n = 17 birds)



(c) 2014 winter (n = 11 birds)

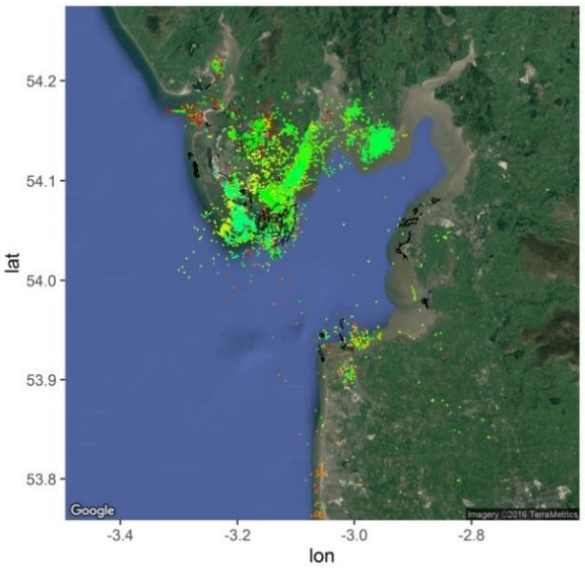
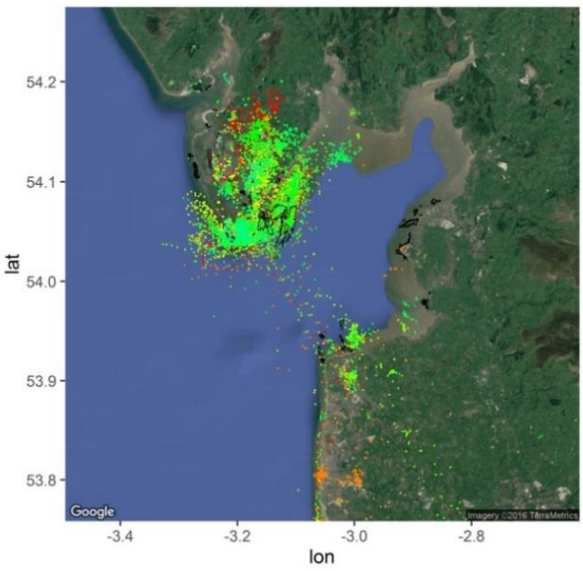
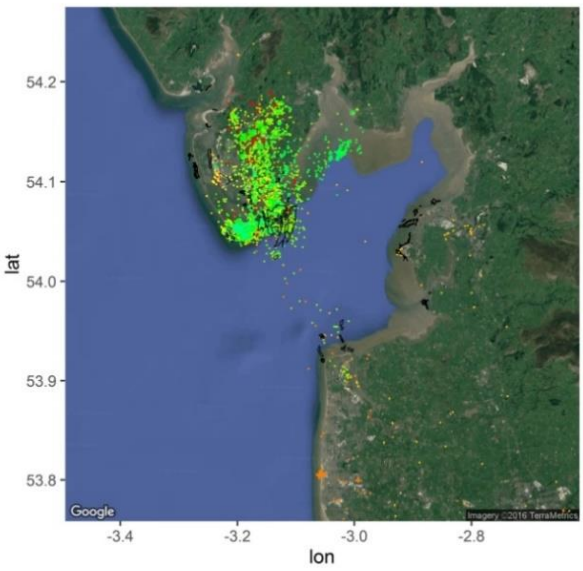


Figure 3.1 Movements of Herring Gulls tagged at South Walney in the 2014 breeding and post-breeding periods and the 2014/2015 winter period; each colour represents a different bird consistent across the different periods.

(a) 2015 pre-breeding (n = 11 birds)



(b) breeding (n = 11 birds)



(c) post-breeding (n = 11 birds)

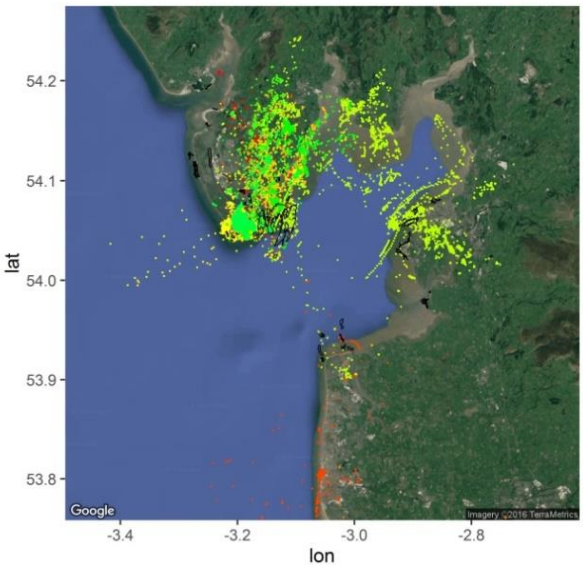


Figure 3.2 Movements of Herring Gulls tagged at South Walney in the 2015 pre-breeding, breeding and post-breeding periods; each colour represents a different bird consistent across the different periods.

3.2 Movement modelling to identify resting and foraging locations

Resolution: 10 minutes

Results of the model for the 10 minute resolution dataset are shown in Fig. 3.3 below. The model converged well with the parameters given in Fig. 3.3 and the fitted lines to the three states are shown in Fig. 3.4; the resultant classification of GPS points based on states is shown in Fig. 3.5. Note, however, the model identified a smaller concentration parameter for state 3, the shape of which (Fig. 3.4) was a mean centred around zero but a shallower distribution compared to state 2, representing commuting behaviour. This state defined periods of on sea resting (see Fig. 3.5) but also encompassed some time spent in terrestrial habitats. Thus both states 1 and 3 also likely encompassed foraging; state 3 was most strongly associated with very stationary activity. Commuting fixes were excluded for further spatial analyses and assessment of overlaps with areas of interest (see methods).

```
---------------------------------------------------------------------
Value of the maximum log-likelihood: -12263.65

Step length parameters:
----------------------
        state 1  state 2   state 3
mean 0.01246760 3.292517 0.4451567
sd   0.01002765 1.947750 0.5761965

Turning angle parameters:
------------------------
                 state 1     state 2   state 3
mean          -3.1396993  0.02327938 0.0682443
concentration  0.3608569 10.22316456 0.3587237

Regression coeffs for the transition probabilities:
--------------------------------------------------
             1 -> 2    1 -> 3    2 -> 1    2 -> 3    3 -> 1    3 -> 2
intercept -63.05657 -2.280317 -1.464686 -0.519719 -1.772614 -1.670913

Transition probability matrix:
-----------------------------
          [,1]         [,2]       [,3]
[1,] 0.9072337 3.737650e-28 0.09276626
[2,] 0.1265997 5.476937e-01 0.32570665
[3,] 0.1251052 1.384980e-01 0.73639678
---------------------------------------------------------------------
```

Figure 3.3 R output showing parameters from the Hidden Markov Model for Herring Gull tracking data filtered to a 10 minute rate; state 1 here = stationary resting/foraging, state 2 = commuting and state 3 = 'other' behaviours including foraging and slow drift on the sea.

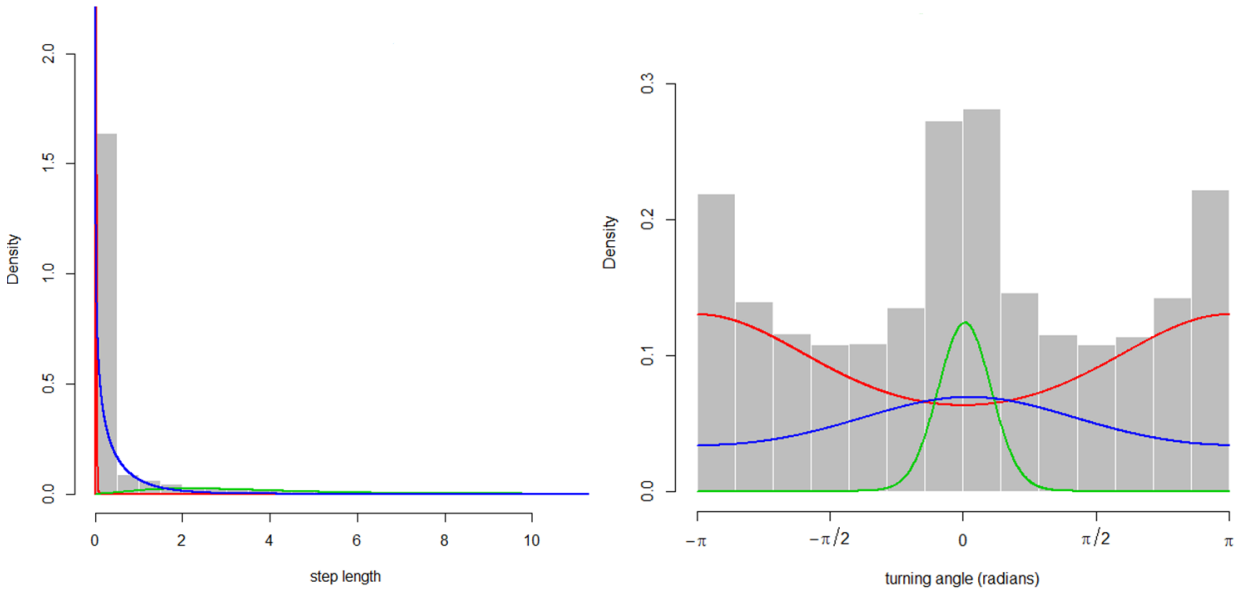
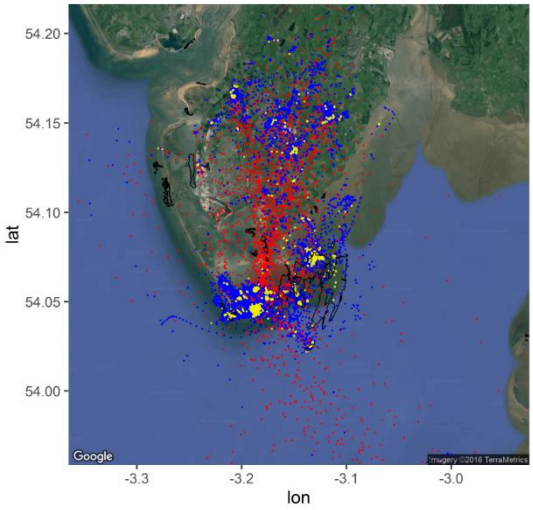
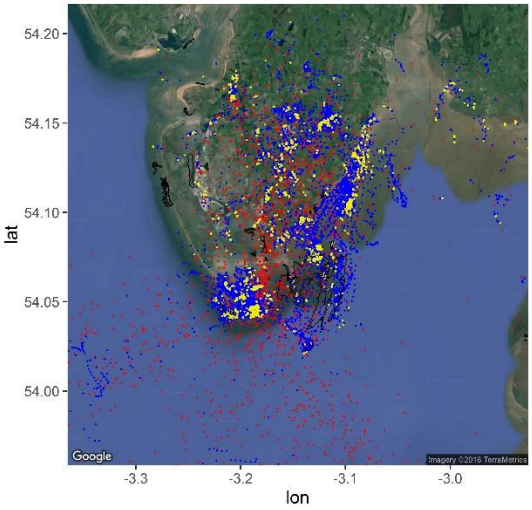


Figure 3.4 Distributions of step length and turning angle for Herring Gull tracking data filtered to a 10 minute rate; red = stationary resting/foraging, green = commuting and blue = 'other' behaviours including foraging and slow drift on the sea.

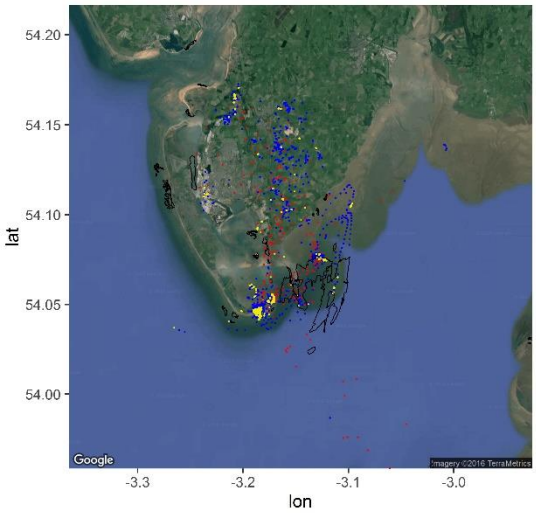
(a) 2014 breeding



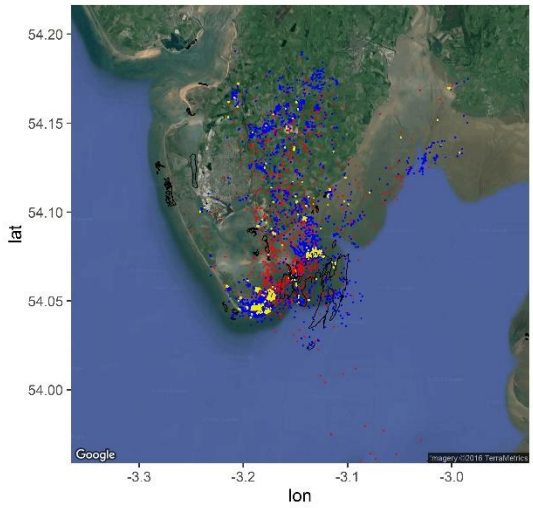
(b) 2014 post-breeding



(c) 2015 pre-breeding



(d) 2015 breeding



(e) 2015 post-breeding

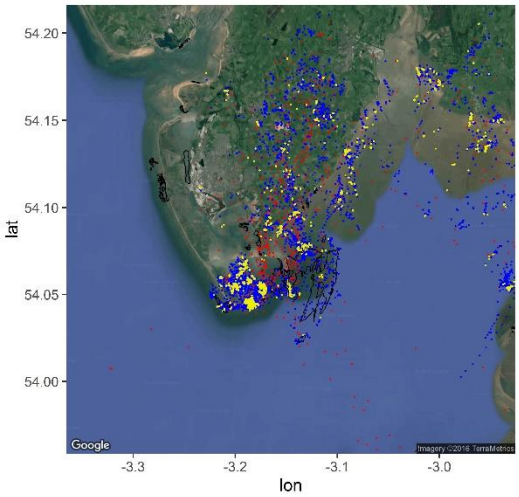


Figure 3.5 Classification of GPS points as states based on the HMM for Herring Gull tracking data filtered to a 10 minute rate; yellow = stationary resting/foraging, red = commuting and blue = 'other' behaviours including foraging and slow drift on the sea.

Resolution: 60 minutes

The model for the 60 minute resolution dataset had greater difficulty in sufficiently distinguishing between states 1 and 3 (see Figs 3.6-3.8), however state 2 for commuting was considered best defined. This allowed a potential distinction between faster straighter movements from 'all other' movements and a two-state model may thus have been sufficient. The models for the 10 minute and 60 minute resolution datasets were fairly congruous in identifying similar overall foraging/resting areas and commuting corridors. However, greater uncertainty was apparent in the model for the latter. Note also, the dataset filtered to the 60 minute rate spanned the whole breeding period whereas, for some birds, that filtered to the 10 minute rate did not (see methods), hence it is possible some slightly different patterns could emerge due to those differences alone. Commuting fixes were excluded for further spatial analyses and assessment of overlaps with areas of interest (see methods).

```
---------------------------------------------------------------------
Value of the maximum log-likelihood: -166231.4

Step length parameters:
-----------------------
        state 1   state 2   state 3
mean 0.02049491  2.770723  1.734490
sd   0.01677800  3.434884  2.255593

Turning angle parameters:
-------------------------
              state 1      state 2    state 3
mean         2.7489650  0.008214259 2.76001215
concentration0.2751155 23.660302430 0.06587852

Regression coeffs for the transition probabilities:
---------------------------------------------------
             1 -> 2    1 -> 3    2 -> 1   2 -> 3   3 -> 1     3 -> 2
Intercept -81.07577 -1.171052 0.4216448 1.715826 -2.36557 -0.6053859

Transition probability matrix:
------------------------------
          [,1]         [,2]      [,3]
[1,] 0.7633351 4.698473e-36 0.2366649
[2,] 0.1885379 1.236746e-01 0.6877875
[3,] 0.0572619 3.328926e-01 0.6098455
---------------------------------------------------------------------
```

Figure 3.6 R output showing parameters from the Hidden Markov Model for Herring Gull tracking data filtered to a 60 minute rate; state 1 here = stationary resting/foraging, state 2 = commuting and state 3 = 'other' behaviours including foraging and slow drift on the sea.

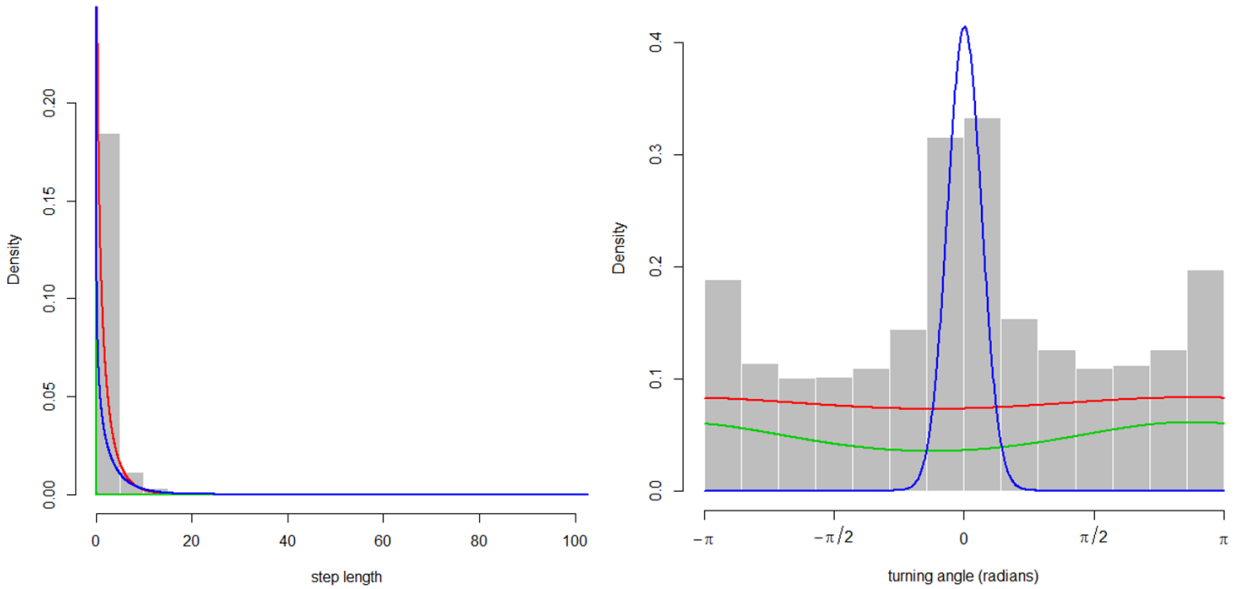
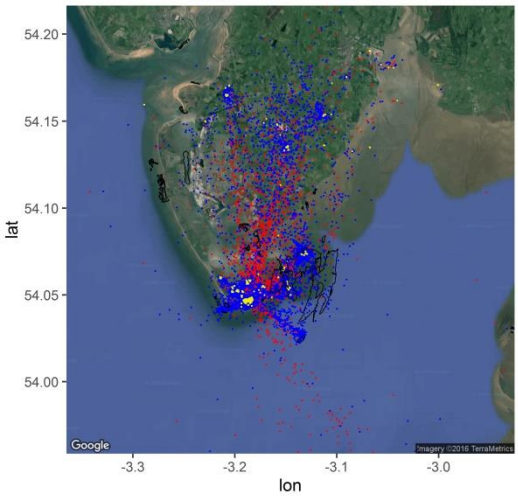
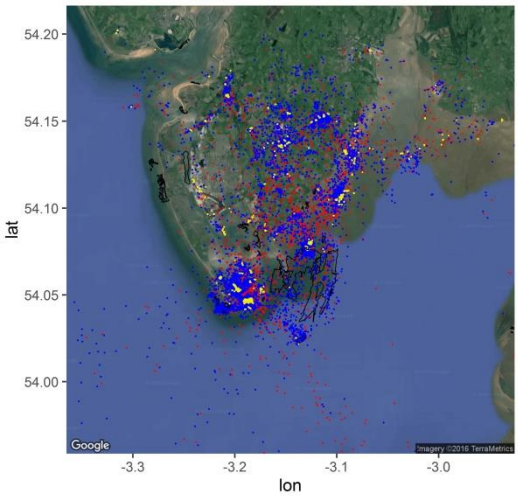


Figure 3.7 Distributions of step length and turning angle for Herring Gull tracking data filtered to a 60 minute rate; red = 'other' behaviours including foraging and slow drift on the sea, green = stationary resting/foraging and blue = commuting.

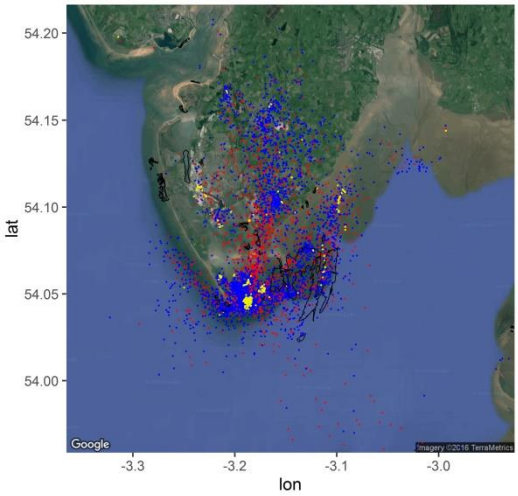
(a) 2014 breeding



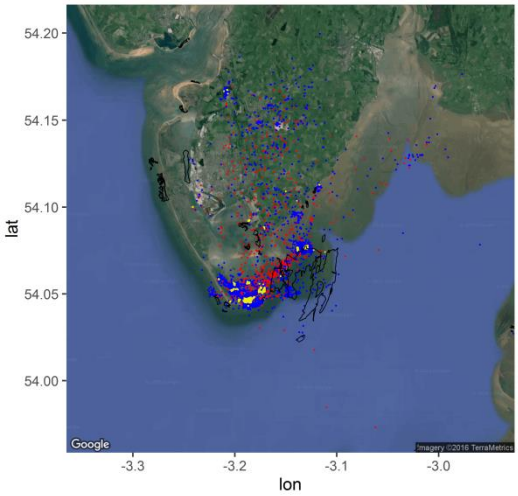
(b) 2014 post-breeding



(c) 2015 pre-breeding



(d) 2015 breeding



(e) 2015 post-breeding

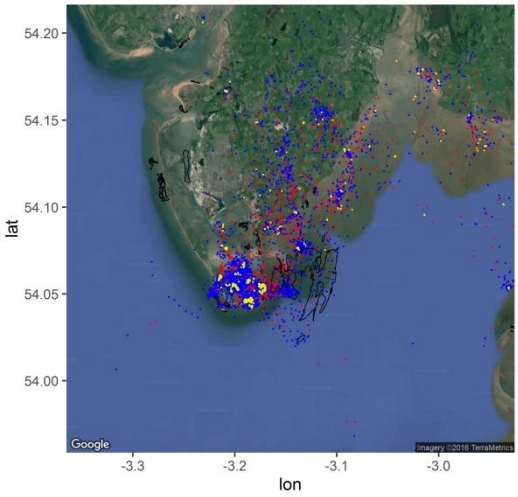


Figure 3.8 Classification of GPS points as states based on the HMM for Herring Gull tracking data filtered to a 60 minute rate; yellow = stationary resting/foraging, red = commuting and blue = 'other' behaviours including foraging and slow drift on the sea.

Resolution: 1080 minutes

The upper quartile of the step length distribution was calculated as 9.73 km for the winter 2014/15 period and 8.41 km for the 2015 pre-breeding period. These cut-offs were used to separate points indicating likely commuting (red in Fig. 3.9 below) from likely resting or foraging (yellow in Fig. 3.9 below). Commuting fixes were excluded for further spatial analyses and assessment of overlaps with areas of interest.

(a) Winter 2014/15 (b) Pre-breeding 2015

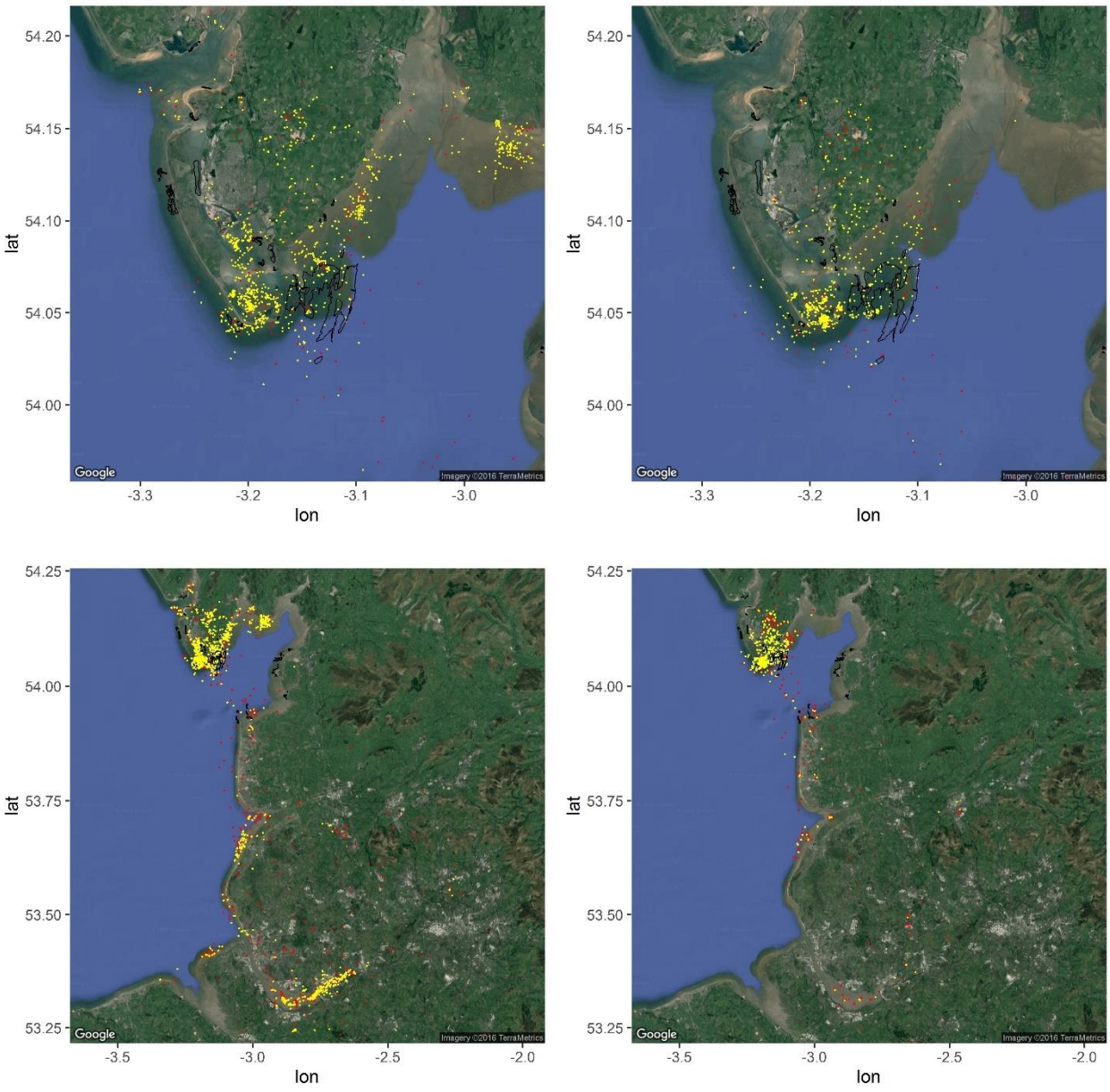


Figure 3.9 GPS points (shown at two extents) for all 11 Herring Gulls tagged at South Walney providing data for (a) winter 2014/15 and (b) pre-breeding 2015; yellow = stationary resting/foraging and 'other' behaviours including resting on the sea, red = commuting, based on the upper quartile of the distribution of step lengths.

3.3 Spatial area usage

Individual hotspots of foraging and resting activity (combining data from states 1 and 3 from HMM models) were clearly identified in all periods. Example maps are provided below for the 2014 breeding and post-breeding periods (Figs 3.10 and 3.11). Full results will be available in Thaxter *et al.* (in prep).

The KDE utilisation distributions showed use of both terrestrial and intertidal habitats, with clear hotspots for individual birds over mussel bed areas (see for example bird 12674 in Fig. 3.10 below). Other intertidal areas surrounding the colony were also favoured, including coast east of Barrow-in-Furness. The large area of mussel bed area to the south of Barrow-in-Furness was particularly used, particularly during breeding, with a clear corridor apparent between the colony and this location.

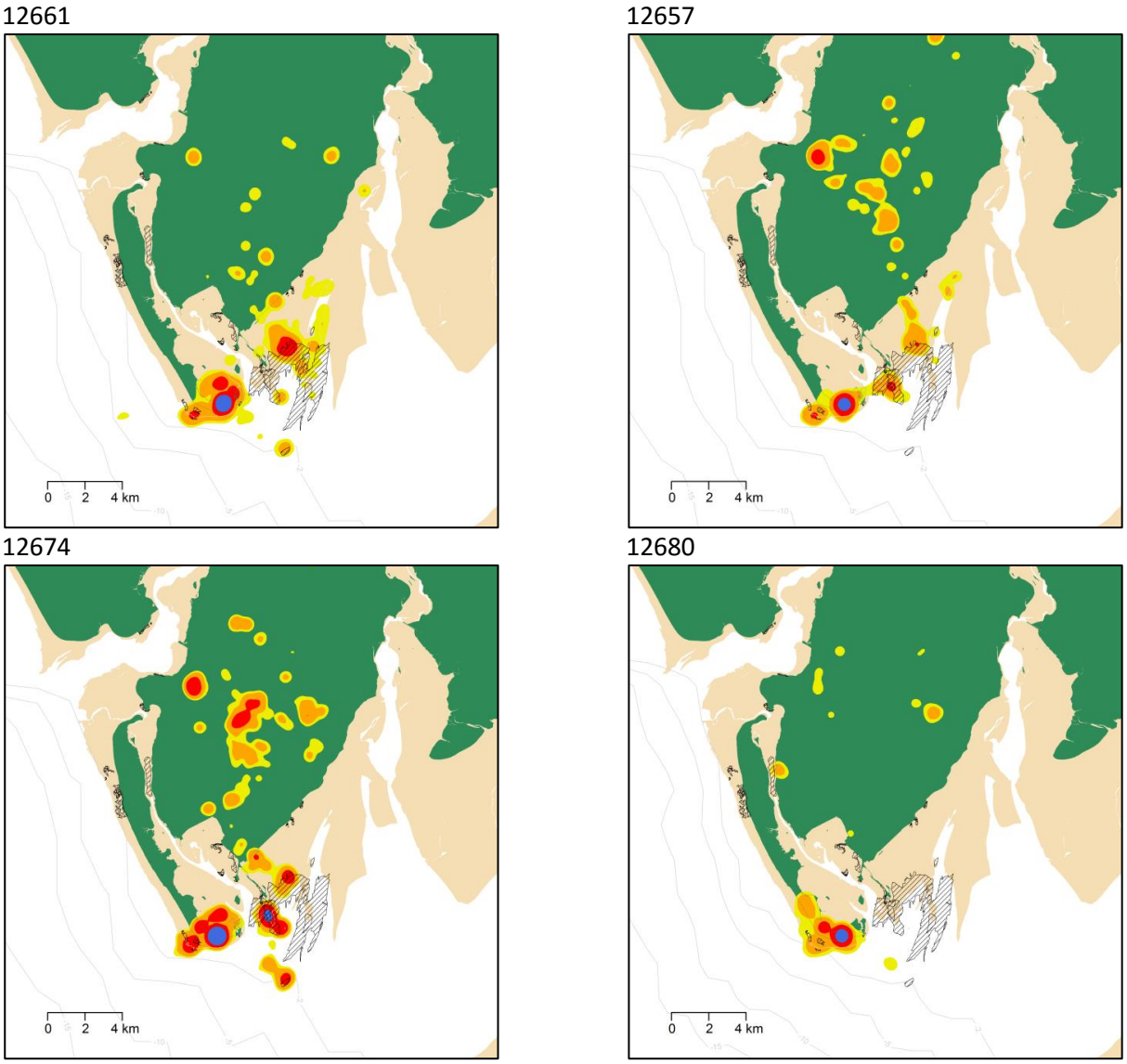


Figure 3.10 2014 breeding season: examples of individual bird utilisation distributions for Herring Gulls tagged at South Walney, using points identified as 'not commuting' from HMM models, based on data filtered to a 10 minute rate; shown are the 50% KDE (blue), 75% KDE (red), 90% KDE (orange) and 95% KDE (yellow).

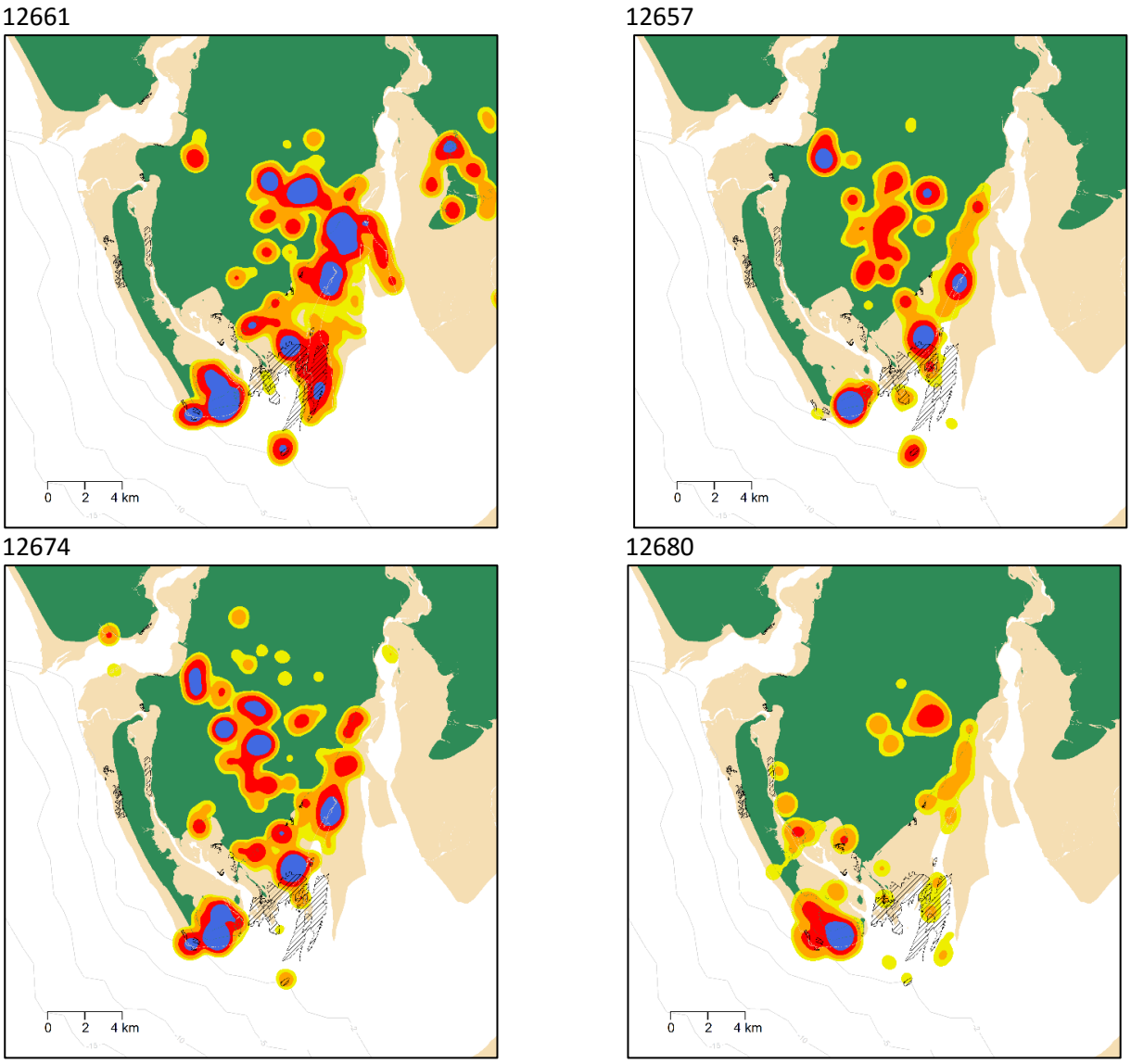
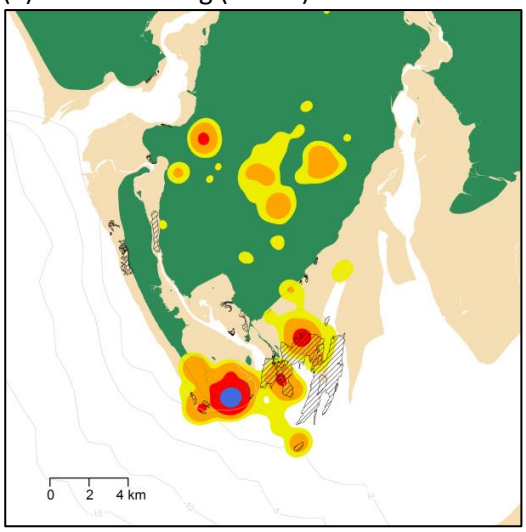


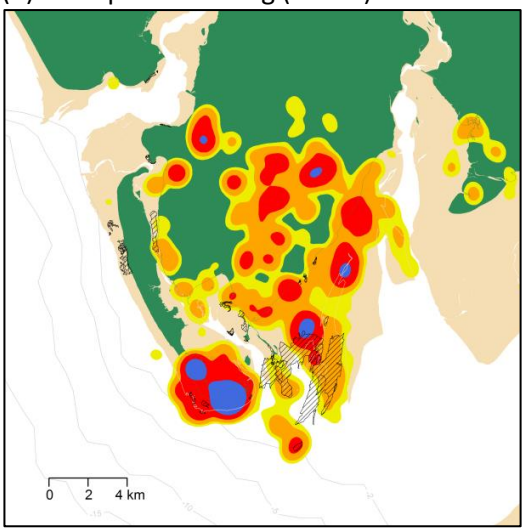
Figure 3.11 2014 post-breeding season: examples of individual bird utilisation distributions for Herring Gulls tagged at South Walney , using points identified as 'not commuting' from HMM models, based on data filtered to a 10 minute rate; shown are the 50% KDE (blue), 75% KDE (red), 90% KDE (orange) and 95% KDE (yellow).

Some differences in spatial patterns were apparent between the KDEs based on data filtered to 10 minute and 60 minute rates, after excluding commuting behaviour; clearer defined hotspots were seen with the 10 minute resolution dataset; these patterns are notable in kernel contours based on all birds in Figs 3.12 and 3.13. This is likely a reflection of the coarseness of the 60 minute resolution data with the HMM being less able to pinpoint as many commuting points as the 10 minute resolution data, hence flight corridors potentially have greater representation in the 60 minute resolution dataset. The KDEs based on data filtered to 1080 minutes for the 2014/15 winter period and the 2015 pre-breeding are provided in Fig. 3.14.

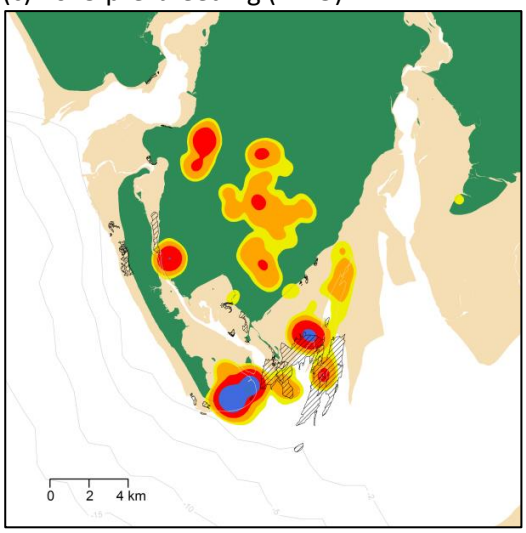
(a) 2014 breeding (n = 19)



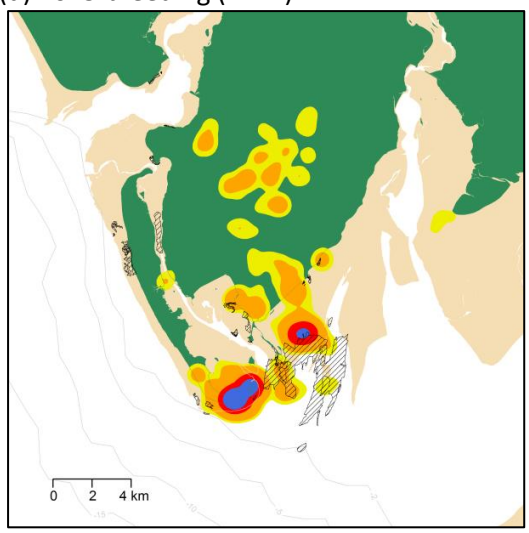
(b) 2014 post-breeding (n = 14)



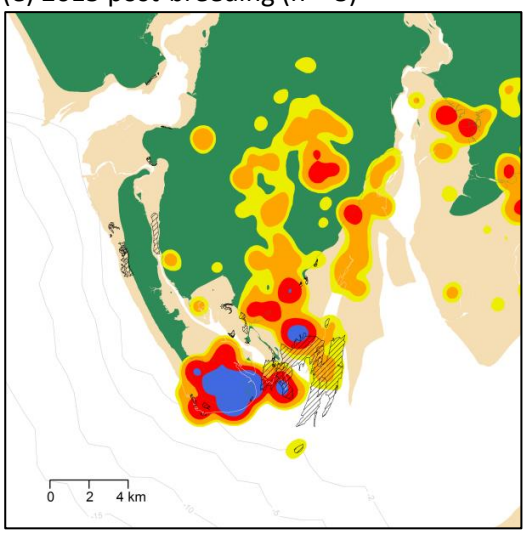
(c) 2015 pre-breeding (n = 5)



(d) 2015 breeding (n = 7)



(e) 2015 post-breeding (n = 8)



(f) 2015 post-breeding (wide extent)

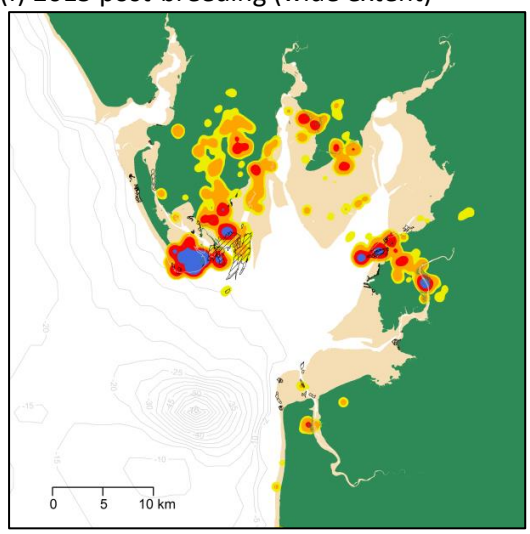
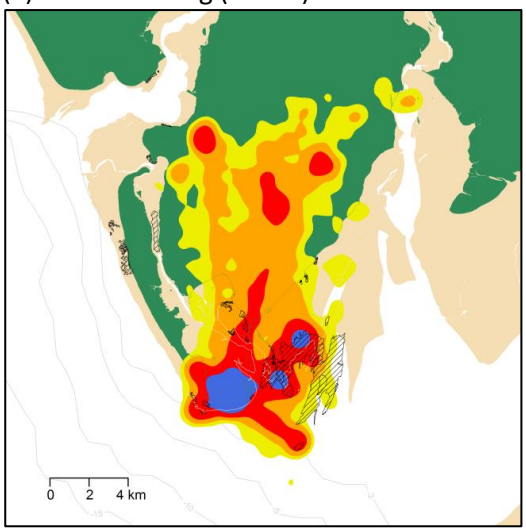
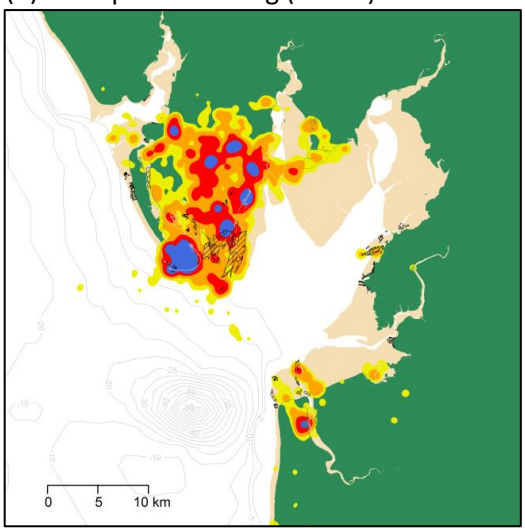


Figure 3.12 Bird utilisation distributions for Herring Gulls tagged at South Walney for all periods using the 'all-bird' kernel, using points identified as 'not commuting' from HMM models, based on data filtered to a 10 minute rate; shown are the 50% KDE (blue), 75% KDE (red), 90% KDE (orange) and 95% KDE (yellow).

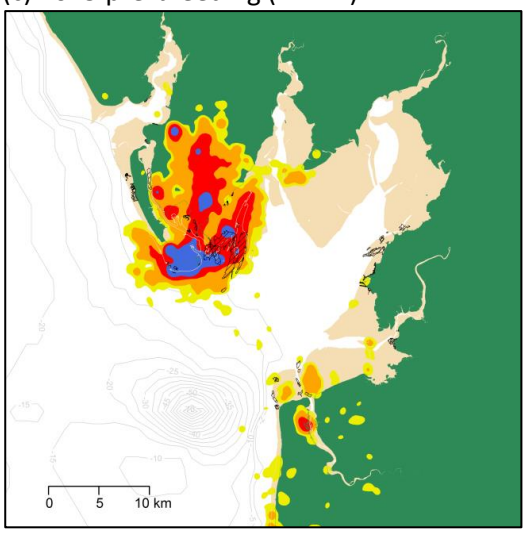
(a) 2014 breeding (n = 24)



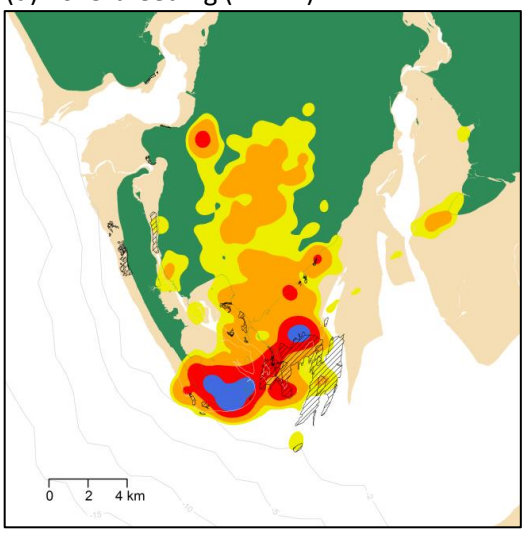
(b) 2014 post-breeding (n = 17)



(c) 2015 pre-breeding (n = 11)



(d) 2015 breeding (n = 11)



(e) 2015 post-breeding (n = 10)

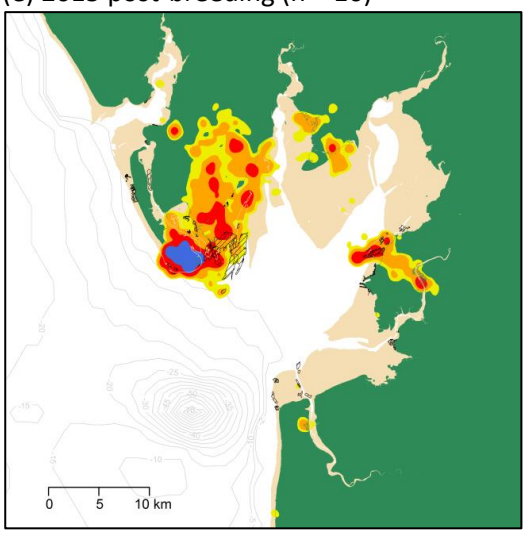
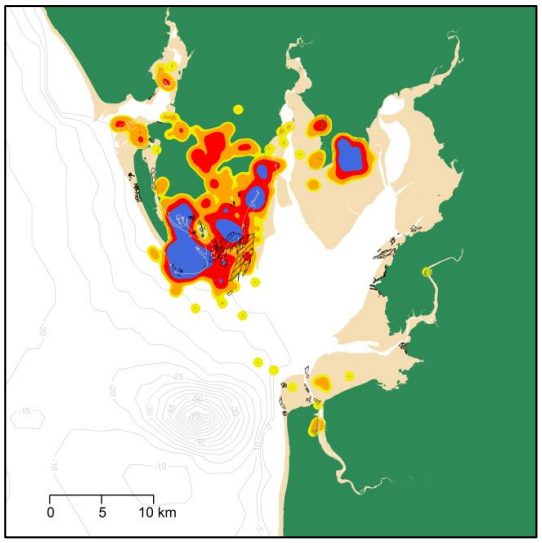


Figure 3.13 Bird utilisation distributions for Herring Gulls tagged at South Walney for all periods using the 'all-bird' kernel, using points identified as 'not commuting' from HMM models, based on data filtered to a 60 minute rate; shown are the 50% KDE (blue), 75% KDE (red), 90% KDE (orange) and 95% KDE (yellow).

(a) 2014 winter



(b) 2015 pre-breeding

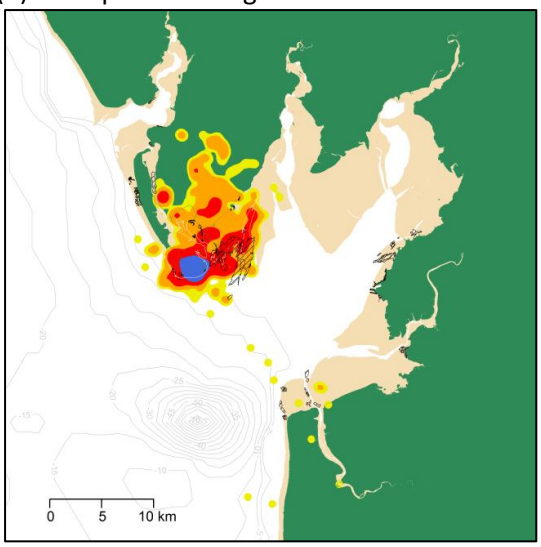


Figure 3.14 Bird utilisation distributions for Herring Gulls tagged at South Walney for all periods using the 'all-bird' kernel, using points identified as 'not commuting', based on data filtered to a 1080 minute rate; shown are the 50% KDE (blue), 75% KDE (red), 90% KDE (orange) and 95% KDE (yellow).

3.3.1 Spatial overlap of kernel density estimates with areas of interest

The overlaps of the 50% and 95% KDEs for Herring Gulls tagged at South Walney with different areas of interest are shown in Tables 3.1 to 3.9 below, split by whether these were assessed using data filtered to 10 minute, 60 minute or 1080 minute rates, and by period. Note, overlaps were not recorded with the Roudsea Wood and Mosses SSSI, hence a table for this site is not presented.

Overlaps with mussel bed areas

Comparisons between overlaps assessed using the 10 minute and 60 minute resolution datasets generally showed good agreement. Overlaps of the 95% KDE with mussel bed shapes were highest during breeding and post-breeding periods in 2014 and 2015, for example ranging up to 5.4% (10 minute) and 3.6% (60 minute) across birds during the 2014 breeding period for shapefile 1. Overlap of the 95% KDEs for the post-breeding period with shapefile 1 were also over 3% for many birds. However overlaps of the 95% KDEs with shapefile 2 were more substantial, being up to 24.4% during the 2014 breeding season using the 10 minute resolution dataset, however that overlap was based on a bird with an indicative 'very low' data amount (bird 12654); spatial overlaps of the 95% KDE were more than 15% for eight out of 24 birds using the 60 minute resolution dataset. Use of all mussel beds generally decreased from breeding to post-breeding and through to winter and pre-breeding when use of the areas began to increase again towards the subsequent 2015 breeding season.

Overlaps of the 50% KDE with mussel bed areas were relatively small for most birds and 50% KDEs overlapped more with mussel bed areas outside of the breeding season. Such a result is not wholly surprising given the relative use of the breeding colony at this time is reduced as birds no longer have a central place foraging constraint, spending more time in other areas.

During winter and pre-breeding, some birds spent considerable amounts of time in the local Morecambe Bay area. The 95% KDEs for the 2014/15 winter for birds 12648 and 12658 showed the greatest overlap with areas of mussel beds in shapefile 2 (over 10%). In the 2015 pre-breeding period, the 95% KDE for bird 12646 showed the greatest overlap with areas of mussel beds (13.75% with shapefile 2, based on data filtered to 1080 minutes, 17.07% based on data filtered to 60 minutes).

An overall final assessment of overlaps of the South Walney Herring Gull breeding population with mussel bed areas is given in Table 3.10. Here, we suggest that the 60 minute filtered dataset provides the most appropriate rate for assessing overlaps for the breeding, pre-breeding and post-breeding periods (as it provided greatest spans of data which were indicated as having higher confidence in quality and for the most number of individuals) and the 1080 minute dataset for winter. However, the 10 minute dataset for the 2014 breeding season was considered preferential for the spatial overlap assessment (albeit that it provided very similar in final values compared to 60 minutes). Across periods, the spatial overlap of the 95% KDE with mussel bed areas was up to 11.6% for shapefile 2 (mean across birds using highest quality data, n = 16 birds) and 3.7% for the 50% KDE (n = 11 birds during winter). Interestingly, when pooling all data together as an all-bird distribution, there was no overlap of the 50% KDE with mussel beds during the 2014 breeding period (Table 3.10).

Overlaps with the Morecambe Bay SPA and SSSIs

Perhaps unsurprisingly, the greatest overlaps of 95% and 50% KDEs were with the South Walney and Piel Channel Flats SSSI, encompassing the breeding colony where birds spent most of their time and adjacent intertidal areas. The 50% KDEs for many birds for the 2014 breeding season overlapped completely with this SSSI (whether using the 10 minute or 60 minute resolution datasets). Use of this SSSI decreased as birds moved away for the winter. The Morecambe Bay SSSI was also used extensively with the 95% KDEs

showing overlaps of *ca*. 10-30% (approximate range across birds) during breeding and for many birds use of this SSSI increased during post-breeding. During the winter, overlaps of 95% KDEs with both the South Walney and Piel Channel Flats SSSI and Morecambe Bay SSSI were *ca*. 35%. Across all times of the year, far less use was made of the Lune Estuary and Wyre Estuary SSSIs, although bird 12661 showed particular use of these areas.

Owing to the substantial use of the component SSSIs, substantial overlap was recorded for both 50% and 95% KDEs with the Morecambe Bay SPA.

An overall final assessment of overlaps with the SPA and SSSIs is presented in Table 3.10 using the highest quality data. These summaries show the overlap of the 95% KDE with SPAs and SSSIs was up to 43.5% during the 2014 breeding season (mean across birds, using the 10 minute rate) and slightly larger still during the 2015 breeding season at 47.1% (Table 3.10). Of these totals up to ca. 30% overlap of the 95% KDE was recorded with the South Walney and Piel Channel Flats SSSI. During the two breeding seasons, 50% KDE overlaps with the whole SPA were over 90%, again primarily driven through use of the South Walney and Piel Channel Flats SSSI.

Table 3.1 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with mussel bed shapefile 1 as provided by Natural England; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014		2015			2014		2015			2014		2015			2014		2015		
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Mussel	12646	0	0			0	0	0			1.14	0	0	0	0	0	0.77	0.96	2.58	0.55	1.27
bed	12647	0	0				1.6	3.39				0	0.09				1.2	0.76			
shapefile	12648	0		0	0	0	1.69		1.14	0.17	0.86	0		0.24	0.35	0.43	3.45		0.52	0.95	0.99
1	12649				0					0		0	1.22	0	0	0.06	0.34	0.27	0.84	0.48	0.81
	12651	0					0.6					0	0				1.57	0.83			
	12652											0					0.31				
	12653	0	0	0	0	0.94	3.88	2.14	1.5	3.89	1.32	0	0	0	0.54	1.17	3.55	1.59	1.71	2.59	1.05
	12654	0					2.9					0					1.69				
	12657	0	0	0	0		1.73	0.73	0.91	0.1		0	0	0.26	0		1.01	0.94	0.84	0.6	
	12658	0	0			0	2.1	1.33			0.67	0	0	0	0	0	0.92	0.46	0.97	1.11	0.73
	12659		0					3.22				0	0				3.04	1.11			
	12661	0	2.32	3.48	0	10.69	1.42	1.93	0.96	1.97	1.45	0	1.21	0.3	0	5.39	2.41	1.26	0.62	1.72	1.11
	12662	0	0				1.89	0.63				0	0.38				1.28	0.55			
	12665	0					4.76					0					2.27				
	12666											0					3.63				
	12669	0	0				2.18	0				0	0				2.32	0.54			
	12670											0.13	0		0	0.49	0.69	0.25		2.23	0.52
	12672	0					2.97					0					2.07				
	12673	0					1.54					0					1.65				
	12674	13.11	0.38		0	0	1.92	0.77		0.46	1.47	4.11	0	0.23	0	0.39	1.22	0.65	1.35	1.69	0.9
	12675	0	0	0	0	0	3.24	0.99	0	1.84	0.3	0	0	0	0	0	1.56	0.49	0.78	1.48	0.44
	12676	0	0			0	0.05	0.93			1.53	0	0	0	0	0	2.7	0.71	1.38	3.58	0.92
	12678	0	0				5.38	0				0	0.06				2.24	0.94			
	12680	0	0				1.44	2.24				0	0.55				0.7	1.09			
	all	0	0	0	0	5.46	1.78	1.45	0.96	2.08	1.59	2.76	0.74	1.47	0.21	0.18	1.03	0.88	0.45	1.03	1.21

Table 3.2 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with mussel bed shapefile 2 as provided by Natural England; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014			2015		2014			2015		2014			2015		2014			2015	
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Mussel	12646	0	0			0	0	0			7.74	0	0	0	0	0	0.01	0.63	17.0	4.48	5.48
bed	12647	0	0				7.53	18.6				0	0				7	4.53			
shapefi	12648	0		0	0	0	25.3		7.07	6.74	6.66	0		1.52	2.17	2.23	26.0		4.07	10.0	8.08
le 2	12649				0					0		0	0	0	0	4.25	3.36	0.36	6.6	2.35	4.73
	12651	0					18.3					0	0				8.22	7.86			
	12652											0					0.53				
	12653	0	0	7.86	2.28	5.1	11.7	7.76	10.3	11.8	5.8	0	0	0	3.61	5.89	19.2	7.29	10.4	14.1	6.12
	12654	0					24.3					0					22.4				
	12657	0	0.78	6.32	8.37		9.36	5.44	8.9	6.88		0	5.15	0	7.19		7.1	6.01	6.66	9.68	
	12658	0	0			0	4	0			0.21	0	0	0	0	0	7.89	0	0.18	3.9	1.61
	12659		0					7.17				0	2.77				19.2	5.46			
	12661	0	6.58	14.2	0	8.87	12.4	6.41	6.68	11.2	6.24	0	6.88	0	0	4.98	16.7	5.35	4.33	13.4	4.74
	12662	0	0.05				7.77	3.86				0	0.25				6.72	3.59			
	12665	0					17.9					0					13.3				
	12666											0					32.8				
	12669	0	0				7.47	0				0	0				11.8	1.39			
	12670											0	0		0	0	6.18	1.61		12.4	7.12
	12672	0					19.0					0					19.0				
	12673	0					12.4					0					9.97				
	12674	20.9	3.1		0.99	0.8	7.89	2.62		4.96	8.6	10.5	3.09	0	4.01	2.73	5.81	3.49	10.1	14.5	6.98
	12675	0	0	0	0	0	10.1	0	3.8	8.21	5.02	0	0	0	0	0	7.61	0	5.76	10.4	5.94
	12676	28.2	0			0	15.4	2.83			7.04	0	0	0	0	0	19.6	3.93	7.1	13.6	4.94
	12678	0	0				16.1	0				0	0				9.67	6.2			
	12680	0	0				1.11	4.05				0	0				4.54	2.68			
	all	0	1.67	7.39	2.89	7.845	9.56	5.32	6.66	8.15	5.88	15.4	3.02	9.83	5.24	0.95	5.87	3.86	2.56	5.3	4.698

Table 3.3 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with the Lune Estuary SSSI; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014		2015			2014		2015			2014		2015			2014		2015		
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Lune	12646	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
Estuary	12647	0	0				0	0				0	0				0	0			
SSSI	12648	0		0	0	0	0		0	0	3.41	0		0	0	0	0		0.74	0	1.82
	12649				0					0		0	5.86	0	0	0	2.79	6.83	7.39	0.74	0
	12651	0					0					0	0				0	0			
	12652											0					0				
	12653	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12654	0					0					0					0				
	12657	0	0	0	0		0	0	0	0		0	0	0	0		0	0	1.02	0	
	12658	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
	12659		0					0				0	0				0	8.17			
	12661	0	6.35	0	0	15.15	0	7.98	6.12	0	3.18	0	3.74	0	0	12.36	0	7.89	5.12	0	3.36
	12662	0	0				0	0				0	0				0	0.17			
	12665	0					0					0					0				
	12666											0					0				
	12669	0	0				0	0				0	0				0	0			
	12670											0	0		0	0	0	0		0	0
	12672	0					0					0					0				
	12673	0					0					0					0				
	12674	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
	12675	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.63	0	0
	12676	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
	12678	0	0				0	0				0	0				0	0			
	12680	0	0				0.28	1.8				0	0				0.93	3.71			
	all	0	0	0	0	8.23	0	3.74	1.716	0	2.59	0	0	0	0	0	0	3.59	3.179	0.36	1.46

Table 3.4 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with the Morecambe Bay SSSI; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014			2015		2014			2015		2014			2015		2014			2015	
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Morecombe	12646	0	0			0	0	0			2.42	0	0	0	0	0	0	1.32	14.63	0.57	7.94
Bay SSSI	12647	0	0				2.06	26.14				0	26.17				7.05	37.76			
	12648	0		0.07	12.23	9.61	32.21		12.07	32.47	18.9	0		0	21.45	3.17	23.41		9	22.77	16.35
	12649				0					0		0	0	0	0	0.88	7.62	0	4.69	4.76	6.47
	12651	0					1.45					0	0				11.7	23.86			
	12652											0					10.08				
	12653	0	0	11.96	9.75	23.44	19.8	27.71	22.12	27.71	30.64	0	0.25	0	10.77	20.42	16.78	29.18	21.39	29.55	29.78
	12654	0					13.89					0					12.54				
	12657	0	35.5	9.24	32.21		17.39	28.84	10.51	15.56		0	37.53	0	22.36		13.54	25.06	8.33	20.73	
	12658	0	0			0	5.14	0			0	0	0	0	0	0	10.51	0	0	10.62	6.01
	12659		0					4.17				0	23.45				25.98	22.15			
	12661	0	36.98	16.38	0	34.31	30.22	44.33	20	20.17	37.48	0	32	4.03	0	33.5	23.25	35.59	13.24	15.79	37.07
	12662	0	3.48				4.69	5.55				0	7.3				3.91	9.18			
	12665	0					19					0					14.94				
	12666											0					30.43				
	12669	0	0				6.15	0				0	0				6.38	1.49			
	12670											0	31.18		0	4.73	22.05	37		20.8	46.16
	12672	0					21.38					0					19.58				
	12673	0					13.27					0					15.08				
	12674	13.76	31		28.99	31.01	11.81	31.04		23.07	21.42	6.53	29.12	0	23.43	20.81	10.56	21.63	14.27	22.98	15.56
	12675	0	0	0	0	9.68	6.07	17.59	26.54	55.54	33.49	0	0	0	0	8.35	11.03	24.36	22.64	47.17	44.37
	12676	28.53	0			0	41.55	13.09			17.54	0	0	0	0	0	18.23	20.47	9.88	3.16	2.22
	12678	0	0				6.24	0				0	0				5.3	31.03			
	12680	0	0				0	13.41				0	0				4.15	7.6			
	all	0	19.47	12.34	16.22	18.87	14.4	25.16	12.01	20.08	32.18	12.99	27.59	8.86	18.99	0	11.57	22.19	10.45	13.4	26.72

Table 3.5 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with the South Walney and Piel Channel Flats SSSI; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014		2015			2014		2015			2014		2015			2014		2015		
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
South	12646	100	98.54			91.7	93.5	84.3			66.9	100	95.7	99.1	100	84.6	35.2	62	36.6	70.6	31.3
Walney	12647	100	100				17.6	14.4				100	40.9				13.3	7.22			
& Piel	12648	100		74.27	86.8	57.6	31.7		17.4	27.0	11.0	100		48.4	72.6	66.6	28.1		4.21	13.6	10.8
Channel	12649				100					89.3		100	31.0	93.7	49.0	50.9	12.0	6.78	11.7	6.55	12.9
Flats	12651	100					73.0					98.2	92.2				19.2	20.6			
SSSI	12652											100					71.2				
	12653	100	100	78.57	89.8	58.6	54.3	12.2	33.8	35.4	19.8	100	88.4	59.4	81.1	47.5	28.1	9.77	20.5	28.7	14.2
	12654	100					64.3					99.8					52.6				
	12657	100	37.92	73.69	67.6		15.6	7.29	17.5	20		99.6	30.9	57.5	75.6		13.2	7.09	9.19	17.0	
	12658	100	61.12			32.0	59.2	64.0			70.2	100	67.3	63.5	100	58.6	40.7	37.6	43.9	52.1	64.6
	12659		100					82.1				100	53.8				24.9	6.97			
	12661	100	22.07	42.78	100	25.8	24.5	7.09	7.94	13.6	6.02	98.5	24.9	61.0	99.2	19.8	18.6	5.57	4.79	13.5	5.61
	12662	100	43.03				41.8	13.9				100	32.2				23.2	9.83			
	12665	100					38.6					100					24.8				
	12666											99.0					44.2				
	12669	100	100				13.5	65.7				100	100				14.0	26			
	12670											94.8	20.2		99.8	80.7	9.58	7.46		22.4	10.5
	12672	100					16.2					100					18.2				
	12673	100					23.0					99.3					14.7				
	12674	78.71	27.41		70.9	65.7	16.7	13.7		45.8	21.9	79.0	25.1	70.1	75.0	63.9	16.8	10.2	17.6	29.1	17.6
	12675	100	100	100	100	70.8	29.2	29.2	60.8	12.6	29.6	100	99.7	96.0	99.9	67.7	16.3	15.0	6.45	15.1	15.0
	12676	71.47	95.3			88.8	37.6	52.2			46.1	100	93.8	92.3	89.3	83.6	36.2	39.2	24.4	58.0	44.8
	12678	100	82.68				24.0	60.8				100	79.9				19.2	13.6			
	12680	100	59.04				26.9	18.0				99.6	47.0				11.7	11.6			
	all	100	51.79	79.98	83.7	52.1	17.5	9.48	9.32	17.6	8.54	68.6	34.9	39.7	74.5	77.1	13.7	7.90	5.97	12.6	10.1

Table 3.6 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with the Wyre Estuary SSSI; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014		2015			2014		2015			2014		2015			2014		2015		
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Wyre	12646	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
Estuary	12647	0	0				0	0				0	0				0	0			
SSSI	12648	0		0	0	0	0		5.3	0.35	5.62	0		0	0	0	0		0.94	0.22	4.24
	12649				0					0		0	6.61	0	0	0	0.67	5.23	2.39	1.56	0
	12651	0					0					0	0				0	0			
	12652											0					0				
	12653	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12654	0					0					0					0				
	12657	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0.48	0	
	12658	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
	12659		0					0				0	3.46				0	2.83			
	12661	0	0.15	3.12	0	0	0	1.25	3.76	0	0.38	0	0.34	0.4	0	0	0	2.05	2.02	0	0.69
	12662	0	0				0	0.75				0	0				0	1.26			
	12665	0					0					0					0				
	12666											0					0				
	12669	0	0				0	0				0	0				0	0			
	12670											0	0		0	0	0	0		0	0
	12672	0					0					0					0				
	12673	0					0.01					0					0				
	12674	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
	12675	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.03	0	0
	12676	0	0			0	0	0			0	0	0	0	0	0	0	0	0	0	0
	12678	0	0				0	0				0	0				0	0			
	12680	0	2.04				1.48	4.63				0	4.42				5.68	3.63			
	all	0	0	0	0	0	0.08	1.03	2.43	0.04	0.98	0	0.07	0	0	0	0.16	2.65	1.8	0.11	0.29

Table 3.7 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with the Morecambe Bay SPA; overlaps are presented separately for data filtered to 10 minute and 60 minute rates for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter overlaps are assessed using the 1080 sampling rate (18 hours) and are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

		10 minute										60 minute									
		50% KDE					95% KDE					50% KDE					95% KDE				
		2014		2015			2014		2015			2014		2015			2014		2015		
Area	bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
Whole	12646	100	98.63			91.97	93.64	84.53			68.65	100	95.87	99.24	100	84.74	34.64	62.75	49.32	70.72	38.66
SPA	12647	100	100				19.84	40.14				100	68.02				20.44	44.76			
	12648	100		74.4	99.15	67.35	61.18		34.79	59.99	38.18	100		48.54	94.14	69.98	50.75		14.25	36.08	32.87
	12649				100					81.27		100	43.27	93.84	49.13	51.87	23.1	18.42	26.3	13	19.38
	12651	100					74.63					98.27	92.27				31.04	43.59			
	12652											100					81.45				
	12653	100	100	90.52	99.61	82.3	74.34	39.91	55.84	63.33	51.08	100	88.76	59.49	92.03	68.05	44.69	37.91	40.91	57.74	43.49
	12654	100					78.45					99.85					65.34				
	12657	100	75.9	82.93	99.84		33.53	35.22	26.84	35.53		99.69	68.78	57.66	98.07		26.59	31.37	18.29	37.25	
	12658	100	61.12			32	57.1	57.74			63.19	100	62.82	55.38	100	38.26	47.09	34.04	38.15	56.92	65.62
	12659		100					86.38				100	80.75				50.63	39.72			
	12661	100	66.85	54.99	100	75.35	54.86	59.79	37.06	32.98	47	98.64	61.57	66.45	99.28	65.73	41.44	50.75	24.71	28.56	46.29
	12662	100	48.1				46.65	19.59				100	40.7				27.17	20.02			
	12665	100					57.92					100					40.11				
	12666											99.09					74.1				
	12669	100	100				18.74	65.73				100	100				20.24	27.51			
	12670											94.91	51.93		99.88	85.54	31.69	44.24		43.29	55.91
	12672	100					37.04					100					37.11				
	12673	100					35.9					99.36					29.36				
	12674	93.65	60.05		99.91	96.82	28.62	44.22		67.23	43.47	86.1	53.95	70.17	98.5	84.85	27.42	31.52	30.67	50.1	33.2
	12675	100	100	100	100	80.54	35.48	47.64	87.33	67.04	63.81	100	99.77	96.12	99.92	76.19	27.37	40.61	35.07	61.05	59.4
	12676	100	95.37			88.96	79.35	66.08			62.55	100	93.94	92.41	89.46	83.73	54.34	59.4	33.7	59.87	45.61
	12678	100	82.68				30.44	60.85				100	79.97				24.59	44.12			
	12680	100	60.96				24.65	36.66				99.67	51.37				21.64	25.91			
	all	100	72.71	92.35	99.96	79.42	30.72	38.14	25.57	37.17	43.65	81.92	62.5	47.46	93.68	74.14	24.66	35.66	20.81	25.07	37.73

Table 3.8 Area (km^2) of 50% and 95% KDEs for Herring Gulls tagged at South Walney, based on data filtered to10 minute and 60 minute rates, for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr); note winter area sizes are presented separately in Table 3.9. Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

	10 minute										60 minute									
	50% KDE					95% KDE					50% KDE					95% KDE				
	2014			2015		2014			2015		2014			2015		2014			2015	
bird	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr	Br	PoBr	PrBr	Br	PoBr
12646	0.51	0.19			0.88	2.41	0.87			8.08	1.4	1.97	1.51	1.41	2.96	21.31	17.17	20.67	7.84	30.94
12647	0.24	0.33				10.99	13.8				1.04	6.32				36.46	103.41			
12648	0.26		1.07	0.76	1.47	8.09		12.69	8.23	23.48	0.92		5.86	2.57	3.28	18.36		199.37	35.46	58.84
12649				0.21					2.13		1.16	10.59	1.77	5.15	8.91	51.04	89.2	60.56	146.51	71.68
12651	0.54					3.93					1.57	1.81				51.58	29.56			
12652											0.74					4.6				
12653	0.22	0.66	1.13	1.05	2.75	5.02	35.22	11.81	11.59	37.09	0.95	2.39	3.89	2.64	8.64	20.7	57.6	64.73	26.36	70.74
12654	0.71					4.61					2					10.57				
12657	0.32	2.28	1.16	1.06		24.74	41.56	19.25	20.03		1.3	7.97	5.48	2.55		61.26	76.79	119.93	36.72	
12658	0.32	0.53			0.61	7.17	10.46			6.65	1.26	2.21	2.21	1.08	2.47	23.11	35.87	17.47	13.22	20.19
12659		0.19					1.68				1.16	4.3				25.25	86.42			
12661	0.56	9.4	2.38	0.59	5.12	23.91	91.29	39.94	35.17	100.66	1.68	17.76	6.09	1.72	14.03	43.82	150.07	209.57	53.68	163.7
12662	0.23	2.44				8.41	48.07				1.05	11.91				51.43	155.21			
12665	0.32					9.45					1.24					24.27				
12666											1.31					10.28				
12669	0.25	0.19				14.97	1.75				1.1	0.9				40.72	17.44			
12670											2.01	6.19		1.17	2.93	69.21	62.13		17.93	51.96
12672	0.34					10.47					1.01					30.46				
12673	0.38					16.82					1.39					51.47				
12674	0.9	5.47		0.93	1.1	32.2	51.27		9.72	17.37	3.26	15.25	5.79	2.89	3.59	72.91	107.45	79.89	28.56	48.58
12675	0.25	0.27	0.21	0.28	1.43	6.84	9.9	2.17	14.34	17.21	1.09	1.28	1.71	1.25	4.2	40.93	33.89	122.86	38.2	50.48
12676	0.68	1.34			1.81	8.68	12.85			11.37	1.63	2.01	2.39	1.7	1.69	19.41	26.2	52.78	13.37	22.57
12678	0.31	0.47				6.96	3.48				1	2.99				29.33	64.23			
12680	0.33	1.5				16.79	45.13				1.39	6.82				101.74	182.54			
all	0.41	2.89	1.45	1.07	5	39.02	115.98	48.5	35.42	111.17	6.78	18.97	18.42	4.86	7.84	137.74	273.43	371.24	139.74	189.29

Table 3.9 Percentage overlaps of 50% and 95% KDEs for Herring Gulls tagged at South Walney with (a) mussel beds and (b) the Morecambe Bay SPA and constituent SSSIs, based on data filtered to a1080 minute rate for the 2014/15 winter (Wi) period and the 2015 pre-breeding (PoBr) periods. The areas of KDEs used are shown in (a). Colours of cells indicate confidence in the overlap analysis based on the sample size of points feeding into the spatial analysis – see Table 2.3 for details; "all" represents an assessment carried out using data from all birds combined.

(a)	Mussel bed shapefile 1				Mussel bed shapefile 2				Area of KDE (km^2)			
	50% KDE		95% KDE		50% KDE		95% KDE		50% KDE		95% KDE	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
bird	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr
12646	0	0	1.32	2.88	0	0	9.41	13.75	6.55	2.85	84.88	30.38
12648	0.81	0.36	1.7	0.98	18.47	3.55	12.05	6.93	8.86	3.97	39.26	60.22
12649	0	1.15	0	0.52	0	0.32	0	3.56	14.66	6.93	84.01	59.63
12653	0.75	0.15	0.41	1.55	6.79	0	3.26	10.6	21.27	9.75	125.88	62.98
12657	0.1	0.3	0.52	0.89	5.96	0.02	3.56	9.04	23.59	4.81	127.51	70.64
12658	0	0	2.05	0.97	0	0	13.38	1.5	4.44	2.79	37.76	16.43
12661	0.09	0.26	0.19	1.06	0.69	6.12	1.95	7.5	33.27	5.54	168.19	78.8
12670	0	1.71	0.17	1.61	0	5.75	1.81	8.37	12.33	10.17	74.32	56.07
12674	0.37	0.81	0.69	1.49	9.32	12.97	4.58	12.41	23.46	9.58	140.94	65.65
12675	0	0.16	0.1	1.14	0	0	0.96	7.43	9.98	3.75	110.64	68.8
12676	0.85	0.71	0.87	2.29	0.15	0	4.84	6.23	9.85	4.53	99.77	32.4
all	0.57	0.47	0.4	1.02	3.5	0.13	2.4	6.23	41.99	6.15	383.77	141.39

(b)	Lune Estuary SSSI				Morecombe Bay SSSI				South Walney & Piel Channel				Wyre Estuary SSSI				Whole SPA			
	50% KDE		95% KDE		50% KDE		95% KDE		50% KDE		95% KDE		50% KDE		95% KDE		50% KDE		95% KDE	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
bird	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr	Wi	PrBr
12646	0	0	4.74	0	0	0	11.86	4.16	86.67	93.79	22.71	30	0	0	2.09	0	86.3	93.86	39.38	32.75
12648	0	0	0	0	12.72	0	13.19	9.75	1.28	66.25	2.58	9.76	0	0	0	0	13.6	66.39	15.16	19.09
12649	0	0	0	0	0	0	0	3.53	0	72.02	0	21.18	0	0	0	0.86	0	72.09	0	24.93
12653	0	0	0	0	50.3	2.42	18.27	17.06	18.21	52.82	10.64	26.95	0	0	0	0	68.45	55.28	28.45	43.21
12657	0	0	0	0	31.05	0	18.69	12.1	0.74	69.91	5.14	9.87	0	0	0	0	32.5	70.02	23.52	21.62
12658	0	0	0	0	0	0	8.9	0.25	68.95	71.69	48.13	53.26	0	0	0	0	56.99	70.41	53.2	45.51
12661	0	0	2.31	3.23	26.15	0.72	16.55	18.01	0	59.51	2.6	10.52	0	0	1.72	3.08	25.85	60.31	22.88	34.57
12670	0	0	0	0	82.01	34.76	62.72	30.17	0	35.45	4.35	18.09	0	0	0	0	83.07	68.17	66.86	47.9
12674	0	0	0	0	39.48	10.06	14.24	17.69	14.83	53.38	11.01	21.8	0	0	0	0	54.19	67.01	24.84	38.39
12675	0	0	1.74	5.45	83.84	0	34.27	18.66	0	80.5	3.01	13.97	0	0	0.34	1.11	83.83	80.57	39.42	37.77
12676	0	0	0	0	0	0	14.12	11.09	81.86	92.67	20.79	42.44	0	0	0	0	81.85	92.75	34.03	51.13
all	0	0	1.02	1.17	34.75	0	16.55	15.38	34.71	75.6	5.75	14.52	0	0	0.47	0.31	67.66	75.72	23.28	29.94

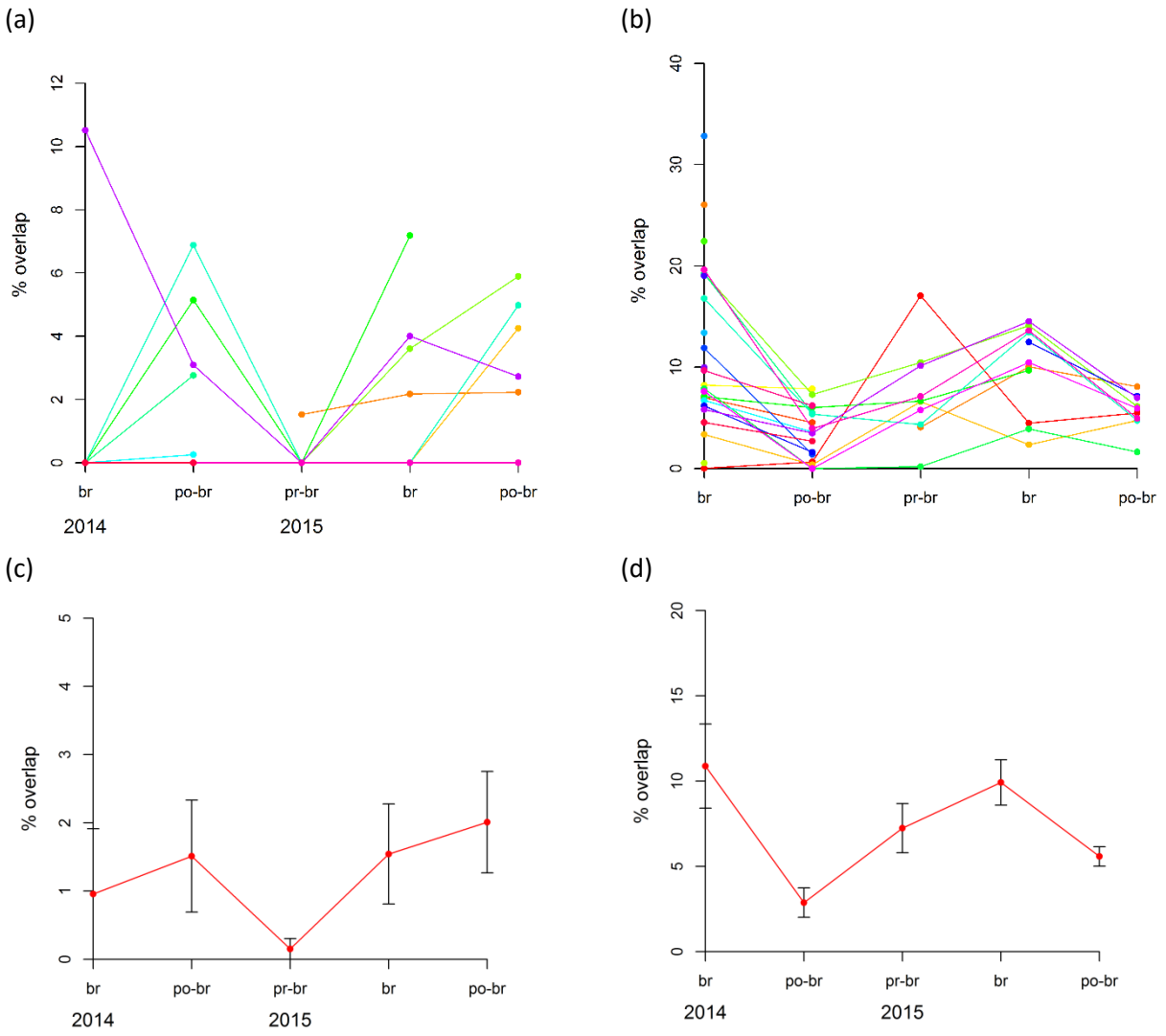


Figure 3.15 Percentage overlap of 50% KDEs (a and c) and 95% KDEs (b and d) for Herring Gulls tagged at South Walney with the largest mussel bed shapefile 2, showing values for individual birds (top row) and the mean across all birds (bottom row); values are based on data filtered to a 60 minute rate, hence exclude the winter period; errors are represented by ±1 SE. Note, sample sizes decreased from 24 birds in the first 2014 breeding season to 17 birds in the 2014 post-breeding period and to 11 birds thereafter (see text). Values in this graph are those values presented in Table 3.2 above; abbreviations used: br = 'breeding', 'po-br' = post-breeding; 'pr-br' = pre-breeding. Maps are based on HMM kernel overlaps, and means in (c) and (d) are calculated using data available for birds present across both years.

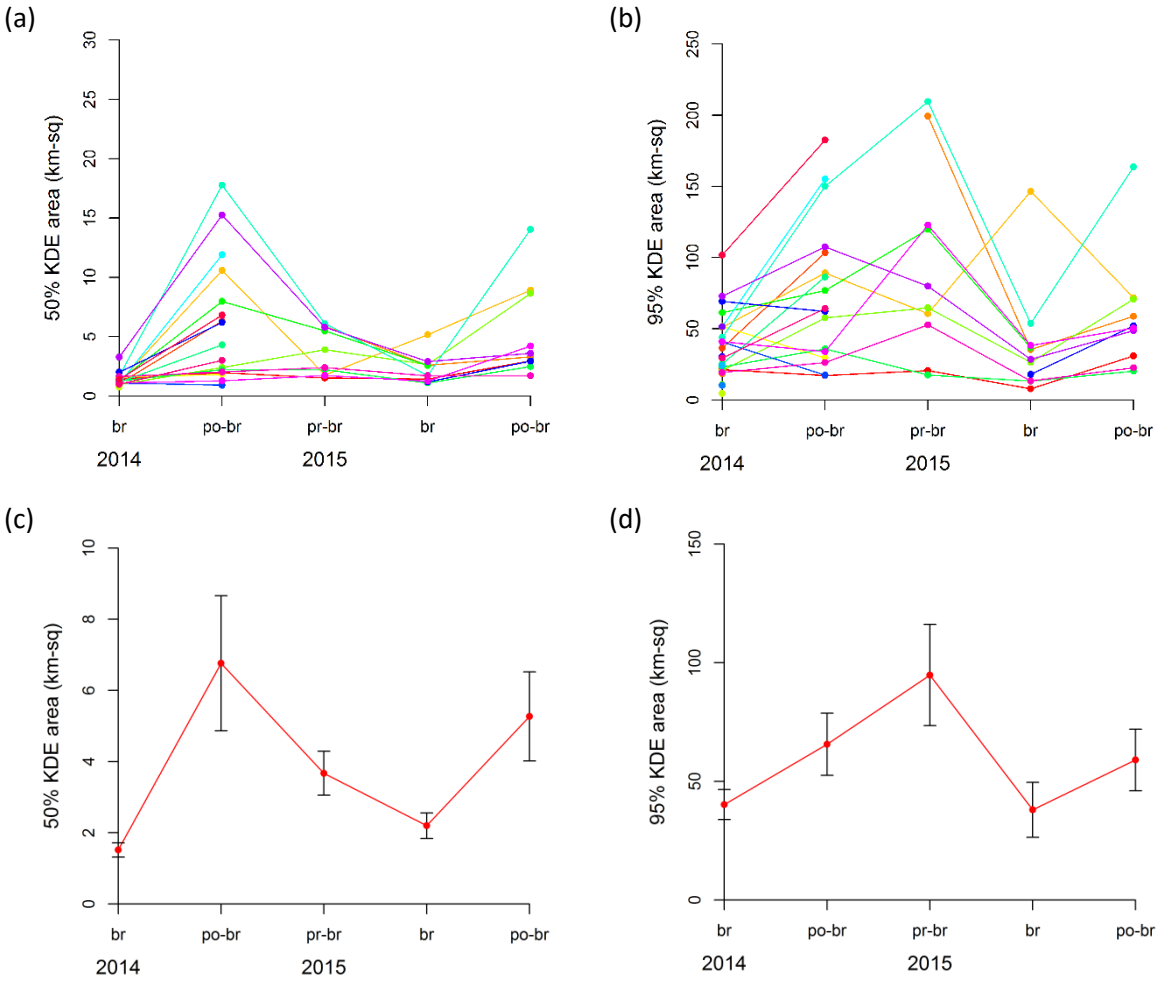


Figure 3.16 Area of 50% KDEs (a and c) and 95% KDEs (b and d) for Herring Gulls tagged at South Walney, showing values for individual birds (top row) and means across all birds (bottom row); values are based on data filtered to a 60 minute rate, hence exclude the winter period; errors are represented by ±1 SE. Note, sample sizes decreased from 24 birds in the first 2014 breeding season to 17 birds in the 2014 post-breeding period and to 11 birds thereafter (see text). Values in this graph are those values presented in Table 3.8 above; abbreviations used: br = 'breeding', 'po-br' = post-breeding; 'pr-br' = pre-breeding. Maps are based on HMM kernel overlaps, and means in (c) and (d) are calculated using data available for birds present across both years.

Trends in spatial patterns

Results also showed that the mean core (50% KDE) and total (95% KDE) area size, as would be expected, was greatest outside the breeding season as birds no longer had a central place foraging constraint (Fig.3.16). The largest percentage overlaps of the 95% KDE with mussel bed areas (mussel bed shapefile 2 presented in Fig. 3.15 were during breeding, with a greater proportion of the smaller home range overlapping with mussel beds in close proximity to the breeding colony. In contrast, the overlap between the 50% KDE and mussel beds was smallest during the breeding season – this was most likely due to the large proportion of time spent at the breeding colony at this time. The core usage of mussel beds also showed an increasing trend through time. Although this assessment was conducted over coarse time periods with uncertainty in the exact nesting status of individuals, the trend suggests possible differences in the use of mussel bed areas between years.

Table 3.10 Final summary of spatial values for (a) 95% KDE overlaps and (b) 50% KDE overlaps for the South Walney Herring Gull population, excluding those data with low or very low quality (see Table 2.3), for different sampling rates – sample sizes of birds here ('N') are for medium quality or higher; the 'total' all-bird kernel is also provided based on all data for the given period based on the full sample of birds; shown in bold are the values recommended, although sample sizes of bird information feeding into the KDE >6 birds are also here considered adequate.

(a) 95% KDE				Mussel bed shape 1		Mussel bed shape 2		Lune Estuary SSSI		Morecombe Bay SSSI		South Walney & Piel Channel Flats SSSI		Wyre Estuary SSSI		Whole SPA	
Year	Period	Rate	N	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total
2014	Br	10	**16**	**2.36±1.37**	**1.78**	**11.61±6.09**	**9.57**	**0.02±0.07**	**0**	**14.81±12.01**	**14.4**	**29.45±13.75**	**17.5**	**0.09±0.37**	**0.08**	**43.48±18.73**	**30.72**
		60	21	1.76±0.93	1.03	10.92±6.68	5.88	0.18±0.63	0	12.91±7.32	11.57	20.9±8.74	13.76	0.3±1.24	0.16	33.88±10.76	24.66
	PoBr	10	10	1.51±0.89	1.45	5.16±5.35	5.33	0.98±2.53	3.74	20.77±13.29	25.16	23.24±19.62	9.49	0.66±1.46	1.03	44.7±13.71	38.14
		60	**15**	**0.79±0.36**	**0.88**	**3.55±2.58**	**3.87**	**1.57±3.03**	**3.59**	**19.28±13.4**	**22.19**	**17.46±15.51**	**7.9**	**0.88±1.6**	**2.65**	**38.63±12.38**	**35.66**
	Wi	1080	**11**	**0.73±0.69**	**0.4**	**5.07±4.53**	**2.4**	**0.8±1.54**	**1.02**	**19.35±16.57**	**16.55**	**11.91±14.17**	**5.75**	**0.38±0.77**	**0.47**	**31.61±18.18**	**23.28**
2015	Br	10	6	1.41±1.47	2.08	8.31±2.72	8.15	0±0	0	29.09±14.22	20.08	25.78±13.06	17.61	0.06±0.14	0.04	54.35±15.81	37.17
		60	**10**	**1.48±0.99**	**1.03**	**9.66±4.57**	**5.3**	**0.07±0.23**	**0.35**	**17.81±14.13**	**13.4**	**30.47±22.13**	**12.6**	**0.18±0.49**	**0.11**	**47.13±17.82**	**25.07**
	PoBr	10	6	1.09±0.45	1.59	6.68±1.31	5.88	1.1±1.7	2.59	24.06±12.76	32.18	25.9±21.75	8.54	1±2.27	0.98	52.03±11.88	43.65
		60	**7**	**0.91±0.24**	**1.21**	**5.4±1.8**	**4.7**	**0.58±1.21**	**1.46**	**18.42±15.13**	**26.72**	**24.13±19.34**	**10.18**	**0.55±1.4**	**0.29**	**42.72±14.03**	**37.73**
	PrBr	10	1	0.91	0.96	8.9	6.67	0	1.72	10.51	12.01	17.59	9.32	0	2.43	26.84	25.57
		60	**9**	**1.19±0.65**	**0.45**	**7.31±4.83**	**2.57**	**1.28±2.08**	**3.18**	**12.6±6.92**	**10.45**	**18.66±14.32**	**5.98**	**0.61±0.87**	**1.8**	**31.68±11.1**	**20.81**
		1080	11	1.4±0.68	1.02	7.94±3.57	6.23	0.79±1.82	1.17	12.95±8.58	15.38	23.44±14.04	14.52	0.46±0.96	0.31	36.08±10.72	29.94

(b) 50% KDE				Mussel bed shape 1		Mussel bed shape 2		Lune Estuary SSSI		Morecombe Bay SSSI		South Walney & Piel Channel Flats SSSI		Wyre Estuary SSSI		Whole SPA	
Year	Period	Rate	N	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total	Mean±SD	Total
2014	Br	10	**16**	**0.82±3.28**	**0**	**3.07±8.51**	**0**	**0±0**	**0**	**2.64±7.71**	**0**	**96.89±8.61**	**100**	**0±0**	**0**	**99.6±1.59**	**100**
		60	21	0.2±0.89	2.76	0.5±2.29	15.48	0±0	0	0.31±1.43	12.99	98.54±4.61	68.63	0±0	0	98.89±3.15	81.92
	PoBr	10	10	0.27±0.73	0	1.05±2.17	1.67	0.64±2.01	0	10.7±16.52	19.47	64.59±31.82	51.79	0.22±0.64	0	76.83±20.17	72.71
		60	**15**	**0.21±0.41**	**0.74**	**1.07±2.12**	**3.03**	**0.56±1.64**	**0**	**11±14.76**	**27.59**	**60.21±30.57**	**34.96**	**0.87±1.98**	**0.07**	**72.57±20.33**	**62.5**
	Wi	1080	**11**	**0.27±0.36**	**0.57**	**3.76±5.95**	**3.5**	**0±0**	**0**	**29.6±31.65**	**34.75**	**24.78±35.73**	**34.71**	**0±0**	**0**	**53.33±30.93**	**67.66**
2015	Br	10	6	0±0	0	1.94±3.28	2.9	0±0	0	13.86±13.92	16.22	85.87±13.94	83.75	0±0	0	99.79±0.31	99.96
		60	**10**	**0.09±0.19**	**0.21**	**1.7±2.51**	**5.25**	**0±0**	**0**	**7.8±10.63**	**18.99**	**84.21±16.77**	**74.59**	**0±0**	**0**	**92.05±15.54**	**93.68**
	PoBr	10	6	1.94±4.3	5.46	2.46±3.71	7.84	2.52±6.18	8.25	18.01±13.63	18.87	61.76±21.53	52.14	0±0	0	82.39±10.76	79.42
		60	**7**	**0.83±1.75**	**0.18**	**2.23±2.38**	**0.95**	**1.37±4.12**	**0**	**9.68±12.29**	**0**	**60.4±19.79**	**77.16**	**0±0**	**0**	**69.27±15.88**	**74.14**
	PrBr	10	1	0	0	6.32	7.39	0	0	9.24	12.34	73.69	79.98	0	0	82.93	92.35
		60	**9**	**0.11±0.14**	**1.47**	**0.17±0.51**	**9.84**	**0±0**	**0**	**0.45±1.34**	**8.86**	**71.98±18.86**	**39.79**	**0.04±0.13**	**0**	**71.72±19.24**	**47.46**
		1080	11	0.51±0.54	0.47	2.61±4.2	0.13	0±0	0	4.36±10.52	0	68±17.44	75.6	0±0	0	72.44±12.14	75.72

3.3.2 Temporal overlap with areas of interest

Temporal overlaps for Herring Gulls tagged at South Walney with different areas of interest are shown in Tables 3.11 to 3.16 below, split by period. Note, overlaps were not recorded with the Roudsea Wood and Mosses SSSI, hence a table for this site is not presented. Given the agreement between spatial analyses based on the 10 minute and 60 minute resolution data presented above, temporal overlaps are presented for the 60 minute dataset for all periods except winter, where the 1080 minute dataset was used. An equivalent assessment excluding periods when birds were at the colony is provided in Appendix 1 (see methods).

Overlaps with mussel bed areas

Results from the assessment of time budgets were broadly similar to those from the spatial analysis presented above. The time spent resting or foraging in mussel bed areas was highest during the breeding season; this was despite the fact that analyses also included time spent at the nest. For example, percentage use of mussel bed shapefile 2 (across all birds) was 4.2% in the 2014 breeding season and 3.7% during 2015, but lowest for post-breeding and winter periods. For individual birds, the percentage overlaps ranged up to c. 5% in any given period. For some individuals for which less data were obtained (see caveats in spatial table – individuals 12654 and 12666), analyses suggested larger overlaps in the 2014 breeding season but should be treated with caution. Of note with the temporal analysis, is the overall interaction of all birds with mussel bed areas, with very few zero percentages in Tables 3.11 and 3.12 below.

Final summaries of time budgets are given in Table 3.17. The greatest overlaps in the foraging and resting behaviour of South Walney Herring Gulls with mussel beds was 4.5% for shapefile 2 during the 2014 breeding season (based on average values across birds) – a further 1.3% of time was spent commuting in these areas. Further lesser use was made of the patchier and smaller mussel bed areas in shapefile 1. Similar, albeit slightly smaller, values were also recorded in the 2015 breeding season.

Overlaps with SPAs and SSSIs

As with the spatial analyses, the greatest temporal overlaps were with the South Walney and Piel Channel Flats SSSI, encompassing the breeding colony. This summary, however is against a backdrop of considerable individual variation between birds (Table 3.15). Many birds spent over 70% of their time budgets (including commuting time) during breeding in this area – this is not a surprising result given a large amount of time will have been spent incubating eggs and raising chicks in the SSSI. Across all birds, the total time resting or foraging in this SSSI was ca. 60% during the 2014 and 2015 breeding periods, ca. 40% in pre-breeding and post-breeding periods when birds were still associated with the colony and ca. 20% during winter, when many birds dispersed more widely (Table 3.15). The Morecambe Bay SSSI was also used but to a lesser extent (ca. 5-15% of time budgets) and was highest outside of breeding. The Roudsea Woods and Marshes SSSI was not used at all, and across all birds, the time spent in the Lune Estuary and Wyre Estuary SSSIs was generally used less than 1% in any period.

In summary, as with spatial overlap assessments, the greatest amount of overall time spent foraging/resting for the South Walney Herring Gull population was in the South Walney and Piel Channel Flats SSSI, being up to 64% in the 2014 breeding period. However, over 40% of time was also spent foraging/resting here during pre-breeding and post-breeding periods (Table 3.17).

Table 3.11 Percentage temporal overlaps for Herring Gulls tagged at South Walney with mussel bed shapefile 1 as provided by Natural England; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Mussel bed	12646	42.29	0.33	0.06	50	0.16	0.08	141.8	0.52	0.12	32.54	0.41	0.22	37.67	0.08	0.02	62.25	0.15	0.11
shapefile 1	12647	42.83	0.3	0.07	58.3	0.34	0.12												
	12648	51.67	0.5	0.1				24.75	0.4	0.04	91	0.35	0.25	37.92	0.22	0.12	32.54	0.47	0.34
	12649	40.54	0.24	0.11	10.9	0.56	0.02	168	0	0	13.92	0.15	0.17	35	0.18	0.08	11	0.26	0.2
	12651	55.63	1.95	1.04	13.5	0.78	0.46												
	12652	3.04	0.14	0.02															
	12653	40.58	2.1	0.43	57.8	0.76	0.41	135	0.5	0.03	66.67	0.42	0.45	37.75	0.76	0.2	67.58	0.68	0.24
	12654	0.71	0.75	0															
	12657	42.83	0.65	0.27	57.8	0.6	0.27	151.5	0.25	0.12	74.04	0.55	0.31	31.04	0.28	0.13			
	12658	41.21	0.29	0.05	49.1	0.23	0.07	153.8	0.75	0.09	27.67	0.7	0.11	37.17	0.23	0.08	99.17	0.16	0.07
	12659	40.92	1.91	0.46	56.9	0.59	0.16												
	12661	56.75	0.65	0.19	57.4	1.63	0.22	142.5	0.1	0.05	96.04	0.51	0.25	37.92	0.46	0.16	67.75	3.5	2.03
	12662	56.42	0.34	0.08	57.1	0.18	0.06												
	12665	18.04	1.55	0.76															
	12666	0.96	1.41	0															
	12669	41.92	2.3	0.2	22.9	0.15	0.14												
	12670	45.75	0.32	0.18	28.8	0.04	0.03	66.75	0	0.04	0.21	0	1.72	4.13	0.36	0.09	16.33	0.17	0.17
	12672	45.21	0.39	0.22															
	12673	45.88	0.58	0.35															
	12674	41.75	1.82	0.44	59	0.76	0.24	137.3	0.32	0.24	68.33	0.9	0.6	37.83	0.32	0.07	19.92	0.84	0.26
	12675	41.17	0.28	0.07	42.6	0.22	0.13	150.8	0.04	0.04	45.79	0.48	0.32	36.21	0.63	0.25	40.08	0.12	0.1
	12676	42.96	0.31	0.39	45.6	0.3	0.08	165.8	0.55	0.01	27.5	0.39	0.26	27.92	0.07	0.02	62.46	0.06	0.06
	12678	41.38	1.43	0.31	41.8	0.32	0.05												
	12680	41.29	0.25	0.09	49.8	0.33	0.15												
	TOTAL	921.7	**0.85**	0.27	759	**0.49**	0.16	1438	**0.32**	0.07	543.7	**0.51**	0.32	360.5	**0.33**	0.11	479.1	**0.74**	0.41

Table 3.12 Percentage temporal overlaps for Herring Gulls tagged at South Walney with mussel bed shapefile 2 as provided by Natural England; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Mussel	12646	42.29	0.19	0.03	50	0.4	0.19	141.8	3.55	0.36	32.54	2.86	1.12	37.67	0.65	0.07	62.25	2.33	0.99
bed	12647	42.83	1.78	0.48	58.3	1.44	0.7												
shapefile 2	12648	51.67	5.93	1.72				24.75	4.89	0.07	91	2.23	1.43	37.92	3.49	1.75	32.54	4.45	2.69
	12649	40.54	0.84	0.3	10.9	0.04	0.02	168	0	0	13.92	1.06	0.29	35	0.68	0.24	11	2.82	1.87
	12651	55.63	6.46	2.73	13.5	2.35	1.18												
	12652	3.04	1.89	0.54															
	12653	40.58	4.58	0.96	57.8	3.1	1.48	135	1.41	0.11	66.67	2.99	2.36	37.75	9.62	2.18	67.58	2.83	1.21
	12654	0.71	11.76	0															
	12657	42.83	3.88	1.28	57.8	2.83	0.99	151.5	1.52	0.39	74.04	3.05	1.61	31.04	7.14	2.49			
	12658	41.21	1.19	0.37	49.1	0	0	153.8	2.75	0.36	27.67	0.57	0.2	37.17	0.73	0.35	99.17	0.17	0.31
	12659	40.92	8.3	2.77	56.9	2	1.05												
	12661	56.75	9.91	2.18	57.4	5.25	1.33	142.5	0.65	0.62	96.04	2.66	1.27	37.92	3.93	1.14	67.75	3.68	2.46
	12662	56.42	1.4	0.4	57.1	0.87	0.38												
	12665	18.04	5.73	2															
	12666	0.96	21.09	0															
	12669	41.92	4.84	0.5	22.9	0.46	0.24												
	12670	45.75	4.34	1.5	28.8	0.56	0.21	66.75	0.54	0.91	0.21	0	1.22	4.13	3.09	1.77	16.33	2.09	1.4
	12672	45.21	3.44	1.58															
	12673	45.88	6.83	2.73															
	12674	41.75	5.68	1.86	59	1.91	1.11	137.3	3.37	0.92	68.33	4.81	2.87	37.83	5.16	1.9	19.92	3.57	1.29
	12675	41.17	1.63	0.33	42.6	0.28	0.19	150.8	0.55	0.37	45.79	1.62	1.18	36.21	4.57	1.4	40.08	2.4	1.4
	12676	42.96	5.61	2.77	45.6	0.64	0.33	165.8	1.64	0.12	27.5	1.06	0.56	27.92	1.94	0.69	62.46	0.36	0.36
	12678	41.38	2.83	0.82	41.8	2.04	0.85												
	12680	41.29	0.76	0.25	49.8	0.8	0.27												
	TOTAL	921.7	**4.2**	1.32	759	**1.65**	0.68	1438	**1.68**	0.37	543.7	**2.65**	1.54	360.5	**3.8**	1.23	479.1	**2.09**	1.2

Table 3.13 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Lune Estuary SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Lune	12646	42.29	0	0	50	0	0	141.8	1.56	0.37	32.54	0	0	37.67	0	0	62.25	0	0
Estuary	12647	42.83	0	0	58.3	0	0												
SSSI	12648	51.67	0	0				24.75	0	0.03	91	0.15	0.03	37.92	0	0	32.54	0.13	0.13
	12649	40.54	0.48	0	10.9	5.3	2.18	168	0	0	13.92	1.36	0.93	35	0.4	0.18	11	0	0
	12651	55.63	0	0	13.5	0	0												
	12652	3.04	0	0															
	12653	40.58	0	0	57.8	0	0	135	0	0.19	66.67	0	0	37.75	0	0	67.58	0	0
	12654	0.71	0	0															
	12657	42.83	0	0	57.8	0	0	151.5	0	0.05	74.04	0.23	0.14	31.04	0	0			
	12658	41.21	0	0	49.1	0	0	153.8	0	0	27.67	0	0	37.17	0	0	99.17	0	0
	12659	40.92	0	0	56.9	2.67	1.26												
	12661	56.75	0.04	0	57.4	4.77	1.35	142.5	0.69	1.12	96.04	1.91	0.6	37.92	0	0	67.75	8.45	1.62
	12662	56.42	0	0	57.1	0.11	0.09												
	12665	18.04	0	0															
	12666	0.96	0	0															
	12669	41.92	0	0	22.9	0	0												
	12670	45.75	0	0	28.8	0	0	66.75	0	0	0.21	0	0	4.13	0	0	16.33	0	0
	12672	45.21	0	0															
	12673	45.88	0	0															
	12674	41.75	0	0	59	0	0	137.3	0	0.16	68.33	0	0	37.83	0	0	19.92	0	0
	12675	41.17	0	0	42.6	0	0	150.8	0.36	0.18	45.79	0.99	0.41	36.21	0	0	40.08	0	0
	12676	42.96	0	0	45.6	0	0	165.8	0	0.18	27.5	0	0	27.92	0	0	62.46	0	0
	12678	41.38	0	0	41.8	0	0												
	12680	41.29	0.2	0.11	49.8	1.11	0.41												
	TOTAL	921.7	**0.03**	0.01	759	**0.72**	0.26	1438	**0.26**	0.23	543.7	**0.51**	0.19	360.5	**0.04**	0.02	479.1	**1.2**	0.24

Table 3.14 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Morecambe Bay SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Morecambe	12646	42.29	0.14	0.03	50	0.6	0.35	141.8	3.38	0.98	32.54	1.8	0.54	37.67	0.19	0	62.25	1.19	0.81
Bay SSSI	12647	42.83	1.78	0.71	58.3	19.59	8.98												
	12648	51.67	3.97	1.36				24.75	2.6	0	91	3.49	1.68	37.92	20.48	3.81	32.54	8.12	4.66
	12649	40.54	1.43	0.49	10.9	0	0	168	0	0	13.92	0.85	0.6	35	2.05	0.66	11	1.7	1.95
	12651	55.63	5.94	2.55	13.5	7.4	2.86												
	12652	3.04	1.9	0.69															
	12653	40.58	2.35	0.42	57.8	15.73	5.68	135	24.91	1.44	66.67	5.02	3.29	37.75	18.22	3.37	67.58	16.28	7.82
	12654	0.71	5.15	0															
	12657	42.83	2.92	1.24	57.8	17.96	6.17	151.5	14.16	1.95	74.04	3.1	1.94	31.04	18.18	6.28			
	12658	41.21	1.16	0.27	49.1	0	0	153.8	1.49	2.8	27.67	0.21	0.01	37.17	1.12	0.6	99.17	1.38	0.84
	12659	40.92	8.05	2.65	56.9	14.85	6.54												
	12661	56.75	12.67	3.38	57.4	22.7	8.32	142.5	10.28	3.98	96.04	4.94	2.46	37.92	10.1	2.76	67.75	24.61	12.67
	12662	56.42	0.63	0.21	57.1	3.76	1.33												
	12665	18.04	4.68	1.34															
	12666	0.96	18.22	0															
	12669	41.92	1.83	0.17	22.9	0.53	0.15												
	12670	45.75	8.82	2.92	28.8	23.35	10.59	66.75	62.9	10.43	0.21	0	0	4.13	4.51	1.73	16.33	16.57	8.67
	12672	45.21	3.66	1.64															
	12673	45.88	6.75	2.28															
	12674	41.75	4.24	2.06	59	20.7	9.45	137.3	21.82	2.51	68.33	4.95	3.28	37.83	16.18	5.22	19.92	11.29	4.05
	12675	41.17	3.01	0.88	42.6	6.08	3.84	150.8	49.02	4.88	45.79	5.78	3.88	36.21	17.83	7.46	40.08	14.75	7.31
	12676	42.96	4.91	2.04	45.6	3.23	1.44	165.8	4.17	0.94	27.5	1.48	0.6	27.92	0.14	0	62.46	1	0.3
	12678	41.38	1.42	0.46	41.8	11.49	7.02												
	12680	41.29	0.83	0.36	49.8	2.28	1.3												
	TOTAL	921.7	**4.01**	1.35	759	**11.18**	4.8	1438	**16.01**	2.47	543.7	**3.82**	2.2	360.5	**10.57**	3.03	479.1	**9.21**	4.65

Table 3.15 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the South Walney and Piel Channel Flats SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
South	12646	42.29	77.69	12.02	50	73.03	20.26	141.8	48.56	1.08	32.54	70.39	14.51	37.67	82.24	13.04	62.25	62.79	14.4
Walney &	12647	42.83	66.28	7.95	58.3	32.28	5.22												
Piel	12648	51.67	76.02	4.61				24.75	0.6	0.12	91	34.2	5.13	37.92	48.97	7.74	32.54	44.56	6.9
Channel	12649	40.54	64.93	6.02	10.9	26.99	3.4	168	0	0.02	13.92	46.36	8.07	35	34.51	4.89	11	29.84	10.44
Flats SSSI	12651	55.63	58.22	8.87	13.5	51.43	8.71												
	12652	3.04	93.21	1.78															
	12653	40.58	76.52	8.89	57.8	49	5.1	135	10.11	0.36	66.67	39.93	12.4	37.75	56.61	8.97	67.58	33.99	9.11
	12654	0.71	81.32	0															
	12657	42.83	56.65	10.52	57.8	25.34	4.33	151.5	1.48	0.6	74.04	36.39	9.62	31.04	45.82	9.34			
	12658	41.21	70.57	13.35	49.1	51.69	12.13	153.8	55.9	1.85	27.67	39.88	13.94	37.17	74.48	11.54	99.17	36.54	13.2
	12659	40.92	67.16	8.12	56.9	35.41	3.75												
	12661	56.75	60.82	8.67	57.4	22.89	3.44	142.5	0.31	0.65	96.04	36.59	6.23	37.92	58.64	6.6	67.75	16.24	2.34
	12662	56.42	69.55	10.9	57.1	27.66	7.56												
	12665	18.04	66.48	5.37															
	12666	0.96	69.63	8.7															
	12669	41.92	64.55	9.5	22.9	74.92	6.45												
	12670	45.75	45.41	7.68	28.8	11.2	1.76	66.75	1.47	0.63	0.21	0	33.67	4.13	65.9	6.09	16.33	43.8	5.95
	12672	45.21	68.65	5.45															
	12673	45.88	55.59	8.31															
	12674	41.75	44.15	11.3	59	16.06	3.19	137.3	7.97	1.29	68.33	39.57	12.68	37.83	46.74	14.18	19.92	40.86	10.56
	12675	41.17	63.45	9.71	42.6	57.71	7.65	150.8	1.09	0.44	45.79	50.87	8.53	36.21	58.33	6.95	40.08	40.09	10.78
	12676	42.96	67.09	13.56	45.6	72.24	14.11	165.8	51.23	0.79	27.5	54.59	15.08	27.92	75.62	15.19	62.46	71.51	16.71
	12678	41.38	71.45	5.96	41.8	44.27	7.98												
	12680	41.29	52.61	7.52	49.8	28.9	6.7												
	TOTAL	921.7	**64.01**	8.81	759	**39.89**	7.22	1438	**18.76**	0.76	543.7	**41.49**	9.66	360.5	**58.18**	9.71	479.1	**42.39**	10.65

Table 3.16 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Wyre Estuary SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr) and 1080 minute for the winter 2014/14 period. Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015								
		Br			PoBr			Wi			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Wyre	12646	42.29	0	0	50	0	0	141.8	0.89	0.3	32.54	0.03	0	37.67	0	0	62.25	0	0
Estuary	12647	42.83	0	0	58.3	0	0												
SSSI	12648	51.67	0	0				24.75	0	0.68	91	0.06	0.09	37.92	0.09	0.06	32.54	0.95	0.07
	12649	40.54	0.18	0.06	10.9	3.2	1.59	168	0	0.12	13.92	0.58	0.29	35	0.38	0.26	11	0	0
	12651	55.63	0	0	13.5	0	0												
	12652	3.04	0	0															
	12653	40.58	0	0	57.8	0	0	135	0	0.28	66.67	0	0.01	37.75	0	0	67.58	0	0
	12654	0.71	0	0															
	12657	42.83	0	0	57.8	0	0	151.5	0	0.04	74.04	0.17	0.03	31.04	0	0			
	12658	41.21	0	0	49.1	0	0	153.8	0	0	27.67	0	0	37.17	0	0	99.17	0	0
	12659	40.92	0.02	0.06	56.9	1.06	0.53												
	12661	56.75	0.09	0.01	57.4	0.43	0.07	142.5	0.26	0.18	96.04	0.61	0.34	37.92	0.01	0.04	67.75	0.05	0.09
	12662	56.42	0.01	0.02	57.1	0.34	0.24												
	12665	18.04	0	0															
	12666	0.96	0	0															
	12669	41.92	0	0	22.9	0	0												
	12670	45.75	0	0	28.8	0	0	66.75	0	0	0.21	0	0	4.13	0	0	16.33	0	0
	12672	45.21	0	0															
	12673	45.88	0.04	0.07															
	12674	41.75	0	0	59	0	0	137.3	0	0.31	68.33	0	0.01	37.83	0	0	19.92	0	0
	12675	41.17	0	0	42.6	0	0	150.8	0.2	0.12	45.79	0.27	0.13	36.21	0	0	40.08	0	0
	12676	42.96	0	0	45.6	0	0	165.8	0	0	27.5	0	0	27.92	0	0	62.46	0	0
	12678	41.38	0	0	41.8	0	0												
	12680	41.29	0.92	0.72	49.8	1.5	0.99												
	TOTAL	921.7	**0.06**	0.04	759	**0.28**	0.15	1438	**0.13**	0.15	543.7	**0.18**	0.1	360.5	**0.05**	0.04	479.1	**0.07**	0.02

Table 3.17 Final summary of temporal overlaps with areas of interest for the South Walney Herring Gull population, excluding those data with low or very low quality (see Table 2.3) – sample sizes of birds here ('N') are for medium quality or higher; sample sizes of bird information >6 birds are also here considered adequate. Data summarised here are based on 60 minute rates, except for winter where a 1080 minute rate is used.

				Mussel bed shapefile 1		Mussel bed shapefile 2		Lune Estuary SSSI		Morecambe Bay SSSI		South Walney & Piel Channel Flats SSSI		Wyre Estuary SSSI	
Year	**Period**	**Behaviour**	**N**	**Mean±SD**	**Total**	**Mean±SD**	**Total**	**Mean±SD**	**Total**	**Mean±SD**	**Total**	**Mean±SD**	**Total**	**Mean±SD**	**Total**
2014	Br	%R.F	21	0.88±0.74	0.85	4.45±3.07	4.2	0.03±0.11	0.03	3.87±3.16	4.01	63.99±9.25	64.01	0.06±0.2	0.06
		%C		0.28±0.25	0.27	1.25±0.97	1.32	0.01±0.02	0.01	1.31±1.03	1.35	8.78±2.54	8.81	0.04±0.16	0.04
	PoBr	%R.F	15	0.44±0.4	0.49	1.51±1.41	1.65	0.58±1.37	0.72	10.86±8.84	11.18	41.51±20.93	39.89	0.22±0.46	0.28
		%C		0.15±0.1	0.16	0.62±0.48	0.68	0.21±0.46	0.26	4.74±3.75	4.8	7.31±4.87	7.22	0.12±0.28	0.15
	Wi	%R.F	11	0.31±0.26	0.32	1.9±1.54	1.68	0.24±0.49	0.26	17.7±20.86	16.01	16.25±23.18	18.76	0.12±0.27	0.13
		%C		0.07±0.07	0.07	0.38±0.32	0.37	0.21±0.32	0.23	2.72±2.98	2.47	0.71±0.53	0.76	0.18±0.2	0.15
2015	PrBr	%R.F	9	0.52±0.18	0.51	2.43±1.26	2.65	0.36±0.66	0.51	3.42±1.92	3.82	44.71±11.8	41.49	0.13±0.2	0.18
		%C		0.31±0.14	0.32	1.4±0.82	1.54	0.13±0.22	0.19	1.96±1.38	2.2	10.9±3.67	9.66	0.07±0.11	0.1
	Br	%R.F	10	0.32±0.23	0.33	3.79±2.98	3.8	0.04±0.13	0.04	10.45±8.68	10.57	58.2±15.2	58.18	0.05±0.12	0.05
		%C		0.11±0.07	0.11	1.22±0.86	1.23	0.02±0.06	0.02	3.02±2.7	3.03	9.84±3.49	9.71	0.04±0.08	0.04
	PoBr	%R.F	7	0.73±1.24	0.74	2.47±1.53	2.09	1.23±3.19	1.2	9.62±9.23	9.21	43.67±18.49	42.39	0.14±0.36	0.07
		%C		0.42±0.72	0.41	1.34±0.87	1.2	0.25±0.61	0.24	4.92±4.64	4.65	10.49±4.88	10.65	0.02±0.04	0.02

4. DISCUSSION

This study has assessed the local area usage of 24 breeding adult Herring Gulls from the South Walney and Piel Channel Flats Site of Special Scientific Interest (SSSI), within the Morecambe Bay and Duddon Estuary potential Special Protection Area (pSPA).

Two different shapefiles were used to define mussel bed areas in this study. The first shapefile ('shapefile 1', shown in Fig. 2.1) relates specifically to areas surveyed recently in 2015 on behalf of Natural England as part of an intertidal hard substrate/rock survey and provides a more refined and up-to-date representation of mussel bed distribution. However, we also considered a second historic, less-refined shapefile for the whole of Morecambe Bay. Correspondingly, the 2015 survey (shapefile 1) showed a better driver likely driver of distributions both visually and quantitatively.

Across the year, birds remained very local to the South Walney colony area, reaching only as far south as the Mersey Estuary. At all times, clear use was made of local mussel bed habitats, although overall the proportional use of these areas was relatively small, given the availability of other habitats and food resources in the local area. Nonetheless, clear foraging location hotspots were centred upon these areas, notably the mussel bed area south of Barrow-in-Furness.

The use of a Hidden Markov Model (HMM) in this study was a useful interim step to initially identify potential foraging and roosting locations. In essence, this analytical step removed probable commuting behaviours, for example between the colony and important feeding and roosting sites. Therefore, greater confidence can be placed in the spatial area utilisations being representative of functional habitat use and thus in the assessment of use of areas of interest. Herring Gulls spent 50-60% time away from the colony during breeding and over 70% at other times of the year (Appendix 1). Correspondingly, Herring Gulls spent proportionally more time foraging/resting in mussel beds – up to 9.5% in the post-breeding period in 2014 – when expressing use in relation to time spent away from the colony. Such a value is likely a better indication of the extent of active use of mussel beds, but further resource-selection analyses would be needed to formally determine its significance.

Some use of offshore areas was also recorded, particularly during the 2014 post-breeding season. However, predominantly, birds used terrestrial areas and intertidal mudflats. Terrestrial habitats used included (as assessed visually using Google Earth ©) land fill sites, gravel workings, (bathing and roosting sites at local) waterbodies, agricultural areas, industrial sites such as sewage works and urban areas in Barrow-in-Furness. The local oyster farm very close to the South Walney colony may also be important for the birds. Further use of land cover maps and GIS layers is needed to fully assess the relative use of these habitats, and such steps are recommended as further work building on the initial description of habitat use in this study (see below).

Habitat use and the extent of movements varied between individual birds, with repeated foraging trips to particular habitats, including local mudflats and mussel bed areas, being apparent during particular periods of the year. Although beyond the scope of this study, assessment of the repeated use of areas by individual birds, the commonality in the timing of movements between birds and the seasonal variation in these patterns would further aid appraisal of the importance of particular local habitats to this protected population.

Foraging range information from the wider literature suggests that Herring Gulls typically forage 10 km from the breeding colony during the breeding period (mean across all foraging trips), but may typically venture up to a mean maximum foraging range across all trips of birds up to 61 km, and as far as 92 km (absolute maximum recorded across all colonies) – see Thaxter *et al.* (2012) for more information. For Herring Gulls at South Walney, previous analysis of the same dataset used here, suggested that birds

travelled up to a mean maximum of 5.4±9.6 km during in 2014, and 5.4±6.7 km in 2015 during the breeding season, with maximums up to 116 km and 92 km in 2014 and 2015 respectively; note, however, that these movements are likely to include some trips made by individuals that had failed in their breeding attempts (Thaxter *et al.* 2016b). Such values are useful in assessing the potential use of habitats during the breeding season; however, this is the first time that a detailed assessment of area usage has been carried out across the entire year for Herring Gulls.

The approach taken in this study using static dates across the colony to identify different periods of the year (i.e. breeding, post-breeding, winter and pre-breeding) are subject to a degree of error. For example, it is likely for example that some birds could still have had chicks within the defined 'post-breeding' period. However, monitoring of the nests of individuals was problematic, particularly with dense vegetation and excessive visits later in the season (a) risked disturbance to the birds and (b) could not identify chicks to nests given their increased mobility. The approach taken was considered appropriate to characterise general patterns of usage through the year, but should not be taken as definitive that individual birds were at given stages of activity. By contrast, the winter period in this study was defined on a bird-specific basis, and is therefore a bespoke wintering assessment for each individual bird.

The data from GPS telemetry provide a valuable resource to investigate the importance of particular habitats to species. The data collected here for Herring Gulls clearly indicate some use of local mussel beds throughout the year. To further our understanding, however, more formal assessment of the relative use of these habitats in relation to others in the area will need to be quantified. Use of resource-selection functions to determine habitat linkages more formally would be a next logical step in the analyses of these data.

Acknowledgements

This work was funded by Natural England and was based on data collected as part of a study funded by the Department of Energy and Climate Change (DECC). Our thanks to Bart Donato for the support of the work and particular thanks to John Hartley of Hartley Anderson for support and management of the DECC contract. Thanks to Gary Brodin at PathTrack Ltd for supplying the GPS devices and base station for tracking Herring Gulls at South Walney, for assistance with downloading data and technical support. We are very grateful to Matt Lipton and Lawrence Eagle (Cumbria Wildlife Trust) at South Walney for assistance with setting up the tracking systems and monitoring birds and their nests. We also thank Penny Mitchell (BTO) for their contract management support, Maria Knight for help with the report and all those who have provided field assistance at South Walney.

References

Antill, R. & Pérez-Domínguez, R. 2016. *Morecambe Bay SAC Intertidal Reef Surveys 2015: Final Report*. APEM Scientific Report for Natural England, Ref. 414289.

Chabrzyk, G. & Coulson, J.C. 1976. Survival and recruitment in the Herring Gull *Larus argentatus*. *Journal of Animal Ecology* **45:** 187-203.

Davis, J. & Quinn, J.S. 1997. Distribution of parental investment and sibling competition in the Herring Gull, *Larus argentatus*. *Behaviour* **134**: 961-974.

DECC. 2009. *UK Offshore Energy Strategic Environmental Assessment. Future Leasing for Offshore Wind Farms and Licensing for Offshore Oil & Gas and Gas Storage*. Environmental Report, Department of Energy and Climate Change.
https://www.gov.uk/government/publications/uk-offshore-energy-strategic-environmental-assessment-oesea-environmental-report

JNCC. 2014. *Seabird population trends and causes of change: 1986-2013 report.* http://www.jncc.defra.gov.uk/page-3201. Joint Nature Conservation Committee. Updated August 2014. Accessed 12/01/2015.

Keating, K.A. & Cherry, S. 2009. Modeling utilization distributions in space and time. *Ecology* **90**: 1971-80.

Kim, S.Y. & Monaghan, P. 2006. Interspecific differences in foraging preferences, breeding performance and demography in Herring (*Larus argentatus*) and Lesser Black-backed Gulls (*Larus fuscus*) at a mixed colony. *Journal of Zoology* **270:** 664-671.

Klaassen, R.H.G., Ens, B.J., Shamoun-Baranes, J., Exo, K., & Bairlein, F. 2012. Migration strategy of a flight generalist, the Lesser Black-backed Gull *Larus fuscus*. *Behavioural Ecology* **23:** 58-68.

Michelot T., Langrock R., Patterson T. & Rexstad E. 2015. moveHMM. An R package for animal movement modelling.

Mitchell, P.I., Newton, S.F., Ratcliffe, N. & Dunn, T.E. 2004. *Seabird Populations of Britain and Ireland.* T & A D Poyser, London, UK.

Natural England 2016. *Departmental Brief: Morecambe Bay and Duddon Estuary potential Special Protection Area (pSPA), Natural England, January 2016*.
www.gov.uk/government/uploads/system/uploads/attachment_data/file/492891/morecambe-duddon-departmental-brief.pdf [last accessed 10/03/2017]
R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://ww.r-project.org

Robinson, R.A. 2005. *BirdFacts: profiles of birds occurring in Britain & Ireland*. BTO Research Report 407. BTO, Thetford. http://www.bto.org/birdfacts

Ross-Smith, V.H., Thaxter, C.B., Masden, E.A., Shamoun-Baranes, J., Burton, N.H.K., Wright, L.J., Rehfisch, M.M. & Johnston, A. 2016. Modelling flight heights of Lesser Black-backed Gulls and Great Skuas from GPS: a Bayesian approach. *Journal of Applied Ecology* doi: 10.1111/1365-2664.12760.

Shamoun-Baranes, J., Bouten, W., Camphuysen, C.J. & Baaj, E. 2011. Riding the tide: intriguing observations of gulls resting at sea during breeding. *Ibis* **153:** 411-415.

Stienen, E.W.M., Desmet, P., Aelterman, B., Courtens, W., Feys, S., Vanermen, N., Verstraete, H., Van de walle, M., Deneudt, K., Hernandez, F., Houthoofdt, R., Vanhoorne, B., Bouten, W., Buijs, R.-J., Kavelaars, M., Müller, W., Herman, D., Matheve, H., Sotillo, A. & Lens, L. 2016. GPS tracking data of Lesser Black-backed Gulls and Herring Gulls breeding at the southern North Sea coast. *ZooKeys* **555**: 115-124.

Stroud, D.A., Chambers, D., Cook, S., Buxton, N., Fraser, B., Clement, P., Lewis, P., McLean, I., Baker, H. & Whitehead, S. (eds). 2001. *The UK SPA network: its scope and contents*. JNCC, Peterborough

Thaxter, C.B., Ross-Smith, V.H., Clark, J.A., Clark, N.A., Conway, G.J., Marsh, M., Leat, E.H.K. & Burton, N.H.K. 2014a. A trial of three harness attachment methods and their suitability for long-term use on Lesser Black-backed Gulls and Great Skuas. *Ringing & Migration* **29**: 65-76.

Thaxter, C.B., Ross-Smith, V.H., Clark, N.A., Conway, G.J., Johnston, A., Wade, H.M., Masden, E.A., Bouten, W. & Burton, N.H.K. 2014b. *Measuring the interaction between marine features of Special Protection Areas with offshore wind farm development zones through telemetry: final report*. BTO Research Report No. 649. BTO, Thetford.

Thaxter, C.B., Ross-Smith, V.H., Clark, N.A., Barber, L., Clewley, G., Conway, G.J., Masden, E.A., Bouten, W. & Burton, N.H.K. 2015a. *Measuring the interaction between Lesser Black-backed Gulls and Herring Gulls from the Skokholm and Skomer SPA and Morecambe Bay SPA and Offshore Wind Farm Development Sites: First Year Report*. BTO Research Report 664 to DECC. BTO, Thetford.

Thaxter, C.B., Ross-Smith, V.H., Bouten, W., Rehfisch, M.M., Clark, N.A., Conway, G.J. & Burton, N.H.K. 2015b. Seabird-wind farm interactions during the breeding season vary within and between years. *Biological Conservation* **186:** 347-358.

Thaxter, C.B., Ross-Smith, V.H., Clark, J.A., Clark, N.A., Conway, G.J., Masden, E.A., Wade, H.M., Leat, E.H.K., Gear, S.C., Marsh, M., Booth, C., Furness, R.W., Votier, S.C. & Burton, N.H.K. 2016a. Contrasting effects of GPS device and harness attachment on adult survival in the Lesser Black-backed Gull *Larus fuscus* and Great Skua *Stercorarius skua*. *Ibis* **158:** 279-290.

Thaxter, C.B., Ross-Smith, V.H., Clark, J.A., Clark, N.A., Clewley, G., Barber, L., Conway, G.J., Harris, S.J., Masden, E.A., Bouten, W. & Burton, N.H.K. 2016b. *Measuring the interaction between Lesser Black-backed Gulls and Herring Gulls from the Skokholm and Skomer SPA and Morecambe Bay SPA and Offshore Wind Farm Development Sites: Second Year Report*. BTO Research Report 681 to DECC. BTO, Thetford.

Thaxter, C.B., Clark, N.A., Clewley, G., Humphreys, E.M., Ross-Smith, V.H., Scragg, E.S., Barber, L., Conway, G.J., Harris, S.J., Masden, E.A., Bouten, W. & Burton, N.H.K. (In prep). *Measuring the interaction between Lesser Black-backed Gulls and Herring Gulls from the Skokholm and Skomer SPA and Morecambe Bay SPA and Offshore Wind Farm Development Sites: Final Report*. BTO Research Report to DECC. BTO, Thetford.

Tinbergen, N. 1953. *The Herring Gull's world: a study of the social behaviour of birds*. Collins Clear-Type Press, London.

Wade, H.M., Masden, E.A., Jackson, A.C., Thaxter, C.B., Burton, N.H.K., Bouten, W. & Furness, R.W. 2014. Great skua (*Stercorarius skua*) movements at sea in relation to marine renewable energy developments. *Marine Environmental Research* **101**: 69-80.

Wernham, C.V., Toms, M.P., Marchant, J.H., Clark, J.A., Siriwardena, G.M. & Baillie, S.R. (eds.) 2002. *The Migration Atlas: movements of the birds of Britain and Ireland.* T. & A.D. Poyser, London.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* **70:** 164-168.

APPENDIX 1 Assessment of temporal overlaps removing time spent at the colony.

The analyses presented in the main report provide an assessment of habitat use through the year and thus, for comparison between seasons, include time spent at the colony. Birds were present in the area of the South Walney colony not just during the breeding season but also at other times, notably during pre-breeding and post-breeding periods.

Here, we provide an assessment of the temporal usage of mussel beds and the Morecambe Bay SPA (and constituent SSSIs) excluding time spent at the colony which, for the breeding season at least, may give additional perspective on the habitats favoured for foraging. Tables A1.2 to A1.8 below follow the same format as those in the main report.

The mean proportion of time that birds spent away from the colony was 49% in the 2014 breeding season, 57% in the 2015 breeding season and over 70% outside the breeding period, when birds were no longer constrained to central place foraging (Table A1.1). Only considering this time resulted in an increase in the appraisal of the relative time spent in mussel bed areas and all SSSIs excepting the South Walney and Piel Channel Flats SSSI.

Table A1.1 Summary of percentage time spent away from the colony for Herring Gulls tagged at South Walney for data filtered to a 60-minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr).

	2014		2015		
Bird	Breeding	Post-breeding	Pre-breeding	Breeding	Post-breeding
12646	50.25	66.58	53.52	44.69	77.44
12647	47.28	74.2			
12648	35.65		72.3	58.35	64.79
12649	46.25	83.59	66.17	51.9	53.79
12651	56.4	57.23			
12652	10.96				
12653	37.17	65.78	75.81	59.49	82.24
12654	41.18				
12657	60.02	81.53	76.7	63.22	
12658	55.81	80.32	80.72	49.44	95.67
12659	48.78	71.23			
12661	58.15	85.48	74.06	55.38	28.72
12662	47.71	82.85			
12665	43.65				
12666	39.13				
12669	48.11	35.15			
12670	49	69.18	100	51.52	65.31
12672	42.21				
12673	60.04				
12674	76.35	91.25	77.68	69.16	73.22
12675	53.04	52.84	60.6	52.36	71.83
12676	55	72.21	65	70.9	87.12
12678	44.61	69.12			
12680	63.67	81.94			
Mean±SD	48.77±12.29	71.79±13.91	72.96±12.16	56.95±8.23	70.01±18.82

Table A1.2 Percentage temporal overlaps for Herring Gulls tagged at South Walney with mussel bed shapefile 1; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015					
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Mussel bed shapefile 1	12646	21.25	0.65	0.13	33.3	0.24	0.12	17.42	0.75	0.4	16.83	0.18	0.04	48.21	0.19	0.14
	12647	20.25	0.63	0.16	43.3	0.45	0.16									
	12648	18.42	1.39	0.29				65.79	0.48	0.35	22.13	0.39	0.2	21.08	0.73	0.52
	12649	18.75	0.52	0.24	9.13	0.67	0.03	9.21	0.2	0.25	18.17	0.34	0.15	5.92	0.49	0.38
	12651	31.38	3.46	1.84	7.75	1.36	0.8									
	12652	0.33	1.32	0.14												
	12653	15.08	4.51	1.17	38	1.16	0.62	50.54	0.55	0.59	22.46	1.27	0.31	55.58	0.83	0.29
	12654	0.29	0	60.32												
	12657	25.71	1.09	0.45	47.1	0.73	0.32	56.79	0.72	0.4	19.63	0.42	0.21			
	12658	23	0.52	0.09	39.5	0.29	0.08	22.33	0.87	0.13	18.38	0.46	0.16	94.88	0.16	0.07
	12659	19.96	3.93	0.95	40.5	0.83	0.22									
	12661	33	1.07	0.33	49	1.91	0.25	71.13	0.69	0.34	21	0.83	0.29	19.46	4.07	2.21
	12662	26.92	0.71	0.17	47.3	0.21	0.07									
	12665	7.88	3.56	1.73												
	12666	0.38	3.61	0												
	12669	20.17	4.78	0.41	8.04	0.43	0.4									
	12670	22.42	0.66	0.37	19.9	0.05	0.04	0.21	0	1.72	2.13	0.7	0.18	10.67	0.25	0.26
	12672	19.08	0.89	0.53												
	12673	27.54	0.97	0.58												
	12674	31.88	2.39	0.58	53.9	0.72	0.26	53.08	1.16	0.77	26.17	0.46	0.1	14.58	1.14	0.35
	12675	21.83	0.53	0.13	22.5	0.41	0.24	27.75	0.78	0.53	18.96	1.2	0.48	28.79	0.17	0.14
	12676	23.63	0.57	0.7	32.9	0.42	0.11	17.88	0.61	0.39	19.79	0.09	0.02	54.42	0.07	0.07
	12678	18.46	3.21	0.69	28.9	0.46	0.07									
	12680	26.29	0.39	0.14	40.8	0.4	0.18									
	TOTAL	473.9	**1.71**	0.56	562	**1.86**	0.61	392.1	**1.83**	1.15	205.6	**0.77**	0.26	353.6	**1.56**	0.81

Table A1.3 Percentage temporal overlaps for Herring Gulls tagged at South Walney with mussel bed shapefile 2; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014						2015								
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Mussel bed shapefile 2	12646	21.25	0.37	0.05	33.3	0.59	0.29	17.42	5.35	2.09	16.83	1.45	0.15	48.21	2.99	1.28
	12647	20.25	3.78	1.01	43.3	1.94	0.95									
	12648	18.42	16.65	4.81				65.79	3.08	1.98	22.13	5.98	2.99	21.08	6.87	4.15
	12649	18.75	1.82	0.64	9.13	0.05	0.02	9.21	1.61	0.44	18.17	1.3	0.47	5.92	5.25	3.48
	12651	31.38	11.46	4.84	7.75	4.11	1.87									
	12652	0.33	17.26	4.97												
	12653	15.08	10.96	2.58	38	4.72	2.26	50.54	3.91	3.04	22.46	15.94	3.5	55.58	3.44	1.47
	12654	0.29	0	133.3												
	12657	25.71	6.47	2.13	47.1	3.41	1.18	56.79	3.97	2.1	19.63	11.29	3.95			
	12658	23	2.13	0.66	39.5	0	0	22.33	0.71	0.25	18.38	1.47	0.7	94.88	0.17	0.25
	12659	19.96	17.03	5.67	40.5	2.8	1.48									
	12661	33	17.05	3.74	49	6.15	1.56	71.13	3.59	1.71	21	7.09	2.06	19.46	6.88	3.98
	12662	26.92	2.94	0.85	47.3	1.05	0.46									
	12665	7.88	13.13	4.59												
	12666	0.38	53.89	0												
	12669	20.17	10.06	1.03	8.04	1.32	0.7									
	12670	22.42	8.85	3.05	19.9	0.81	0.31	0.21	40	1.22	2.13	5.68	3.44	10.67	3.2	2.15
	12672	19.08	8.15	3.73												
	12673	27.54	11.19	4.55												
	12674	31.88	7.45	2.44	53.9	2.05	1.13	53.08	6.2	3.69	26.17	7.47	2.74	14.58	4.88	1.76
	12675	21.83	3.07	0.63	22.5	0.52	0.37	27.75	2.66	1.92	18.96	8.74	2.66	28.79	3.33	1.95
	12676	23.63	10.2	5.04	32.9	0.88	0.46	17.88	1.63	0.86	19.79	2.66	0.98	54.42	0.41	0.42
	12678	18.46	6.35	1.83	28.9	2.95	1.23									
	12680	26.29	1.19	0.39	40.8	0.97	0.33									
	TOTAL	473.9	**8.56**	2.73	562	**6.3**	2.58	392.1	**9.48**	5.51	205.6	**8.79**	2.83	353.6	**7.05**	3.83

Table A1.4 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Lune Estuary SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015					
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Lune Estuary SSSI	12646	21.25	0	0	33.3	0	0	17.42	0	0	16.83	0	0	48.21	0	0
	12647	20.25	0	0	43.3	0	0									
	12648	18.42	0	0				65.79	0.21	0.04	22.13	0	0	21.08	0.2	0.2
	12649	18.75	1.05	0	9.13	6.34	2.6	9.21	2.05	1.4	18.17	0.78	0.34	5.92	0	0
	12651	31.38	0	0	7.75	0	0									
	12652	0.33	0	0												
	12653	15.08	0	0	38	0	0	50.54	0	0	22.46	0	0	55.58	0	0
	12654	0.29	0	0												
	12657	25.71	0	0	47.1	0	0	56.79	0.29	0.18	19.63	0	0			
	12658	23	0	0	39.5	0	0	22.33	0	0	18.38	0	0	94.88	0	0
	12659	19.96	0	0	40.5	3.75	1.77									
	12661	33	0.06	0	49	5.58	1.58	71.13	2.57	0.81	21	0	0	19.46	2.85	0.46
	12662	26.92	0	0	47.3	0.13	0.1									
	12665	7.88	0	0												
	12666	0.38	0	0												
	12669	20.17	0	0	8.04	0	0									
	12670	22.42	0	0	19.9	0	0	0.21	0	0	2.13	0	0	10.67	0	0
	12672	19.08	0	0												
	12673	27.54	0	0												
	12674	31.88	0	0	53.9	0	0	53.08	0	0	26.17	0	0	14.58	0	0
	12675	21.83	0	0	22.5	0	0	27.75	1.63	0.68	18.96	0	0	28.79	0	0
	12676	23.63	0	0	32.9	0	0	17.88	0	0	19.79	0	0	54.42	0	0
	12678	18.46	0	0	28.9	0	0									
	12680	26.29	0.31	0.18	40.8	0.71	0.15									
	TOTAL	473.9	**0.07**	0.01	562	**2.63**	0.93	392.1	**1.83**	0.67	205.6	**0.09**	0.04	353.6	**0.48**	0.1

Table A1.5 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Morecambe Bay SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015					
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Morecambe Bay SSSI	12646	21.25	0.28	0.05	33.3	0.91	0.53	17.42	3.36	1	16.83	0.42	0	48.21	0.9	0.96
	12647	20.25	3.76	1.5	43.3	26.4	12.1									
	12648	18.42	11.13	3.81				65.79	4.83	2.32	22.13	35.1	6.53	21.08	12.54	7.19
	12649	18.75	3.1	1.07	9.13	0	0	9.21	1.28	0.91	18.17	3.94	1.27	5.92	3.15	3.63
	12651	31.38	10.52	4.51	7.75	11.32	4.74									
	12652	0.33	17.36	6.28												
	12653	15.08	6.04	1.12	38	23.91	8.63	50.54	6.46	4.22	22.46	30.43	5.52	55.58	19.79	9.51
	12654	0.29	0	58.17												
	12657	25.71	4.86	2.03	47.1	21.75	7.28	56.79	4.04	2.52	19.63	28.75	9.93			
	12658	23	2.07	0.48	39.5	0	0	22.33	0.26	0.01	18.38	2.26	1.22	94.88	1.26	0.76
	12659	19.96	16.51	5.44	40.5	20.85	9.18									
	12661	33	21.8	5.82	49	26.56	9.73	71.13	6.67	3.32	21	18.24	4.93	19.46	14.09	6.78
	12662	26.92	1.33	0.43	47.3	4.53	1.61									
	12665	7.88	10.72	3.06												
	12666	0.38	46.57	0												
	12669	20.17	3.81	0.35	8.04	1.51	0.42									
	12670	22.42	11.46	3.86	19.9	23.86	10.6	0.21	0	0	2.13	7.79	3.35	10.67	23.8	12.5
	12672	19.08	8.66	3.89												
	12673	27.54	11.24	3.81												
	12674	31.88	5.56	2.7	53.9	22.16	10.1	53.08	6.38	4.22	26.17	23.39	7.55	14.58	15.43	5.53
	12675	21.83	5.68	1.66	22.5	11.51	7.27	27.75	9.54	6.4	18.96	33.62	14.15	28.79	20.53	10.18
	12676	23.63	8.93	3.7	32.9	4.47	2	17.88	2.28	0.92	19.79	0.19	0	54.42	1.14	0.35
	12678	18.46	3.19	1.03	28.9	15.66	10.15									
	12680	26.29	1.3	0.57	40.8	2.78	1.59									
	TOTAL	473.9	**7.92**	2.68	562	**41.57**	17.83	392.1	**13.65**	7.85	205.6	**24.51**	7.01	353.6	**23.52**	11.77

Table A1.6 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the South Walney & Piel Channel Flats SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015					
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
South Walney & Piel Channel Flats SSSI	12646	21.25	62.45	17.07	33.3	68.62	21.54	17.42	54.01	19.46	16.83	70.42	19.04	48.21	59.51	16.19
	12647	20.25	30.52	14.97	43.3	9.69	6.07									
	12648	18.42	33.68	12.05				65.79	11.84	4.25	22.13	18.2	7.62	21.08	17.99	7.09
	12649	18.75	27.13	10.58	9.13	12.66	4.06	9.21	20.38	10.84	18.17	16.69	8.27	5.92	27.31	12.75
	12651	31.38	29.5	12.27	7.75	20.51	11.86									
	12652	0.33	38.02	16.22												
	12653	15.08	40.98	21.43	38	23.23	6.99	50.54	24.36	13.45	22.46	32.87	9.65	55.58	21.86	9.06
	12654	0.29	99.88	1108												
	12657	25.71	28.78	16.62	47.1	9.89	4.81	56.79	19.27	10.34	19.63	19.39	9.67			
	12658	23	49.45	21.74	39.5	40.87	14.61	22.33	26.83	15.98	18.38	49.52	22.2	94.88	34.77	13.67
	12659	19.96	33.93	15.4	40.5	9.68	5.06									
	12661	33	34.91	12.66	49	10.55	3.43	71.13	14.9	7.89	21	28.49	9.71	19.46	15.85	6.85
	12662	26.92	38.82	20.45	47.3	14.88	6.97									
	12665	7.88	24.57	11.24												
	12666	0.38	34.38	11.11												
	12669	20.17	30.24	15.82	8.04	28.66	18.35									
	12670	22.42	24.09	12.57	19.9	3.85	1.71	0.21	1400	33.67	2.13	38.35	9.86	10.67	18.63	6.77
	12672	19.08	28.93	10.51												
	12673	27.54	27.94	12.34												
	12674	31.88	28.41	13.24	53.9	10.38	2.94	53.08	24.81	13.73	26.17	30.17	13.34	14.58	22.96	10.71
	12675	21.83	32.24	17.17	22.5	20.7	13.73	27.75	21.61	11.75	18.96	22.84	11.44	28.79	21.56	10.66
	12676	23.63	47.73	17.07	32.9	66.37	14.73	17.88	37.83	17.01	19.79	68.12	19.11	54.42	69.31	17.19
	12678	18.46	37.14	12.23	28.9	20.96	10.97									
	12680	26.29	27.64	9.9	40.8	17.15	6.85									
	TOTAL	473.9	**36.26**	15.46	562	**62.67**	23.35	392.1	**55.97**	28.16	205.6	**46.28**	16.93	353.6	**104.8**	35.14

Table A1.7 Percentage temporal overlaps for Herring Gulls tagged at South Walney with the Wyre Estuary SSSI; overlaps are presented for data filtered to a 60 minute rate for the 2014 and 2015 breeding (Br) and post-breeding (PoBr) periods and the 2015 pre-breeding period (PrBr). Shown are the percentage time spent resting or foraging (%R.F) and commuting (%C), as identified from HMMs or IQR approaches (see methods), expressed as a proportion of the total days available per period.

		2014									2015					
		Br			PoBr			PrBr			Br			PoBr		
Area	Bird	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C	T.Days	%R.F	%C
Wyre Estuary SSSI	12646	21.25	0	0	33.3	0	0	17.42	0.06	0	16.83	0	0	48.21	0	0
	12647	20.25	0	0	43.3	0	0									
	12648	18.42	0	0				65.79	0.08	0.12	22.13	0.16	0.1	21.08	1.47	0.1
	12649	18.75	0.38	0.14	9.13	3.83	1.91	9.21	0.87	0.44	18.17	0.67	0.45	5.92	0	0
	12651	31.38	0	0	7.75	0	0									
	12652	0.33	0	0												
	12653	15.08	0	0	38	0	0	50.54	0	0.02	22.46	0	0	55.58	0	0
	12654	0.29	0	0												
	12657	25.71	0	0	47.1	0	0	56.79	0.22	0.04	19.63	0	0			
	12658	23	0	0	39.5	0	0	22.33	0	0	18.38	0	0	94.88	0	0
	12659	19.96	0.03	0.12	40.5	1.48	0.74									
	12661	33	0.16	0.02	49	0.51	0.08	71.13	0.82	0.45	21	0.02	0.07	19.46	0.13	0.13
	12662	26.92	0.02	0.05	47.3	0.41	0.29									
	12665	7.88	0	0												
	12666	0.38	0	0												
	12669	20.17	0	0	8.04	0	0									
	12670	22.42	0	0	19.9	0	0	0.21	0	0	2.13	0	0	10.67	0	0
	12672	19.08	0	0												
	12673	27.54	0.07	0.12												
	12674	31.88	0	0	53.9	0	0	53.08	0	0.01	26.17	0	0	14.58	0	0
	12675	21.83	0	0	22.5	0	0	27.75	0.44	0.22	18.96	0	0	28.79	0	0
	12676	23.63	0	0	32.9	0	0	17.88	0	0	19.79	0	0	54.42	0	0
	12678	18.46	0	0	28.9	0	0									
	12680	26.29	1.44	1.12	40.8	1.51	0.94									
	TOTAL	473.9	**0.12**	0.09	562	**1.02**	0.53	392.1	**0.65**	0.36	205.6	**0.1**	0.08	353.6	**0.27**	0.04

Table A.1.8 Final summary of temporal overlaps with areas of interest for the South Walney Herring Gull population, excluding those data with low or very low quality (see Table 2.3) – sample sizes of birds here ('N') are for medium quality or higher; sample sizes of bird information >6 birds are also here considered adequate. Data summarised here are based on 60 minute rates.

Year	Period	N	Behaviour	Mussel bed shapefile 1	Mussel bed shapefile 2	Lune Estuary SSSI	Morecambe Bay SSSI	Roudsea Woods & Marshes SSSI	South Walney & Piel Channel Flats SSSI	Wyre Estuary SSSI
2014	Br	21	%R.F	1.73±1.5	8.56±5.27	0.07±0.23	7.92±5.43	0±0	36.26±9.5	0.12±0.32
			%C	0.56±0.5	2.73±1.84	0.01±0.04	2.68±1.78	0±0	15.46±3.3	0.09±0.24
	PoBr	15	%R.F	1.86±0.46	6.3±1.72	2.63±1.67	41.57±10.41	0±0	62.67±20.04	1.02±0.53
			%C	0.61±0.15	2.58±0.62	0.93±0.59	17.83±4.46	0±0	23.35±6.03	0.53±0.3
	PrBr	9	%R.F	1.83±0.2	9.48±1.7	1.83±0.93	13.65±2.76	0±0	55.97±12.83	0.65±0.28
			%C	1.15±0.18	5.51±1.02	0.67±0.32	7.85±2	0±0	28.16±4.71	0.36±0.15
2015	Br	10	%R.F	0.77±0.41	8.79±4.84	0.09±0.25	24.51±14.55	0±0	46.28±20.1	0.1±0.21
			%C	0.26±0.14	2.83±1.35	0.04±0.11	7.01±4.66	0±0	16.93±5.22	0.08±0.14
	PoBr	7	%R.F	1.56±1.43	7.05±2.7	0.48±1.07	23.52±8.83	0±0	104.84±21.55	0.27±0.55
			%C	0.81±0.78	3.83±1.57	0.1±0.18	11.77±4.3	0±0	35.14±4.22	0.04±0.06