BTO Research Report No. 689

# Assessing behaviour of Lesser Black-backed Gulls from the Ribble and Alt Estuaries SPA using GPS tracking devices

Authors

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

October 2016



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Registered Charity No. 216652

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## EXECUTIVE SUMMARY


1. This report provides findings from the first year of a study that has used Movetech 'GPS-GSM' tracking devices to track the movements of Lesser Black-backed Gulls from a breeding colony at the Ribble and Alt Estuaries SPA and so investigate their use of the SPA and the Warton Aerodrome. The study had two main objectives: (i) to assess the flight altitudes of adult Lesser Black-backed Gulls from the breeding colony at Banks Marsh in the Ribble and Alt Estuaries SPA during the 2016 breeding season; and (ii) to assess the home ranges of adult Lesser Black-backed Gulls from this colony and their temporal and spatial overlap with the SPA and the area of potential risk of collision with aircraft.

2. A total of 11 tags were deployed in the 2016 season and usable data received from 10 of these. Birds were caught on the nest using wire mesh traps and fitted with GPS loggers using a permanent wing harness.

3. Tags were set up specifically to be used to collect data in three dimensions, including flight altitude data. To increase the precision of the GPS altitude measurements, tags were set to stay on for five minutes for each fix, thus allowing time to connect to more satellites.

4. Movetech tags produced accurate estimates of altitude (generally <2m) once corrections for number of satellites (more than five) and the ellipsoid of the earth had been accounted for. Precision (which we define as two standard deviations from the mean) was 18-26 m therefore being at or a little above that previously recorded elsewhere using different GPS tags. Ground speed was also of little value from the Movetech tags.

5. Altitude measurements indicated that the majority of flights were at heights of less than 100 m. Birds flew higher during the day-time, although most of their time was still spent at around ground height.

6. Movetech tags were very appropriate for assessing home range area usage, although with the caveat that fewer data were available to assess night-time area usage. Birds used mainly inland areas, with only a handful of individual trips going offshore. Frequent trips were recorded to the Mersey Estuary as well as further inland to urban areas, fields and landfill sites and ground workings. Locally, birds also frequented the intertidal mudflats and saltmarsh of the Ribble Estuary. Overlap of home ranges with the SPA was greater during the night than during the day. The overlap of home ranges with Warton Aerodrome was small, being less than 3% for both day and night periods for individual birds, and less than 1% for all-birds combined. Temporal overlaps with the Warton aerodrome were also very small – less than 0.5% for all-birds combined across the day and night.

7. Currently, an alternative system, the University of Amsterdam Bird Tracking System (UvA-BiTS), that requires data download through a fixed base station, offers a better option to the Movetech system used in 2016 for study of flight heights of adult gulls. The UvA-BiTS offers greatest user interface flexibility and fast GPS sampling rates and greater precision in raw data. This recommendation is subject to funding restrictions. Accelerometers may help identify behaviours of birds useful for refining flight height curves, which are tried and tested for UvA-BiTS.

8. For young gulls, the Movetech system would be most appropriate given the lack of need for a central base station when birds are away from their natal colony following fledging. Consequently, an acceptance would be needed for potential reduction in altitude precision. However, for both UvA-BiTS and Movetech data it is highly recommended to model the data to take account of these sources of error variation to produce flight height distributions (Ross-Smith *et al.* 2016).

# 1. INTRODUCTION

## 1.1 Background

Lesser Black-backed Gulls have undergone recent population declines, making them a conservation priority. However, the species is also subject to licensed control at some sites – under the general licence – on conservation grounds, or because of risks to human health and safety. The Ribble and Alt Estuaries Site of Special Scientific Interest (SSSI) / Special Protection Area (SPA) population has been subject to proposals for control by British Aerospace (BAe) due to the risk of collision with aircraft from the nearby Warton Aerodrome. Similarly, other populations outside of SPAs are also subject to control under the general licence, but may have originated from SPA colonies.

This report provides findings from the first year of a study that has used Global Positioning System-Global System for Mobile communication ('GPS-GSM') tracking devices to track the movements of Lesser Black-backed Gulls from their principal breeding colony at the Ribble and Alt Estuaries SPA and so investigate their use of the SPA and the Warton Aerodrome. The study aims to inform on risks of bird-strike issues and thus the evidence base for Natural England's discussions with BAe.

## 1.2 Project Objectives

The study had two main objectives:

1. To assess the flight altitudes of adult Lesser Black-backed Gulls from the breeding colony at Banks Marsh in the Ribble and Alt Estuaries SPA during the 2016 breeding season; and

2. To assess the home ranges of adult Lesser Black-backed Gulls from this colony and their temporal and spatial overlap with the SPA and the area of potential risk of collision with aircraft.

Objective 1 encompassed:

i. Ground-truthing of the GPS altitude data from the Movetech tags deployed at the Ribble and Alt Estuary SSSI/SPA during the 2016 breeding season;

ii. An assessment of the precision and accuracy of GPS altitude data collected from the Movetech tags deployed at the Ribble and Alt Estuary SSSI/SPA during the 2016 breeding season, with a summary comparison to data collected from University of Amsterdam tags through work undertaken in northwest England for the Department of Energy and Climate Change (DECC) (Thaxter *et al.* 2015, 2016);

iii. A summary analysis of the data collected on flight altitude from the Movetech tags deployed at the Ribble and Alt Estuary SSSI/SPA during the 2016 breeding season.

Objective 2 encompassed:

i. An assessment of the home ranges of lesser black-backed gulls from the Ribble and Alt Estuary SSSI/SPA during the 2016 breeding season.

ii. An assessment of the extent to which the home ranges of lesser black-backed gulls from the Ribble and Alt Estuary SSSI/SPA during the 2016 breeding season overlapped that protected area and the area of potential risk of collision with aircraft.

## 2. METHODS

### 2.1 Focal Species

The Lesser Black-backed Gull (the UK sub-species of which is *L. fuscus graellsii*) is a qualifying feature of four breeding colony SPAs and one potential SPA in England, two in Scotland and one in Wales (SPA Review: Stroud *et al*. 2001; SNH SPA extensions[1]). At-sea data have been used to investigate the species' distributions and habitat associations, for instance in the German North Sea (Schwemmer & Garthe 2008), and placement within multi-species feeding associations (Camphuysen & Webb 1999). Research has also focused particularly on general breeding biology, diet, and kleptoparasitism (Camphuysen *et al.* 1995; Calladine 1997; Galván 2003; Kubetzki & Garthe 2003; Kim & Monaghan 2006). However, only recently has the species been tracked, e.g. in studies of birds breeding in the Netherlands (Shamoun-Baranes *et al*. 2011), Germany (Corman & Garthe 2014) and in eastern England (Thaxter *et al.* 2011, 2012a, 2013, 2014b, 2015, 2016) and hence limited data are available concerning foraging movements. Previous information suggests that Lesser Black-backed Gulls may forage up to 180 km offshore during the breeding season (Ens *et al*. 2008; Shamoun-Baranes *et al*. 2011, Thaxter *et al*. 2012b). Hence, there is potential for birds to interact with both areas of proposed development, e.g. wind farms, as well as with airfields.

During the non-breeding season, the extent of migration varies between and within populations. Lesser Black-backed Gulls tracked from colonies in the Netherlands (sub-species *L. fuscus graellsii* and *L. fuscus intermedius*) are known to migrate initially to the UK immediately after breeding, before travelling further south to over-winter on the coasts of the Iberian Peninsula and north-west Africa (Ens *et al*. 2008). This pattern is also well-documented for other populations of the same sub-species from ringing data (Wernham *et al*. 2002). However, *L. fuscus graellsii* breeding in the UK may differ in their migratory strategy to those on the continent, and to members of the *L. fuscus intermedius* sub-species, which overlap with *L. fuscus graellsii* in their breeding range.

### 2.2 Field Site

The movements of Lesser Black-backed Gulls were studied using GPS tags at a mixed colony of Lesser Black-backed Gull and Herring Gull at Banks Marsh on the Ribble Estuary (53° 42' 52"N, -2° 56' 33W).

Hesketh and Banks Marshes on the Ribble Estuary supported a population of 4,100 Apparently Occupied Nests (AONs) of Lesser Black-backed Gulls during Seabird 2000 in 1998-2002 (Mitchell *et al.* 2004). More recent surveys suggest that the colony has increased, with around 8,500 Lesser Black-backed Gull AONs (JNCC 2016).

The GIS shapefile of the Ribble and Alt Estuary SPA was downloaded from the Joint Nature Conservation Committee (JNCC) (http://jncc.defra.gov.uk/page-1409). A shapefile for the Warton Aerodrome was derived by hand to approximate the main area of interest. This covered not just the Aerodrome itself but surrounding Warton and Freckleton urban area areas and adjacent fields alongside the aerodrome (Fig. 2.1).

[1] http://www.snh.org.uk/about/directives/ab-dir15j.asp


**Figure 2.1** The defined area of the Warton Aerodrome, overlain onto a Google Earth image, highlighting the inclusion of adjacent urban areas and fields within the area of interest.

## 2.3 Capture and Attachment Methods

A total of 12 tags were available for deployment in the 2016 season and of these, 11 of were deployed; the last tag was too heavy and would have required a 950 g bird to be caught (based on previous experience birds over this weight are caught once in around 20 successful captures, which was thought to be not worth the extra field time).

Nine incubating Lesser Black-backed Gulls were captured on 29th June 2016, nine more on 6th July 2016, and a further two on the 9th July 2016, with wire mesh traps placed over nests (Bub 1991). Of these 20 birds, eleven were fitted with GPS loggers using a permanent wing harness (see Thaxter *et al*. 2014a, 2014b for wing harness design details). Birds were handled 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

The GPS devices used in this study were developed by Movetech, a consortium of scientific partners (the BTO, the University of Lisbon and the University of East Anglia) and development partners (led by Fleetronic). They include a GPS sensor, accelerometer, solar panel, battery and battery charger, thermometer, a SIM card and flash drive.

The GPS data were collected at varying rates, typically one and a half hours, although this varied depending on the available battery power.

To increase the precision of the GPS altitude measurements the tags were set to stay on for five minutes for each fix: thus allowing time to connect to more satellites.

These devices allow for continual data collection, potentially over long periods (e.g. up to 2 years). They communicate their data through the mobile phone (GSM) network, and thus there is a continual live stream of data throughout the tag's life.

Tags weighed 20-25.5g, which represented < 3% body mass for the birds in this study: mean: 868 ± 71 g, range: 780-1010 g. A possible sample bias was introduced as only heavier birds, which are more likely to be males, were tagged in order that the combined weight of tag and harness was below 3% of body mass. For all Lesser Black-backed Gulls caught, mean weight was 818 ± 84 g, and range was 700-1010 g.

## 2.5 Data

Data used in this report were collected between the point of tag deployment for each individual until 9th August 2016. No birds had started to migrate away from the colony at this point. Data were examined to determine the last nest attendance date for each bird, and to determine the number of fixes of each individual at the nest and away from the nest (Table 2.1).

11 tags were deployed, and of these, one (464) did not transmit any data at all, and a further three (450, 465, 484) were excluded from the majority of individual analyses due to insufficient data.

Data were filtered to remove null records (that did not contain a GPS/altitudinal position), and to remove records with low (<5) satellite connections.

Data collection rates by the tags were lower at night, which was deliberate programming by the tag manufacturer in order to reduce battery drain (Figure 3.6). Assuming that the four tags that collected fewer data were somehow malfunctioning, we tracked the remaining seven birds for a total of 470 bird days. At half hour intervals during the day and three hour intervals at night (9 pm-6 am), we would expect approximately 15,500 data points. The total number of data points from these tags was 10 144 – around a third less than expected. This could be due to the tags functioning at around threshold battery (3.8V) for a lot of the time, which would reduce the number of fixes that they are able to obtain. Figure 2.2 demonstrates that most of the fixes obtained were around 3.8-3.9V, which is consistent with this theory.

**Table 2.1** Number of fixes from each individual between tag deployment and 9th August 2016, split by nest attendance. Last date of attendance at the nest was also calculated where possible.

| Bird_ID | Fixes away from nest | Fixes at nest | Total fixes | Date of tagging | Last date of attendance at nest |
|---|---|---|---|---|---|
| 179 | 1,328 | 755 | 2,083 | 06/06/16 | Still attending at point of data download |
| 205 | 881 | 400 | 1,281 | 06/06/16 | 02/08/16 |
| 242 | 1,103 | 1019 | 2,122 | 29/05/16 | Still attending at point of data download |
| 243 | 1,455 | 683 | 2,138 | 29/05/16 | Still attending at point of data download |
| 446 | 912 | 458 | 1,370 | 29/05/16 | Still attending at point of data download |
| 450 | 39 | 2 | 41 | 06/06/16 | Insufficient data |
| 464 | 0 | 0 | 0 | 06/06/16 | Insufficient data |
| 465 | 103 | 1 | 104 | 29/05/16 | Predated by other gull on day of capture |
| 467 | 524 | 231 | 755 | 29/05/16 | 01/08/16 |
| 469 | 379 | 16 | 395 | 09/06/16 | 12/07/16 |
| 484 | 11 | 0 | 11 | 06/06/16 | Insufficient data |

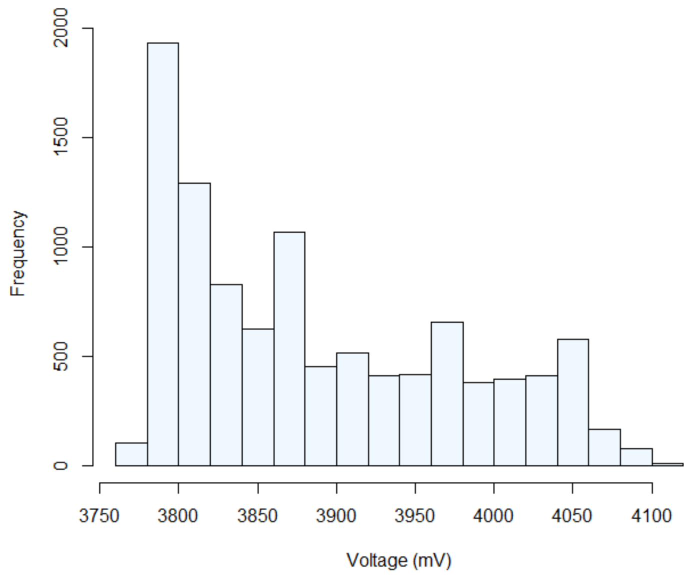



**Figure 2.2** Tag voltage during each GPS fix.

# 3. ASSESSMENT OF FLIGHT HEIGHTS

## 3.1 Introduction

Collection of accurate (flight) height information has been a key recent development in GPS tagging technology, particularly due to its use in modelling collision risk of birds with wind turbines, although the information is salient for a number of other purposes. GPS altitude measurements can be both inaccurate (incorrect mean of measurements) or imprecise (large variation of points around the mean), and these can be affected by the number of satellites that the tags connect to, the position of these satellites, temperature, humidity and pressure (among others). Understanding the type and spread of error in this measurement is key in being able to correctly interpret results.

Here we present an examination of flight altitude data collected for Lesser Black-backed Gulls from the Ribble and Alt Estuary SSSI and SPA during the 2016 breeding season.

Previous work using a similar tag system (University of Amsterdam tags) allows us to make a comparison between different types of GPS tag. Studies using these tags have demonstrated that altitude measurements also improve with sampling rate (Bouten *et al.* 2013). However, the tags we used are currently unable to increase their sampling rates to provide us with short bursts of more precise data.

We also present a preliminary examination of the flight height information obtained from the Movetech tags during the 2016 breeding season.

## 3.2 Methods

### 3.2.1 Data processing

Data were investigated in two phases: (1) using pre-deployment data to assess the accuracy and precision of flight altitude data and (2) investigating data after tags had been deployed to assess bird behaviour and flight altitude, for example in relation to time of day and ground speed.

All data were taken and filtered to remove data which did not have either GPS or height information (for example, the tags record 'Time Alive'/'Power Up' when there is insufficient battery to obtain a fix but the tag is still active). The location data were put through the OSGM02 transformation to obtain Ordnance Survey Newlyn (OSN) height above Mean Sea Level (MSL).

### 3.2.2 Accuracy and precision of altitude data

Locations with more than 10 GPS locations in the pre-deployment data were taken, and where possible, an OS value of height was calculated at these locations from OS maps. These locations included specific height test locations: Walney (around spring high tide level) and Birkrigg (136 m), and sites where we had left all undeployed tags out to charge (Pennington, Ribble, Bowland 1 and Bowland 2).

The difference between the OS map ('real') and calculated ('tag') height was calculated for each fix.

Histograms were produced of these data in order to examine the accuracy (difference between the mean of the tag height values and the OS 'real' height) and precision (spread of points around the mean) of the tag altitude compared to the real values. The effects of a number of other variables (number of satellites, location and location error) on the data were also investigated.

Errors outside of more than two standard deviations from the mean were examined to see if any other factor (height, site, time of day, battery voltage) influenced the probability of obtaining larger errors.

### 3.2.3 Examining flight height information

Data from deployment until 9th August 2016 were examined, and records with fewer than five satellites were removed (n = 281). One bird (205) had died during this period, and the last points of this bird's tracking data were also removed.

A digital elevation model (http://www2.jpl.nasa.gov/srtm/) was used to find height above ground at each GPS location by subtracting the OSN heights from it.

Fixes were too infrequent to enable calculation of bird speed from the GPS data, however, the tags record a snapshot value of 'ground speed', although it is worth noting that we have no way of ground-truthing or verifying the accuracy of this data field. An examination of this field was thus also undertaken.

Using ArcGIS, fixes when birds were attending the nest were ascertained (based on clusters of GPS points in a single area of the colony). Land type data (inland, marine, intertidal, river, colony, other saltmarsh) were obtained from digitising aerial imagery data from an ArcGIS base map.

Histograms and heatmaps were produced in R in order to investigate a number of relationships between flight height and other variables. Initially we examined flight height at different bird speeds: stationary, slow (between 0 and 4 $kmh^{-1}$) and fast (> 4 $kmh^{-1}$). 4 $kmh^{-1}$ is the speed at which flight is sustainable by gulls, so slow birds are likely to be birds sat on water or walking (Shamoun-Baranes *et al.* 2011, Shamoun-Baranes & van Loon 2006, Pennycuick 2008).

Other relationships that were investigated included: flights height vs habitat, flight height vs time of day, and vs day/night. Data for the six individuals with the most fixes were also examined to determine if any individuals had different flight height distributions, both generally, and whilst birds were not at the colony.

## 3.3 Results

### 3.3.1 Accuracy and precision of altitude data

In total, 528 suitable pre-deployment locations were examined from 10 high altitudinal-precision Movetech tags.

The precision of the tag's altitude measurements increased when they had connected to more satellites to take a fix. When the tag had connected to fewer satellites, there were larger errors in recorded altitude (Figure 3.1 and Figure 3.2).

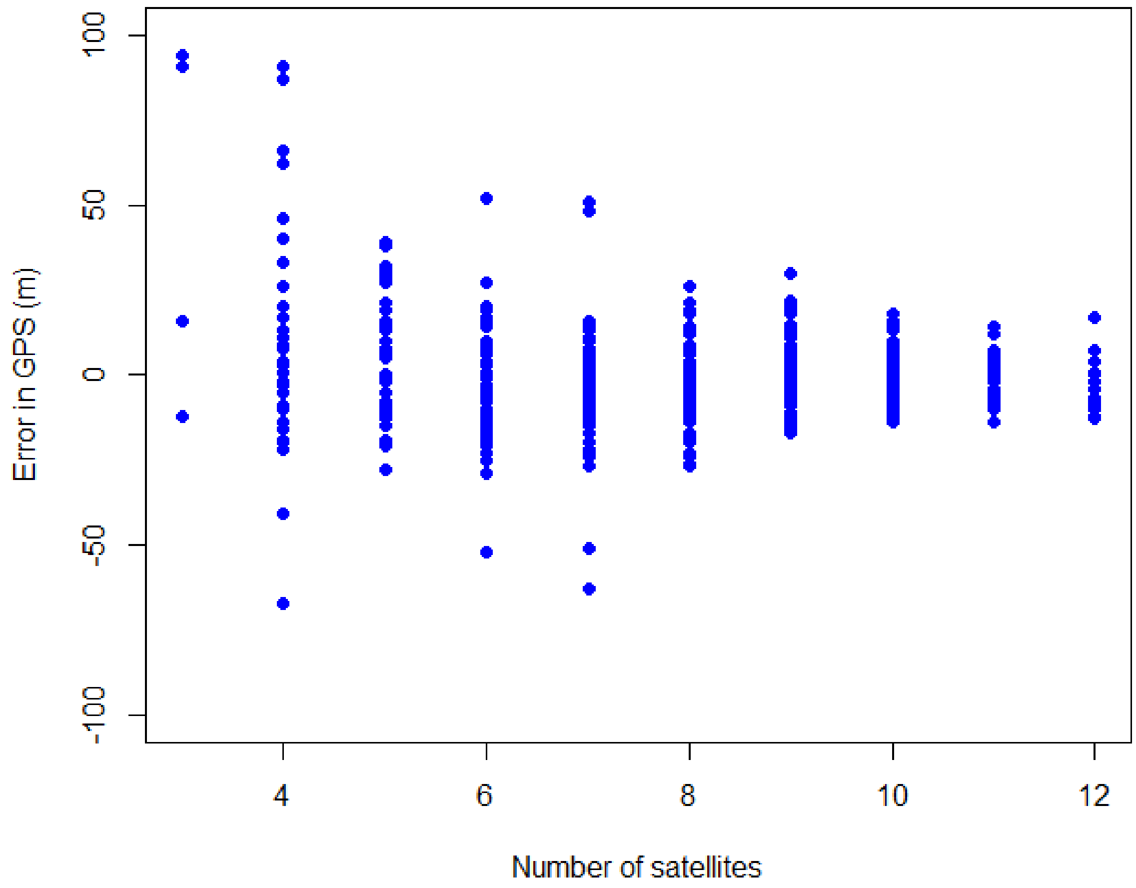



**Figure 3.1** Outliers occurred more often when tags were connected to fewer satellites.

a) b)

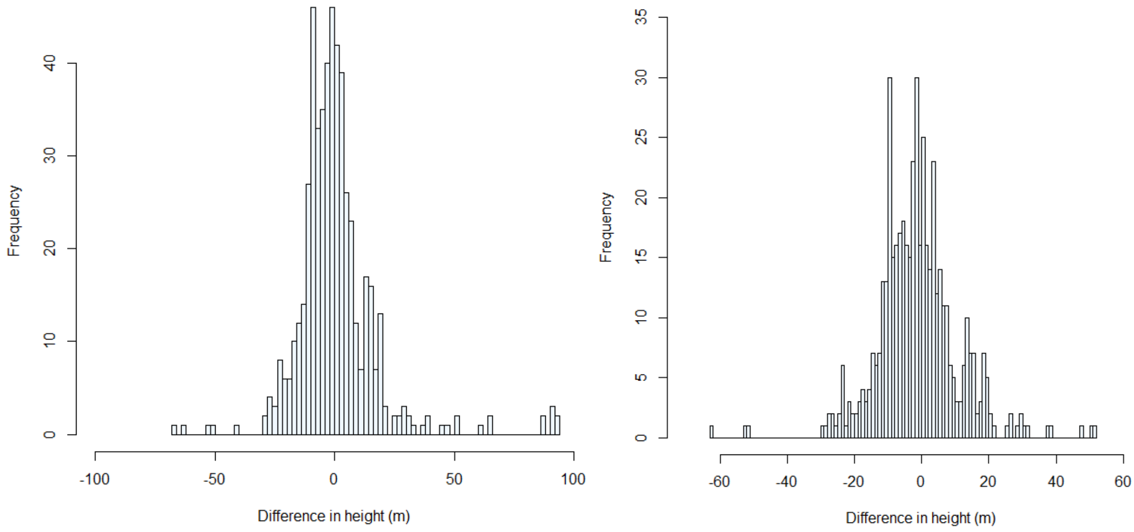



**Figure 3.2** Differences in height measurement between tag altitude and real altitude for a) all data and b) fixes which connected to five or more satellites

Data were consistently non-normally distributed (Shapiro-Wilk test, $p < 0.001$), which is likely due to the long tails of outliers. Precision was increased by around 10 m through removing fixes with fewer than five satellites (Table 3.1).

**Table 3.1** Accuracy (mean) and precision (two standard deviations) of GPS altitudinal data by site (see methods for more details).

| Site | Height (m) | Number of fixes | Accuracy (mean (m)) | Standard deviation (m) | Precision (two standard deviations (m)) |
|---|---|---|---|---|---|
| All | Mixed | 528 | 0.84 | 17.37 | 34.74 |
| all (nsat>4) | Mixed | 445 | -0.80 | 12.24 | 24.48 |
| Pennington | 80 | 230 | 0.11 | 13.15 | 26.30 |
| Walney | 5 | 131 | 0.61 | 10.80 | 21.60 |
| Ribble | 3 | 42 | 0.44 | 13.09 | 26.18 |
| Bowland 1 | 450 | 20 | -0.55 | 11.98 | 23.96 |
| Bowland 2 | 485 | 44 | 4.20 | 8.96 | 17.92 |
| Birkrigg | 136 | 16 | -2.06 | 9.26 | 18.52 |

Among results from different test sites, our height estimate for Bowland 2 is likely to be more inaccurate as the site is located on much more of a slope: we believe this difference in the mean is mainly due to human error rather than tag error.

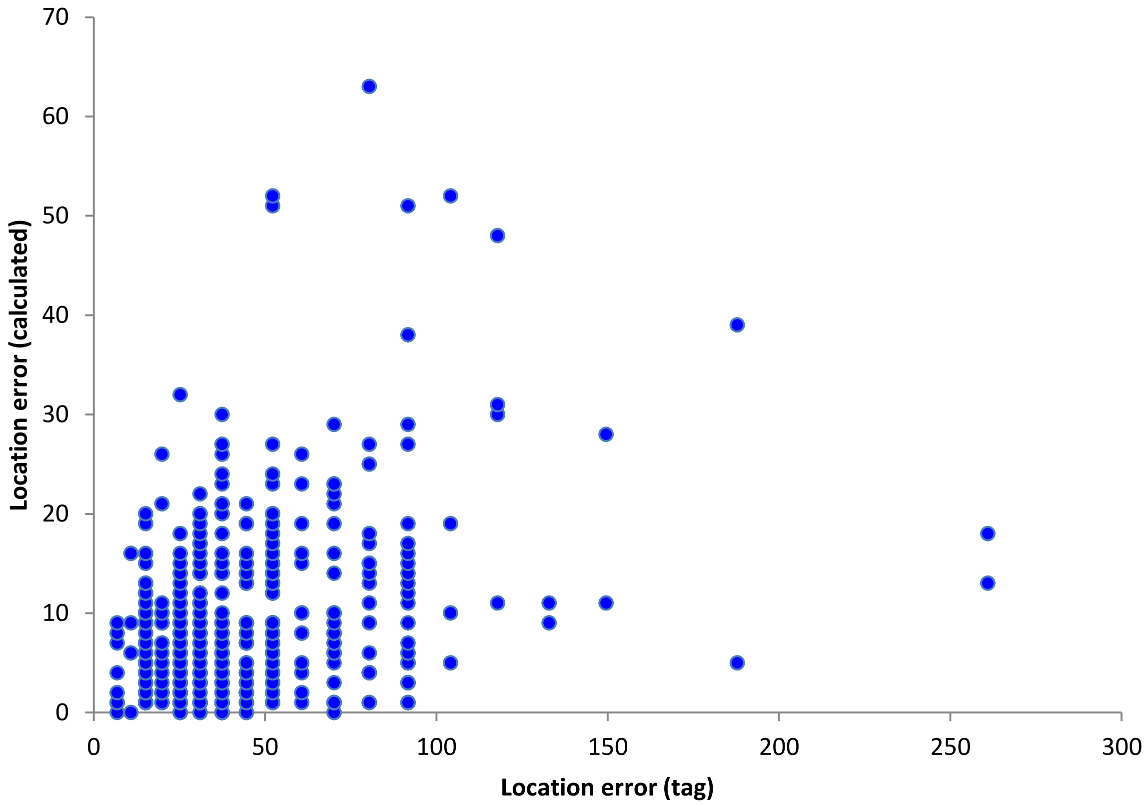



**Figure 3.3** Location error (calculated by tag in reference to horizontal error) did not correlate strongly with our calculated value of error.

The measure of error contained in the data did not appear to be useful in reference to altitudinal values (Figure 3.3).

### 3.3.2 Examining flight height information

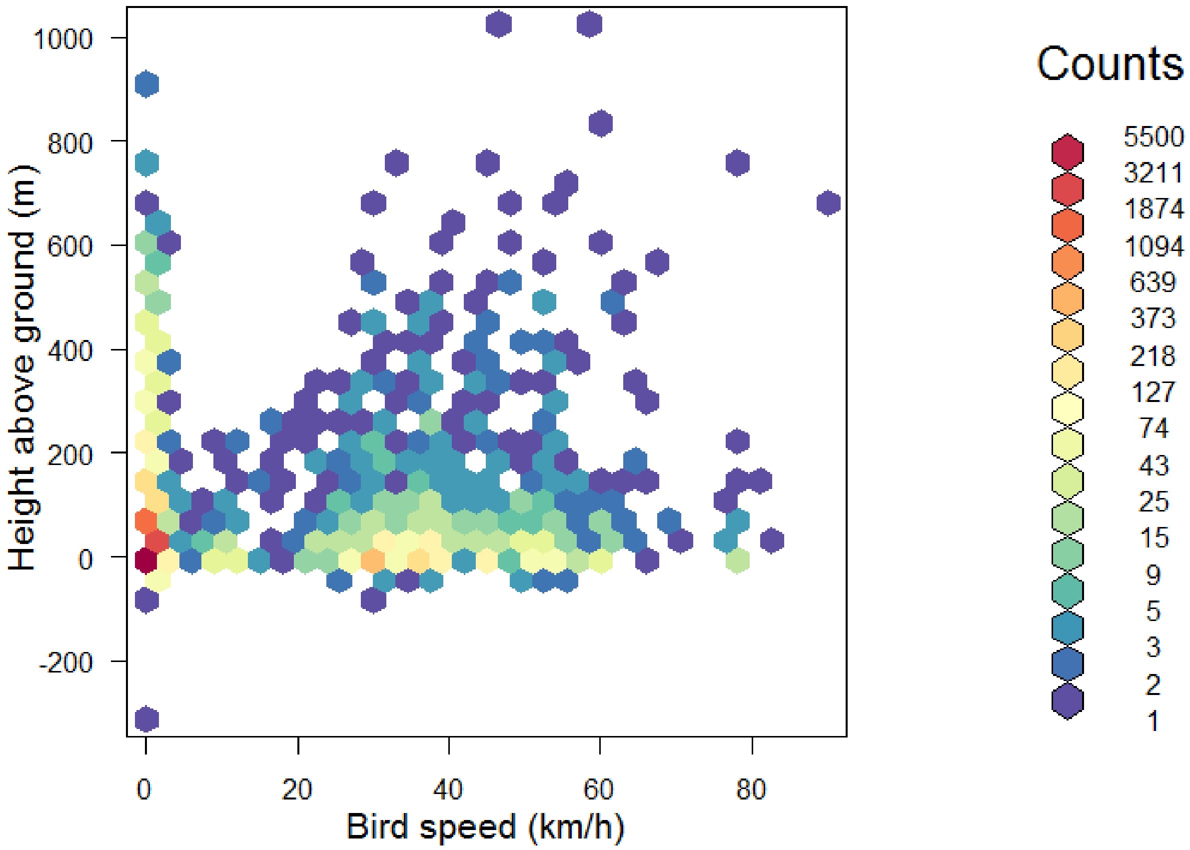



**Figure 3.4** Heatmap showing log-transformed frequency of GPS fixes over flight height (m) and bird speed (km/h).

Most stationary birds were recorded at locations 0 m height above ground, however, there was a large tail of 0 $kmh^{-1}$ birds that are recorded at much higher altitudes (Figure 3.4), indicating that the ground speed value may not be entirely reliable. Higher altitudes were much less common than lower ones.

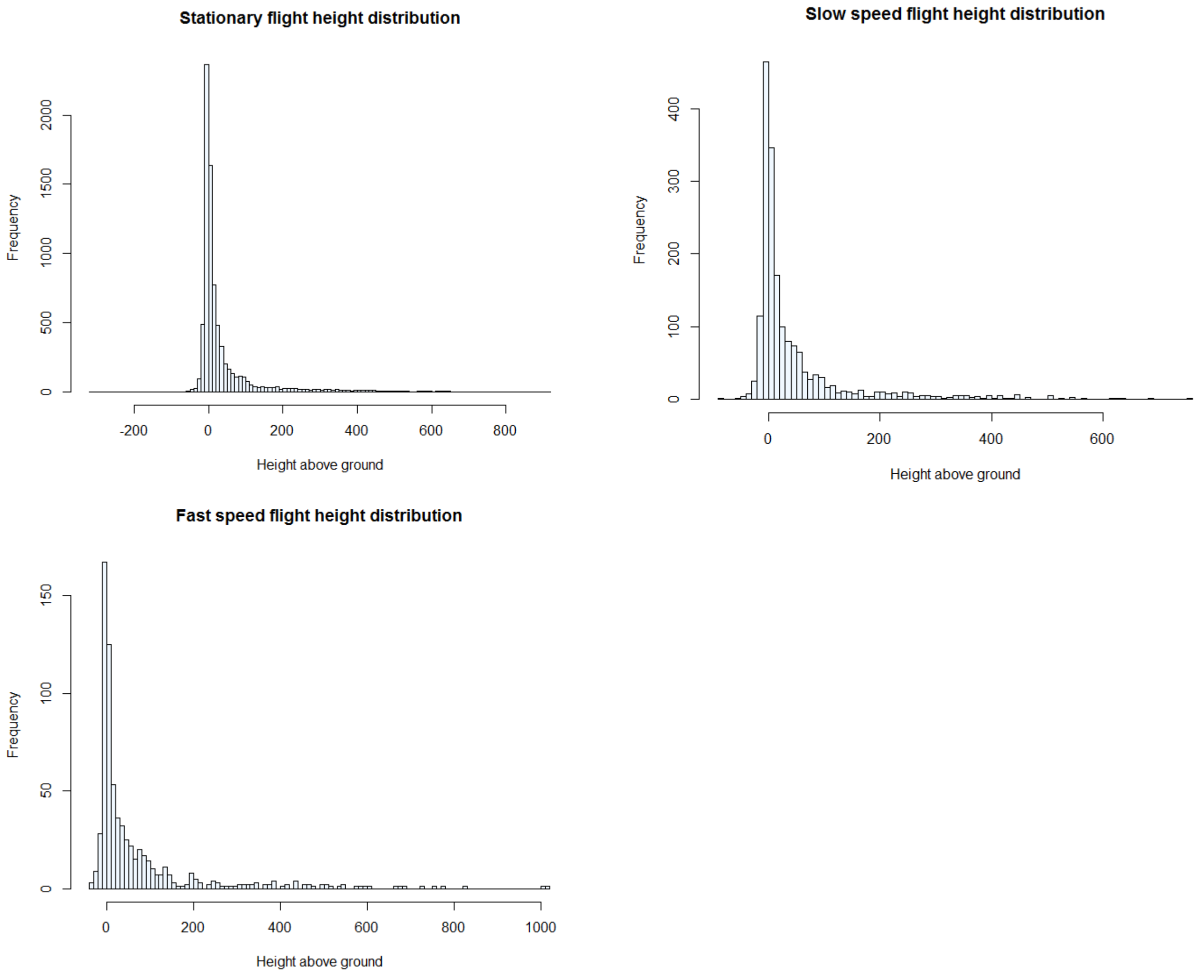



**Figure 3.5** Flight height distributions for stationary birds (ground speed =0 $kmh^{-1}$), slow speed (0 < ground speed < 4 $kmh^{-1}$) and fast speed (ground speed < 4 $kmh^{-1}$).

Flight height distributions were very similar for all groundspeed value categories (Figure 3.4 and Figure 3.5), which suggests that ground speed may be unreliable.

Fixes were most frequent at lower altitudes and during the latter half of the day. Fixes during the night were much less frequent (Figure 3.6).

Birds flew higher during the day-time, although most of their time was still spent at around ground height (Figure 3.7); however, the sample was much smaller for night-time fixes (n=583) compared to day-time fixes (n=9,718).

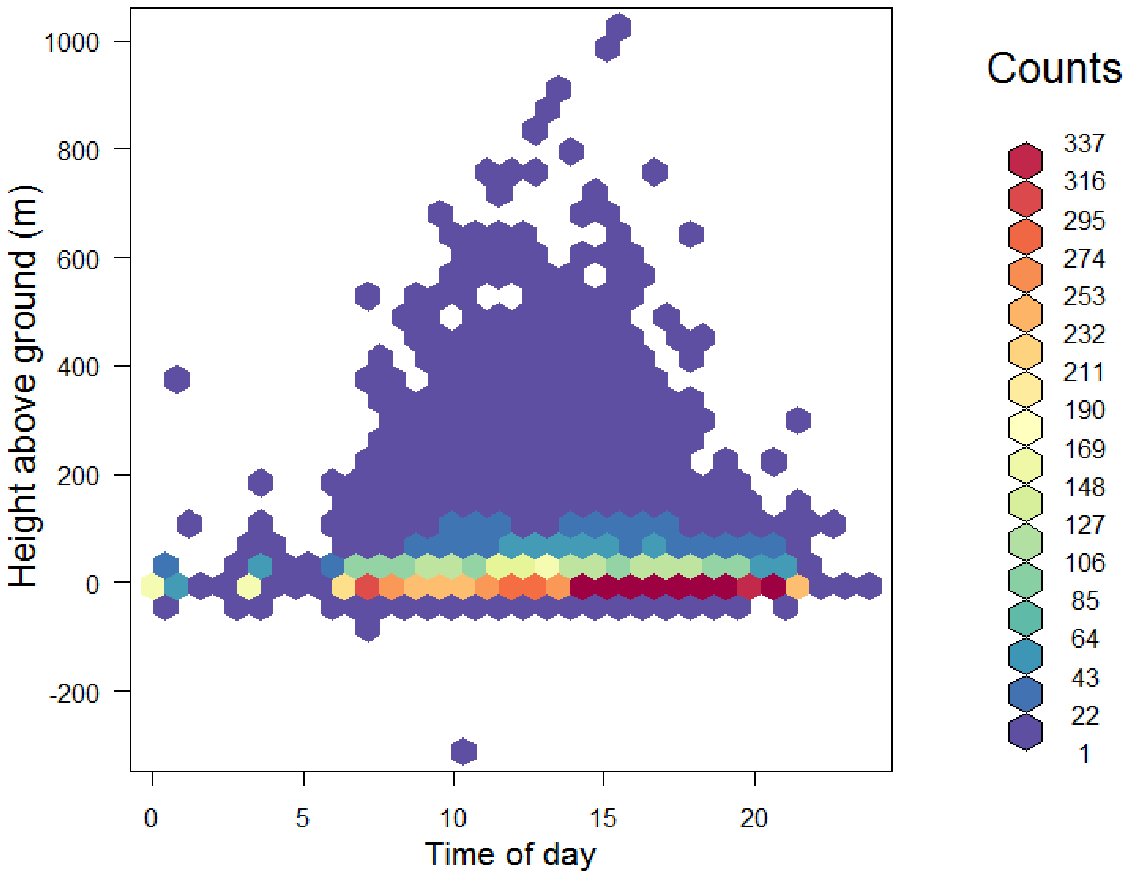



**Figure 3.6** Heatmap showing number of fixes for each time of day at different heights

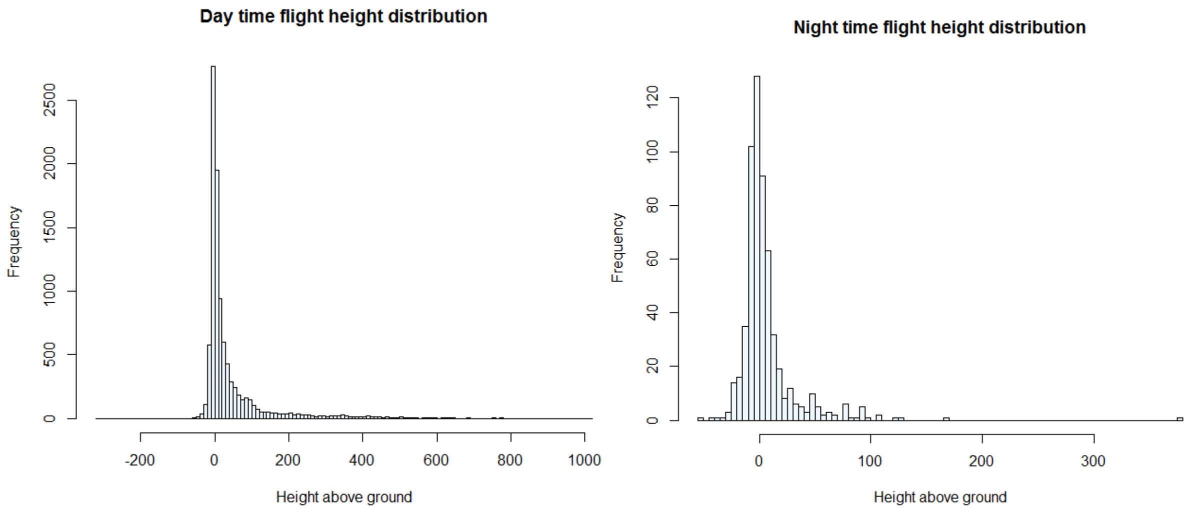



**Figure 3.7** Comparison of day time and night time flight height distributions.

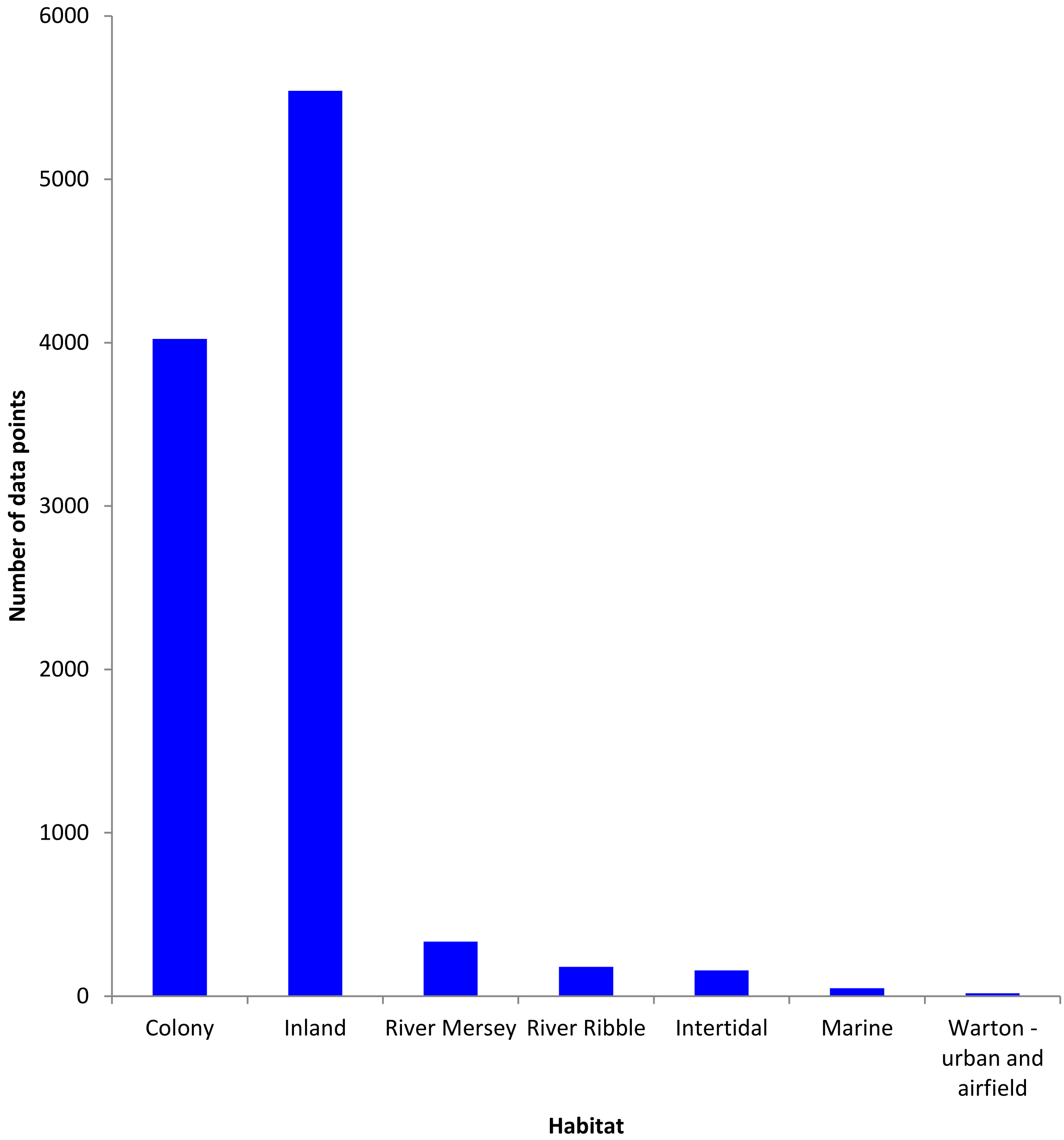



**Figure 3.8** Number of fixes recorded in each habitat type.

Most of the fixes obtained from the birds were either from the colony area or inland (Figure 3.8). Very few fixes (n=18, <1% of fixes) were at or around the Warton urban and airfield area, or in marine habitat (n=48, <1% of fixes). Of the fixes within the Warton urban and airfield area, 11/18 (61%) were from a single individual.

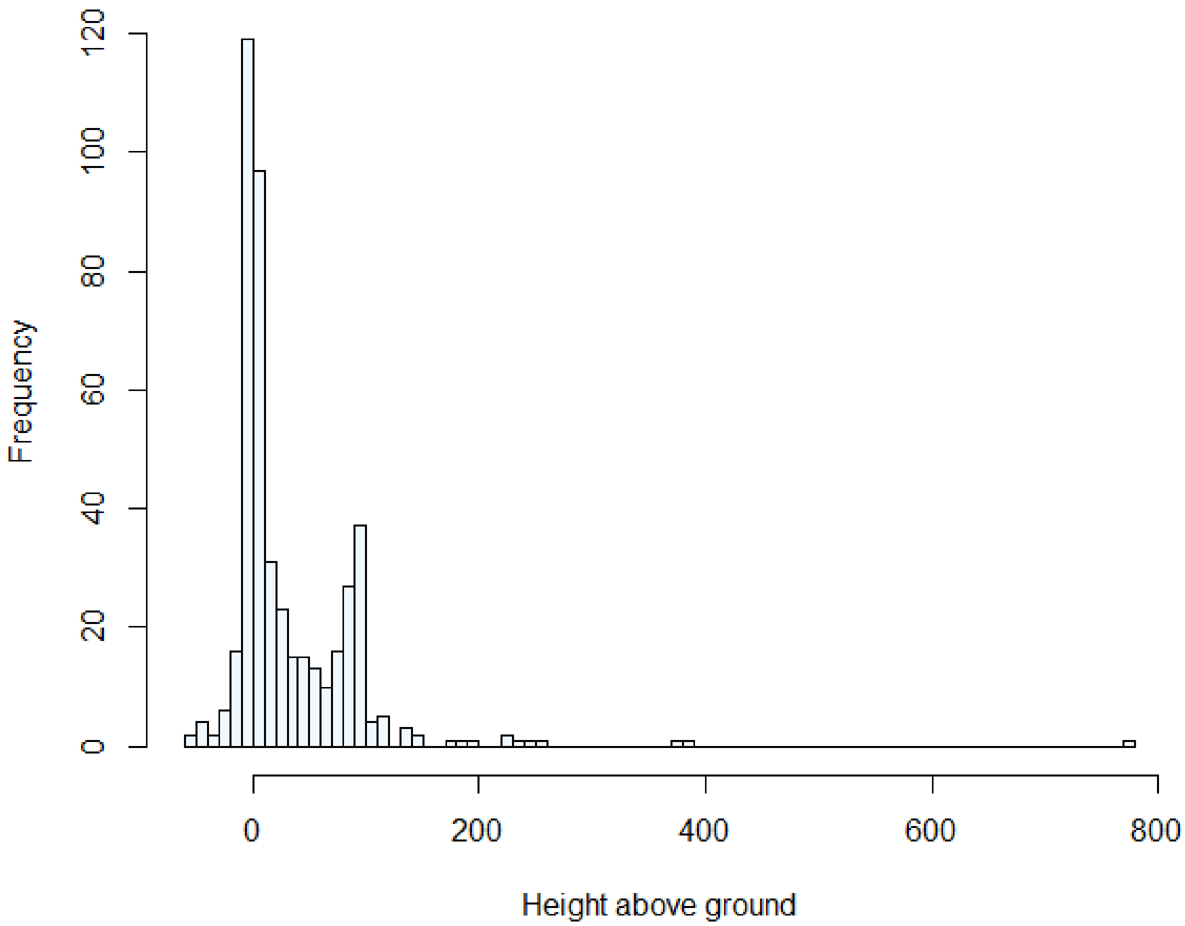



**Figure 3.9** Altitude distribution at the colony when birds were not at the nest.

Birds spent most of their time in the colony at the nest (Table 2.1). When not at the nest, they still spent most of their time at ground level (Figure 3.9). Flight at the colony appears to be at relatively low altitude when it occurs (~100m).

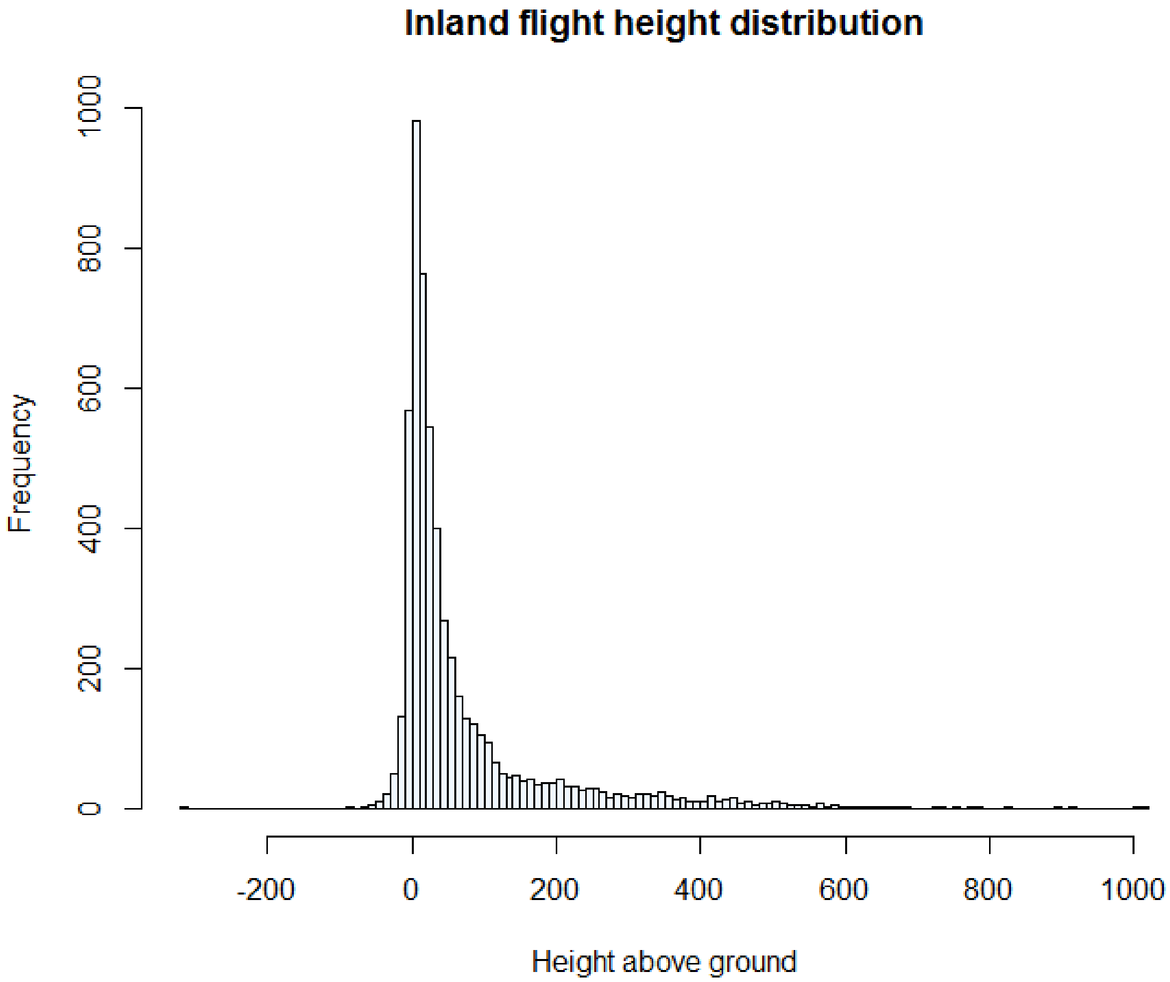



**Figure 3.10** Altitude distribution of birds inland.

Birds flew higher over land than they did at the colony (Figures 3.9 and 3.10).

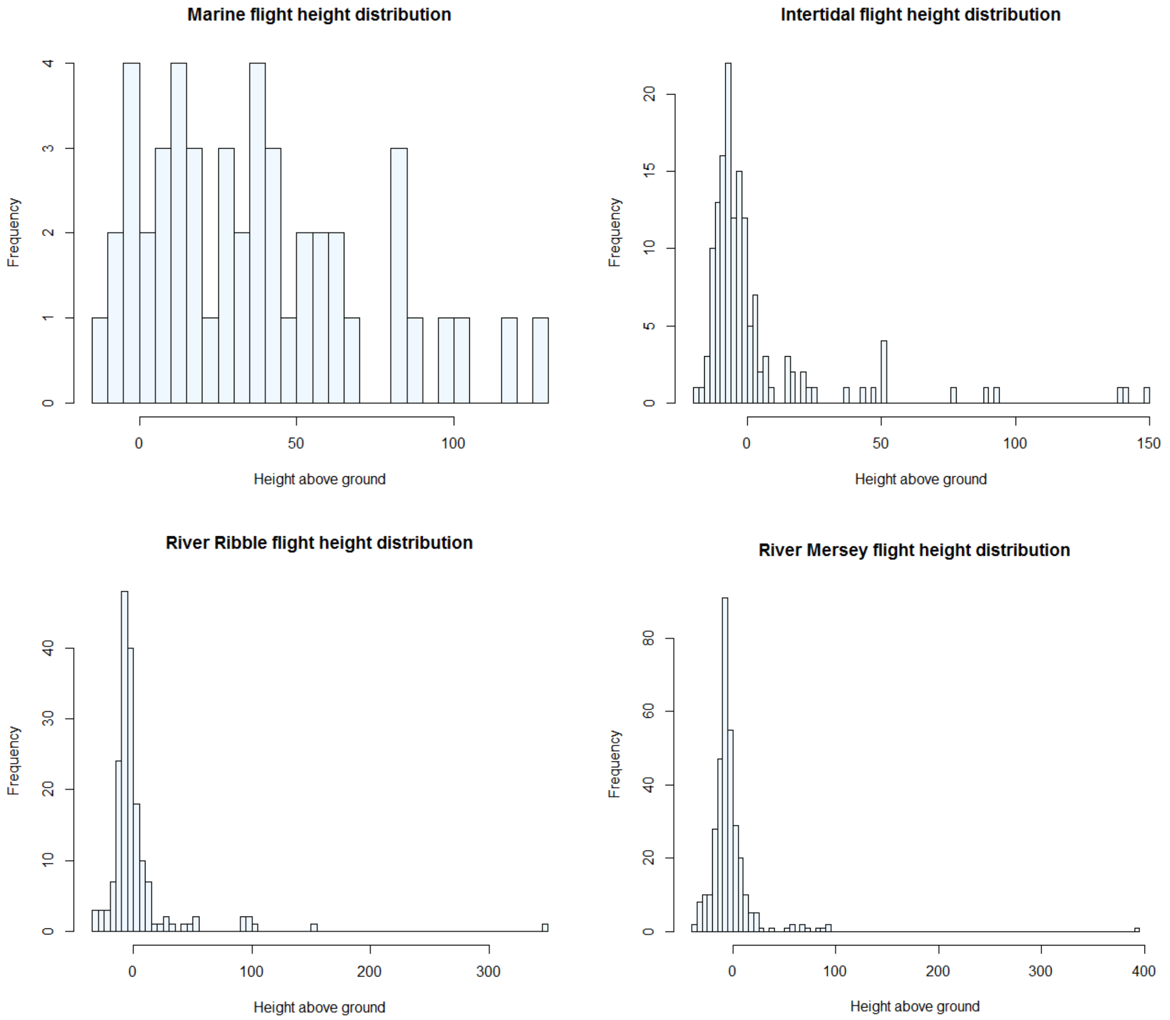



**Figure 3.11** Altitudes when birds were in different habitats: Marine, Intertidal, River Ribble and River Mersey.

Time spent in river habitats was mostly spent at ground level (Figure 3.11, indicating birds were sat on the water). The intertidal ditribution were centered just below 0, which is consistent with birds at sea level either sitting or foraging, with some birds flying over. Birds appear to be slightly more likely to fly over marine habitat than intertidal, and the proportionally longer tail in marine habitats may indicate birds are more likely to be flying here, although the sample size is small and thus may not be representative of true behaviour.

Birds spent more time at higher altitudes inland than over any other habitat type (Figures 3.10 and.3.11).

Most recorded altitudes for individuals were around zero, regardless of whether birds were in the colony or not (Figures 3.12 and 3.13). For most individuals, there was also a second drop off in the distribution of altitudes at around 100m, which could indicate another common flight height. The histograms of altitudes for most birds showed long tails, indicating fewer fixes at much higher altitudes.

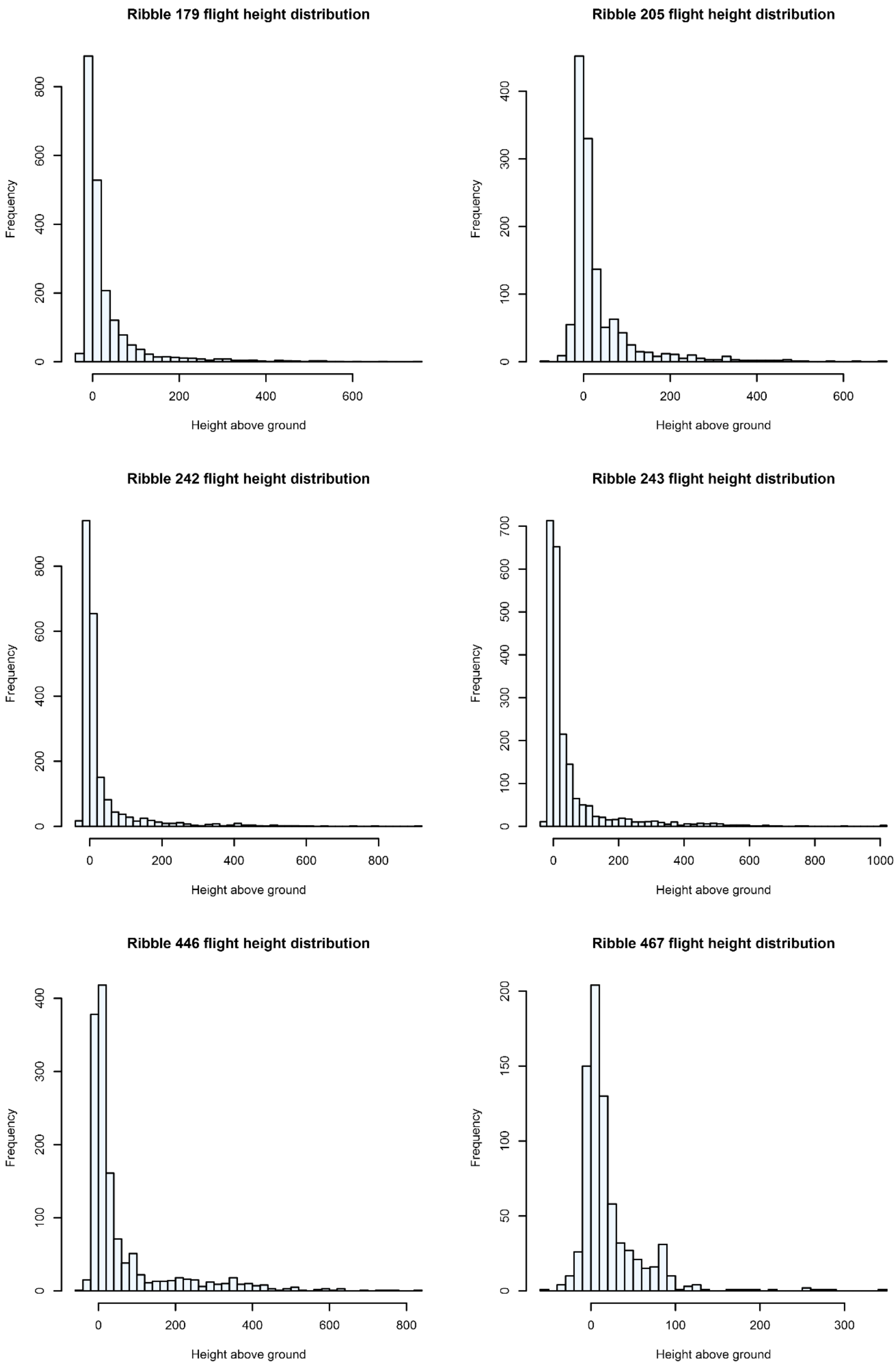



**Figure 3.12** Altitude distributions for individuals.

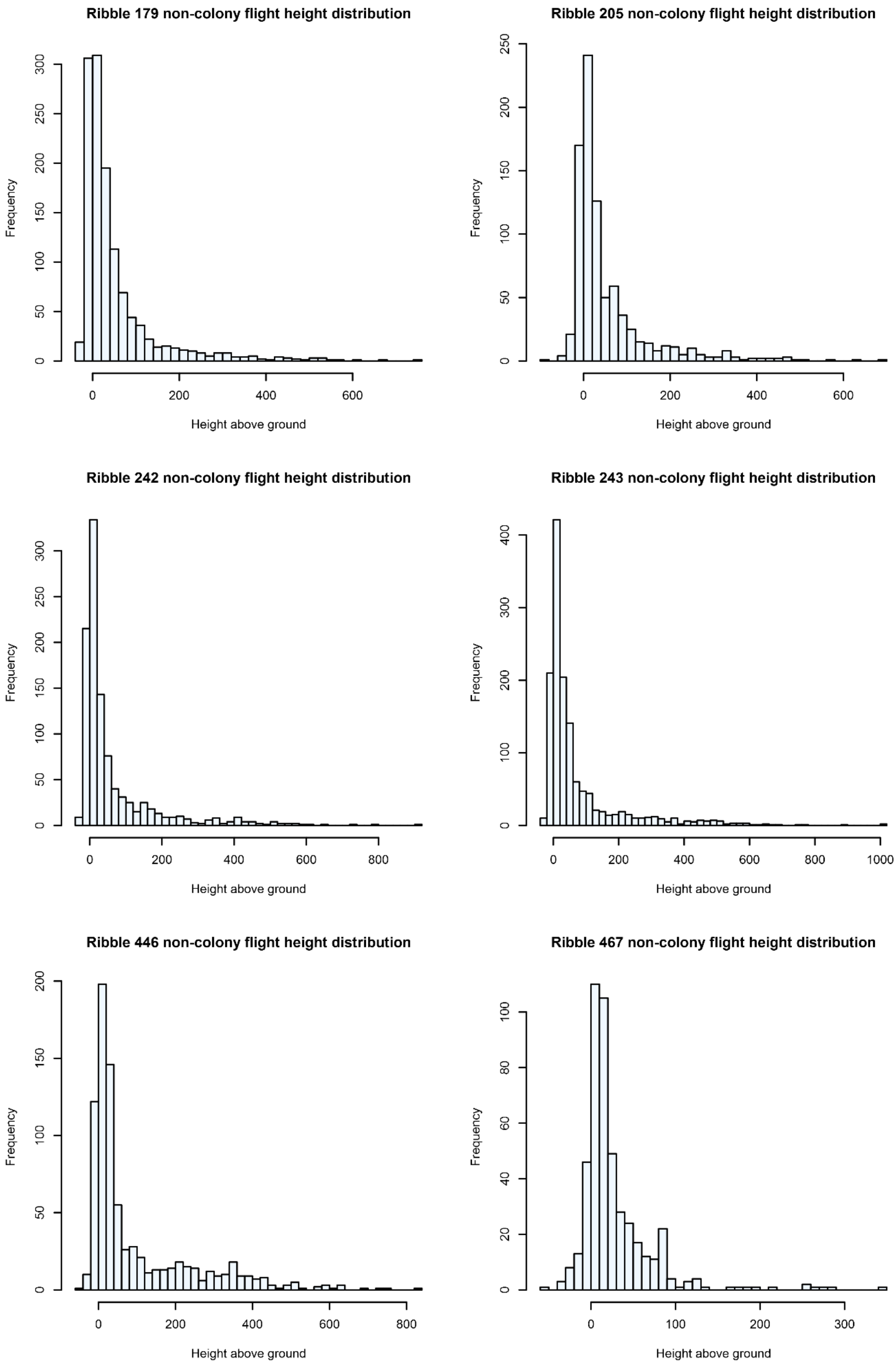



**Figure 3.13** Non-colony altitude distributions for individuals.

# 4. SPATIAL MOVEMENTS OF LESSER BLACK-BACKED GULLS AND OVERLAP WITH RIBBLE AND ALT ESTUARY SPA AND WARTON AERODROME

## 4.1 Introduction

In this chapter, we report investigation of the area usage of Lesser Black-backed Gulls from the Ribble and Alt Estuary SPA. Within the aims of the overall study, in this chapter we report on investigations of:

i. Area usage and spatial overlap of Lesser Black-backed Gulls with the Ribble and Alt Estuary SPA
ii. Area usage and spatial overlap of Lesser Black-backed Gulls with Warton Aerodrome.

## 4.2 Methods

### 4.2.1 Area usage

We investigated the movements of 11 individual Lesser Black-backed Gulls from Banks Marsh in the Ribble and Alt Estuaries SPA during the 2016 breeding season. One individual (bird 464) produced no GPS data; hence the total sample size to assess spatial distributions was 10 birds (Table 2.1). The same dataset used for assessment of flight heights of birds was also used for spatial analyses, thus covering the same periods of the breeding season.

We used time-invariant Kernel Density Estimation (KDE) to estimate the home range area usage for each bird and all birds combined. Area usage analyses focussed on observations during trips only, and thus the areas that might have been used for foraging and other activities away from the colony. Area utilisation was assessed using kernel density estimation (KDE, Worton 1989). 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. KDEs were calculated following the approach of Thaxter *et al.* (2015), using fixed smoothing parameters, deemed most appropriate through visual assessment of utilisation distributions across a range of band widths.

For each individual, we then calculated the total area of the 95% and 50% KDEs, and the area within the SPA and the Warton aerodrome. 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)

### 4.2.2 Time budgets

For each individual, we calculated the time spent in the SPA and in the area of the Warton aerodrome. GPS data points were interpolated to 10s and where points overlapped these areas, they were identified and the time entering and leaving the SPA or Warton aerodrome was then calculated. Time budgets for each bird were then calculated, expressing time in these areas as a function of total time budgets and time spent away from the colony. Where points were more than 24 hours apart, we considered this a data gap and did not calculate temporal overlaps for these periods.

Night-time and day-time periods have been kept separate in the temporal assessment to: (1) match the spatial analyses, and (2) allow caveats to be placed on the results derived for the night-time period. Given coarser sampling rates, there is likely to be greater error in the assessment of overlaps for the night-time period, due to the interpolation between GPS points spaced further apart in time.

### 4.2.3 GPS devices, area delineation and sampling rates

Time-stamped GPS data were downloaded and processed in R 3.2.2 (R Core Team 2016). To specify areas away from the breeding colony, we identified locations away from the saltmarsh and intertidal areas within the colony as periods away from the nest. Due to differences in sampling rates of the Movetech GPS devices between day and night, these periods had to be treated separately (see chapter 2 for details). To make the most of available data during the day, and to avoid having to sub-sample the whole dataset to meet a reduced sampling rate at night-time, we split the dataset into day and night periods and carried out separate area usage and overlap assessments for each period. The same delineation of day and night was used as in the flight height chapter (3) above.

Sample sizes with which to assess spatial distributions varied between birds (see chapter 2). Although here we produce values for all individuals, we place caveats on the results from birds for which only limited data were available using the following logic: (a) sample sizes of less than 10 data points in a day or night periods were considered unreliable to assess individual patterns; (b) sample sizes of more than 10 but less than 100 data points were considered suitable but should be treated with caution; (c) sample sizes of 100 points or more were considered representative and suitable for area usage assessment. For consideration of the population, however, all birds with data in day and night periods were included giving a full sample of 10 birds.

## 4.3 Results

### 4.3.1 Data overview

In total, 10 Lesser Black-backed Gulls provided data for the 2016 breeding season. Initial review of these data showed individual patterns in habitat use and variations in the level of interaction that birds had with the Ribble and Alt Estuaries SPA and the area of Warton Aerodrome. Birds used mainly inland areas, with only a handful of individual trips going offshore.

Frequent trips were recorded into the Mersey Estuary as well as further inland to urban areas, fields and landfill sites and ground workings. Locally, birds also frequented the intertidal mudflats and saltmarsh of the Ribble Estuary (Fig 4.2). Movements during the day-time revealed trips down to the Mersey Estuary, a pattern that was not seen at night; night-time movements were restricted to areas closer to the Ribble and Alt Estuaries SPA (Fig 4.3). Individual variations in movements were also apparent between birds. For example, one individual also made trips up to the Blackpool area to the north (Fig 4.4). However, six birds showed a striking consistency in patterns of movements between the Ribble and Mersey estuaries.

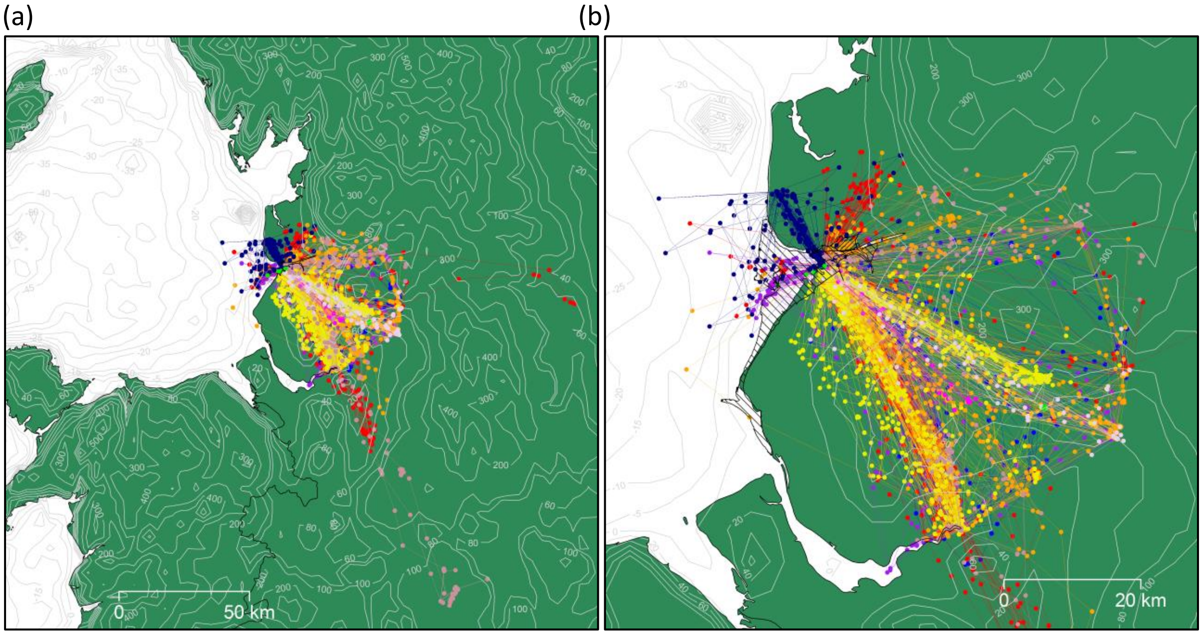
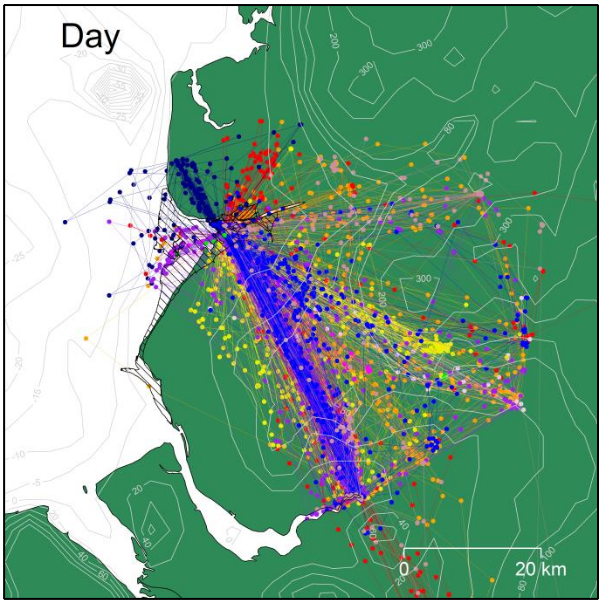



**Figure 4.2** Tracks of 10 Lesser Black-backed Gulls tracked from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season (see Table 2.1 for the extent of data for each bird) showing (a) the total extent of movements, and (b) a finer-scale representation with the SPA (diagonal hash top-left to bottom-right) and Warton Aerodrome (diagonal hash bottom-left to top-right) overlain. Each bird's movements are represented as a different colour.



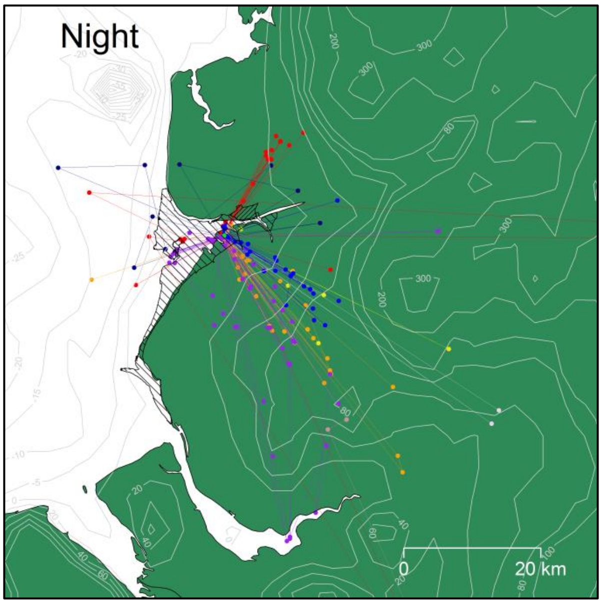




**Figure 4.3** Tracks of 10 Lesser Black-backed Gulls tracked from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season, showing movements during (a) day-time, and (b) night-time for which overlaps were assessed with the SPA (diagonal hash top-left to bottom-right) and Warton Aerodrome (diagonal hash bottom-left to top-right) overlain. Each bird's movements are represented as a different colour.

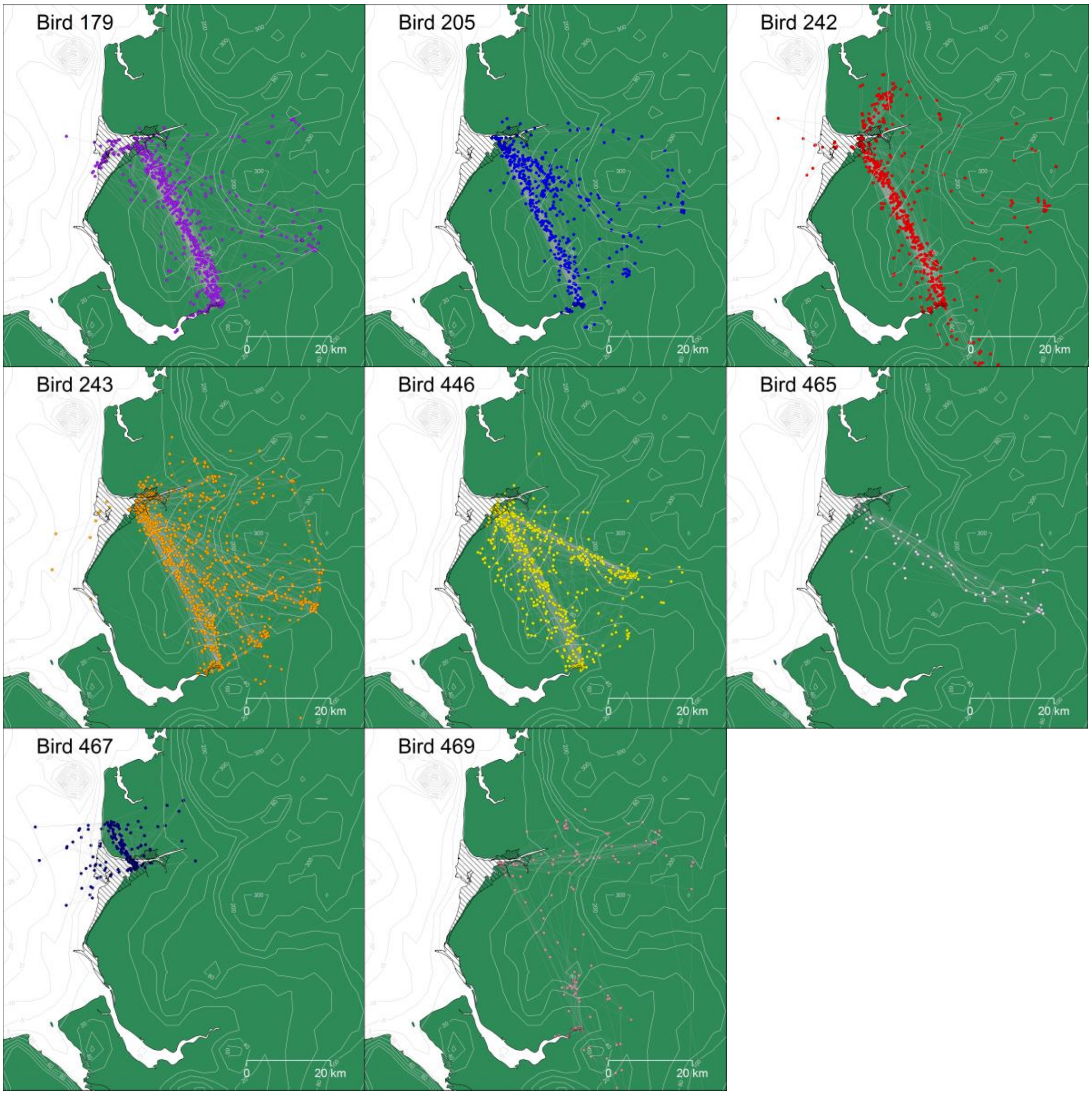



**Figure 4.4** Tracks of individual Lesser Black-backed Gulls from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season, for which it was deemed that sufficient data were available to assess overlaps with the SPA (diagonal hash top-left to bottom-right) and Warton Aerodrome (diagonal hash bottom-left to top-right).

### 4.3.2 Connectivity and Spatial overlaps with the SPA and Warton Aerodrome

***SPA overlaps***

Total area usage, as indicated by the 95% KDE, was bigger during the day than at night for all birds; the night-time 95% KDE for all birds was only 42% the size of the total 95% KDE for all birds during the day-time.

Overlaps of individual bird home ranges with the SPA also varied between day and night periods. The core (50%) and total (95%) area usage overlapped the SPA for all birds, but by varying amounts. These are shown in Table 4.1 and shown graphically in Fig 4.5. Generally, birds showed greater proportional overlaps of the 95% KDE with the SPA during the night than during the day, due to the smaller night-time 95% KDE area size. During the day, the greatest 95% KDE overlaps with the SPA were seen for bird 484, for which the overlap with the SPA area was 51%; it should be noted, however, that few data were available for this bird. A more reliable maximum estimate across individual birds was for bird 467, for which the overlap between the 95% KDE and the SPA area was 29% (see Fig 4.6). The overlap with the SPA for the all-bird kernel, representing the total population, was much smaller, at 5% (Table 4.1). During the night, the maximum overlap between the 95% KDE and the SPA was 28% for bird 446 (Table 4.1). During the day, the maximum overlaps between the 50% KDE and the SPA was 67% for bird 242 – generally overlaps were greater for those birds for which most data were available. During the night, the 50% KDE fell completely within the SPA for birds 242 and 446.

**Table 4.1** Summary of 95% KDE and 50% KDE utilisation distributions for individual Lesser Black-backed Gulls tracked from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season.

| | | | Area of KDE ($km^2$) | | Percentage overlap | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | SPA | | Warton | |
| **Period** | **Bird** | **N fixes** | **50** | **95** | **50** | **95** | **50** | **95** |
| Day | 179 | 1866 | 38.79 | 735.24 | 50.32 | 11.28 | 0 | 0.80 |
| | 205 | 1166 | 68.06 | 747.94 | 33.90 | 5.27 | 0.82 | 0.85 |
| | 242 | 1934 | 28.65 | 820.86 | 67.27 | 5.59 | 0 | 0.78 |
| | 243 | 1870 | 102.52 | 1227.75 | 26.53 | 3.56 | 0.98 | 0.52 |
| | 446 | 1272 | 63.46 | 830.92 | 39.75 | 4.72 | 0 | 0.38 |
| | 450[a] | 39 | 26.52 | 187.31 | 19.30 | 26.89 | 0 | 0.39 |
| | 465[a] | 98 | 77.90 | 503.31 | 29.56 | 6.58 | 0 | 0.35 |
| | 467 | 720 | 22.97 | 199.32 | 47.17 | 28.54 | 0 | 2.34 |
| | 469 | 387 | 140.79 | 1427.98 | 10.91 | 2.23 | 0.21 | 0.42 |
| | 484[a] | 10 | 22.41 | 106.75 | 69.39 | 51.00 | 0 | 0.74 |
| | Total | 9362 | 77.42 | 1638.80 | 37.20 | 5.01 | 1.59 | 0.39 |
| Night | 179 | 124 | 24.27 | 413.48 | 83.87 | 17.11 | 0 | 0.61 |
| | 205[b] | 70 | 15.64 | 163.18 | 92.45 | 18.19 | 0 | 1.53 |
| | 242 | 148 | 11.65 | 202.09 | 100.00 | 26.72 | 0 | 2.33 |
| | 243 | 139 | 12.78 | 215.34 | 97.74 | 16.39 | 0 | 1.21 |
| | 446[b] | 47 | 10.83 | 122.21 | 100.00 | 28.32 | 0 | 1.97 |
| | 450[a] | - | - | - | | | | |
| | 465[a] | 6 | 26.13 | 121.10 | 58.16 | 28.24 | 0 | 0.16 |
| | 467[b] | 26 | 18.07 | 268.12 | 94.60 | 20.72 | 0 | 0.63 |

| Period | Bird | N fixes | Area of KDE (km$^2$) | | Percentage overlap | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | SPA | | Warton | |
| | | | 50 | 95 | 50 | 95 | 50 | 95 |
| | 469[b] | 7 | 33.38 | 152.70 | 31.97 | 14.60 | 0.05 | 2.27 |
| | 484[a] | - | - | - | - | - | - | - |
| | Total | 567 | 77.42 | 687.72 | 92.70 | 11.64 | 0 | 0.91 |

[a] Fewer than 100 data points were available for birds 450, 465 and 484 for day-time assessment and so results should be treated with caution;

[b] For night-time periods, too few data (less than 10 points) were available for birds 465 and 469 to reliably assess area usage; fewer than 100 data points were also available for birds 467, 446, and 470 and so results should be treated with caution

***Overlaps with the Warton Aerodrome***

The overlap of the total 95% KDE with Warton Aerodrome was generally very small, being less than 3% for both day and night periods across individual birds, and less than 1% for the population all-bird assessment. Moreover, for seven out of 10 birds during the daytime, the core area 50% KDE had no overlap with the aerodrome area. Only one bird (469) had any overlap of their 50% KDE during the night with the aerodrome, and this was only a negligible amount (<0.1%). Hence, the 50% KDE in the total all-bird assessment had no spatial overlap (Table 4.1, Fig 4.5).

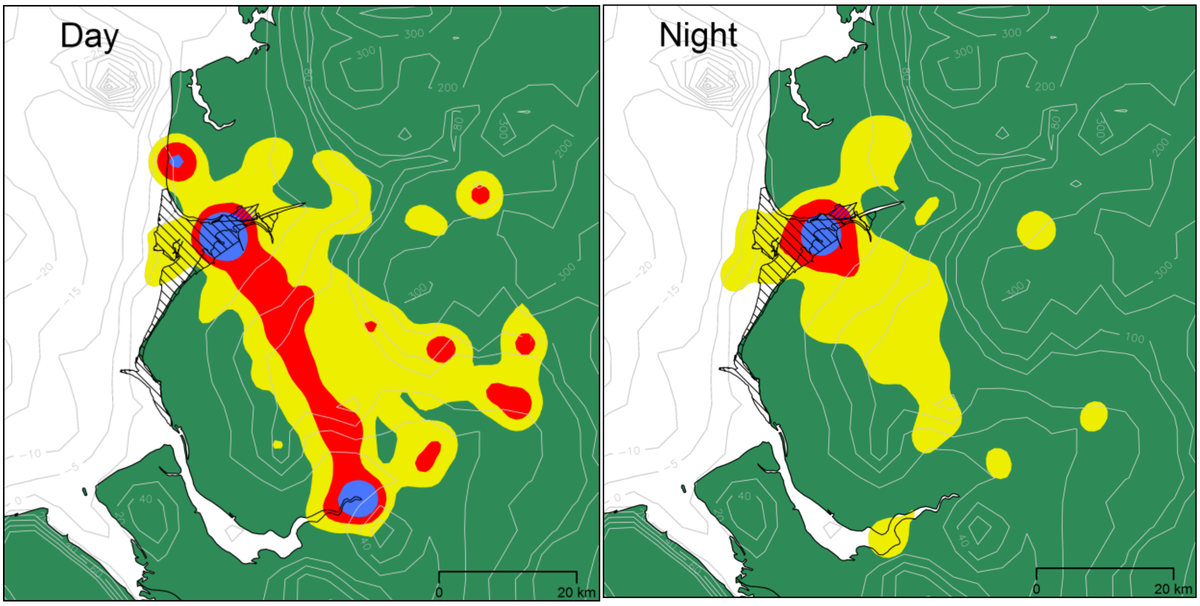



**Figure 4.5** Kernel density estimate utilisation distributions for Lesser Black-backed Gulls (day, n = 10; night n = 8 – see Table 4.1) tracked from Ribble and Alt Estuaries SPA during the 2016 breeding season; data are separated into fixes during the day (n = 9,362) and at night (n = 567) (smoothing parameter, day h = 1,600 m; night h = 1,900 m).

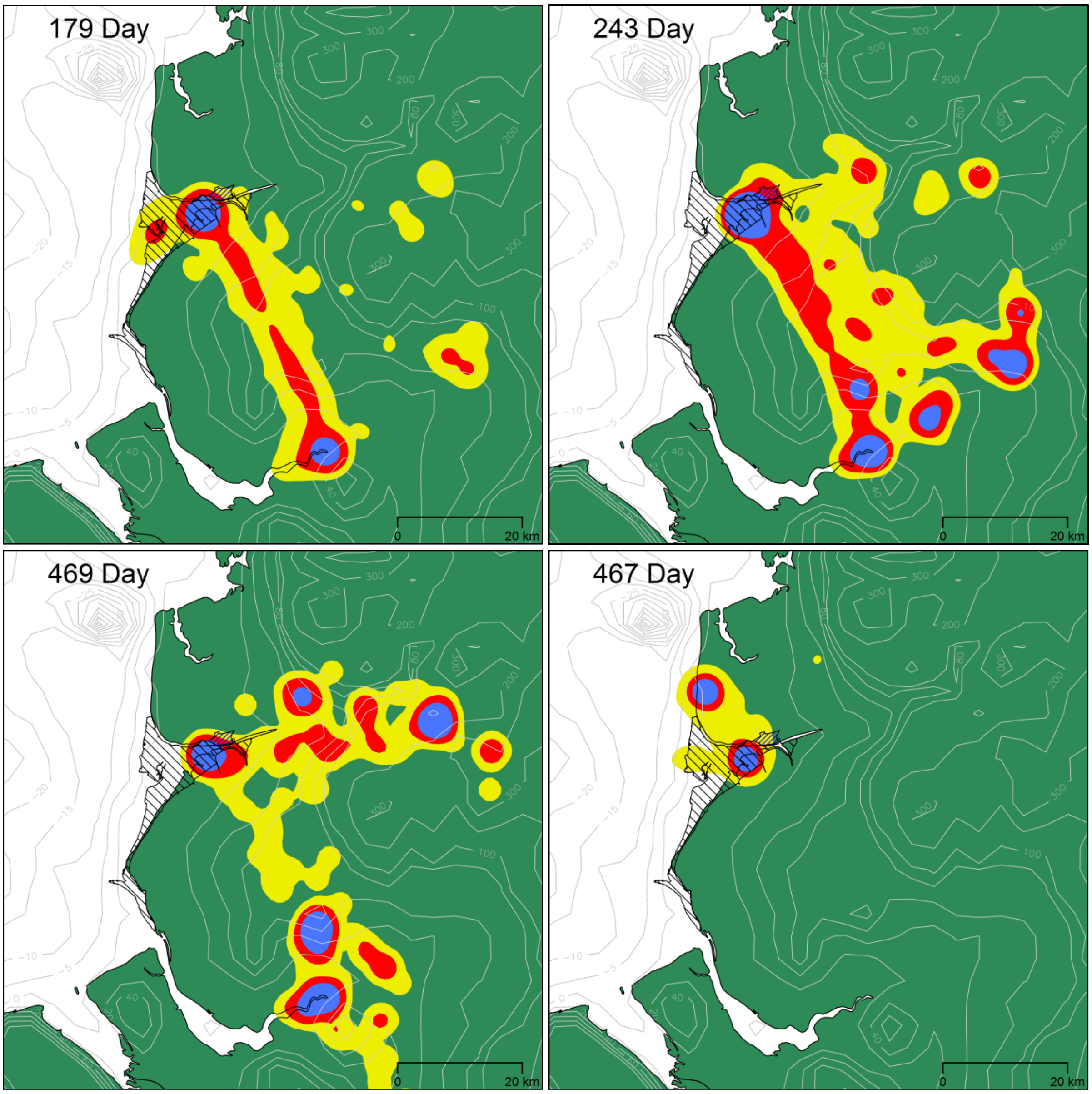



**Figure 4.6** Daytime kernel density estimate utilisation distributions for four example Lesser Black-backed Gulls tracked from Ribble and Alt Estuaries SPA during the 2016 breeding season.

### *Temporal overlaps*

Temporal overlaps for all data (across day and night periods) are shown below in Table 4.2 and split by day and night periods in Table 4.3.

The greatest temporal overlap with the Ribble and Alt Estuaries SPA (including time at the colony) was shown by bird 484; however, the dataset for this bird was relatively limited, hence as with the spatial analysis presented above, results for this bird are not considered fully representative. The second highest overlap was for bird 242, which spent 58% of its time in the SPA and 14% when away from the colony (8% during the day). Birds 205 and 467 also spent relatively high amounts of time in the SPA when away from the colony (bird 467 also showing the greatest spatial overlap, when excluding results from bird 484). It should be noted that the results of the temporal assessment need not be fully congruous with those from the spatial assessment due to fundamental differences in the treatment of the data. Overall, temporal overlaps with the SPA when away from the colony were 8% across the day and night and 7% for the day-time alone, and thus were similar to the overall spatial overlap of 5% (based on the 95% KDE) for the day-time presented above. Night-time use of the SPA away from the colony was apparently much higher at 19%, but this assessment was based on fewer overall data (as represented both through number of fixes in spatial assessments and duration of time here for temporal investigation).

Temporal overlaps with the Warton aerodrome, as with the spatial analysis, were very small, being less than 0.5% across birds both for the day and across the day and night. The overlap during the night-time was just over 1%, although the same caveat above regarding the limited dataset should be noted. Among individuals, birds 242 and 243 showed 0.66% and 0.75% overlaps with the Warton aerodrome during the day, these values being of similar magnitude to those found by the spatial day-time assessment for the 95% KDE. Bird 467 showed a spatial overlap of over 2% that was not reflected in the temporal assessment. It is worth noting that when dealing with smaller spatial areas, particularly in close proximity to the colony, spatial assessment may run the risk of slightly overestimating use when use of the area is relatively small, due to the difficulties of defining the suitable smoothing parameter.

**Table 4.2** Summary of temporal overlaps for individual Lesser Black-backed Gulls tracked from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season. Note, caveats and cautions regarding sample sizes in Table 4.1 are valid here.

| | | **All time (incl. colony)** | | | **Away from colony** | | |
|---|---|---|---|---|---|---|---|
| **Area** | **Bird** | **Total time (hrs)** | **Overlap (hrs)** | **%** | **Time (hrs)** | **Overlap (hrs)** | **%** |
| SPA | 179 | 1518.85 | 714.22 | 47.02 | 714.32 | 56.62 | 7.93 |
| | 205 | 1213.79 | 413.31 | 34.05 | 683.80 | 70.57 | 10.32 |
| | 242 | 1720.70 | 1004.95 | 58.40 | 715.63 | 98.73 | 13.80 |
| | 243 | 1722.62 | 738.56 | 42.87 | 851.93 | 68.12 | 8.00 |
| | 446 | 1711.99 | 715.49 | 41.79 | 749.46 | 31.21 | 4.16 |
| | 450 | 156.32 | 9.49 | 6.07 | 90.06 | 4.83 | 5.36 |
| | 465 | 446.81 | 100.93 | 22.59 | 330.57 | 29.06 | 8.79 |
| | 467 | 1705.63 | 574.71 | 33.70 | 986.80 | 114.83 | 11.64 |
| | 469 | 1276.48 | 122.21 | 9.57 | 1073.54 | 26.77 | 2.49 |
| | 484 | 53.21 | 48.42 | 90.99 | 4.76 | 0.00 | 0.00 |
| | **Total** | **11526.40** | **4442.28** | **38.54** | **6200.89** | **500.72** | **8.07** |
| Warton | 179 | 1518.85 | 0.06 | 0.00 | 714.32 | 0.00 | 0.00 |
| | 205 | 1213.79 | 0.54 | 0.04 | 683.80 | 0.08 | 0.01 |
| | 242 | 1720.70 | 15.74 | 0.91 | 715.63 | 7.69 | 1.07 |
| | 243 | 1722.62 | 7.26 | 0.42 | 851.93 | 5.57 | 0.65 |
| | 446 | 1711.99 | 0.52 | 0.03 | 749.46 | 0.14 | 0.02 |
| | 450 | 156.32 | 0.00 | 0.00 | 90.06 | 0.00 | 0.00 |
| | 465 | 446.81 | 0.00 | 0.00 | 330.57 | 0.00 | 0.00 |
| | 467 | 1705.63 | 5.73 | 0.34 | 986.80 | 4.36 | 0.44 |
| | 469 | 1276.48 | 2.32 | 0.18 | 1073.54 | 2.32 | 0.22 |
| | 484 | 53.21 | 0.00 | 0.00 | 4.76 | 0.00 | 0.00 |
| | **Total** | **11526.40** | **32.17** | **0.28** | **6200.89** | **20.15** | **0.32** |

**Table 4.3** Summary of temporal overlaps for individual Lesser Black-backed Gulls tracked from the Ribble Estuary (Ribble and Alt Estuaries SPA) during the 2016 breeding season for both day and night periods. Note, caveats and cautions regarding sample sizes in Table 4.1 are valid here.

(a) Day

| | | **All time** | | | **Away from colony** | | |
|---|---|---|---|---|---|---|---|
| **Area** | **Bird** | **Total time (hrs)** | **Overlap (hrs)** | **%** | **Time (hrs)** | **Overlap (hrs)** | **%** |
| SPA | 179 | 1114.18 | 544.95 | 48.91 | 577.16 | 44.60 | 7.73 |
| | 205 | 957.72 | 315.13 | 32.90 | 599.79 | 53.98 | 9.00 |
| | 242 | 1263.84 | 666.30 | 52.72 | 605.69 | 49.41 | 8.16 |
| | 243 | 1277.05 | 486.76 | 38.12 | 744.77 | 47.14 | 6.33 |
| | 446 | 1490.92 | 609.58 | 40.89 | 731.43 | 30.08 | 4.11 |
| | 450 | 156.32 | 9.49 | 6.07 | 90.06 | 4.83 | 5.36 |
| | 465 | 371.79 | 70.82 | 19.05 | 293.03 | 25.04 | 8.54 |
| | 467 | 1494.10 | 486.82 | 32.58 | 904.62 | 105.75 | 11.69 |
| | 469 | 1236.77 | 119.80 | 9.69 | 1044.54 | 25.80 | 2.47 |
| | 484 | 42.55 | 37.75 | 88.74 | 4.76 | 0.00 | 0.00 |
| | **Total** | **9405.22** | **3347.40** | **35.59** | **5595.84** | **386.61** | **6.91** |
| Warton | 179 | 1114.18 | 0.06 | 0.01 | 577.16 | 0.00 | 0.00 |
| | 205 | 957.72 | 0.54 | 0.06 | 599.79 | 0.08 | 0.01 |
| | 242 | 1263.84 | 4.48 | 0.35 | 605.69 | 4.01 | 0.66 |
| | 243 | 1277.05 | 6.99 | 0.55 | 744.77 | 5.57 | 0.75 |
| | 446 | 1490.92 | 0.52 | 0.03 | 731.43 | 0.14 | 0.02 |
| | 450 | 156.32 | 0.00 | 0.00 | 90.06 | 0.00 | 0.00 |
| | 465 | 371.79 | 0.00 | 0.00 | 293.03 | 0.00 | 0.00 |
| | 467 | 1494.10 | 4.02 | 0.27 | 904.62 | 2.66 | 0.29 |
| | 469 | 1236.77 | 0.77 | 0.06 | 1044.54 | 0.77 | 0.07 |
| | 484 | 42.55 | 0.00 | 0.00 | 4.76 | 0.00 | 0.00 |
| | **Total** | **9405.22** | **17.38** | **0.18** | **5595.84** | **13.22** | **0.24** |

(b) Night

| | | All time | | | Away from colony | | |
|---|---|---|---|---|---|---|---|
| **Area** | **Bird** | **Total time (hrs)** | **Overlap (hrs)** | **%** | **Time (hrs)** | **Overlap (hrs)** | **%** |
| SPA | 179 | 404.66 | 169.27 | 41.83 | 137.17 | 12.02 | 8.76 |
| | 205 | 256.07 | 98.18 | 38.34 | 84.02 | 16.59 | 19.75 |
| | 242 | 456.87 | 338.65 | 74.12 | 109.94 | 49.32 | 44.86 |
| | 243 | 445.58 | 251.79 | 56.51 | 107.16 | 20.98 | 19.58 |
| | 446 | 221.07 | 105.91 | 47.91 | 18.03 | 1.13 | 6.25 |
| | 450 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 465 | 75.02 | 30.11 | 40.13 | 37.55 | 4.02 | 10.71 |
| | 467 | 211.53 | 87.89 | 41.55 | 82.19 | 9.08 | 11.05 |
| | 469 | 39.70 | 2.41 | 6.07 | 29.00 | 0.97 | 3.35 |
| | 484 | 10.67 | 10.66 | 99.98 | 0.00 | 0.00 | 0.00 |
| | **Total** | **2121.18** | **1094.88** | **51.62** | **605.05** | **114.11** | **18.86** |
| Warton | 179 | 404.66 | 0.00 | 0.00 | 137.17 | 0.00 | 0.00 |
| | 205 | 256.07 | 0.00 | 0.00 | 84.02 | 0.00 | 0.00 |
| | 242 | 456.87 | 11.26 | 2.46 | 109.94 | 3.68 | 3.34 |
| | 243 | 445.58 | 0.27 | 0.06 | 107.16 | 0.00 | 0.00 |
| | 446 | 221.07 | 0.00 | 0.00 | 18.03 | 0.00 | 0.00 |
| | 450 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 465 | 75.02 | 0.00 | 0.00 | 37.55 | 0.00 | 0.00 |
| | 467 | 211.53 | 1.70 | 0.80 | 82.19 | 1.70 | 2.07 |
| | 469 | 39.70 | 1.55 | 3.91 | 29.00 | 1.55 | 5.35 |
| | 484 | 10.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Total** | **2121.18** | **14.79** | **0.70** | **605.05** | **6.93** | **1.15** |

## 5. DISCUSSION

Previous studies have revealed that even for the very best and fastest tracking systems available, such as the University of Amsterdam Bird Tracking System (UvA-BiTS, Bouten *et al.* 2013[2]), the precision of the altitude measurements may still be subject to error up to 15-20 m (Ens *et al.* 2008, Thaxter *et al.* 2011). These studies were conducted through calibration of tags at known height, and further tests have been conducted using UvA-BiTS devices over a range of sampling rates for White Stork and Honey Buzzard, revealing that faster sampling may greatly increase precision with a vertical mean error of 2.2 m for a 3 s sampling rate (W. Bouten pers. comm.); these improvements are partly due to the greater time the GPS sensor was switched on, and increasing numbers of satellites available for a 3D GPS fix. This was also confirmed by Thaxter *et al.* (2014) demonstrating that precision was increased with an increased sampling rate with an overall spread of data ranging 10-15m (this estimate was approximated from histograms of the altitudinal data of known height, without more formal analyses). Modelling techniques are also now available to refine flight estimates and produce altitude distributions with confidence limits across different habitats and behavioural states (Ross-Smith *et al.* 2016). As systems such as the UvA are at the upper specification on the market, where cost or other factors may be a particular issue raising the question of feasibility of other systems.

This study has assessed the behaviour of Lesser Black-backed Gulls traced from the Ribble and Alt Estuaries SPA during the 2016 breeding season using an alternative type of device – Movetech GPS-GSM tags. These tags were set up specifically to be used to collect flight altitude data, in particular through an increased duration that the GPS sensor was left switched on, thus increasing the number of satellites available and increasing potential precision. These tags, however, had not been previously used for assessing flight altitudes of birds.

### 5.1 Flight heights

#### 5.1.1 Accuracy and precision of altitude data: ground truthing before deployment

Movetech tags produced accurate estimates of altitude (generally <2 m error) once corrections for the ellipsoid of the earth had been accounted for. Precision (which we define as two standard deviations from the mean) was 18-26 m, therefore being at or above that previously recorded for UvA-BiTS devices. However, a short-coming of the Movetech system was the overall sampling rate of the tag. The general performance was lower than the UvA-BiTS system, with lower sampling rates, partly due to the tags being at threshold voltage a high proportion of the time. Fewer fixes (less than 600 in total) were collected at night-time compared to the day, which prevented a comparative examination of day-time and night-time data, and a combined day and night flight height histogram was not possible due to this sampling bias.

#### 5.1.2 Flight height data

Tags recorded a value for ground speed that appeared not to be very reliable, as apparently stationary birds were recorded with high altitudes, and flight height distributions were similar over different ground speed categories. Given that fixes are relatively infrequent (compared to the Amsterdam tags), we could not calculate a reliable estimate of speed based on distance/time between consecutive locations.

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[2] http://www.uva-bits.nl/ [accessed 01/09/2016]

In keeping with previous studies of Lesser Black-backed Gulls at Orford Ness (Ross-Smith *et al.* 2016), birds at the Ribble Estuary spent more time at higher altitudes inland than over any other habitat type. However, it was not possible to disentangle the effect of sampling rates, day and night differences, and behaviour such as commuting and foraging from this overall conclusion.

Altitude measurements indicated that the majority of flights were at heights of less than 100 m, although that some flights were at much higher altitudes, up to several hundred metres. Birds flew higher during the day-time, although most of their time was still spent at around ground height.

## 5.2 Home ranges

### 5.2.1 Suitability of Movetech tags

Identifying behaviours from GPS data is a clear priority when assessing altitudes of birds, to rule out any locations when birds are known to be sitting, loafing, swimming, or at the nest, and in turn are not at risk of collision with aircraft. Given the coarser temporal sampling of fixes from the Movetech tags, ground speed of birds was not considered to be a useful value from Movetech tags. This sampling rate may be useful to pick out when birds may be flying but assessment of fine-scale behaviour is not currently possible through these devices. However, the tags also contain an accelerometer which is a useful tool with which to obtain finer-scaled behaviour of animals than can be inferred from GPS locations of movement alone (e.g. Shamoun-Baranes et al. 2016).

Although Movetech tags had a reduced sampling rate at night, they nonetheless produced enough data points to approximate area usage in day and night periods. The Movetech tags therefore produced very clear spatial patterns in the horizontal dimension. These tags are therefore considered highly suitable for quantifying two-dimensional xy interactions with the Aerodrome and thus potential for bird strike.

### 5.2.2 Home range data and overlap with the Ribble and Alt Estuaries SPA and Warton Aerodrome

Birds mainly used inland areas, with only a handful of individual trips going offshore. Frequent trips were recorded to the Mersey Estuary as well as further inland to urban areas, fields and landfill sites and ground workings. Locally, birds also frequented the intertidal mudflats and saltmarsh of the Ribble Estuary.

Overlap of home ranges with the SPA was greater during the night than during the day. The overlap of home ranges with Warton Aerodrome was small, being less than 3% for both day and night periods for individual birds, and less than 1% for all-birds combined. Temporal overlaps with the Warton aerodrome were also very small – less than 0.5% for all-birds combined across the day and night. Nevertheless, scaled up over a colony of around 8,500 Lesser Black-backed gulls this may potentially constitute a large gull presence in this area across the breeding season. Although the sample size considered here is small (and thus may be unrepresentative), there is evidence to suggest that collision risk may not be distributed evenly among individuals. However, more data need to be collected in order to investigate this further.

Together the flight height data and information on the extent of spatial and temporal overlap of birds' movements with the area of the Warton aerodrome provide the potential to assess risks of collision with aircraft. However, larger samples of both adults and juvenile/immature birds would need to be tracked, potentially through the year, and more detailed information of the flight altitudes and paths of aircraft would be required to better assess this potential risk.

### 5.3 Summary comparison of Movetech and UvA-BiTS tags

The advantages and disadvantages of the Movetech system are assessed in Table 5.1 alongside the UvA-BiTS system for: gathering of flight height data, gathering xy data on spatial location, general use of the system and use on age groups of birds.

Assessment of the suitability of Movetech tags for providing data on flight heights is considered above. However, in choosing particular devices for flight height assessment, there a balance relating to decisions of tag type, design and attachment method, weighed up against species- and age-specific restrictions, site-specific aspects, and study-specific requirements. The species must be able to accommodate the device and attachment method. Furthermore, if young birds are of interest, then decisions of tag type and attachment may drive the type of device alone. It is not considered feasible to use permanent harnesses on juvenile gulls, and it would thus be wasteful to use a device that is designed to be attached with a harness and record many years. Moreover, a GSM tag would be the only logical method of obtaining data on dispersing individuals that are not constrained to returning to the colony. The site itself may also dictate tagging, if catching is restricted to certain locations. For example, setting up a central base station for downloading data from non-GSM GPS tags may be an additional complication for remote sites. If repeated visits to a remote site are not possible and if an internet connection is not possible, then the advantage of a static base station is reduced further, as one would not be able to make full use of the ability offered by systems to remotely alter tag settings. Further study-specific aspects such as cost, budget available and period of investigation are also likely to factor heavily in making distinctions for tags. Should a period of the annual cycle only be of interest, then a different capture and tagging method may be required, and longer-life higher-spec tags may not therefore be appropriate, despite their superior potential for assessing altitude.

**Table 5.1** Comparison of advantages and disadvantages of Movetech and UvA-BITS tracking systems for gathering of flight height data, with consideration of the general use of the system and the applicability of tags to the ages of birds studied.

| Tag type | Applicability | Advantage | Disadvantage |
|---|---|---|---|
| UvA-BiTS | Flight heights | - A proven system for gathering data on flight heights (Ross-Smith *et al.* 2016). Very frequent sampling allows for more precise measurements<br>- In the UK, a 5 min night-time sampling rate can be sustained for an adult bird during breeding (depending on length of trip) with no day/night bias in sampling rate; a 30 minute rate can also be sustained in winter, | - As with all GPS systems, error of flight altitudes is coarser than xy spatial dimension.<br>- UvA-BiTS tags still have error ca. 15-20 m even with fast sampling, thus careful consideration is always needed to quantify this (Thaxter *et al.* 2011; Ross-Smith *et al.* 2016) |
| | Spatial xy data | - Can give suitable spatial information on movements to characterise area usage<br>- Finer-scale fast-sampling xy locations are also possible | - Still requires use of a base station to collect GPS data |
| | General use of the system | - User interface is reliable, with flexible software options; tags can be communicated with post-deployment altering settings; remote access to the base station through internet<br>- No need for recapture of bird to recover data<br>- Tags themselves are state-of-the-art and carry multiple high quality sensors such as a gyroscopic accelerometer, ideal for very fine-scale behaviour assessment<br>- High quality solar panels and batteries mean that the tags can sample with very fast frequency, up to 3s, with accelerometer synchronisation available | - Typically requires power supply and internet connection to make use of interactive tag communication; remote solutions such as solar powered base stations and mobile internet are ways around this but represent complications<br>- Remote sites that cannot be accessed frequently may pose problems if settings need to be re-configured<br>- Without careful monitoring of tag performance, datasets can be incomplete if too higher sampling rates are used<br>- Cannot download data when more than a few kilometres away from a base station |
| | Age groups of birds | - Base station set up is ideal for central place foraging adult birds during breeding, and can be used to monitor movements over long time-scales | - A base station set up may not be suitable for other age classes such as young birds – data are obtained only when bird comes back to in range |
| Movetech | Flight heights | - Good accuracy of estimating flight height after geoid correction for location<br>- Option to leave GPS turned on for longer periods to access more satellite and improve precision | - As with all GPS systems, error of flight altitudes is coarser than xy spatial dimension.<br>- Currently unable to maintain constant higher sampling rates during night periods, resulting in a sampling bias<br>- Flight height precision error was greater than UvA-BiTS, even after correction for number of satellites available |
| | Spatial xy data | - Can give suitable spatial information on movements to characterise area usage for day and night periods separately | - Sampling rate bias between day and night<br>- Finer-scale fast-sampling xy locations not possible |
| | General use of the system | - No base station required, data transmitted via GSM<br>- Tag communicated post-deployment<br>- No need for recapture of bird to recover data<br>- Although most tag manufacturers can offer variations from a standard design, bespoke configuration of tags specific to requirements, such as sensor activation times was very simple using Movetech tags<br>- Can be used in remote locations where access is infrequent, as there is no need for a fixed base station<br>- Data collection not restricted to central place foraging birds<br>- Voltage for many tags was often around 3.8V too low for very frequent sampling | - Depends heavily on research goals of the study; lack of regular access to tags remotely may be an issue should tag settings need to be adjusted or tested once deployed; for example very fast sampling causes<br>- If very fast sampling is required for fine-scale assessment of behaviour, Movetech is not as suitable as UvA-BiTS<br>- Without careful monitoring of tag performance, datasets can be incomplete if too higher sampling rates are used |
| | Age groups of birds | - Given the GSM system, there are no restrictions on the need for a base station and thus no restriction to central place foraging adult birds<br>- Remote data gathering allows possibilities for study of young birds, even if only for short periods of the year, and can also be allowed to determine mortality of individuals (if tags stop moving) | - For adult birds, the UvA-BiTS system may be better suited to research needs, especially for flight height data |

## 5.4 Other tag manufacturers

All GPS tags give altitude information. The UvA-BiTS system is the most tried and tested system. In addition to Movetech, many other manufacturers, such as Ecotone, and PathTrack, offer GPS tags which can be used for long periods of tracking and could also yield flight height estimates. However, the choice of tags depends on the research question. PathTrack tags, to our knowledge are also untested for flight heights of birds, although are highly suitable for characterising space use. Liaison with the manufacturer over the specific needs of the tag is typically therefore needed prior to any study.

## 5.5 Future upgrades and tag / system improvements

Future developments should also be borne in mind and Movetech, along with other manufacturers are developing new tag options that are likely to offer additional advantages to those used in the present study.

For UvA-BiTS too, the continued expansion of tags and range of devices continues[3], including an additional hybrid GPS-GSM tag[4], but that still requires a fixed base station to download complete data. The on-board accelerometer has also been refined to now include gyroscopic measurements and more dimensions of axis rotation allowing even finer-scaled assessment of behaviour. The weight of tags also continues to decline, opening up possibilities of tagging on smaller species.

## 5.6 Conclusions and recommendations

Movetech tags produced accurate estimates of altitude (generally <2m) once corrections for number of satellites (more than five) and the ellipsoid of the earth had been accounted for. Precision (which we define as two standard deviations from the mean) was 18-26 m therefore being at or a little above that previously recorded elsewhere using different GPS tags.

Altitude measurements indicated that the majority of flights were at heights of less than 100 m. Birds flew higher during the day-time, although most of their time was still spent at around ground height.

Movetech tags were very appropriate for assessing home range area usage, although with the caveat that fewer data were available to assess night-time area usage. Birds used mainly inland areas, with only a handful of individual trips going offshore. The overlap of home ranges with Warton Aerodrome was small – less than 3% for both day and night periods for individual birds, and less than 1% for all-birds combined. Temporal overlaps with the Warton aerodrome were also very small – less than 0.5% for all-birds combined across the day and night.

Currently, for study of flight heights of adult gulls, the UvA-BiTS system offers the best option, being a proven tool with which to obtain flight height data (Ross-Smith *et al.* 2016); UvA-BiTS offers greatest user interface flexibility, fast GPS sampling rates and without any restrictions of day and night sampling biases. The precision of the Movetech tags was good but less than that provided by UvA-BiTS tags and suffered sampling biases, although the accuracy of both systems is high. These recommendations, however, are obviously subject to the constraints of funding. Both systems

[3] http://www.uva-bits.nl/gps-trackers/ [accessed 01/09/2016]
[4] http://www.uva-bits.nl/news/new-gps-tracker-with-sms/ [accessed 01/09/2016]

include accelerometers, which may help identify behaviours of birds and so may be useful for refining flight height curves.

As juvenile gulls, once fully fledged, will not be constrained to the colony, use of a GPS-GSM is required to reliably retrieve data and to study post-colony dispersal movements; thus the Movetech system would be most appropriate (Table 5.1). Therefore, acceptance of a reduced precision of raw flight height estimates may be needed. However, as with all GPS data, it is possible to undertake modelling to take account of sources of error variation (Ross-Smith *et al.* 2016). Through such modelling, it is possible to refine error around flight estimates and produce altitude distributions with confidence limits, thereby better allowing for assessment of risk of collision with, for example wind farms or aircraft. Such modelling would therefore also be recommended.

**Acknowledgements**

This work was funded by Natural England and our particular thanks go to Emily Hardman, Hannah Birtles, Dave Mercer, Stephen Ayliffe and Tim Frayling for help and support in setting up this project. Thanks to Phil Atkinson for his liaising and development time with Movetech, and for providing post-tagging advice and support on tag performance. We'd like to thank UvA and DECC for reference to flight data from previous studies. We also thank Emily Coleman and Penny Mitchell (BTO) for their contract management support, Maria Knight for help with the report, and Helen Hipperson for fieldwork assistance.

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