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Assessing movements of Lesser Black-backed Gulls using GPS tracking devices in relation to the Galloper Wind Farm.

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Assessing Movements of Lesser Black-backed Gulls using GPS Tracking Devices in Relation to the Galloper Wind Farm

Final Report

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EXECUTIVE SUMMARY

1. A programme of Lesser Black-backed Gull *Larus fuscus* tagging and tracking work was initiated within the Alde-Ore Estuary Special Protection Area (SPA) during the 2019 breeding season, and continued throughout the 2020 breeding season, in order to fulfil requirements of the Galloper Wind Farm (GWF) Ornithological Monitoring Programme (OMP) and test key predictions of the Environmental Statement (ES).

2. The results from both the 2019 and 2020 breeding seasons of tracking are summarised within this report. Specifically, in order for GWF Ltd (GWFL) to be able to achieve the objectives of the OMP, the project aimed to produce data and analyses to provide an assessment of:

    i. The area use of Lesser Black-backed Gulls breeding at the Alde-Ore Estuary SPA and thus the relative time spent within the GWF;
    ii. Their relative behaviours within and outside the wind farm.
    iii. Their relative flight heights within and outside the wind farm; and
    iv. Their movements within and outside the wind farm.

3. **Methods (Chapters 2 and 3).** In total, 30 breeding adult Lesser Black-backed Gulls were caught at the nest at Havergate Island within the Alde-Ore Estuary SPA in May 2019 and fitted with GPS tracking devices – 15 with University of Amsterdam (UvA) GPS devices and 15 with Movetech GPS-GSM devices. Data collection covered both the 2019 and 2020 breeding seasons and the 2019/20 non-breeding season (and therefore the species' full annual cycle). Comparison is provided with data from pre-construction studies undertaken between 2010 and 2015 (Thaxter et al., 2014b; RSPB, unpublished) at Havergate and Orford Ness, also within the Alde-Ore Estuary SPA.

4. All tracked birds were monitored throughout the 2019 and 2020 breeding seasons (although there was limited access to the colony in 2020, due to restrictions associated with the Covid-19 pandemic). Comparison of the breeding success and return rates of tagged and control birds suggested no detrimental effects of the tagging procedure and devices.

5. **Data summary (Chapter 4).** From the 30 birds tracked during the 2019 breeding season, 2187.1 days of data were collected that were of sufficiently high quality for analysis. On average 78.8 ± 27.6 days of data were collected from each individual. The mean date of departure from the colony was 9th August, with the final tracked bird departing on 20th October. In the 2020 breeding season, 19 birds were tracked, providing 2085.1 days of analysable data, with an average of 128.0 ± 41.5 days per individual. The mean departure date was 6th August, with the final bird departing on 28th September.

6. **Trip statistics.** In 2019, data were collected on 4,340 complete trips away from the colony. Birds had an average offshore foraging range of 31.5 ± 27.0 km, and an overall average foraging range (including onshore trips) of 12.4 ± 14.5 km, with trips covering an average total distance of 31.1 ± 47.6 km and lasting 5.2 ± 16.2 hours. In 2020, data were collected on 4,266 complete trips, with birds having an average offshore foraging range of 21.3 ± 19.1 km, and an overall average foraging range of 8.3 ± 9.8 km. Trips covered an average total distance of 19.5 ± 26.8 km and lasted on average 3.6 ± 5.4 hours.

7. **Connectivity.** In 2019, 19 (63%) of the tracked individuals displayed some connectivity with operational offshore wind farms (OWFs), with 17 (57%) individuals showing connectivity with the GWF. The majority of interactions occurred with Galloper and Greater Gabbard Wind Farms, with only single individuals interacting with five other OWFs. In 2020, 11 (59%) individuals displayed connectivity with both the Galloper and Greater Gabbard Wind Farms, with only one individual displaying connectivity with another OWF.

8. **Area use.** Area use was assessed through a Time-In-Area approach (TIA), which defines areas representing the birds' 50% (core), 75%, 95% and 100% utilisation distributions (UDs). In 2019, 4.30% of the 95% UD calculated for all birds overlapped with OWFs, and 1.87% with the GWF. In 2020, the percentage overlap was much lower, with 0.98% of the 95% UD for all birds overlapping with OWFs, and just 0.33% with the GWF. Differences in trip statistics and the relative use of offshore areas and OWFs, including the GWF, may relate to the poorer breeding success seen at the Havergate colony in 2020, as Lesser Black-backed Gulls tend to forage offshore more when provisioning chicks. In both 2019 and 2020, offshore area use and thus overlap with the GWF and other OWFs was greater during trips that began in the daytime than those that began at night.

9. **Behaviours within the GWF and other OWFs.** Three methods (Hidden Markov Models (HMMs), Expectation Maximisation Binary Clustering (EMbC) and a Random Forest (RF) model) were used to understand behaviour based on data collected at a standard five minute sampling rate and at a fast-sampling rate of 5-10 seconds. Initial assessment showed a commuting corridor between the colony and the Galloper and Greater Gabbard Wind Farms, with offshore substations/service platforms within these sites being used regularly as resting/perching locations. Offshore foraging locations were identified between the colony and the GWF, within the GWF and beyond the GWF to the south-east. A 'foraging/searching' and 'floating' area was also identified within the northern section of the GWF, next to the GWF offshore substation/service platform, where two turbine rows were more separated. Generally, most time spent within OWFs was spent 'commuting' or foraging/searching and less time was spent 'stopped' or floating, which was in contrast to other areas offshore outside OWFs, where generally birds spent most time floating and commuting. This pattern, however, varied between method of classification used, and year and also between the Galloper and Greater Gabbard Wind Farms.

10. **Altitudes within the GWF and other OWFs.** Analysis of offshore altitudes was carried out using data acquired through both GPS and barometric pressure sensors and based on data collected at both five minute and 5-10 second rates. Analyses considered (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models. Estimates of the altitudes and the proportions of fixes within the RSZs of the Galloper and Greater Gabbard Wind Farms, and altitudes in areas outside of OWFs, are presented for all periods, the day-time and night-time. Mean altitudes estimated from GPS and barometric pressure sensor data were similar, when based on data collected at a five minute resolution. Mean overall altitudes were 8.91 m and 10.06 m respectively within the GWF, with an estimated 17% of all fixes within the GWF being within the RSZ. In contrast, at the 5-10 second resolution, mean altitudes estimated from GPS were consistently higher than those from pressure sensor data. Mean overall altitudes were 13.41 m and 8.54 m respectively within the GWF, with an estimated 23% of all fixes within the GWF being within the RSZ according to data from GPS, compared to 14% according to pressure sensor data. Altitudes were higher during the day than at night across both methods.

11. **Movements within the GWF and other OWFs.** While Lesser Black-backed Gulls showed little macro-avoidance of the Galloper and Greater Gabbard Wind Farms, and there was evidence of attraction to structures within these sites, analyses of movements within the Galloper and

Greater Gabbard Wind Farms suggested significant meso-avoidance of the turbine rows. No GPS fixes were recorded in the turbine rotor swept zones and the distribution of observed fixes within the three-dimensional space was significantly different from a random distributions of points.

12. **2019/20 Non-breeding season movements.** Additional data were collected on the wintering destinations and migration strategies of Lesser Black-backed Gulls over the 2019/20 non-breeding season. Birds reached destinations up to 3800 km from the Havergate colony in Western Sahara and Mauritania, with other wintering destinations including Morocco, Spain, Portugal; only one bird spent the non-breeding season in the UK.

13. **Comparison with historical datasets (Chapter 5).** Comparative analyses of the foraging trips, wind farm connectivity, area use and altitudes of Lesser Black-backed Gulls tracked during pre-construction studies undertaken between 2010 and 2015 (Thaxter et al., 2014b; RSPB, unpublished) at Havergate and Orford Ness are also presented. These results indicated that trip metrics, such as foraging distance offshore and trip duration, were similar in these earlier studies, albeit with variation between years and according to the duration of tag deployments (reflecting the different devices used). Further, while data collected in 2019 and 2020 provided evidence of attraction to structures within the Galloper and Greater Gabbard Wind Farms, the overall use of the GWF was also similar in these earlier studies.

14. **Conclusions (Chapter 6).** The tracking study undertaken in 2019 and 2020 revealed that Lesser Black-backed Gulls from the Alde-Ore Estuary SPA showed significant use of both the Galloper and Greater Gabbard Wind Farms, although overall use of the GWF was similar to pre-construction studies. While Lesser Black-backed Gulls showed little macro-avoidance of these sites, and there was evidence of attraction to substations/service platforms, analyses of movements within the Galloper and Greater Gabbard Wind Farms suggested significant meso-avoidance of the turbine rows.

1. INTRODUCTION

1.1 Background

1.1.1 Galloper Wind Farm

Galloper Wind Farm (GWF) is a 353 MW capacity operational offshore wind farm (OWF) located in the Outer Thames Estuary, approximately 27 km from the Suffolk coast. The offshore assets of GWF comprise 56 wind turbine generators, one offshore substation platform (OSP), subsea inter-array cables and two export cables. The wind farm array covers a total area of approximately 180 km^2 and became fully operational in March 2018.

The Marine Licence issued by the Marine Management Organisation (MMO) for the construction of GWF included ornithological monitoring requirements in order to identify and assess the impacts of the wind farm on key interest species. Pre-construction monitoring was undertaken in 2014 and 2015, the results and analysis of which are detailed in a pre-construction report (Goddard et al., 2016). Post-construction monitoring commenced in March 2019.

Ornithological monitoring requirements are prescribed through the GWF deemed Marine Licence (dML) Variation 3. Condition 18 of the dML specifies that post construction:

1. The undertaker shall, in discharging condition 10(2)(a), submit details for approval by the MMO of proposed post-construction surveys, including methodologies and timings, and proposed format, content and timings for providing reports on the results. The survey proposals shall specify each survey's objectives and explain how it will assist in either informing a valid comparison with the pre-construction position and enable the validation or otherwise of key predictions in the environmental statement.
2. The post-construction surveys shall comprise, in outline an ornithological survey covering the area(s) within the offshore Order limits in which construction works were carried out, and any wider area(s) where appropriate, which is required to test predictions in the environmental statement concerning key ornithological interests of relevance to the authorised scheme.

The Marine Licence conditions detailed above are designed to detect and measure any change in the key ornithological interest and test the predictions made in the GWF Environmental Statement (ES).

Specifically, the post-construction monitoring requirements of dML condition 18(2) (b) have been addressed by a combination of aerial surveys and a tagging and tracking study of the key interest species, Lesser Black-Backed Gulls *Larus fuscus*, so as to assess the impact of GWF on the population, distribution and activities of the species' breeding population from the Alde-Ore Estuary Special Protection Area (SPA).

1.1.2 Ornithological Monitoring Programme

The dML conditions have informed the five key objectives of the GWF Ornithological Monitoring Programme (OMP):

1. Assessing if or how Lesser Black-Backed Gull use of the array areas has significantly changed as a consequence of the operation of the GWF;
2. Assessing the ES assumption regarding the proportion of Lesser Black-Backed Gulls at collision risk which are from the Alde-Ore Estuary SPA breeding population;

3. Assessing the ES prediction that the operational wind farm has not had a significant impact on population size;
4. Providing a means to contribute to the understanding of how Lesser Black-Backed Gulls may or may not avoid operational wind turbines; and
5. Providing a means to further assess the proportion of the population flying at collision risk height.

The purpose of the OMP is to test the key predictions made in the GWF ES regarding ornithological interests relevant to the GWF development. The primary prediction to be tested through post-construction monitoring is that "there will be no significant impact on the population size of the Lesser Black-Backed Gull population as a result of the GWF development". The tagging and tracking programme has supported the aerial survey programme by providing information with regard to the response of and risks (collision risk, displacement, barrier effects) to the Lesser Black-Backed Gull breeding population of the Alde-Ore Estuary SPA (as the key ornithological interest) during the operational phase of GWF. The data and analysis resulting from this programme should therefore act as a means of supporting achievement of the five OMP objectives detailed above, and in turn enabling GWF Ltd (GWFL) to discharge the ornithological monitoring conditions of the dML.

1.2 Aims

This final report provides the results of the tracking study of Lesser Black-Backed Gulls from the Alde-Ore Estuary SPA. Tagging commenced in May 2019 and data collection continued through to September 2020, coincident with the post-construction aerial survey programme. The study thus aimed to provide data across both the 2019 and 2020 breeding seasons and the 2019/20 non-breeding season (and therefore across the species' full annual cycle). Comparison is also provided with data from pre-construction studies undertaken between 2010 and 2015 (Thaxter et al., 2014b; RSPB, unpublished).

Key deliverables from the tracking programme identified by GWFL were:

1. A tagging and tracking monitoring methodology to meet Condition 18 of the dML (V3) and the five OMP objectives;
2. Landowner permissions required to undertake tagging;
3. Relevant licences required to undertake tagging;
4. Tagging of 30 Lesser Black-backed Gulls in May/June 2019;
5. Tracking data from the tagged birds for a period of up to 18 months, through to September 2020;
6. An interim report after the first field season and a final programme report following completion of the tracking programme;
7. Data recorded during the tracking programme in an appropriate GIS-compatible format at the end of the first field season and upon completion of the tracking programme**.**

Specifically, in order for GWFL to be able to achieve the objectives of the OMP, the project aimed to produce data and analyses to provide an assessment of:

i. The area use of Lesser Black-Backed Gulls breeding at the Alde-Ore Estuary SPA and thus the relative time spent within the GWF;
ii. Their relative behaviours within and outside the wind farm;
iii. Their relative flight heights within and outside the wind farm; and
iv. Their movements within and outside the wind farm.

2. FIELD METHODS

2.1 Focal Species

Many seabird species are included as features of breeding colony SPAs and travel large distances at sea. All of these have the potential to interact with offshore structures, and may be exposed to risks that would otherwise not have existed within their natural environment. The Lesser Black-backed Gull (the UK sub-species of which is *Larus fuscus graellsii*) has been identified as one species that may be likely to interact with OWF areas (Garthe & Hüppop, 2004; Banks et al., 2005; Shamoun-Baranes & van Loon, 2006). Research using tracking devices to follow their movements has shown that they regularly travel up to 180 km offshore to forage during the breeding season, and so have the potential to travel through and forage within operational, consented, and proposed OWF areas (Thaxter et al., 2012). This research has also identified that the species may regularly fly at heights that put individuals at risk of interaction with the rotor swept area of offshore turbines (Ross-Smith et al., 2016; Thaxter et al., 2018b).

To inform the consenting process, an Environmental Impact Assessment (EIA) is conducted to assess the potential impacts of the key effects associated with OWF developments on seabird populations. When preparing applications for Nationally Significant Infrastructure Projects (NSIPs) in England or Wales, developers are legally required as part of the Habitats Regulations Assessment or Appraisal (HRA) process to consider if the project is likely to affect European protected / national sites.

If Likely Significant Effects (LSEs) on the features of a European protected site cannot be ruled out after HRA screening, the HRA report provided with the application should enable the competent authority to then carry out an Appropriate Assessment (AA). The purpose of the AA is to ascertain whether or not there are any Adverse Effects On Integrity (AEOI) on the relevant sites. These assessments determine whether populations within the site may be negatively affected by a development, for seabirds, typically through the use of demographic models.

Post-consent monitoring requirements within the licence conditions agreed with the regulatory authority are largely designed to detect any unforeseen impacts and validate predictions made in an EIA or HRA. With respect to birds, monitoring programmes have focused on at-sea surveys or, more recently, tracking programmes as a means to provide the data required to assess displacement or barrier effects and collision risk from operational wind farms and so to meet consent conditions.

The Lesser Black-backed Gull is a breeding qualifying feature of five SPAs in England, two in Scotland and one in Wales (Stroud et al., 2016), including the Alde-Ore Estuary SPA. Through tracking programmes, there is now a wealth of data available on Lesser Black-backed Gull movements and flight characteristics. These data are helping to provide a detailed picture of the variations in movements and habitat use between colonies, between years at the same colony, and between individuals within the same colony (Thaxter et al., 2015). While generic information from across colonies may be valuable (Thaxter et al., 2012), these variations are highlighting the need to continue gathering site-specific data to inform on potential impacts.

Interactions with GWF are most likely during the breeding season, when birds are foraging from their colony in the Alde-Ore Estuary SPA. During the non-breeding period, individuals may stay within the UK to winter or move abroad, most typically to southern Iberia / North Africa. Birds may also be vulnerable to collisions with wind farms in these areas and on their migrations (Thaxter et al., 2019).

2.2 The GPS Systems

To best enable data collection over the required study period and comparability with results from studies of Lesser Black-backed Gulls from the Alde-Ore Estuary SPA undertaken between 2010 and 2015 (Thaxter et al., 2014b; Thaxter et al., 2015; Ross-Smith et al., 2016; Thaxter et al., 2017; RSPB unpublished) and other recent projects (Thaxter et al., 2018a; Thaxter et al., 2018b), the tracking project in 2019 and 2020 was conducted using a mix of University of Amsterdam (UvA) tags (Bouten et al., 2013) (http://www.uva-bits.nl/gps-trackers/) and Movetech tags (http://movetech-telemetry.com/).

2.2.1 University of Amsterdam (UvA) tags

We used long-life high-performance GPS tags developed at the University of Amsterdam (University of Amsterdam Bird-tracking System, 'UvA-BiTS'). These are lightweight (~14g), medium sized (62 x 25 x 10 mm; length x width x height), solar-powered, high energy-efficient storage devices (model '5CDLE') that provide the highest temporal and spatial resolution data currently possible for a tag of this weight. The data collected therefore have the potential to allow analyses that can describe space use and behaviour in relation to individual turbines, as well as in relation to whole wind farms. Each tag consists of a GPS sensor, a microcontroller with a 4 Mb flash-memory, an accelerometer, a solar panel, a battery and a battery charger. A pressure sensor was also included as extra, to better enable measurement of flight heights. The tags include a two-way wireless VHF (Very High Frequency) transceiver that communicates to a central base station. Once the tags are deployed, GPS data can therefore be downloaded remotely through a field-based receiver and laptop. The functional data retrieval area of the central receiver was extended by deploying two relay antennae around the gull colony on Havergate Island within the Alde-Ore Estuary SPA (see section 2.3 for details of the study site), which amplified the range of the signal. The data from tags that were deployed on birds that came within range of this 'network' were automatically downloaded. Furthermore, new sampling rate settings and communication intervals could be uploaded remotely to specific tags through this network. This was advantageous as issues with battery performance during high sampling frequencies were noted after deployment, and so settings could be adjusted to mitigate for these issues post-deployment. This system overcomes some of the shortcomings in alternative commercial systems and, in particular, avoids the need for recapture of tagged birds to retrieve data.

A system of 'geofences' was used to vary GPS fix rates, and communication with the base station, to maintain the battery charge of tags and maximise data collection in line with the aims of the project. This allowed bespoke settings to be specified during the breeding season, to sample most frequently when birds entered 'geofenced' wind farms, at an intermediate fix rate when birds were otherwise away from the colony (but outside wind farms), and least frequently when birds were at the colony. Different settings were also applied during the non-breeding season. The geofences and associated settings are depicted in Figure 2.1, and are described in more detail in Appendix 1.

Two main temporal sampling rates were used during the breeding season while birds were away from the colony on foraging trips: (1) a five minute rate, and (2) a 'fast-sampling' rate based on rates of either 5 s or 10 s (hereafter '5-10 seconds'). Details of precisely how these were achieved through the UvA-BiTS software are depicted in Fig 2.1 and discussed further in Appendix 1. The five-minute protocol was the primary base sampling rate for UvA tagged birds when away from the colony and so covered all times of the day. However, data at the fast-sampling 5-10 second rate were collected either: (i) across the day when tags could manage to sample at this rate with a surplus battery charge (i.e. during sunlight) (Appendix 1, Fig 2.1), and (ii) within the specified geofence around OWFs as shown in Fig 2.1. In the latter case, the fast-sampling rate was specified for 03:00 to 21:00 UTC to avoid draining the tag's battery that would result in unwanted gaps in the temporal GPS record.

Consequently, the fast-sampling data represent a general bias to daytime activity. Fig 2.1 also shows fall-back options for safety-net approaches to data collection: this entailed specifying a percentage of the tag's memory (10%) that, should it be surpassed, switched the tag to collect data at a much coarser rate. Thus if birds for some reason left the colony early in the season, this would enable the battery and memory of the tag to be sustained, should the bird then return the following season and connect with the system, maximising tag efficiency and data collection in the longer term.

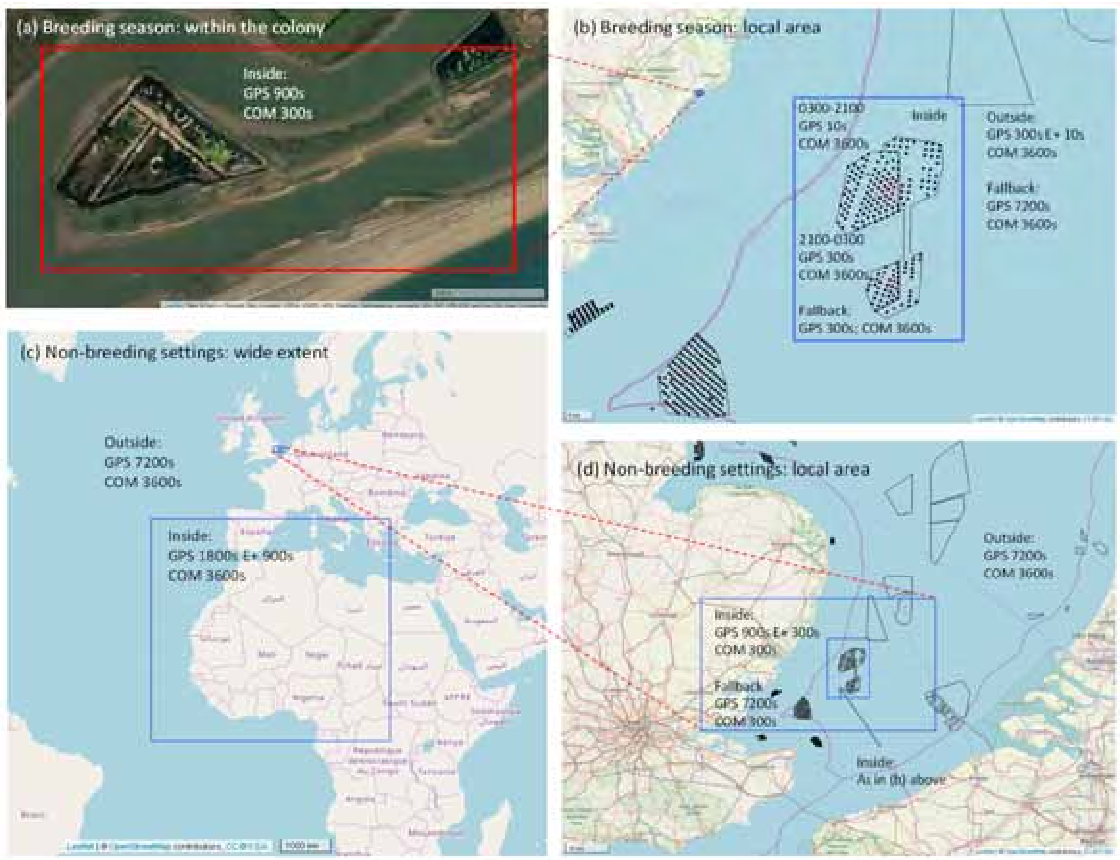


Figure 2.1 Depiction of GPS settings used for University of Amsterdam tags during the 2019 and 2020 breeding seasons (a and b), and those specified in July 2019 ahead of the non-breeding season (c and d). A combination of three geofences was used to vary schedules of GPS fix rates and communication ('COM') with the base station, to maintain the battery charge of tags and maximise data collection in line with the aims of the project. Energy surplus ('E+') settings were used to maximise data collection when tags were at maximum battery charge; 'fallback' options switched rates to coarser settings when data filled 10% of the memory (see Appendix 1).

The tags record both x,y locational and altitude data. Measurements of altitude in GPS systems are considered particularly error prone in terms of both precision (error around central estimate) and accuracy (deviation of the central estimate from the 'true' value). Ross-Smith et al. (2016) analysed data for Lesser Black-backed Gulls from Orford Ness and Great Skuas using a Bayesian modelling framework to incorporate these sources of uncertainty into the confidence limits around flight height distributions. The precision of GPS altitude measurements is greater with faster sampling; a recent analysis of data from South Walney, Cumbria, found that a precision of between 3-5 m and 10-16 m per bird was possible for data collected at sampling rates of 10 s and 16 s respectively (Thaxter et al., 2018b). Therefore, to enable a secondary, more precise measure of flight height, a pressure sensor was incorporated into the UvA tags. A total of 10 barometric pressure measurements were taken per GPS fix (see sections 3.5 and 4.6 for more detail of analyses of flight heights).

We also collected 20 acceleration measurements per GPS fix that, through a machine-learning classification method previously developed for this species (Shamoun-Baranes et al., 2016), allowed behaviour to be classified (see sections 3.4 and 4.5 for more detail on analyses of behaviours).

2.2.2 Movetech GPS-GSM tags

Movetech Telemetry Flyway-18 tags were also used for this project. These are GPS devices that download their stored data over the mobile phone (GSM) network, and are solar recharging. They can therefore download data anywhere with GSM signal, and are not limited to data downloads to a stationary base-station, as the UvA tags are. They have been developed by Movetech (a consortium of scientific partners involving the University of East Anglia, cE3c from the Faculty of Sciences of the University of Lisbon, CIBIO/InBIO from the University of Porto and the BTO), and report data on date, time, GPS location (and the number of satellites used to triangulate this), acceleration, external temperature, ground speed, height above a standard ellipsoid, and battery voltage. The tags weigh between 17.5 and 19 g, with height-length-width dimensions of 15 x 60 x 26.5 mm. Tags of this weight cannot be deployed on birds that are lighter than 800 g, for licensing reasons, and so cannot be deployed on lighter female Lesser Black-backed Gulls. These tags do not include pressure sensors, but altitude estimates can be calculated from the GPS data using methods as described in Scragg et al*.* (2018) and Ross-Smith et al*.* (2016).

When deployed in May 2019, all Movetech tags were set to collect GPS data every 60 minutes between 05:00 and 20:00BST, and every 180 minutes between 20:00 and 05:00 BST. Once it was established that the solar recharging capacity of the tags was sustaining this data collection rate, all Movetech tags were rescheduled to collect data every 30 minutes between 04:00 and 21:00 BST, and every 90 minutes between 21:00 and 04:00 BST. The tags remained on these settings until late-November, when there was no longer enough consistent solar energy to recharge the batteries and sustain this higher rate. The tags were then rescheduled to collect data every 60 minutes between 05:00 and 21:00 BST, and every 90 minutes between 21:00 and 05:00 BST, which was sustained through the winter season. At the beginning of June 2020, all tags were rescheduled to collect data every 30 minutes between 04:00 and 21:00 BST, and every 90 minutes between 21:00 and 04:00 BST. The batteries sustained this rate until 10th September 2020, when all tags were again rescheduled to collect data every 60 minutes between 05:00 and 21:00 BST, and every 90 minutes between 21:00 and 05:00 BST.

Table 2.1 Summary of tag types used, the information obtained using each, along with their function and means of data collection/transmission to the user.

Tag type	Data	Fast-sampling fixes inside geofence (fine-scale behaviour)	Remote data transmission	Download range	Battery	Duration
University of Amsterdam (UvA)	x,y location, GPS and pressure sensor altitude, speed, acceleration,	Yes	Yes – VHF	Local base station (*e.g.* 4 km)	Lithium + solar	2-4 years
Movetech	x,y location, GPS altitude, speed, acceleration	No	Yes – GSM	GSM mobile cellular download, no range limit	Lithium + solar	2 years +

2.3 Study Colony and UvA System Deployment

Two previous tracking studies of Lesser Black-backed Gulls have been undertaken at the Alde-Ore Estuary SPA. The first, which ran from 2010-14, was funded by the Department for Energy and Climate Change (DECC, now the Department for Business, Energy and Industrial Strategy, BEIS) Offshore Energy Strategic Environmental Assessment (OESEA) programme, was based at a colony on Orford Ness. A second, shorter study was undertaken in 2010 and 2011 by the Royal Society for the Protection of Birds (RSPB) as part of a project funded jointly by the RSPB and NE, under the "Action for Birds in England (AfBiE)" partnership, with birds tagged both at Orford Ness and neighbouring Havergate Island, also within the Alde-Ore Estuary SPA.

Orford Ness was the primary colony within the SPA at the time of designation, although the size of the colony here has decreased markedly from historical numbers of 14,070 Apparently Occupied Nests (AONs) in 1994-1998 at the time of designation[1], to 5,500 AONs during the last national seabird census in 2001 (Mitchell et al., 2004) and 550 AONs in 2010 (Marsh, 2013; https://app.bto.org/seabirds/public/index.jsp). By 2018, there were just 239 AONs at Orford Ness (data for 2017-18: National Trust), with 77 pairs breeding within the Lantern Marsh colony used in the 2010-14 study (Marsh, M., pers. comm.). In 2019, there were no AONs on the ground at Lantern Marsh and across Orford Ness, the few breeding Lesser Black-backed Gulls remaining all nested on the roofs of buildings, which were inaccessible. In contrast, numbers on Havergate Island have increased: in 2010, there were 1,053 AONs and, in 2019, 1,670 AONs (https://app.bto.org/seabirds/public/index.jsp).

Given the shift in colony distribution from Orford Ness to Havergate, it was only practical to catch and tag Lesser Black-backed Gulls for this study on Havergate Island. Site managers at Havergate (RSPB) gave the appropriate permissions to work on the island (site and RSPB scientific project approval), and the necessary SPA permissions were gained from Natural England. Site managers also identified suitable areas for the work to take place, which were easily accessible for tagging, would enable

[1] http://jncc.defra.gov.uk/pdf/SPA/UK9009112.pdf

appropriate placement of the UvA VHF relay system, and would allow subsequent monitoring. Figure 2.2 displays the three distinct sections of the colony where tagging took place, and the placement of the UvA VHF network.

A VHF receiver and relay system for the UvA tags was set up on Havergate Island by the RSPB warden and BTO staff in 2019, with energy to charge the laptop and receiver provided by the RSPB's onsite wind turbine. The remote relays were charged by 12v batteries which needed to be replaced once during the data collection period in 2019. At the end of the 2019 breeding season the UvA system was taken down and stored over winter. It was redeployed in early-March 2020 as adult Lesser Black-backed Gulls returned to the island. An extra relay was placed north-east of the laptop and receiver in order to collect data from a gull that had moved north-east on the island to breed. The UvA system remained in place until early-September when all UvA tagged birds had stopped connecting to it.

Figure 2.2 Location of the three distinct sections of the Havergate colony where tagging took place in 2019, and the location of the UvA network system.

The densest nesting in the colony occurred in an area known as "Dovey's", which is thought to be the core of this colony, and is where the first eggs were laid in 2019 and 2020. The "Pit" area at the edge of this colony, is thought to be slightly less optimal, and nests here were established and eggs laid later than in the Dovey's area. This slight difference is reflected in the first egg hatching dates presented in Appendix 2.

2.4 Catching and Tagging in 2019

Through funding from GWFL, the sample size required to characterise area use for Lesser Black-backed Gulls from Orford Ness had previously been assessed (Thaxter et al., 2017), concluding that a minimum of 13 birds and a maximum of 41 birds were needed to describe 95% of the estimated area use of the population, for a period of 145 days. The 41-bird value may be considered as an upper precautionary number, and comparisons of results indicated that the number of birds actually tracked in the 2010-14 study (24) was sufficient to characterise area use for that population. To ensure a robust overall sample from the Havergate Island colony, 30 adult Lesser Black-backed Gulls were caught and tagged; 15 of these were tagged with UvA tags and 15 with Movetech tags.

When catching Lesser Black-backed Gulls on Havergate Island, the same catching techniques were used as in the 2010 and 2011 study at Orford Ness, at Skokholm (part of the Skokholm and Skomer SPA) in 2014 (Thaxter et al., 2014a), at South Walney (in the Morecambe Bay and Duddon Estuary SPA) and Barrow-in-Furness between 2014 and 2018 (Thaxter et al., 2018b), at the Bowland Fells SPA between 2015 and 2017 (Clewley et al., 2017) and at the Ribble between 2016 and 2019 (Scragg et al., 2016; Scragg et al., 2018), which proved very successful. Individuals were caught during late incubation or the very early chick-rearing phase of the breeding season, when adults are relatively reluctant to spend time away from the nest. A cage nest trap of small mesh chicken wire with a funnel entrance was placed over the nest and monitored continuously by observers until a bird walked inside and was captured. Traps were only set over nests that contained two or more eggs which were being incubated (warm eggs). Birds enter the trap through the funnel entrance and then settle down on the eggs until they are retrieved. Using these methods it is possible to set multiple (2-6) traps on multiple nests simultaneously, and capture up to six adults at one time. This method reduces the number of times the colony needs to be disturbed in order to capture the required number of individuals. Once captured, the bird's biometric measurements were taken, and a total of 30 birds in suitable condition were fitted with a tag, a numbered metal ring and a colour-ring, inscribed with a unique code, to enable subsequent identification in the field.

As the intended data collection period – i.e. 18 months, covering both the 2019 and 2020 breeding seasons and 2019/20 non-breeding season – spanned multiple feather-moult periods for this species, it was not possible to attach the tags to feathers directly. Therefore, the most suitable long-term tag deployment method was using a harness design, which has proven effective for Lesser Black-backed Gulls in the past (Thaxter et al., 2014a; Thaxter et al., 2016). Previous studies have used a harness that remains attached to the bird for its whole life (permanent-harness), unless it can be recaptured to have it removed. This has proved very effective, but does mean that if the bird cannot be recaptured it will retain the harness and tag for a long time after the tag ceases to collect data. This creates potential long-term welfare issues, and so a new weak-link harness design has been developed. This is intended to work exactly the same as a permanent-harness, but should safely detach from the bird after a period of 3 months to ~5 years, depending on the weak-link material used. The material used can be adjusted such that the harness detaches in a timeframe that is approximately equivalent to the expected functioning lifespan of the tag being used. This design ensures that birds do not have to be recaptured in order to remove the harness and tag once the data collection period has ended. Overall, this design should be better for the welfare of the individual carrying a tracking device, compared to permanent harnesses. Details of the weak-link harness design and the trials used to develop it can be found in Thaxter et al*.* (2014a), Thaxter et al*.* (2016) and Clewley et al*.* (2021). All 30 harnesses fitted on Havergate Island in 2019 were of a piping cord weak-link harness design. Tags were fitted under licence approval from the independent Special Methods Technical Panel (SMTP) of the BTO Ringing Committee.

In order to assess any potential effects of tagging on the birds' welfare – a requirement of licencing by the SMTP – the breeding success and survival of tagged birds were compared to those of a matched cohort of control birds. The control sample included further birds captured during the study, and also fitted with a metal ring and a colour-ring, and additional birds previously colour-ringed as part of a long-term monitoring study at the site. Details of the results of the monitoring undertaken to assess these potential effects are provided in Appendix 2.

A summary of the birds caught and tagged on each field day in 2019 is presented in Table 2.2. Appendix 3 contains a full list of all individuals caught, associated ringing and biometric data collected, and the types and weights of the tags deployed on them (where applicable).

Table 2.2 Summary of the numbers of Lesser Black-backed Gulls caught during the study on Havergate Island in 2019. A break-down of the numbers of birds fitted with a harness and tracking device (tagged), and those that were not tagged (control), is presented. M: Movetech tag; U: UvA tag.

Date	Total tagged	Total control	Total caught
20/05/2019	3 (3M)	5	8
21/05/2019	7 (5M, 2U)	4	11
22/05/2019	10 (7M, 3U)	4	14
23/05/2019	10 (10U)	10	20
Total	**30 (15M, 15U)**	**23**	**53**

On the 20th May 2019, a team of four people caught 10 adult gulls (8 Lesser Black-backed [LB] and 2 Herring Gulls *Larus argentatus* [HG]) between 10:00 and 16:00 BST at the Pit (Figure 2.2). On 21st May, a team of six people caught 12 gulls (11 LB, 1 HG) between 09:00 and 14:30, at Dovey's. On 22nd May, a team of five people caught 15 gulls (14 LB, 1 HG) between 09:30 and 14:30, again in the Dovey's area. On 23rd May, a team of eight people caught 26 gulls (20 LB, 6 HG). These were caught at Dovey's between 08:00 and 09:00, and then along the Ridge (Figure 2.2) between 09:30 and 15:00. The catching efforts were moved away from the Dovey's area after it was noted that some birds, from nests where traps had not been set, were taking longer than normal to return to their nests, and that some eggs, from unknown nests, were being predated. It was deemed that that area of the colony had been disturbed too much over the previous days, so the catching operations were moved away to avoid further disturbance.

Nine individuals that were caught on these days were already ringed (see Appendix 3). Two had been ringed by other ringing groups as adult gulls: one (colour-ring code: BXBX) at Milton Tip, near Cambridge, on 19th March 2013, the other (BXBA) at Castle Hill, near Ipswich, on 24th April 2002. BXBA was fitted with a Movetech tag, and the majority of its movements were between Havergate Island and this same original catching area in Castle Hill. One (BZBB) had been ringed as a chick on Orford Ness on 14th July 1996. The rest of the re-trapped birds had been ringed as chicks (before fledging) in previous breeding seasons on Havergate Island; one in 2012 (DCDJ), one in 2013 (LCLW), and four in 2014 (NFNT, NUNF, NSNZ, NDNU). All of these six birds were tagged. We can therefore be certain of the age of six tagged birds, and (including birds previously colour-ringed at Havergate and included in the control sample) of eight control birds.

3. ANALYTICAL METHODS

This final project report considers the data collected from both the 2019 and 2020 breeding seasons, providing separate results for each, and also provides a summary of additional data collected during the 2019/20 non-breeding season. A summary of the data collected during each period and the results of the analyses outlined here are contained in Section 4.

To provide an initial overview of the movements of birds, we first assessed:

i. Foraging ranges and the duration of individual foraging trips;
ii. The connectivity of individual birds with the GWF (and other operational, consented or proposed OWFs);

Specifically, the analyses then focused on the main aims of the project:

iii. The area use of Lesser Black-Backed Gulls breeding at the Alde-Ore Estuary SPA and thus the relative time spent within the GWF (and other operational, consented or proposed OWFs);
iv. Their relative behaviours within and outside the wind farm.
v. Their relative flight heights within and outside the wind farm; and
vi. Their movements within and outside the wind farm.

While the focus is on GWF, results are also presented for other operational, consented or proposed OWFs, including those under construction, with particular consideration given to the adjoining Greater Gabbard Wind Farm.

Results of comparative analyses of the foraging trips, wind farm connectivity and area use of birds tracked during (a) the 2010-2015 study at Orford Ness (Thaxter et al., 2014b) and (b) by the RSPB from Orford and Havergate in 2010 and 2011 are presented in Section 5. All data manipulation, spatial visualisation and analysis were conducted in R v 4.0.3 (R Core Team, 2020).

3.1 Trip Statistics

Trips were defined as the departure and subsequent return of individuals to the area defined as the 'colony'. As gulls may use a number of areas within the colony in addition to the nest site, e.g. loafing and bathing sites, the 'colony' was defined by a shapefile that encompassed all nest sites monitored as part of this project, and the known local areas that were regularly used for maintenance activities such as bathing and preening. Figure 3.1 displays this colony shapefile. This colony definition was used for birds tagged with Movetech or UvA devices, despite not aligning with the 'geofence' used to define the colony area by the UvA tags (see Figure 2.1a and section 2.2.1 above), and was defined based on visual inspection of the data, and site knowledge gained during the 2019 and 2020 breeding seasons. The UvA 'geofence' was set before these information sources were available. As such, arrival and departure was gauged through departure from and arrival to this shapefile around the functional breeding colony. A trip was deemed incomplete if there was a gap of five or more hours in the data whilst the bird was on a trip (outside the colony shapefile). For all complete trips (no data gap ≥5 hours), statistics were calculated: on (a) trip duration (time elapsed between departure and return); (b) foraging range (the maximum point reached from the colony); (c) foraging distance (distance travelled on the entire trip); and (d) offshore foraging range (the maximum point reached offshore from the colony). A local R package 'BTOTrackingTools' (Thaxter, 2020) was used to assign trips to the GPS data.

Figure 3.1 Visualisation of the bespoke shape that was used around the Havergate colony to delineate when birds were deemed to be "at the colony" for the purposes of defining trips to and from the colony.

3.2 Connectivity of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA with the GWF and Other Offshore Wind Farms

The tracks of all birds for which data were available in the 2019 and 2020 breeding seasons were overlain onto maps showing OWFs and assessed for 'connectivity'. An individual bird was defined as showing connectivity with a wind farm if GPS fixes from at least one trip were located within the wind farm polygon. Instances where interpolation between GPS fixes suggested transit through wind farm areas were also considered. Results are presented separately for connectivity with operational wind farms and those under construction.

Shapefiles for the Galloper and Greater Gabbard Wind Farms (and the export cable corridor between the two Galloper sections) were provided by GWFL, while details of the areas of other OWFs were downloaded from EmodNet[2]. The connectivity with these shapefiles was then assessed using the local R package 'BTOTrackingTools' (Thaxter, 2020).

3.3 Area Use of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA and Overlap with the GWF and Other Offshore Wind Farms

A time-in-area (TIA) approach was used to assess area utilisation in each of the 2019 and 2020 breeding seasons. This method has previously been used in studies of other seabirds (Soanes et al., 2013; Soanes et al., 2015), and specifically for the assessment of sample size required to characterize area use for Lesser Black-backed Gulls from Orford Ness by Thaxter et al. (2017) and in a previous study at South Walney and Barrow-in-Furness funded by Ørsted. This analysis focused on observations

[2] https://www.emodnet.eu/emodnet-datasets-to-support-wind-farm-projects

during trips only and thus the areas that might have been used for foraging and other activities away from the colony.

The TIA approach is analogous to the kernel density estimate (KDE) point-based area approach that is widely used to assess spatial area use (Worton, 1989). However, the TIA method is based on a key metric of relevance (i.e. time) within a grid cell extent. Grid cell size can have an effect on the size of the eventual area produced under the TIA approach (Soanes et al., 2015); such choices always need care and attention at the outset of assessing area utilisation. Here, following Thaxter et al. (2017), a grid cell size of 2 x 2 km was used. The value of 2 km was deemed most suitable for determining wider-scale area use and potential use of OWFs after testing both smaller (1 km, see Soanes et al. 2013) and larger (e.g. 4 km) grid cell sizes; too small values eventually represent the individual lines of the bird's movement paths, and too large values result in overly coarse patterns that mask the general pattern of area use variation across the local area. The grid cell parameter is an important choice also in kernel density analysis, and so all spatial approaches require a level of judgement by the analyst when determining appropriate scales to characterise area use. For each individual bird tracked, the time-spent in grid cells that overlapped with trips away from the colony was computed, excluding portions of trips that had gaps in coverage. For this purpose, the open source R package 'trip' and a local custom R package 'BTOTrackingTools' (Thaxter, 2020) were used, which provide functions for accessing and manipulating spatial data from animal tracking datasets based on line segment interaction with pixels of a raster image. Although other methods for interpolating between points are available, here Sumner (2016) methods were used, along with linear interpolation. The individual grid cells were then ranked according to the time that birds spent in them, from the most time to the least. Cumulatively adding squares together, starting with those squares that contributed the most to bird space-time budgets, we then defined areas representing the birds' 50% (core), 75%, 95% and 100% utilisation distributions. Although any occupancy levels can be selected using these approaches, those chosen reflect the frequently used levels within traditional KDE analyses (e.g. Thaxter et al., 2015). Complexity can arise using the TIA approach if only a few squares are used by birds. However, instances in which just a single grid square represented a bird's 50% core occupancy area were very rare.

Based on the utilisation distributions defined above, each individual's relative use of the areas of operational, consented and proposed wind farms was then assessed. This analysis was carried out by assessing the overlap between GIS wind farm polygons with the 2 x 2 km grid, with the relevant grid cells comprising the respective occupancy levels.

Utilisation distributions and overlaps with wind farm areas were calculated separately for each individual and also for all birds combined in each year separately, providing a total population-level (all-bird) perspective for each year.

Separate analyses of diurnal and nocturnal area use were also undertaken. As the TIA approach is conducted at the level of individual trips (R package 'trip', Sumner, 2016), this required a decision on how to classify trips. First, R package 'suncalc' (Thieurmel & Elmarhraoui, 2019) was used to classify individual GPS fixes as 'day' or 'night' based on sunrise and sunset (time at which sun is first fully above the horizon in the morning and begins to set in the evening; thus 'night' here encompasses civil, nautical and astronomical twilight phases). The start time of each trip was then taken to define whether they were in the day or night; we note this method is approximate and inevitably some trips began in one period and ended in the other (ca. one third of trips). Thus, results should be interpreted as reflecting the conditions when trips started, rather than that all movements belonged to one phase or another.

All GIS and area usage analyses were conducted using 4.0.3 (R Core Team, 2020), and R package 'BTOTrackingTools' (Thaxter, 2020), with the R package 'trip' (Sumner, 2016).

3.4 Behaviours of Lesser Black-Backed Gulls Within and Outside the GWF and Other Offshore Wind Farms

In order to investigate behaviour in more detail, data taken at least every five minutes, and of high quality were required; thus, only data collected from UvA tags were suitable (see sections 2.2.1 and 2.2.2 for details of the GPS sampling rates of tags). The analysis was therefore focused on 15 birds. However, only a subset of these birds used the offshore environment and, in turn, OWFs. During 2019, three birds did not travel offshore, or provided too few offshore data to be included in analyses, meaning the effective sample size for 2019 was reduced to 12 birds. In 2020, 10 birds carrying UvA tags were available for behavioural analysis, of which eight birds provided sufficient data offshore. Of these, just 10 and four birds actually entered OWFs in 2019 and 2020 respectively (10 individuals in total across the two years) and provided sufficient data for the analyses of behaviour within OWFs.

Different methods applied to the same data may provide different behavioural classifications (Thaxter et al., in prep), and it is thus worthwhile exploring more than just a single approach. We therefore considered three different methods to assess the behaviour of gulls within and outside the GWF and other OWFs. These were (a) Hidden Markov Models, (b) Expectation Maximisation binary Clustering and (c) a machine-learning classification approach using accelerometry, with a Random Forest model (Shamoun-Baranes et al., 2016), all of which were based on movement metrics.

3.4.1 Hidden Markov model

A Hidden Markov Model (HMM) is a state-space continuous time movement approach that includes a 'hidden' component modelled as a Markov process, that allows states to be estimated by the relationships to an 'observed component' of the model (in this case, based on the step length between GPS fixes and turning angle). As a pre-requisite, this analysis required that time steps between consecutive GPS fixes were at a constant 'regularised' sampling rate, such that time steps were precisely the same for all points.

Data were regularised to a constant spatial and temporal spacing using R packages 'crawl' (Johnson et al., 2008) and 'momentuHMM' (McClintock & Michelot, 2018). The 'crawl' model was used to fit a correlated random walk through locations (Johnson et al., 2008), and further allowed interpolative prediction of points at five minute intervals. Although the focus of the project was on movements offshore and within OWFs, the HMM was run for both onshore and offshore data for completeness, however, separate models were used for each, given use of each environment may result in quite different characteristics of behaviour. Here, onshore was defined by an isopleth contour of 2 m bathymetry, converted to a spatial shape, and merged (union) with a further UK low-tide shape; this procedure ensured that 'inshore' coastal areas, such as around local tributaries, and estuaries were treated as 'onshore', and all fixes falling outside this shape were thus defined as offshore.

The R package momentuHMM (McClintock & Michelot, 2018) was used to fit a four-state HMM, using a gamma distribution for step lengths and a von Mises distribution for turning angles in R V 4.0.3 (R Core Team, 2020). The four states characterised were: (1) perching (stationary); (2) floating; (3) commuting; and (4) foraging/searching. Parameter starting values for the step length between fixes (i.e. essentially a 'speed' given the constant sampling rate as above) and turning angle for each state were specified as follows:

(1) Perching: step length: 50±50 m SD; turning angle: mean, 0 radians; kappa = 1 (the latter being the concentration parameter of von-Mises distribution);
(2) Floating: step length: 200±100 m SD; turning angle: mean, 0 radians; kappa = 50;
(3) Commuting: step length: 3000±800 m SD; turning angle: mean, 0 radians; kappa = 30;

(4) Foraging/searching: step length: 800±600 m SD; turning angle: mean, 0 radians; kappa = 1.

A single model was run across all birds for both years combined, and distinguished slow variable movements (high spread of turning angles across the distribution, sinuous) from faster straighter movements (low spread of turning angles and a concentrated kappa distribution).

3.4.2 Expectation-maximisation binary clustering

A second approach was also used to identify the same four-level behavioural states described above for the HMM. Expectation-Maximisation Binary Clustering (EMbC) is a further state-space approach that uses a Gaussian mixture model (see Garriga et al., 2016 for more details). Unlike the HMM, the EMbC approach does not strictly need a regularised interpolated dataset, as it based on GPS speed and turning angle rather than distance within a constant time period. The EMbC model by default allows classification of four states grouped by: low speed, low turn ('LL', = floating); low speed, high turn ('LH' = stopped); high speed, low turn ('HL' = commuting); and high speed, high turn ('HH' = potential foraging/searching). By using the maximisation expectation algorithm, the EMbC approach seeks the most optimised split in the data, but does not require prior information for perceived delineations for each category as with HMMs above. The EMbC approach, however, is best applied on a reasonably regular dataset, i.e. without excessively variable sampling resolutions, and so the data were filtered to a rate of five minutes, for a comparable assessment to the HMMs above. An additional classification was also produced based on data collected at very fast-sampling.

As with HMMs (sections 3.4.1), the EMbC approach was run for both onshore and offshore environments separately for completeness, although as the focus of this work was offshore, onshore classifications are not used further.

3.4.3 Random forest accelerometer classification

A further 'Random Forest' (RF) model was also used to assess behaviour using accelerometer and instantaneous speed data. Developed by the University of Amsterdam, this approach used field-based monitoring at a colony at Texel in the Netherlands to ground-truth behaviour classifications for a portion of data, and so 'train' the model to extrapolate classifications to the remainder of the dataset(Shamoun-Baranes et al., 2016). As a caveat/limitation, therefore, the Netherlands model is here assumed to be representative of and 'transferable' to other colonies. This model has previously been 'transferred' to a study at South Walney funded by Ørsted colony with very good results, and the same model was thus also used to provide an alternative classification of behaviour here. The approach classifies GPS fixes into 10 activities (Floating on a water body 'float'; perched on a boat 'Boat'; stationary 'SitStand'; 'Pecking'; Terrestrial locomotion 'TerLoco'; flapping flight 'flap'; soaring flight 'soar'; mixed flight and adjusting body position 'manoeuvre'; extreme flapping flight 'ExFlap'; and an 'other' category for unclassified behaviours <1% data). The model uses data on tri-axial acceleration – surge (*x*), sway (*y*) and heave (*z*) – recorded by the GPS tags (e.g. Shamoun-Baranes et al., 2016) alongside instantaneous speed (m/s). It has a key advantage over HMMs and EMbC in being able to provide an instantaneous classification for each GPS fix, and thus potentially at a much finer temporal resolution, independent of the sampling rate of the tags. However, it is difficult to translate the finer-scale behaviours from this classification to more intuitive high-level groupings, e.g. of 'foraging' activity, as can be approximated from HMMs and EMbC (Thaxter et al., in prep).

3.4.4 Summarising behaviour within the GWF and Other Offshore Wind Farms

The results of each analysis were used to assign a behavioural state to each GPS fix. The proportion of time spent in each behaviour within the GWF and other OWFs, as well as outside of wind farms whilst offshore was then assessed based on either: (a) the summed number of fixes within OWFs (for classifications based on data at five minute rates) or (b) sums of time gaps between successive fixes within OWFs (for classifications based on data at 5-10 second rates).

Variation in behaviours across the day and breeding season, as indicated by Julian date, was also considered. For these analyses, GPS fixes were binned into hours and five-day periods respectively.

3.5 Altitudes of Lesser Black-Backed Gulls within and outside the GWF and Other Offshore Wind Farms

Offshore flight heights of Lesser Black-backed Gulls were examined using data collected from both the 2019 and 2020 breeding seasons. Analyses aimed to provide a comparison of altitudes inside and outside of wind farms, with specific focus on the Galloper and Greater Gabbard Wind Farms. In addition, altitudes were compared between diel periods of night and day. As above in the assessment of behaviour, analyses utilised the higher frequency data collected from UvA tags and from those birds that used the offshore environment and, in turn, OWFs. Examination of flight height incorporated all altitudes, which included data from periods where birds were potentially present on the sea surface.

Two technological methods of recording altitudes were combined within the tag deployments: GPS receivers and barometric pressure sensors. To assess the applicability of these differing methods, altitudes produced though GPS receivers were compared to measurements derived from barometers. Separate analyses considered data collected at high (5-10 second) and low (five minute) fix rates. Understanding altitudes recorded at differing sampling rates may have implications for the assessment of macro- or meso-scale movements in relation to turbines.

Barometric Pressure Conversion

Barometric pressure sensors recorded a mean value of pressure for each fix, derived from a series of 10 pressure values recorded at a rate of 10 Hz. This range of values is taken to allow for the potential error in the pressure sensor: the highest and lowest values are first removed, and then the mean of the remaining eight values is used to represent pressure at the location. Altitude based on barometric pressure was calculated using the following equation reproduced from Cleasby et al. (2015) and Lane et al. (2019, 2020):

$$h = \frac{KT}{mg} \, ln\left(\frac{P}{P_0}\right)$$

h = altitude (m);
K = universal gas constant for air (8.31432 N m mol^{-1} K^{-1});
T = temperature (K) of the atmosphere between h_0 and h;
m = molar mass of air (0.0289644 kg mol^{-1});
g = acceleration due to gravity (9.80665 m s^{-2});
P_0 = atmospheric pressures (Pa) at sea level;
P = atmospheric pressures (Pa) at height h (m).

Values of Mean Sea Level pressure (P_0) were obtained from the European Centre for Medium Range Weather Forecasts (ECMWF) 'ERA5' reanalysis model. Hourly P_0 values were extracted from the ERA5 model from a grid of 30 km^2 resolution (ECMWF, 2019). The nearest values of P_0 in space and time were then matched to the GPS fixes. An additional step to calibrate P_0 was carried out using values of barometric pressure recorded by the tag deployment during periods when birds were presumed to be on the sea surface. These 'floating' periods were inferred using the EMbC behavioural definitions of states 1 (floating) and 2 (stopped) based on velocity and turning angle between successive fixes (see section 3.4.2). Values of mean sea-level pressure attained from ERA5 were then corrected using the nearest available observed value of sea surface pressure. This step was a cautionary step to account for potential in error in ERA5 pressure values, specifically to account for divergent drift over time between the recordings made by the pressure sensor and ERA5 P_0 values. Due to the potential for the accuracy of the tag recorded P_0 to decrease with time since the last floating bout, a threshold of 1 day from the last floating bout was set, beyond which values were excluded from analysis.

Formatting by tidal height and diel period

Data on tidal height were used to correct possible variation in GPS altitude related to the phase of the tide. Tidal height data for Harwich – the nearest available tidal gauge – were provided by the British Oceanographic Data Centre (BODC 2021). Tidal heights above Chart Datum were recorded at a 15 minute temporal resolution. Tidal heights were converted to elevation in relation to mean sea-level by calculating daily means, and then averaging these means to monthly mean sea-levels (Danielle Edgar pers. comm.). Period of day and night were defined using limits of sunrise and sunset derived from the R package: suncalc (Thieurmel & Elmarhraoui, 2019). All presented estimates of altitude are therefore measured in relation to the sea surface, i.e. not Mean Sea Level (MSL) or Lowest Astronomical Tide (LAT).

Estimation of the proportion of fixes within the rotor swept zone (RSZ)

The proportions of fixes within the rotor swept zones (RSZs) of the Galloper and Greater Gabbard Wind Farms were calculated (for those GPS fixes which overlapped with the boundaries of those windfarms) based on each site's turbine blade parameters. Estimates were produced based on heights estimated both relative to the actual sea surface and MSL baselines, with differences potentially expected for altitudes based on pressure measurements as they reflect actual sea surface pressure (see above).

Blade heights are measured in relation to lowest astronomical tide (LAT). Thus, blade heights were first converted to actual sea level (considering the tidal height above LAT concurrent to the time of each GPS fix from the LAT blade height) and to MSL (considering the mean tide height above LAT). Altitudes and the proportions of fixes within RSZs were then compared across wind farms and diel periods of night and day.

Comparison of altitudes between all behaviours and periods in flight only

Analyses of altitudes considered both (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2). In the latter case, EMbC behavioural classifications indicative of commuting (state3, high speed, low turn angle) and foraging/searching (state 4, high speed, high turn angle) were considered.

3.6 Movements Within the GWF and Other Offshore Wind Farms

The behavioural analysis outlined in section 3.4 above was used further to assess the three-dimensional use of space within the GWF and other wind farms in more detail and consequently meso-avoidance. Here, we followed the approach of Thaxter et al. (2018a) and visualized the GPS fixes recorded within the Galloper and Greater Gabbard Wind Farms in relation to distance to nearest wind turbine and altitude, thus presenting as a two-dimensional x,y plot representing three-dimensional space. We used the EMbC unsupervised behavioural classification for three-dimensional assessments, rather than the HMM, as the HMM in using an interpolated method for behavioural distinction essentially decouples covariate data from the original GPS fixes, i.e. flight altitude. While covariates could validly be matched to the nearest fix which, this may also introduce some error into the distribution. Results from the RF model were also used to provide a comparative visualisation of behaviours within the wind farms.

We initially visually assessed the potential attraction of birds to structures within the OWFs using behavioural classification and high-resolution data at 5-10 seconds. For example, potential perching activity on turbine bases and other platforms such as offshore service platforms (OSPs) and metmasts may be indicated by fixes classified as 'stopped' by the EMbC model, and classifications of 'SitStand' (or 'Pecking'), from the supervised RF model.

Kernel density estimation (KDE) was then used to produce a space utilisation distribution (UD) surfaces (with contours at steps of 5% from 0-100%) within the three-dimensional space, for each behavioural class from the EMbC model, using R package MASS and function kde2d (Venables & Ripley, 2002). As in Thaxter et al. (2018a), the three-dimensional rotor swept volumes of individual turbines were also plotted (depicted as semi-circles) using specific metrics of turbines in each of Galloper (hub-height above lowest astronomical tide (LAT): 101.33 m, maximum blade tip height above LAT: 180.5 m), rotor diameter: 154 m) and Greater Gabbard (hub-height above LAT: 77.5 m, maximum blade tip height above LAT: 131 m, rotor diameter 107 m). The same turbine specifications were also used when assessing the proportion of fixes within the RSZs (lower blade tip height to upper blade tip height); the RSZs for Galloper and Greater Gabbard Wind Farms were further corrected for tidal variation (see above) to allow a common dynamic baseline measure in relation to the sea surface for both the fix of the bird and the RSZs. To assess meso-avoidance behaviour within the wind farms, the overlaps of the 95% KDE contour, representing total space use, and the rotor swept volumes for each OWF were assessed, and a simple randomisation t-test was applied to assess whether the observed tracks within OWFs for individual birds differed to a random background distribution that assumed birds showed no avoidance.

Finally, we assessed the directions of flights within OWFs, based on fixes defined as 'commuting' by the EMbC model. This assessment provided a quantification of the overall travel directions through the wind farm, depicted as a rose plot, and we further repeated the three-dimensional quantification of space use for commuting flights split by 0-360 quadrants. This assessment was useful to identify differences in space use and thus meso-avoidance according to whether birds were travelling outward from the breeding colony, in mid-trip or returning to the colony.

3.7 Summary of 2019/20 Non-breeding Season Movements

The GPS tags deployed collected data continuously from deployment in May 2019 to the end of the breeding season in 2020 (September 2020). As well as collecting movement data in and around Havergate and the GWF during the breeding season, they also collected data during the birds' migration and the non-breeding season.

All tracked birds moved away from Havergate during the non-breeding season, and no interactions with the GWF or other UK OWFs were recorded during this period. Information is presented on the duration of data collection and number of GPS fixes, that in turn informed how far birds travelled from the breeding colony (straight-line distance), the total distance travelled, and approximate main over-wintering destinations by country. Maps are also presented of the tracks of all birds during the period they were away from the breeding colony, which demonstrate the variability in migration distances and overwintering locations for these birds.

3.8 Comparison with Historical Datasets

Following the methods described in sections 3.1-3.3, we also provide a summary of the trip statistics, connectivity with the GWF and other OWFs, and area use of Lesser Black-backed Gulls from the Alde-Ore Estuary SPA, using data from the 2010-14 study based at Orford Ness (Thaxter et al., 2014b) and a second study undertaken in 2010 and 2011 at Orford Ness and Havergate Island (RSPB unpublished). The former study used UvA tags and the latter, short-term tesa tape mounted deployments of ‘igotU’ tags.

4. RESULTS

4.1 GPS Data Collected for Lesser Black-backed Gulls Tracked in 2019 and 2020

Data analysed in this chapter relate to the period when birds were linked to their breeding colony, at Havergate, in 2019 and 2020. During this defined breeding period, the movements of birds may vary considerably, with offshore movements most likely during the chick-rearing period (Thaxter et al., 2015). Due to breeding failures, and the difficulty in assessing precisely when the chick rearing stage ended for individual birds, particularly in 2020, this period will also have encompassed some post-breeding movements. In 2020, some pre-breeding movements may also be included, as gulls returned to the colony for brief periods before returning again to nest.

In 2019, a total of 2363.1 'bird-days' of tracking data were collected from 30 birds, of which 2187.1 days of data were useable for further analysis. In 2020, a total of 2431.2 'bird-days' of data were collected from 19 birds, of which 2085.1 days of data were useable for further analysis (Table 4.1). Therefore, despite the smaller sample in 2020, useable data from both years covered approximately the same number of days. However, in 2019 data collection began during incubation, in the last week of May, whereas the 2020 data encompassed the entire breeding period, from first arrival back at the colony. Useable data are those which have a date-time and location associated with them, which includes data at the nest as well as outside the colony.

During the 2019 breeding season, the mean tracking duration across individual birds was 78.8 ± 27.6 days (range 2.1 - 150.5 days), whereas in 2020 it was 128.0 ± 41.5 (range 41.6 – 197.8 days). The difference in tracking data length in each year again reflects the difference in breeding cycle period covered. The end dates reported reflect the date at which each bird left the colony area for over-wintering areas.

The disparity in the number of GPS fixes collected by each tag type (Table 4.1) is worth noting. The batteries in the UvA tags were capable of maintaining a much higher data frequency rate within geofence areas (i.e. within wind farms), which provided many more GPS fixes overall, compared to Movetech tags. This higher fix rate enabled the more detailed analysis of behaviour, flight height and movement presented in sections 4.5 - 4.7.

Table 4.1 Data collection periods over the 2019 and 2020 breeding season for Lesser Black-backed Gulls fitted with GPS tags on Havergate Island. Data came from both Movetech (MT) and University of Amsterdam (UvA) tags.

		2019					2020				
Tag type	**Tag ID**	**Start/tagging date**	**End date**	**Data duration (days)**	**Usable data (days)**	**GPS fixes**	**Start/return date**	**End date**	**Data duration (days)**	**Usable data (days)**	**GPS fixes**
MT	1107	22/05/2019 18:26	18/08/2019 21:31	88.1	11.2	277	13/04/2020 02:06	08/06/2020 09:18	56.3	1.2	31
	1108	21/05/2019 12:09	26/07/2019 04:41	65.7	44.9	1001	Stopped transmitting 05/05/20 on return migration. Seen Havergate 27/05/20.				
	1109	20/05/2019 16:49	08/08/2019 07:21	79.6	69.0	1430	16/04/2020 17:48	31/08/2020 03:20	136.4	98.7	2127
	1111	21/05/2019 15:41	06/08/2019 03:32	76.5	74.5	1935	05/04/2020 15:01	07/09/2020 03:32	154.5	37.3	1313
	1112	21/05/2019 16:34	25/07/2019 02:26	64.4	53.0	834	Stopped moving Norfolk 25/07/2019				
	1113	22/05/2019 16:44	20/10/2019 05:43	150.5	142.3	4266	Likely powerline collision 20/10/2019 05:43				
	1116	22/05/2019 10:13	12/08/2019 03:26	81.7	80.6	2219	30/04/2020 14:16	08/08/2020 16:18	100.1	99.3	2992
	1117	22/05/2019 16:03	29/07/2019 01:55	67.4	65.5	1665	Stopped transmitting Setubal 12/09/19				
	1118	21/05/2019 13:16	23/05/2019 14:34	2.1	2.1	33	Stopped transmitting Havergate 23/05/19. Seen alive Spain 06/10/20.				
	1119	20/05/2019 16:11	01/09/2019 03:29	103.5	100.7	2665	Died on return migration 03/05/20				
	1120	20/05/2019 14:54	23/08/2019 04:55	94.6	91.4	2549	23/04/2020 19:59	09/09/2020 04:17	138.3	128.1	2841
	1122	21/05/2019 16:13	09/08/2019 02:01	79.4	77.9	1956	14/03/2020 15:13	13/08/2020 03:38	151.5	149.2	3617
	1123	22/05/2019 12:08	20/08/2019 03:30	89.6	89.4	2427	06/04/2020 11:26	11/08/2020 03:32	126.7	122.7	3326
	1125	22/05/2019 18:03	19/08/2019 22:52	89.2	74.1	2041	24/03/2020 17:42	23/08/2020 03:35	151.4	139.4	3507
	1127	22/05/2019 13:00	31/08/2019 04:53	100.7	97.7	2512	14/03/2020 15:32	28/09/2020 11:10	197.8	191.0	4726
UvA	5863	23/05/2019 14:09	28/06/2019 12:40	35.9	35.6	16461	Died Havergate (botulism) 19/06/2019				
	5865	23/05/2019 12:23	25/06/2019 10:06	32.9	31.7	8297	-	-	-	-	-
	5866	21/05/2019 12:50	12/08/2019 00:47	82.5	80.7	39351	-	-	-	-	-
	5868	23/05/2019 10:06	06/07/2019 04:55	43.8	42.0	32411	-	-	-	-	-
	5870	23/05/2019 14:37	23/09/2019 05:07	122.6	122.6	40036	01/05/2020 18:24	12/06/2020 07:56	41.6	41.3	11962
	5872	23/05/2019 16:25	28/08/2019 02:17	96.4	96.4	47907	19/04/2020 00:46	09/06/2020 05:39	51.2	49.7	12017
	5873	21/05/2019 14:46	19/08/2019 03:44	89.5	89.2	32890	06/03/2020 19:40	02/08/2020 11:19	148.7	141.3	21303

		2019					2020				
Tag type	**Tag ID**	**Start/tagging date**	**End date**	**Data duration (days)**	**Usable data (days)**	**GPS fixes**	**Start/return date**	**End date**	**Data duration (days)**	**Usable data (days)**	**GPS fixes**
	5874	23/05/2019 11:32	24/07/2019 07:39	61.8	61.3	44383	12/03/2020 20:38	06/08/2020 04:51	146.3	144.4	63816
	5875	23/05/2019 10:31	08/08/2019 03:36	76.7	76.1	18712	07/03/2020 18:27	07/08/2020 05:07	152.4	147.6	43020
	5876	22/05/2019 15:39	18/08/2019 01:45	87.4	86.4	28421	-	-	-	-	-
	5877	23/05/2019 13:26	15/09/2019 05:06	114.7	112.2	39562	28/03/2020 10:10	27/08/2020 06:39	151.9	148.0	32358
	5880	23/05/2019 10:14	02/08/2019 03:56	70.7	70.1	34847	18/03/2020 19:34	02/08/2020 03:24	136.3	134.3	19357
	5881	22/05/2019 13:35	13/08/2019 03:20	82.6	79.0	29349	20/04/2020 21:44	02/09/2020 22:55	135.0	62.0	3724
	5969	23/05/2019 15:44	22/07/2019 03:28	59.5	59.1	35847	04/04/2020 17:07	23/06/2020 16:25	80.0	77.9	25643
	5970	22/05/2019 14:12	03/08/2019 14:02	73.0	70.3	54883	20/02/2020 09:40	13/08/2020 03:44	174.8	171.8	72648
Average		**22/05/2019 11:49**	**09/08/2019 06:18**	**78.8 ± 27.6**	**72.9 ± 29.7**	**17706 ± 17932**	**31/03/2020 17:32**	**06/08/2020 16:34**	**128.0 ± 41.5**	**109.7 ± 50.2**	**17386 ± 20994**

4.2 Trip Statistics for Lesser Black-backed Gulls Tracked in 2019 and 2020

In 2019, 4,593 foraging trips, of which 4,340 were complete, were recorded for 30 Lesser Black-backed Gulls tracked from Havergate Island. Statistics for these trips are summarised in Table 4.2a. A total of 253 incomplete trips were recorded, with at least a 5 hour gap in the data on a trip, which were therefore excluded from analyses. Of these incomplete trips, 224 were from Movetech tag data, and 29 were from UvA tag data. In total, 32 of these incomplete trips were during offshore foraging trips (27 Movetech, 5 UvA), when OWF interactions may have occurred. Some trips were for local movements to coastline areas which may have been trips for the gull to perform maintenance activities, i.e. preening/bathing, rather than foraging trips. The data are not detailed enough to ascertain what behaviours were exhibited during these trips, so they have not been included in analyses for consistency.

In 2020, 4,423 foraging trips, of which 4,266 were complete, were recorded for 19 Lesser Black-backed Gulls. Statistics for these trips are summarised in Table 4.2b. A total of 157 incomplete trips were recorded, of which 125 were from Movetech tag data, and 8 were from UvA tag data. Of these incomplete trips, 16 were during offshore foraging trips (8 Movetech, 8 UvA). Again, despite the variation in sample size between years, a similar number of complete trips were recorded in each year.

In 2019, 25 of the 30 Lesser Black-backed Gulls made at least one offshore trip, and on average the offshore foraging range from the colony was 31.5 ± 27.0 km (max 178.2 km). This is longer on average than onshore foraging trips (mean: 10.7 ± 12.1 km; max 154.4 km). This offshore versus onshore difference was also recorded in 2020, where 17 of the 19 birds made at least one offshore trip. In 2020 the average offshore foraging range was 21.3 ± 19.1 km (max 88.7 km) compared to the average onshore foraging range of 7.6 ± 8.8 km (max 103.4 km). This suggests that these gulls will travel further to forage when offshore, than when making onshore feeding trips.

On average in 2019 foraging trips lasted for 5.2 ± 16.2 hours (max 889.9 hours), covering an average total distance of 31.1 ± 47.6 km (max 919.0 km). In 2020 the average trip lasted less time, at 3.6 ± 5.4 hours (max 137.2 hours), and shorter total distances, at 19.5 ± 26.8 km (max 137.2 hours).

The maximal values of trip duration (and correspondingly distance travelled) are extreme values that represent movements at the start or end of the breeding season, pre- or post-breeding. Such values are common when viewing trip metrics of birds across the full season, i.e. while birds are associated with the colony. The 889.9 hours was from bird 1119 (Movetech tag) that made a very long trip later in the season in 2019. Other birds in 2019 made some longer excursions over 100 hours (Table 4.2), thus protracted absences are to be expected when viewing the movements of birds across the entire March-October time-frame.

For comparison with the movements shown by tag data, the numbers of Lesser Black-backed Gulls colour-ringed at Orford Ness and Havergate from 2010-2021, the numbers resighted and the numbers resighted within East Anglia, during March-August, are shown in Tables A3.2-3.4 in Appendix 3. These resighting data are restricted to onshore locations.

Table 4.2 Foraging statistics for Lesser Black-backed Gulls tracked from Havergate Island during the 2019 and 2020 breeding seasons; totals are calculated across all trips and all birds. MT = Movetech tags, UvA = University of Amsterdam tags.

(a) 2019

Tag type	Tag ID	N trips [incomplete]	N offshore trips [incomplete]	Trip duration (hrs) mean+SD (max)	Foraging range (km) mean+SD (max)	Total distance per trip (km) mean+SD (max)	Offshore foraging range (km) mean+SD (max)	Onshore foraging range (km) mean+SD (max)
MT	1107	29 [18]	0 [5]	2.9±1.3 (5.3)	10.0±10.1 (30.2)	20.2±20.6 (60.7)	-	10±10.1 (30.2)
	1108	92 [45]	3 [5]	6.3±3.7 (18.5)	8.8±13.1 (88.3)	19.0±28.2 (191.4)	50.3±33.1 (88.3)	5.7±2.2 (11.0)
	1109	180 [28]	26 [3]	4.1±3.0 (21.8)	13.2±16.0 (82.9)	29.1±40.0 (224.5)	42.8±17.9 (82.9)	6.5±5.5 (30.9)
	1111	155 [8]	3 [1]	4.6±3.1 (18.0)	11.4±9.6 (60.2)	25.2±23.3 (145.3)	35.8±23.3 (59.7)	10.8±8.6 (60.2)
	1112	117 [36]	15 [11]	6.6±4.1 (30.8)	20.7±20.7 (77.5)	48±54.7 (230.7)	29.4±24.1 (77.5)	16.8±19.2 (53.8)
	1113	203 [30]	4 [0]	9.0±5.1 (21.4)	8.8±5.1 (23.5)	20.8±13.2 (59.4)	5.7±3.0 (9.2)	8.7±5.1 (23.5)
	1116	232 [2]	23 [0]	3.5±2.6 (16.5)	9.7±12.3 (79.7)	21.0±28.2 (202.8)	34.6±24.9 (79.7)	6.4±5.1 (38.2)
	1117	93 [3]	0 [0]	7.5±14.9 (137.4)	13.7±11.7 (60.6)	31.6±33.0 (229.4)	-	13.7±11.7 (60.6)
	1118	5 [0]	0 [0]	3.1±1.3 (5.2)	5.0±1.0 (6.4)	10.6±2.8 (14.9)	-	5.0±1.0 (6.4)
	1119	85 [9]	2 [0]	18.5±101.5 (889.9)	23.5±5.6 (31.8)	55.9±70.6 (654.2)	2.8±1.7 (4.0)	23.5±5.6 (31.8)
	1120	155 [12]	7 [2]	8.7±13.6 (111.9)	13.2±9.8 (48.6)	31±29.6 (172.1)	33.9±14.4 (48.6)	11.6±8.4 (37.3)
	1122	235 [6]	1 [0]	4.6±3.6 (25.4)	9.8±7.0 (42.6)	22.3±17.3 (105.5)	2.8	9.7±7 (42.6)
	1123	198 [0]	15 [0]	5.0±3.7 (17.8)	14.1±12.4 (68.7)	30.9±28.4 (154.7)	44.6±17.8 (68.7)	11.1±8.1 (43.0)
	1125	166 [15]	0 [0]	5.1±3.9 (18.7)	11.5±6.4 (37.3)	25.8±16.8 (89.3)	-	11.5±6.4 (37.3)
	1127	147 [12]	8 [0]	5.5±3.6 (16.1)	8.7±9.1 (66.6)	18.8±20.5 (164.7)	26.7±24.1 (66.6)	7.3±5.7 (30.7)
UvA	5863	45 [1]	6 [0]	3.1±3.7 (24.0)	19.5±10.6 (54.4)	46.1±26.5 (136.0)	36.3±16.6 (54.4)	15.0±7.7 (20.3)
	5865	98 [1]	0 [0]	2.1±1.6 (8.3)	5.0±4.2 (22.0)	10.3±10.3 (60.5)	-	5.0±4.2 (22.0)
	5866	312 [3]	13 [0]	2.1±2.9 (17.0)	8.5±6.7 (38.7)	20.7±18.4 (127.6)	10.0±9.5 (31.4)	8.3±6.5 (38.7)
	5868	135 [1]	21 [0]	2.4±3.1 (18.0)	9.5±11.8 (60.0)	25.5±34 (173.8)	20.6±20.6 (60.0)	6.9±7.7 (32.6)
	5870	192 [0]	28 [0]	8.2±16.5 (159.4)	16.0±15.9 (86.1)	48.2±61.1 (454.8)	21.0±23.2 (86.1)	14.2±14.0 (83.2)
	5872	152 [0]	27 [0]	7.9±25.7 (298.9)	19.1±21.5 (91.8)	52.5±77.1 (639.0)	44.5±24.4 (91.8)	11.8±15.5 (60.8)
	5873	299 [1]	8 [0]	2.9±5.5 (65.2)	11.6±11.1 (58.5)	28.5±30 (207.3)	9.6±8.0 (20.6)	11.6±11.1 (58.5)
	5874	141 [1]	16 [0]	4.7±8.9 (69.0)	16.1±20.4 (97.5)	43.0±72.6 (595.1)	39.5±27.7 (97.5)	12.4±17.4 (78.2)
	5875	110 [1]	1 [0]	5.0±6.6 (33.1)	14.7±22.6 (121.9)	36.4±53.9 (287.3)	8.1	14.7±22.6 (121.9)
	5876	135 [2]	1 [0]	4.5±14.0 (158.5)	7.4±13.3 (154.4)	20.2±42.5 (487.8)	12.2	7.4±13.3 (154.4)
	5877	284 [3]	10 [0]	4.5±7.4 (61.7)	12.3±13.2 (94.0)	32.4±40.4 (344.3)	25.1±19.3 (61.5)	11.6±12.6 (94.0)
	5880	129 [2]	6 [0]	5.1±7.4 (40.1)	16.6±22.8 (95.3)	42.7±60.7 (316.6)	19.3±25.7 (68.7)	15.8±22.4 (95.3)
	5881	125 [5]	21 [3]	8.1±13.1 (75.1)	22.7±29.6 (178.2)	71.6±136.5 (919.0)	56.0±48.6 (178.2)	16.1±19.3 (88.1)
	5969	149 [2]	13 [2]	3.9±4.3 (34.2)	6.4±7.7 (69.2)	17.6±21.3 (169.3)	13.0±9.6 (34.3)	5.7±7.1 (69.2)
	5970	195 [6]	22 [0]	4.5±9.4 (85.8)	14.2±18.7 (86.0)	39.4±63.9 (531.4)	31.5±26.6 (86.0)	11.8±16.4 (81.9)
All birds		**4593 [253]**	**300 [32]**	**5.2±16.2 (889.9)**	**12.4±14.5 (178.2)**	**31.1±47.6 (919.0)**	**31.5±27.0 (178.2)**	**10.7±12.1 (154.4)**

(b) 2020

Tag type	Tag ID	N trips [incomplete]	N offshore trips [incomplete]	Trip duration (hrs) mean+SD (max)	Foraging range (km) mean+SD (max)	Total distance per trip (km) mean+SD (max)	Offshore foraging range (km) mean+SD (max)	Onshore foraging range (km) mean+SD (max)
MT	1107	5 [1]	0 [0]	3.2±0.9 (4.1)	3.9±2.0 (5.3)	7.6±4.2 (10.5)	-	3.9±2.0 (5.3)
	1109	179 [48]	5 [1]	3.9±2.4 (16.4)	8.4±9.7 (57.9)	17.9±22.6 (169.8)	41.2±14.9 (57.9)	6.9±6.9 (34.3)
	1111	88 [8]	2 [1]	2.4±1.9 (12.6)	6.3±6.3 (34.3)	13.3±14.4 (83.5)	34.3±0.1 (34.3)	5.6±4.5 (29.2)
	1116	242 [3]	7 [2]	4.4±4.0 (18.3)	6.3±5.2 (55.1)	13.7±12.5 (119.2)	19.0±17.6 (55.1)	5.8±3.8 (16.5)
	1120	233 [17]	14 [4]	5.7±5.0 (38.7)	11.1±11.0 (72.6)	24.3±25.6 (181.5)	29.0±26.9 (72.6)	9.2±7.8 (36)
	1122	267 [5]	1 [0]	3.8±2.8 (19.4)	5.4±4.4 (27.8)	11.4±10.2 (66.4)	5.3	5.4±4.4 (27.8)
	1123	225 [0]	5 [0]	3.0±2.0 (13.3)	7.5±5.8 (45.7)	15.3±13.2 (111)	22.6±16.5 (45.7)	7.0±4.9 (33.5)
	1125	257 [25]	1 [0]	4.7±3.7 (17.1)	9.5±5.0 (33.7)	21.3±12.9 (78.5)	3.1	9.5±5 (33.7)
	1127	415 [18]	13 [0]	3.8±4.4 (62.6)	7.2±8.8 (92.4)	15.3±19.8 (193.5)	25.3±18.2 (62.9)	6.5±7.6 (92.4)
UvA	5870	92 [0]	2 [0]	2.1±1.8 (11.3)	7.2±3.5 (22.3)	16.6±10.1 (55.6)	5.1±4.2 (8.1)	7.1±3.5 (22.3)
	5872	109 [0]	5 [0]	2.0±1.3 (6.9)	8±6.2 (38.0)	19.8±15.4 (100.6)	23.1±15.1 (38.0)	7.0±4.5 (30.9)
	5873	252 [2]	3 [0]	4.1±7.0 (83.6)	11.5±13.9 (101.7)	28.6±39.0 (333.6)	15.5±12.1 (28.5)	11.4±13.9 (101.7)
	5874	367 [5]	30 [5]	2.8±3.9 (38.8)	9.9±12.0 (88.7)	24.0±32.1 (236.3)	26.6±23.7 (88.7)	7.9±8.9 (71)
	5875	248 [5]	3 [2]	3.6±5.0 (43.1)	10.1±12.8 (95.4)	25.3±37.3 (338.9)	6.6±4.4 (11.7)	10±12.8 (95.4)
	5877	261 [4]	6 [0]	4.4±10.2 (137.2)	10.1±9.6 (59.8)	27.2±32.4 (304.1)	18.3±14.7 (38.3)	9.9±9.3 (59.8)
	5880	309 [5]	0 [0]	2.7±7.0 (81.5)	6.7±11.7 (103.4)	15.1±32.0 (328.7)	-	6.7±11.7 (103.4)
	5881	167 [9]	12 [0]	6.7±7.9 (48.0)	8.3±12.2 (66.5)	23.5±39.1 (289.7)	36.9±19.9 (59.7)	6.1±7.7 (66.5)
	5969	327 [2]	27 [1]	2.7±6.3 (90.4)	5.4±7.5 (59.4)	13.2±23.1 (209.3)	10.5±6.4 (27.9)	5.0±7.2 (59.4)
	5970	380 [0]	22 [0]	2.8±4.6 (58.9)	9.0±10.6 (68.7)	22.5±28.0 (242.4)	12.5±10.0 (38.0)	8.4±10.4 (68.7)
All birds		**4423 [157]**	**158 [16]**	**3.6±5.4 (137.2)**	**8.3±9.8 (103.4)**	**19.5±26.8 (338.9)**	**21.3±19.1 (88.7)**	**7.6±8.8 (103.4)**

4.3 Connectivity of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA with the GWF and Other Offshore Wind Farms.

During the 2019 breeding season, a total of 19 (63%) of the 30 Lesser Black-backed Gulls tracked from Havergate Island showed connectivity with OWF areas, all of which showed some connectivity with existing operational OWFs. All of these birds interacted with the Greater Gabbard Wind Farm, which is closest to the colony, and 17 interacted with GWF (Table 4.3a and Figure 4.1). The data in Table 4.3a display which operational wind farms, or wind farms under construction, each tracked individual displayed connectivity with. In addition to this, several individuals also showed connectivity with areas that currently have consent applications submitted, but which do not actually have physical structures within them yet. Seven individuals (1107, 1109, 1112, 1116, 1120, 5881, 5970) interacted with the East Anglia Two proposed area, two individuals with the Norfolk Vanguard proposed area (1108, 5881), and one (5881) also interacted with the East Anglia One and Norfolk Boreas proposed areas (Figure 4.1).

In the 2020 breeding season, 11 (59%) of the 19 tracked Lesser Black-backed Gulls showed connectivity with operational OWFs. All of these interacted with both the Galloper and Greater Gabbard Wind Farms (Table 4.3b and Figure 4.1). No interactions with wind farms under construction were recorded.

Table 4.3 Connectivity between Lesser Black-backed Gulls tracked from Havergate Island in the Alde-Ore Estuary SPA during the (a) 2019 and (b) 2020 breeding seasons and offshore wind farms. Wind farms are denoted as (1) operational; (2) partial generation/under construction; (3) under construction; and (4) all (operational and under construction). Connectivity is here defined as there being a GPS point (p) within the wind farm polygon, or where the straight line (l) route between two points passes over the wind farm polygon.

(a) 2019

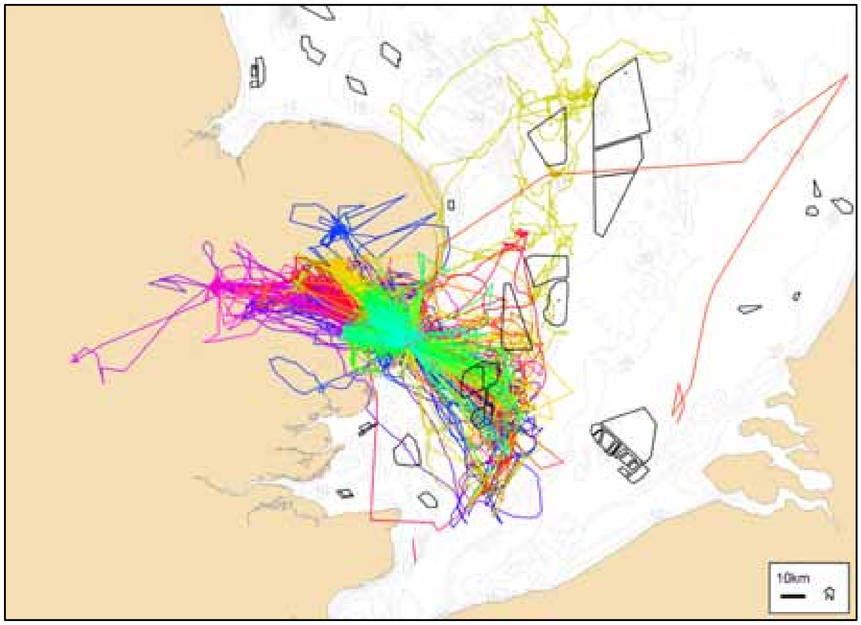
Tag ID	Galloper[1]	Greater Gabbard[1]	London Array[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[4]
1107		p	l					**2**
1108	p	p			l	l *	l *	**5**
1109	p	p						**2**
1111	l	p						**2**
1112	p	p						**2**
1113								**0**
1116	p	p						**2**
1117								**0**
1118								**0**
1119								**0**
1120	p	p						**2**
1122								**0**
1123	p	p						**2**
1125								**0**
1127	l	p						**2**
5863	p	p						**2**
5865								**0**
5866								**0**
5868	p	p						**2**
5870	p	p						**2**
5872	p	p						**2**
5873								**0**
5874	p	p	p					**3**
5875								**0**
5876								**0**
5877	p	p						**2**
5880	p	p						**2**
5881	p	p			p			**3**
5969		p						**1**
5970	p	p		l				**3**
All	**17**	**19**	**1**	**1**	**1**	**1**	**1**	**19**

* Interaction over more than 5 hours between GPS fixes

(b) 2020

Tag ID	Galloper[1]	Greater Gabbard[1]	London Array[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[4]
1107								**0**
1109	p	p						**2**
1111	p	p						**2**
1116	l	l						**2**
1120	p	p						**2**
1122								**0**
1123	p	p						**2**
1125								**0**
1127	p	p						**2**
5870								**0**
5872	p	p						**2**
5873								**0**
5874	p	p	p					**3**
5875								**0**
5877	p	p						**2**
5880								**0**
5881	p	p						**2**
5969	p	p						**2**
5970								**0**
Total	**11**	**11**	**1**	**0**	**0**	**0**	**0**	**11**

(a) 2019



(b) 2020

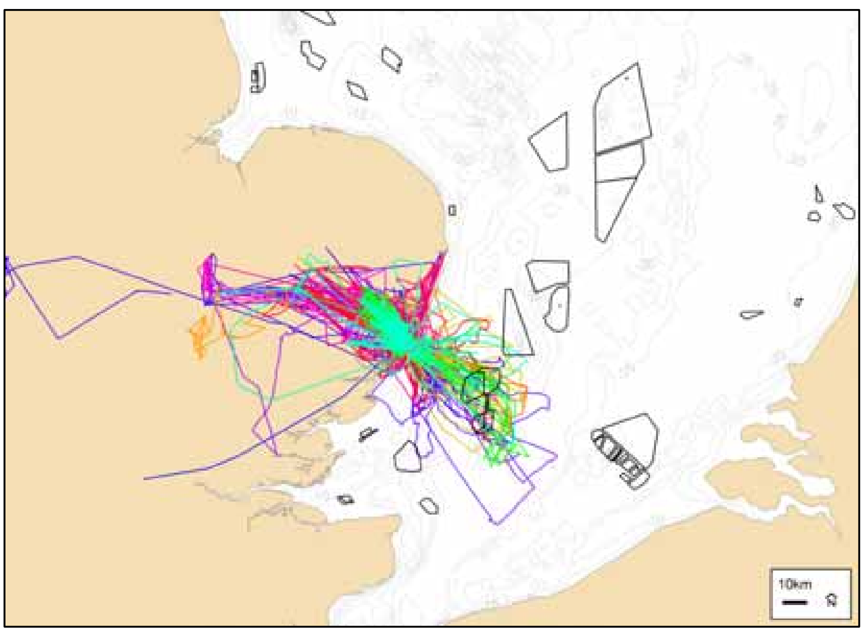
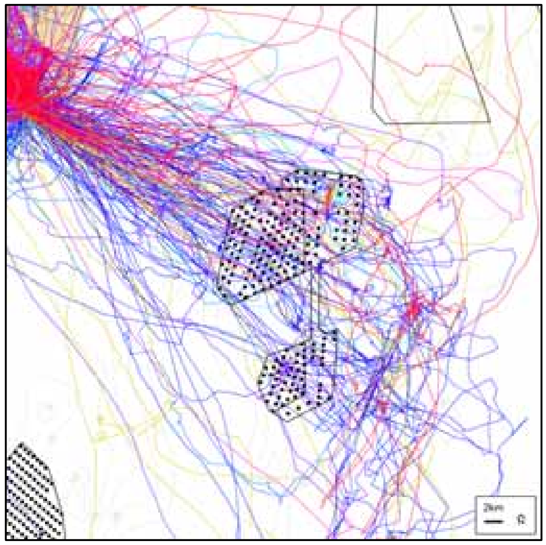
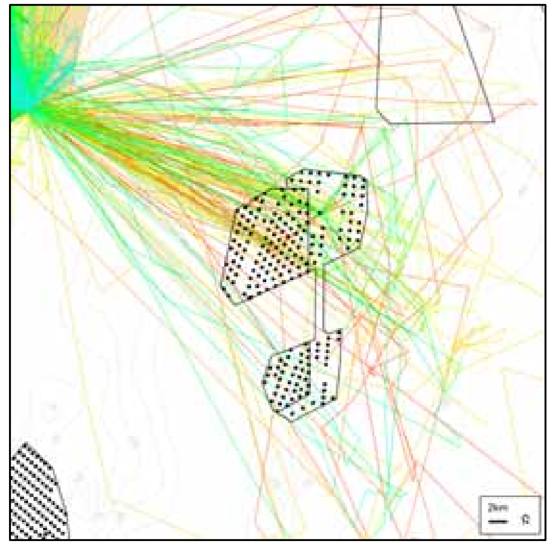


Figure 4.1 All tracking data collected from Lesser Black-backed Gulls tracked from Havergate Island during (a) the 2019 breeding season and (b) the 2020 breeding season. This displays the connectivity with all planned (sites for which the consent application has been formally submitted), authorised, under construction and operational offshore wind farms in the southern North Sea.

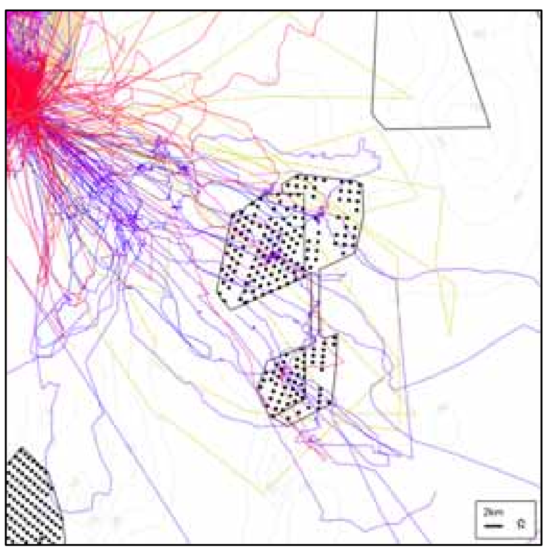
(a) UvA 2019



(b) MT 2019



(c) UvA 2020



(d) MT 2020

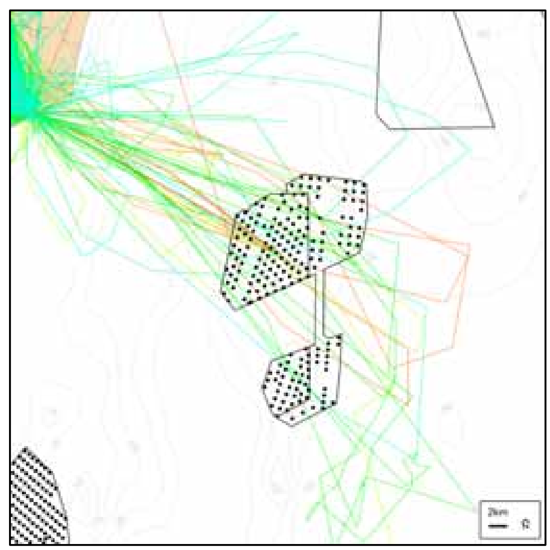


Figure 4.2 All tracking data collected on the movements of Lesser Black-backed Gulls between Havergate Island and the Galloper and Greater Gabbard Wind Farms during the 2019 breeding season (a & b) and the 2020 breeding season (c & d), split also by tag type (UvA[a & c] or Movetech [MT: b & d]). This displays the strong connectivity between the colony and these offshore wind farms.

4.4 Area Use of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA and Overlap with the GWF and Other Offshore Wind Farms

Percentage overlaps of the 50%, 95%, and 100% Utilisation Distributions (UD) with the areas of OWFs were calculated for each individual bird, as well as from an all bird 'population' analysis. Results for 2019 are presented for analyses using all data (including all behaviours, e.g. foraging, resting, commuting) whilst birds were on trips away from the colony, and are detailed in Table 4.4a. Results for 2020 are presented in Table 4.4b.

In 2019, 4.30% and 2.66% of the 95% and 100% UDs respectively for all birds overlapped with areas of operational or under-construction OWFs. The majority of temporal overlaps with OWFs occurred with Galloper and Greater Gabbard Wind Farms, with only single individuals interacting with other operational wind farms. Only one bird overlapped with a wind farm in its 50% UD (5874 with Greater Gabbard). A total of 14 individuals (47% of all tracked) had overlaps with GWF at the 95% level, ranging from a 0.26 to 5.04% overlap (Table 4.4a). In contrast, 11 birds (37% of those tracked) showed no overlap between their respective UDs and any OWF areas.

In 2020, 0.98% and 3.24% of the 95% and 100% UDs respectively for all birds overlapped with areas of operational OWFs. In contrast to 2019, no overlaps with OWFs under-construction were recorded, and only one bird (5874 with London Array) had an overlap that was for an OWF other than the Galloper Greater Gabbard Wind Farms (Table 4.4b). A total of four individuals (21% of all tracked) had overlap with GWF at the 95% UD level (0.65-2.33% overlap), though 12 (63%) had overlap at the 100% UD level (0.09-5.84% overlap). As in 2019, 37% of tracked birds (7) showed no temporal overlap with any OWFs.

Figure 4.3 displays results for all birds across their entire spatial distribution in (a) 2019 and (b) 2020. This shows how little time overall was spent offshore by all birds (generally <5%), though in 2019 the area between the colony and the Galloper and Greater Gabbard Wind Farms was used more frequently than other offshore areas. In 2020, the only frequently used areas (i.e. within the 95% UD) more than 20 km offshore were the three substations within Galloper and Greater Gabbard Wind Farms.

Figure 4.4 displays a selection of the results for individuals in 2019, whilst Figure 4.5 displays a similar selection for individuals tracked in 2020. This highlights the variability in movement strategies between individuals, and the variation in time spent offshore. This demonstrates the importance of tracking a representative sample of birds in order to accurately characterise which areas the entire population are using most frequently. Maps for all individuals can be found in Appendix 4.

Day and night area utilisations are shown in Figure 4.6 and corresponding overlaps with OWFs are shown in Tables 4.5 and 4.6. These revealed that, typically, area use by Lesser Black-backed Gulls was greater during the day than at night, most especially so in 2019. Overlaps with OWFs were greatest during daytime trips, again most clearly in 2019. These results should be treated with a degree of caution, as the delineation in producing 'day' and 'night' utilisation distributions at the trip level inevitable encompasses phases of trips that are in one or other category when using a methodology based on the start-times of the trips.

Table 4.4 Summary of utilisation distribution (UD) analyses for individual Lesser Black-backed Gulls tracked from Havergate Island during (a) the 2019 breeding season and (b) the 2020 breeding season. This summary is based on all observations during trips, including all bird kernel sizes and percentage overlap of the 100% UD (full area use), 95% UD (considered typical of total area use) and 50% UD (representing core area use) with: (1) operational; (2) partial generation/under construction; and (3) all (operational and under construction) offshore wind farm areas.

(a) 2019

				Overlaps with each UD (%)																	
	UD area (km^2)			Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	8	320	592					0.41	2.78											**0.41**	**2.78**
1108*	12	848	2384		0.49	1.65		2.12	3.35											**2.60**	**5.00**
1109	16	1372	3200		3.03	3.05		6.04	4.10											**9.07**	**7.15**
1111	24	280	1148			0.72			2.82												**3.54**
1112	56	1464	3228		1.45	3.09		2.39	3.95											**3.84**	**7.05**
1113	4	72	332																		
1116	8	700	2120		4.42	3.65		4.62	3.97											**9.03**	**7.61**
1117	32	396	1052																		
1118	4	20	28																		
1119	4	128	556																		
1120	16	272	1024		1.86	6.24		2.55	3.23											**4.41**	**9.47**
1122	28	264	684																		
1123	20	856	2496		3.01	3.92		3.33	3.94											**6.34**	**7.86**
1125	24	172	504																		
1127	4	172	1152			2.62			3.56												**6.18**
5863	8	360	1012		3.67	5.89		0.63	6.35											**4.29**	**12.25**
5865	8	52	156																		
5866	12	208	1048																		
5868	24	660	1664		5.04	4.59		3.79	7.01											**8.83**	**11.6**
5870	96	1536	4676		0.26	2.00			1.90											**0.27**	**3.90**
5872	68	1464	3552		2.43	3.27		1.73	3.90											**4.17**	**7.17**
5873	72	508	1484																		
5874	28	1472	3868		2.36	2.44	14.29	4.15	3.39		0.54	0.92			0.01				**14.29**	**7.05**	**6.76**
5875	32	492	1612																		
5876	12	296	1172																		
5877	60	808	2932		0.50	1.09			2.27											**0.50**	**3.36**
5880	24	872	2528			0.68		0.46	0.71											**0.46**	**1.39**
5881	180	3736	7712		1.28	1.29		1.04	1.64								1.54	1.59		**3.85**	**4.52**
5969	4	160	1168					2.50	3.44											**2.50**	**3.44**
5970	80	1664	4040		1.22	1.65		0.72	2.19						0.02					**1.94**	**3.86**
All birds	**56**	**2708**	**16068**		**1.87**	**0.76**		**2.43**	**0.91**			**0.22**						**0.76**		**4.30**	**2.66**

(b) 2020

				Overlaps with each UD (%)																	
	UD area (km^2)			Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	4	12	24																		
1109	4	284	1280			5.84		2.82	4.82											**2.82**	**10.66**
1111	20	352	972			0.22		3.32	3.97											**3.32**	**4.19**
1116	8	76	812			2.93			6.55												**9.49**
1120	12	416	1592		1.43	5.43			7.93											**1.43**	**13.36**
1122	8	100	336																		
1123	8	92	704			2.99			6.63												**9.62**
1125	24	172	940																		
1127	4	324	2268			1.63			2.91												**4.55**
5870	8	84	236																		
5872	8	172	680		2.33	0.90			3.54											**2.33**	**4.44**
5873	56	1124	3452																		
5874	16	844	3300		1.63	2.59		4.42	3.70			0.29								**6.05**	**6.58**
5875	44	476	1540																		
5877	48	612	1624		0.65	1.69			2.71											**0.65**	**4.40**
5880	16	428	1472																		
5881	4	320	2540			3.09			3.39												**6.48**
5969	20	496	1948			1.48		0.81	2.80											**0.81**	**4.29**
5970	32	628	2024			0.09			0.06												**0.15**
All birds	**20**	**1220**	**8572**		**0.33**	**1.42**		**0.66**	**1.71**			**0.11**								**0.98**	**3.24**

Table 4.5 Summary of utilisation distribution (UD) analyses for individual Lesser Black-backed Gulls tracked from Havergate Island during (a) the 2019 breeding season and (b) the 2020 breeding season, based on observations during daytime trips.

(a) 2019

				Overlaps with each UD (%)																	
	UD area (km²)			Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	12	344	572					1.31	2.88											**1.31**	**2.88**
1108*	12	996	2300		0.76	1.71		2.13	3.47											**2.89**	**5.18**
1109	8	1008	2244		4.30	4.35		7.36	5.84											**11.66**	**10.2**
1111	16	272	1012		0.49	0.82		8.46	3.19											**8.95**	**4.02**
1112	48	968	2092			0.83		2.07	2.61											**2.07**	**3.44**
1113	8	64	200																		
1116	4	92	668			3.31		4.35	6.89											**4.35**	**10.20**
1117	24	300	636																		
1118	4	20	28																		
1119	4	104	472																		
1120	8	232	664		15.44	9.63		4.77	4.34											**20.21**	**13.96**
1122	24	200	556																		
1123	20	740	1768		3.54	4.04		1.40	2.26											**4.94**	**6.30**
1125	12	120	416																		
1127	4	108	508																		
5863	8	368	972		4.67	6.14		0.61	6.61											**5.29**	**12.75**
5865	8	60	152																		
5866	12	184	964																		
5868	12	284	852		1.55	3.27		1.41	8.86											**2.95**	**12.13**
5870	24	1076	2948		1.97	3.18		0.17	3.01											**2.14**	**6.19**
5872	44	1260	3164		2.68	3.21		2.42	4.37											**5.10**	**7.58**
5873	24	348	1020																		
5874	24	1300	3164		2.84	2.34	16.67	4.67	3.69		0.61	1.12			0.01				**16.67**	**8.12**	**7.17**
5875	12	624	1484																		
5876	12	292	1100																		
5877	16	244	1060		1.64	2.45			3.99											**1.64**	**6.44**
5880	12	876	2324			0.74		0.46	0.78											**0.46**	**1.52**
5881	96	2864	5796		1.11	1.05		0.71	1.76								2.14	2.12		**3.97**	**4.93**
5969	4	100	716																		
5970	60	1044	2676		1.15	1.36		0.38	2.35											**1.53**	**3.71**
All birds	**32**	**2436**	**13648**		**2.31**	**0.90**		**2.83**	**1.07**			**0.26**						**0.9**		**5.14**	**3.13**

(b) 2020

	UD area (km²)			Overlaps with each UD (%)																	
				Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	4	12	24																		
1109	4	140	764			2.10		2.86	6.55											**2.86**	**8.65**
1111	8	188	556			0.38		2.13	6.95											**2.13**	**7.33**
1116	12	64	420			1.37			6.34												**7.72**
1120	8	224	944		2.65	5.61			7.03											**2.65**	**12.64**
1122	4	76	296																		
1123	8	56	440						7.23												**7.23**
1125	20	148	516																		
1127	4	268	1852			2.00		2.99	3.57											**2.99**	**5.57**
5870	8	72	208																		
5872	8	60	264																		
5873	36	432	1572																		
5874	12	580	2280		1.77	2.81		5.92	5.11											**7.69**	**7.93**
5875	36	336	1008																		
5877	16	292	884					1.37	3.99											**1.37**	**3.99**
5880	12	324	1164																		
5881	4	272	2028			3.39			4.20												**7.59**
5969	20	392	1408																		
5970	36	596	1780																		
All birds	**16**	**824**	**6288**		**0.49**	**1.74**		**0.97**	**2.16**											**1.46**	**3.90**

Table 4.6 Summary of utilisation distribution (UD) analyses for individual Lesser Black-backed Gulls tracked from Havergate Island during (a) the 2019 breeding season and (b) the 2020 breeding season, based on observations during night-time trips.

(a) 2019

				Overlaps with each UD (%)																	
	UD area (km^2)			Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	4	28	52																		
1108*	4	68	252					5.88	6.23											**5.88**	**6.23**
1109	36	876	1692		2.69	2.43		7.08	4.11											**9.77**	**6.54**
1111	20	208	504																		
1112	60	1220	2192		2.37	4.09		3.00	5.31											**5.37**	**9.4**
1113	4	68	304																		
1116	12	1016	2000		4.44	3.87		3.81	4.21											**8.25**	**8.07**
1117	28	332	888																		
1118	-	-	-																		
1119	8	124	372																		
1120	20	196	624			1.26			4.09												**5.35**
1122	28	224	460																		
1123	20	424	1408		0.19	3.86		4.40	4.43											**4.58**	**8.29**
1125	36	168	360																		
1127	8	164	844			3.58			4.86												**8.44**
5863	4	80	148																		
5865	4	24	52																		
5866	8	156	368																		
5868	40	640	1336		6.86	4.73		6.16	6.27											**13.02**	**11.00**
5870	108	1164	2628																		
5872	84	828	1528		2.81	3.12			2.10											**2.81**	**5.22**
5873	76	456	984																		
5874	40	756	1692		1.35	2.67		0.53	3.93											**1.88**	**6.6**
5875	36	228	684																		
5876	12	68	176																		
5877	72	840	2496			0.32			1.32												**1.64**
5880	36	360	828																		
5881	180	1884	3560	2.22	1.38	1.69		0.71	1.96										**2.22**	**2.09**	**3.65**
5969	8	236	740					1.69	5.42											**1.69**	**5.42**
5970	80	1288	2644		1.35	2.4		1.16	2.34					0.05	0.02					**2.56**	**4.76**
All birds	**88**	**2116**	**9272**		**1.63**	**1.32**		**1.82**	**1.58**						**0.01**					**3.45**	**2.91**

(b) 2020

	UD area (km²)			Overlaps with each UD (%)																	
				Galloper[1]			Greater Gabbard[1]			London Array[1]			Gunfleet Sands[1]			East Anglia One[2]			Total[3]		
Tag ID	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
1107	-	-	-																		
1109	12	372	888		2.44	6.62		0.78	4.30											**3.23**	**10.91**
1111	32	252	544																		
1116	8	88	644			3.23			7.02												**10.26**
1120	16	324	1188			5.15			7.53												**12.68**
1122	8	104	220																		
1123	12	120	428			4.91			4.01												**8.93**
1125	28	136	700																		
1127	8	180	684																		
5870	12	48	84																		
5872	32	380	596		1.33	1.03		3.46	4.04											**4.79**	**5.07**
5873	40	1064	2604																		
5874	32	616	1820		2.39	1.89		0.65	2.92		0.50	0.52								**3.53**	**5.32**
5875	36	420	1120																		
5877	64	572	1268		1.40	2.17			0.68											**1.40**	**2.85**
5880	20	344	856																		
5881	4	196	908			3.47			0.17												**3.64**
5969	16	364	1036			2.79		1.10	5.27											**1.10**	**8.06**
5970	20	332	960			0.18			0.13												**0.31**
All birds	**28**	**1192**	**6588**		**0.34**	**1.71**		**0.34**	**2.01**			**0.14**								**0.67**	**3.87**

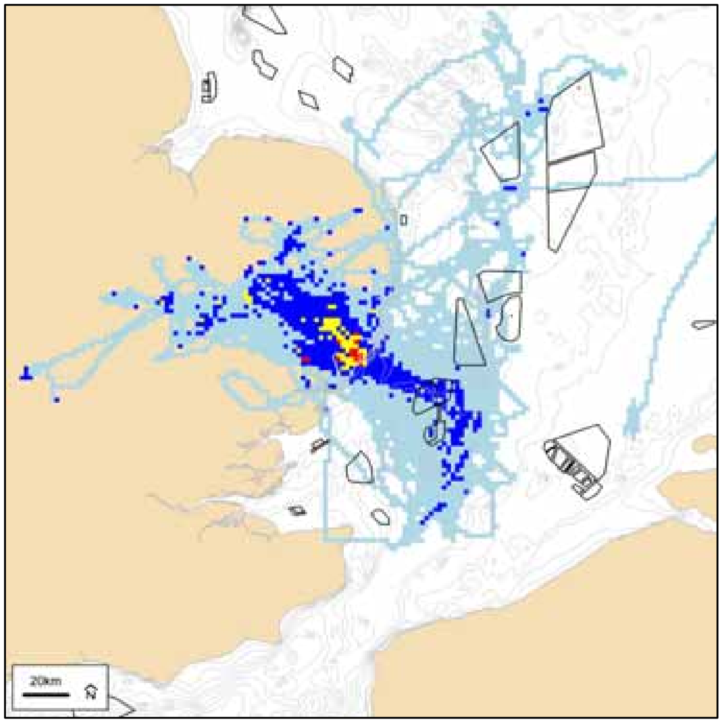
The relative use of the Galloper and Greater Gabbard Wind Farms during diurnal and nocturnal periods was estimated based on the mean percentage use of those areas across individuals during the 2019 and 2020 breeding seasons, as presented in Tables 4.5 and 4.6. This summary indicated that birds tended to use OWFs relatively more during the day than on the night. Relative diurnal to nocturnal use of the GWF was similar in 2019 and 2020, whereas relative diurnal to nocturnal use of the Great Gabbard Wind Farm was approximately double in 2020 compared to 2019.

An alternative assessment of relative use of the Galloper and Greater Gabbard Wind Farms during diurnal and nocturnal periods, based on time budgets, and an assessment of the relative proportion of time spent in flight is provided in Appendix 5.

Table 4.7 The relative diurnal to nocturnal use of the Galloper and Greater Gabbard Wind Farms by Lesser Black-backed Gulls tracked from Havergate Island during the 2019 and 2020 breeding seasons, as based on results of utilisation distribution (UD) analyses. A value greater than 1 = bias to greater diurnal activity, less than 1 = bias to nocturnal activity.

Year	**Wind farm**	**Overlap with OWFs (%)**		**Relative diurnal to nocturnal use**
		Day	Night	
2019	Galloper	2.31	1.63	1.42
	Gabbard	2.83	1.82	1.55
	All OWFs	5.14	3.45	1.49
2020	Galloper	0.49	0.34	1.44
	Gabbard	0.97	0.34	2.85
	All OWFs	1.46	0.67	2.18

(a) 2019



(b) 2020

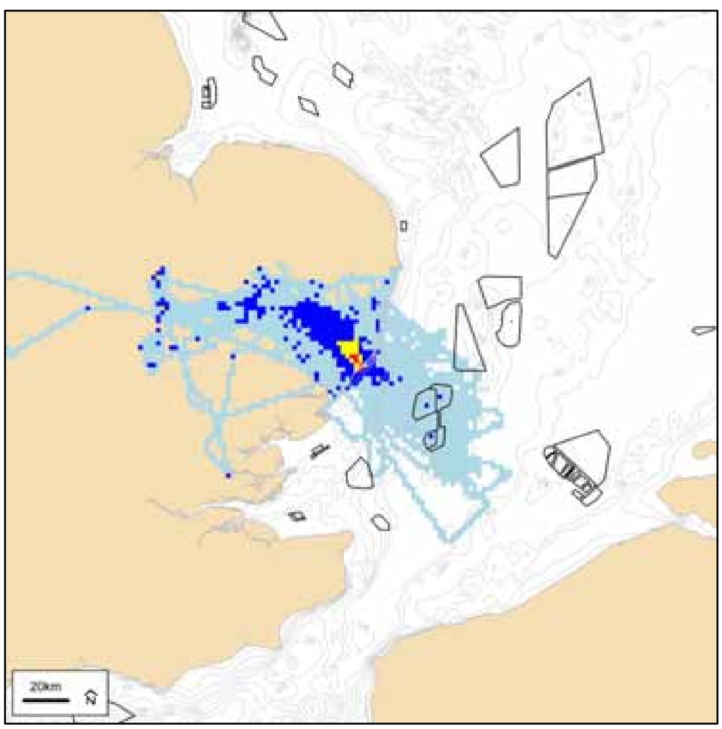


Figure 4.3 Utilisation distributions for all Lesser Black-backed Gulls tracked from Havergate Island in (a) 2019; and (b) 2020. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD.

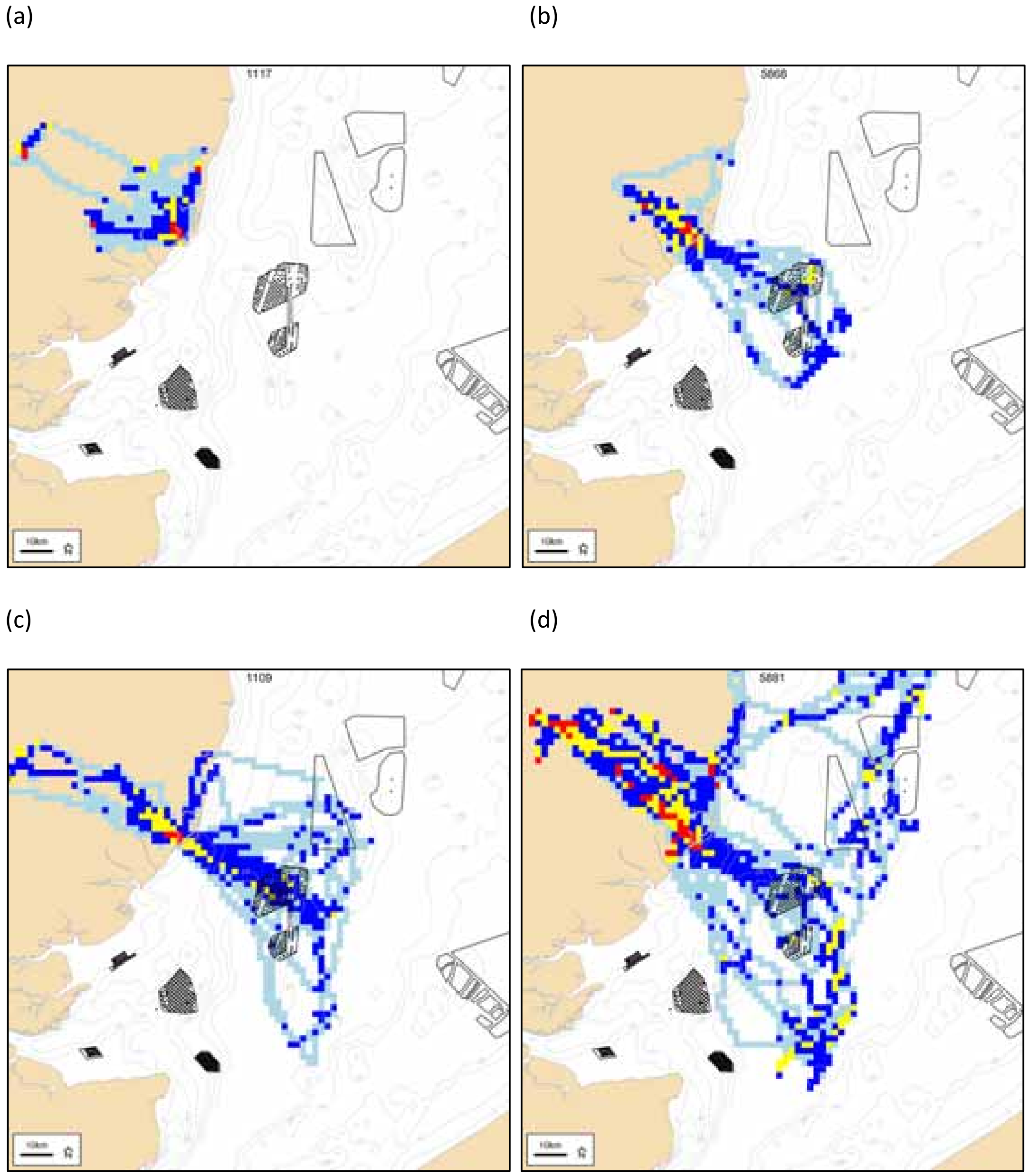
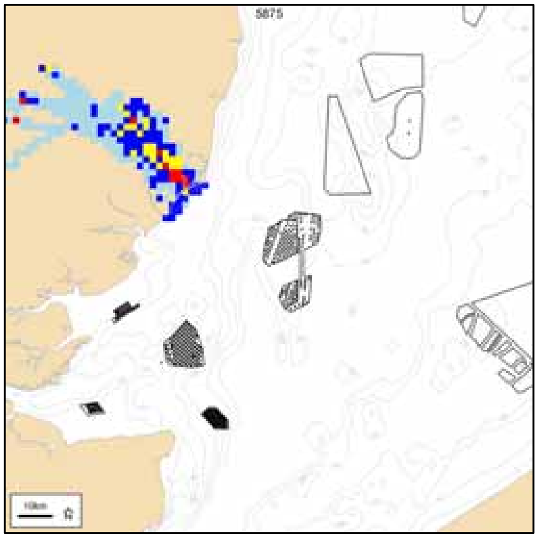
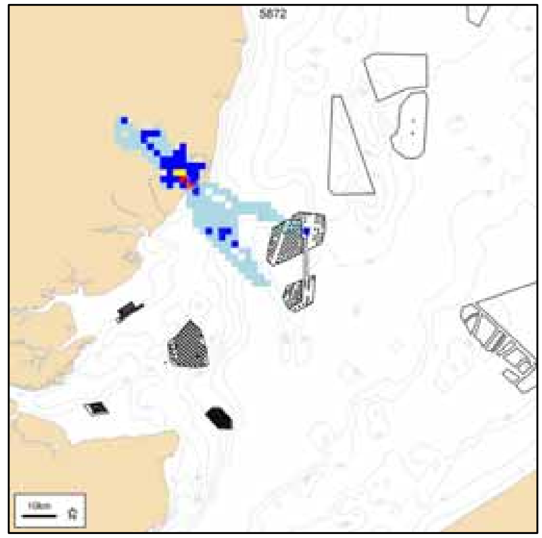


Figure 4.4 Utilisation distributions for four example Lesser Black-backed Gulls tracked from Havergate Island during the 2019 breeding season, showing: (a) 1117 (MT), which made no offshore movements; (b) 5868 (UvA), which had the greatest 95% distribution overlap with GWF; (c) 1109 (MT), which had the greatest 95% distribution overlap with Greater Gabbard Wind Farm; and (d) 5881 (UvA), which had the furthest ranging offshore distribution. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD. UvA = University of Amsterdam tags; MT = Movetech tags.

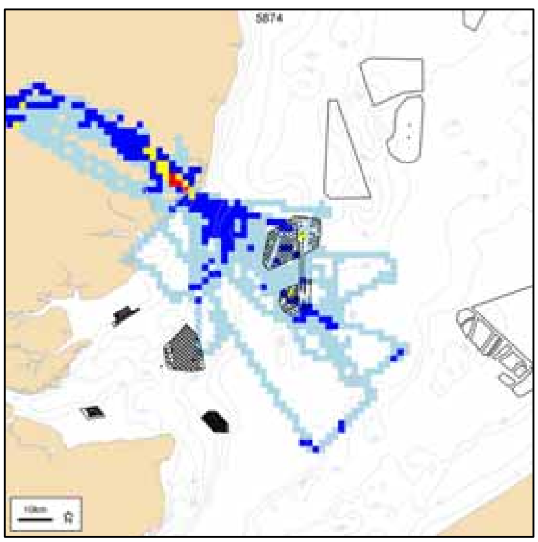
(a)



(b)



(c)



(d)

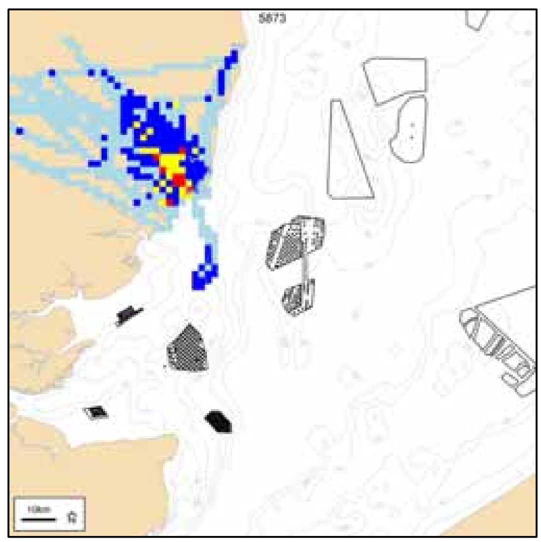
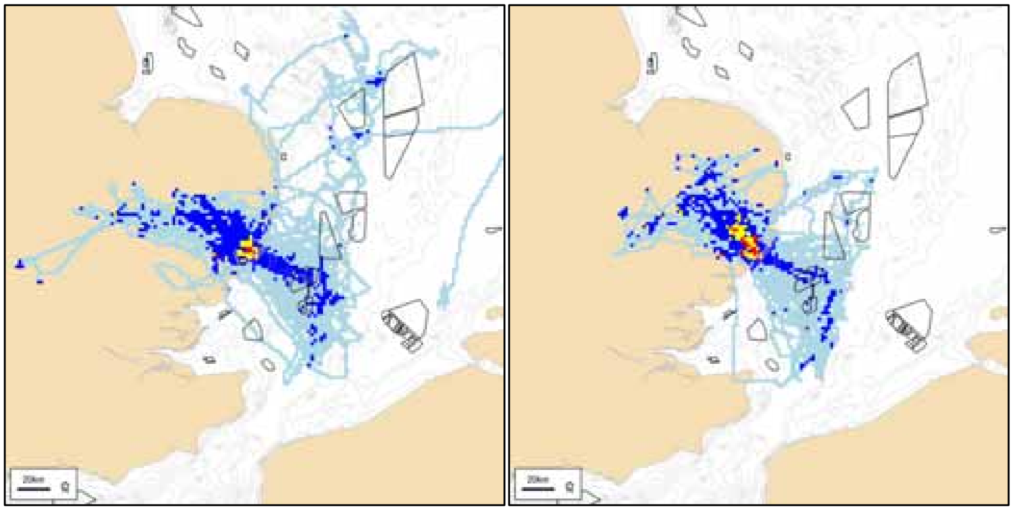


Figure 4.5 Utilisation distributions for four example Lesser Black-backed Gulls tracked from Havergate Island during the 2020 breeding season, showing: (a) 5875 (UvA), which made no offshore movements; (b) 5872 (UvA), which had the greatest 95% distribution overlap with GWF; (c) 5874 (UvA), which had the greatest 95% distribution overlap with Greater Gabbard Wind Farm; and (d) 5873 (UvA), which had the furthest ranging distribution (albeit mostly inland). Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD. UvA = University of Amsterdam tags; MT = Movetech tags.

(a) 2019

DAY (n = 30 birds, 3273 trips) NIGHT (n = 29 birds, 1328 trips)



(b) 2020

DAY (n = 19 birds, 3325 trips) NIGHT (n = 18 birds, 1098 trips)

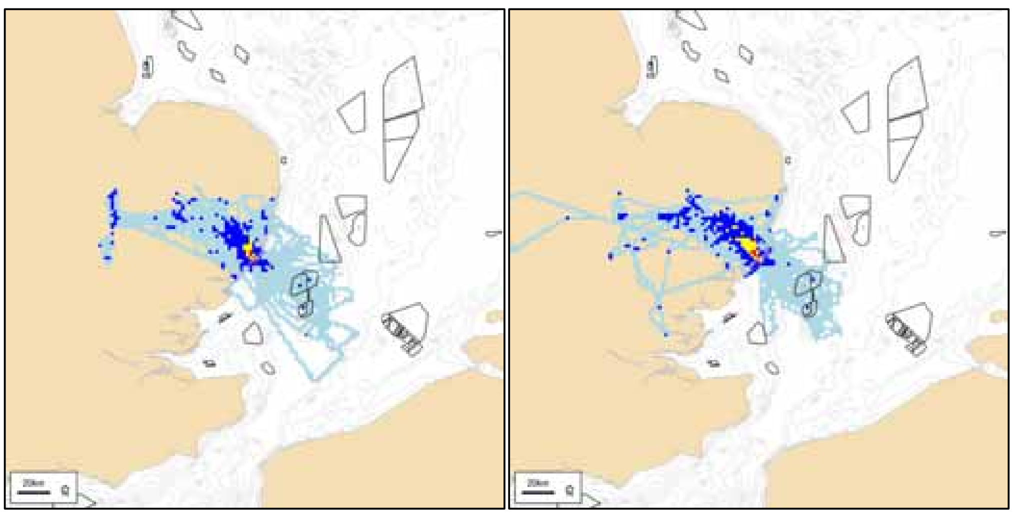


Figure 4.6 Utilisation distributions for all Lesser Black-backed Gulls tracked from Havergate Island in (a) 2019; and (b) 2020, with trips categorised as 'day' or 'night' (see methods). Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD.

4.5 Behaviours of Lesser Black-Backed Gulls Within and Outside the GWF and Other Offshore Wind Farms

4.5.1 Initial investigation of wind farm use

From simply mapping the routes of individual birds (Figure 4.7), it was clear that birds were frequently entering OWFs. Visualisation of finer scale movements within both the Galloper and Greater Gabbard Wind Farms also revealed apparent movements between turbine rows and also movements directed to offshore (Figure 4.8).

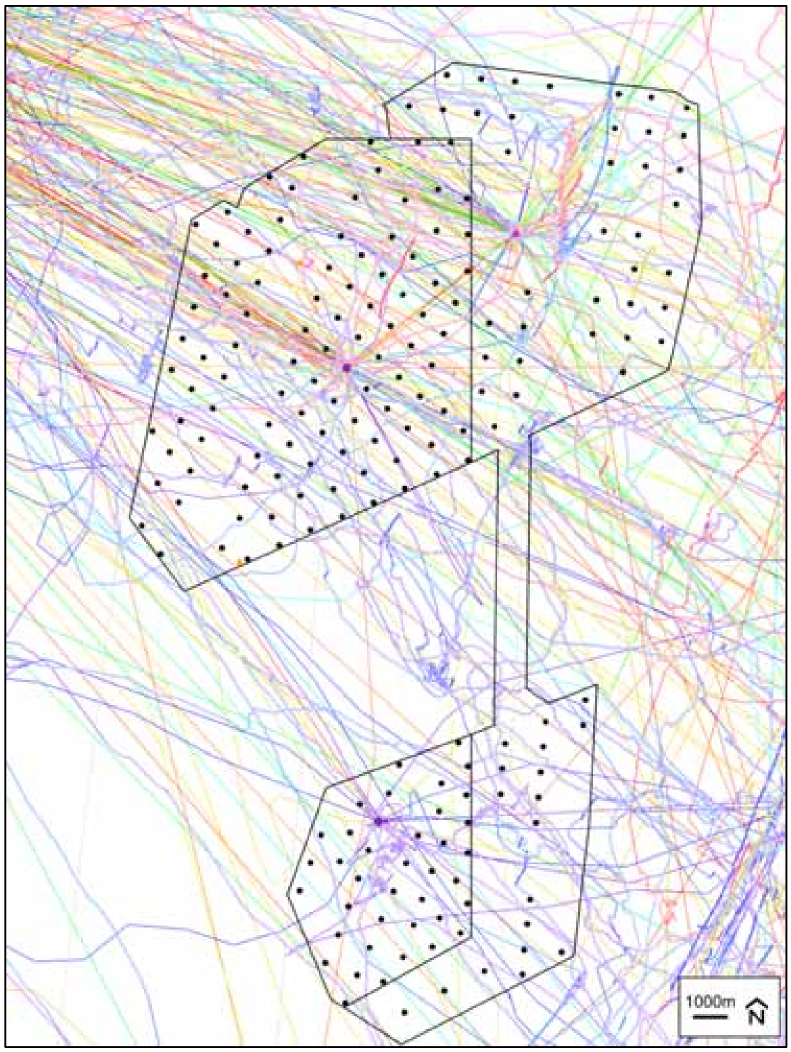


Figure 4.7 Movements of Lesser Black-backed Gulls (each bird is a different colour) tracked from Havergate (Alde-Ore Estuary SPA) during the 2019 breeding season (ca. May to September); finer scale extent for the local Galloper and Greater Gabbard Wind Farm complex; polygons represent the wind farm footprint and cable corridor; turbines are shown as black circles, offshore service platforms as purple triangles and met-masts as orange triangles.

4.5.2 Hidden Markov models

Results of behavioural classification from the HMM are shown below in Table 4.8a and 4.8b for offshore and onshore classification, respectively. A model based on 5-10 second data was attempted for HMMs, however, likely due to the smaller variation between consecutive fixes, the method did not produce meaningful delineations and so here we present results from the five minute model only.

Although subject to a degree of error in classifications, the model successfully characterised GPS locations as follows: state 1, stopped, typified by very short distances between successive GPS points and variable turning angles; state 2 as floating, characterised by the short mean step lengths, with small variation, and a very high angle concentration parameter; state 3 as commuting, with the fastest step length, with smaller relative variation and relatively 'straight' tracks through a higher angle concentration; and state 4 as foraging/searching, typified by medium step-lengths with high variation, and a widely distributed turning angle distribution. These data indicated suitable convergence of the model with state means and distributions reflecting input parameters as initially specified. The distributions of step length (m) and turning angle distributions for each behaviour are further visualised in Figure 4.8, and the resultant classifications of data are mapped in Figure 4.9.

Table 4.8 Statistical output from the HMM, based on five minute resolution data, for Lesser Black-backed Gulls tracked during the 2019 and 2020 breeding seasons.

(a) Offshore

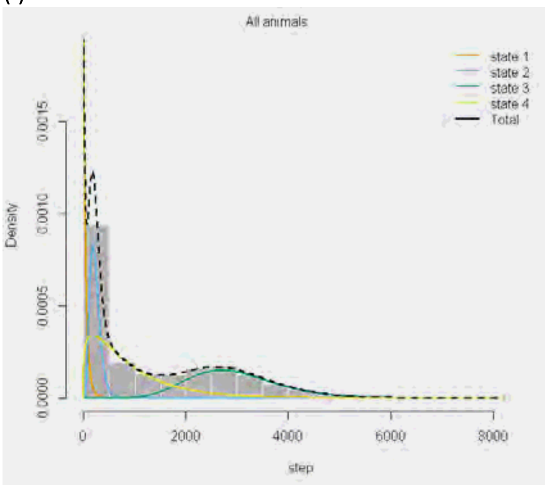
Model evaluation				
Max LogLik	**-100582.6**			
Step length	Mean	SD		
State 1 (perching)	48.0	54.7		
State 2 (floating)	231.2	100.1		
State 3 (commuting)	2952.9	864.4		
State 4 (foraging/searching)	874.8	782.9		
Turning angle	Mean	Concentration		
State 1 (perching)	0	0.1		
State 2 (floating)	0	107.4		
State 3 (commuting)	0	10.1		
State 4 (foraging/searching)	0	0.9		
Model details				
Regression coefficients for transition probabilities	**Perch**	**Float**	**Commute**	**Forage/search**
Perch	-	-3.51	-12.08	-2.69
Float	-4.22	-	-16.61	-2.04
Commute	-5.66	-12.79	-	-1.89
Forage/search	-3.92	-2.73	-2.07	-
Transition probability matrix	Perch	Float	Commute	Forage/search
Perch	0.91	<0.01	<0.01	0.06
Float	0.01	0.87	<0.01	0.11
Commute	<0.01	<0.01	0.87	0.13
Forage/search	0.02	<0.01	0.10	0.83

(b) Onshore

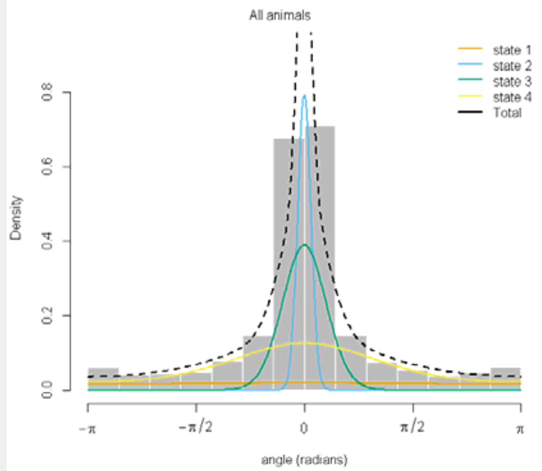
Model evaluation				
Max LogLik	**-903314.5**			
Step length	Mean	SD		
State 1 (perching)	9.6	10.1		
State 2 (floating)	493.3	502.1		
State 3 (commuting)	2199.4	996.0		
State 4 (foraging/searching)	185.3	192.8		
Turning angle	Mean	Concentration		
State 1 (perching)	0	<0.01		
State 2 (floating)	0	36.9		
State 3 (commuting)	0	1.9		
State 4 (foraging/searching)	0	<0.01		
(b) Model details				
Regression coefficients for transition probabilities	**Perch**	**Float**	**Commute**	**Forage/search**
Perch	-	-16.20	-22.14	-1.70
Float	13.24	-	-8.04	15.30
Commute	-20.00	-3.04	-	-1.52
Forage/search	-2.21	-2.47	-1.89	-
Transition probability matrix	Perch	Float	Commute	Forage/search
Perch	0.84	<0.01	<0.01	0.16
Float	0.11	<0.01	<0.01	0.89
Commute	<0.01	0.04	0.79	0.17
Forage/search	0.08	0.06	0.11	0.74

(a) Offshore

(i)

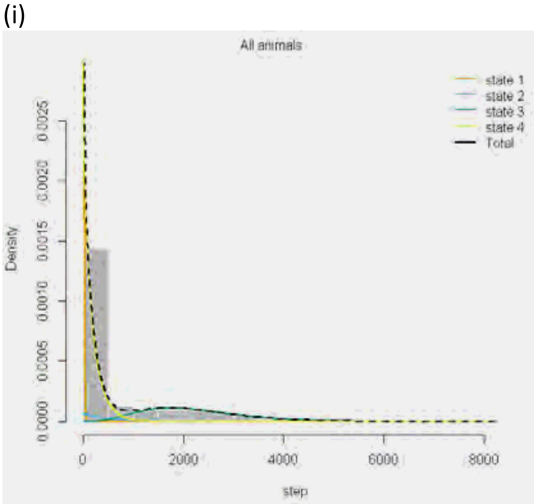


(ii)



(b) Onshore

(i)



(ii)

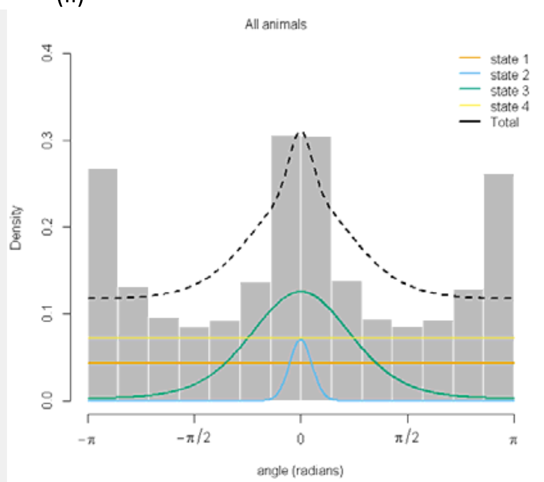
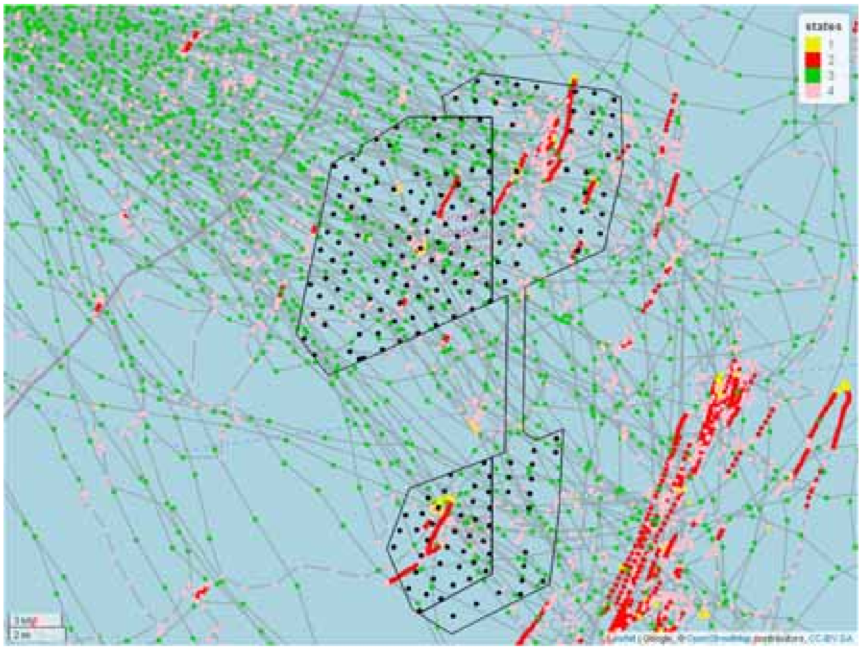


Figure 4.8 Distributions of: (i) step length; and (ii) turning angle identified for each behaviour (perching, floating, commuting and searching) for (a) offshore and (b) onshore stratified HMMs, based on five minute resolution data, for Lesser Black-backed Gulls tracked during the 2019 and 2020 breeding seasons.

(a) 2019



(b) 2020

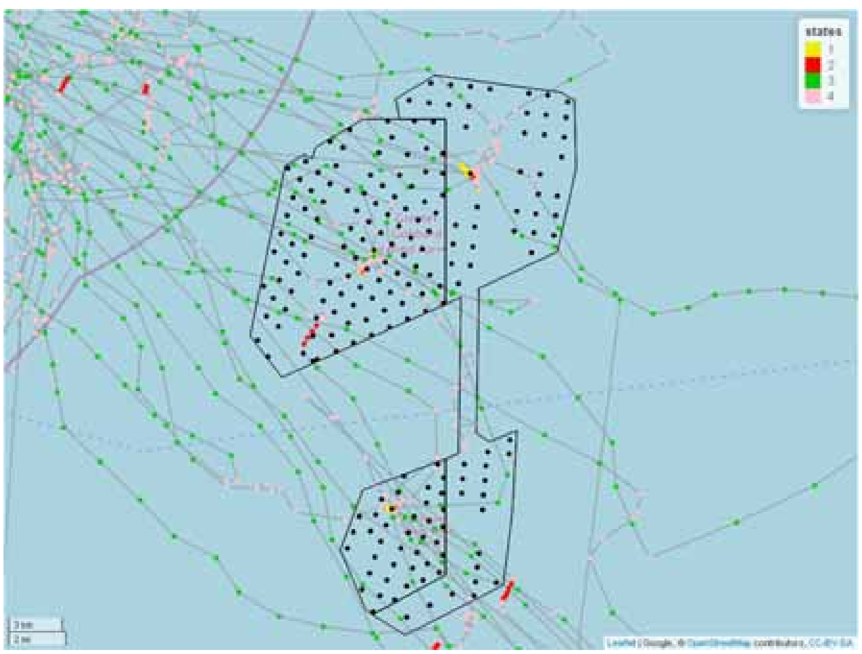


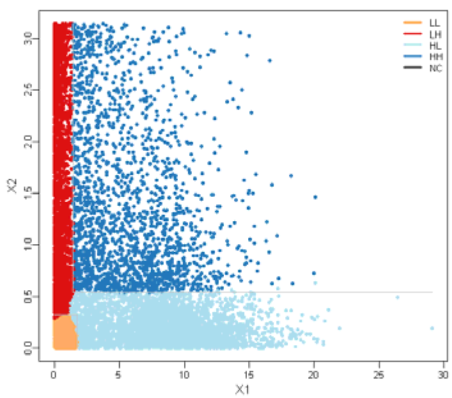
Figure 4.9 Classification of Lesser Black-backed Gull behaviours around the Galloper and Greater Gabbard Wind Farms and cable corridor (black polygons) using HMMs, based on five minute resolution data from the 2019 and 2020 breeding seasons.Turbines, offshore service platforms and metmasts are shown as black circles. HMM behaviours are given as: red: floating, yellow: 'stopped', green: 'commuting' and pink: 'foraging/searching'.

4.5.3 Expectation maximisation binary clustering

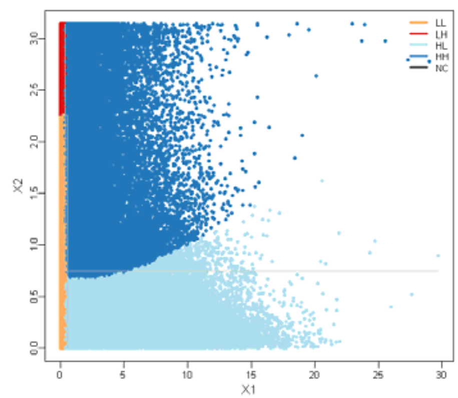
Results of behavioural classification from the EMbC approach are shown in Fig 4.10 below. Models were run for both five minute and 5-10 second filtered data, with the plots depicting the delineation of fixes into states based on turning angle and velocity. Separate models were produced based on offshore data and onshore data, as an initial model of all data combined yielded ambiguous classification, with potential biases from the extrapolation on land behaviours to at-sea and vice-versa. Models based on data collected at the two sampling rates provided differing delineations. The means of parameters for each model are provided in Table 4.9 below. Notably the model based on 5-10 second data showed less difference between the floating and stopped categories, while the threshold in speed that separated floating and stopped behaviours and commuting and foraging/searching speeds was lower; nevertheless both represent valid interpretations of the data and highlight the inherent uncertainty associated with delineating states based on GPS data. Plots of resultant EMbC classifications are mapped in Figure 4.11 for data collected at a five minute resolution and in Figure 4.12 for data collected at a 5-10 second resolution.

(a) Five minute model

(i) Offshore

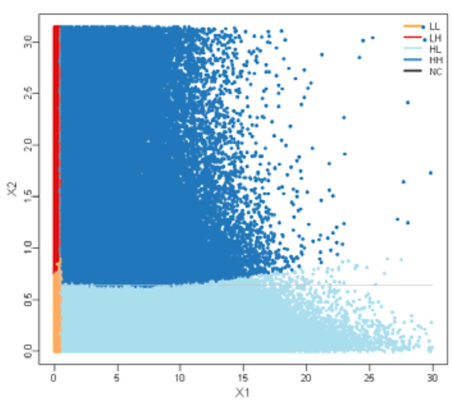


(ii) Onshore



(b) 5-10 second model

(i) Offshore



(ii) Onshore

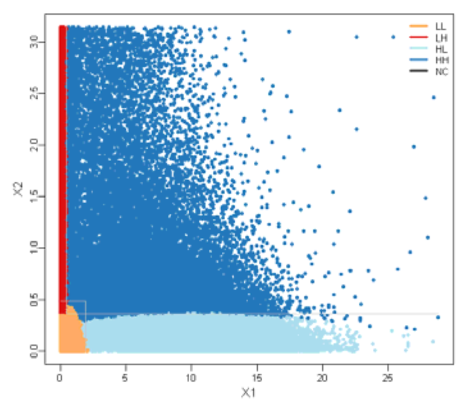


Figure 4.10 Delineation of fixes from GPS tracking of Lesser Black-backed Gulls over the 2019 and 2020 breeding seasons, based on turning angle (on a modulus scale of zero to pi, 'X2' on y-axis) and velocity (m/s) ('X1' on x-axis), with partitions determined by the EMbC model. Four states are defined for low speed, low turn ('LL', = floating), low speed, high turn ('LH' = stopped), high speed, low turn ('HL' = commuting) and high speed, high turn ('HH' = potential foraging/searching); (NC = not classified).

Table 4.9 Mean summary of parameters from the EMbC classification of Lesser Black-backed Gull behaviours, based on data collected at both five minute and 5-10 second resolutions. Four states are defined for low speed, low turn ('LL', = floating), low speed, high turn ('LH' = stopped), high speed, low turn ('HL' = commuting) and high speed, high turn ('HH' = potential foraging/searching)

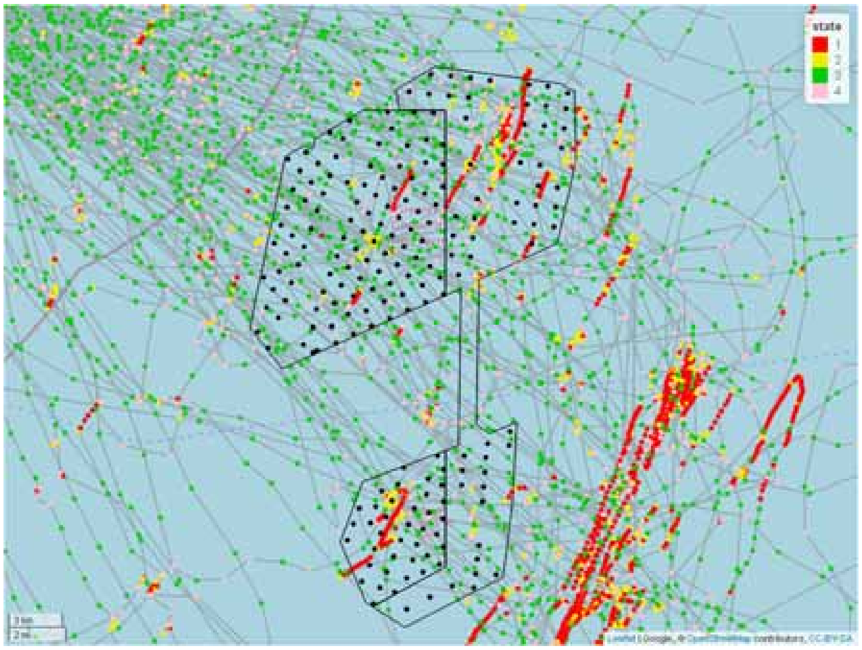
(a) Five minute data

Model	EMbC category	State	Velocity (m/s)	Turning angle (radians)	No. fixes	Percentage
Offshore	LL	Float	0.71±0.36	0.08±0.09	3113	27.14
	LH	Stop	0.44±0.42	1.69±0.95	2325	20.27
	HL	Commute	8.59±4.09	0.19±0.15	4040	35.22
	HH	Forage	5.83±3.53	1.43±0.81	1992	17.37
Onshore	LL	Float	0.05±0.10	1.10±0.73	83034	40.83
	LH	Stop	0.05±0.10	2.72±0.27	60198	29.60
	HL	Commute	6.39±4.20	0.27±0.22	29055	14.29
	HH	Forage	2.32±2.35	2.07±0.85	31078	15.28

(b) 5-10 second data

Model	EMbC category	State	Velocity (m/s)	Turning angle (radians)	No. fixes	Percentage
Offshore	LL	Float	0.69±0.37	0.11±0.10	43204	28.39
	LH	Stop	0.15±0.12	1.57±0.92	16971	11.15
	HL	Commute	10.47±2.88	0.11±0.09	69134	45.42
	HH	Forage	6.31±3.82	1.09±0.76	22895	15.04
Onshore	LL	Float	0.12±0.12	0.32±0.25	71767	21.65
	LH	Stop	0.06±0.10	1.97±0.77	118152	35.64
	HL	Commute	9.77±4.50	0.23±0.18	90641	27.34
	HH	Forage	5.75±3.61	1.64±0.83	50938	15.37

(a) 2019



(b) 2020

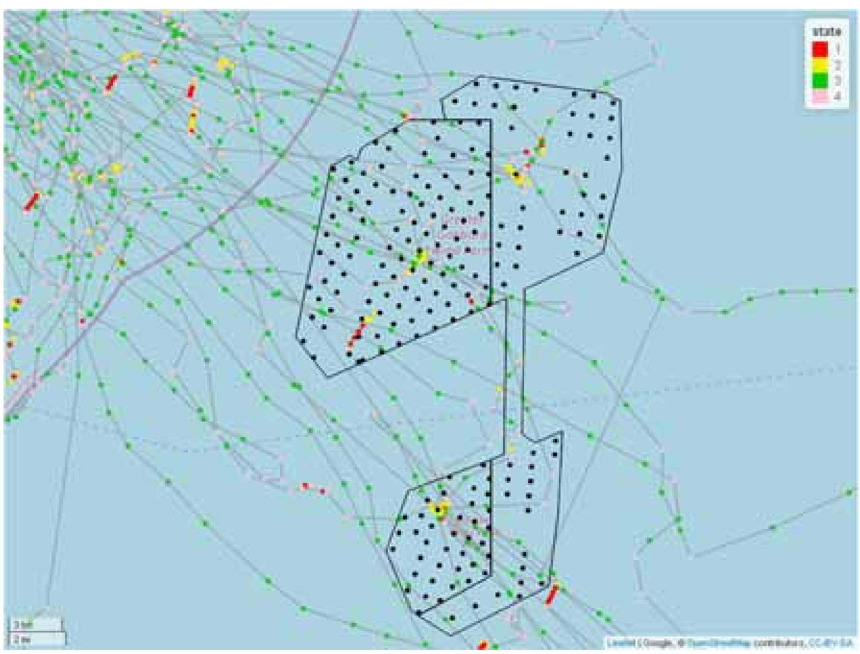


Figure 4.11 Classification of Lesser Black-backed Gull behaviours around the Galloper and Greater Gabbard Wind Farms and cable corridor (black polygons) using EMbC models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Turbines, offshore service platforms and metmasts are shown as black circles. HMM behaviours are given as: red: floating, yellow: 'stopped', green: 'commuting' and pink: 'foraging/searching'.

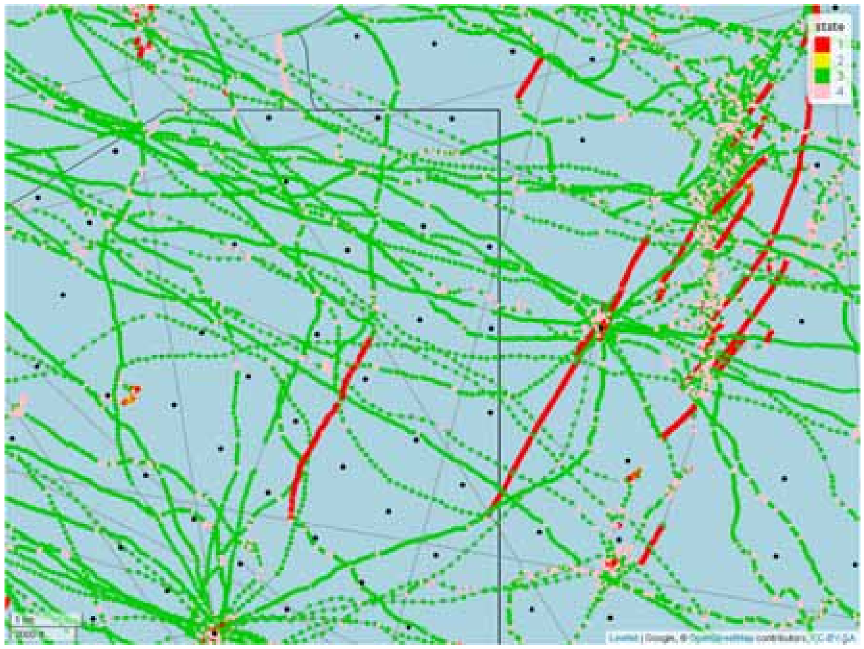
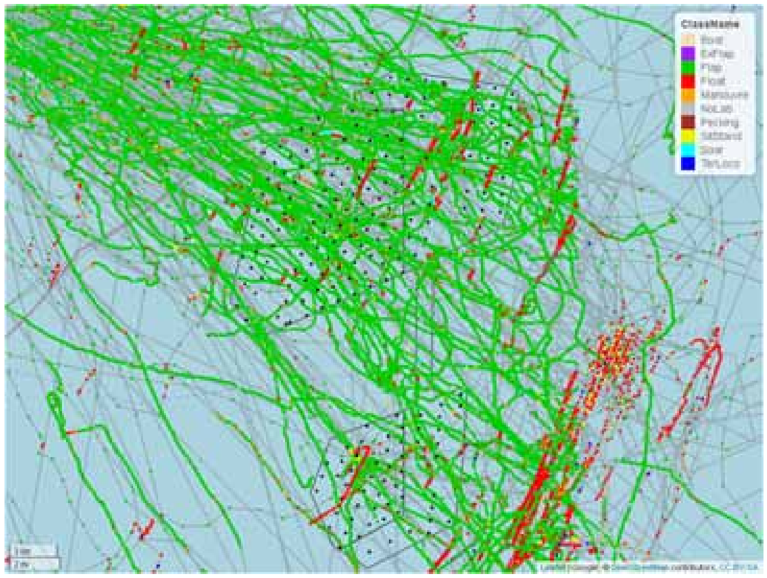


Figure 4.12 Example of the classification of Lesser Black-backed Gull behaviours using EMbC models, based on 5-10 second resolution data from the 2019 and 2020 breeding seasons, zoomed in to the top edge of the northern sections of the Galloper and Greater Gabbard Wind Farms. Data show the use of platforms and finer-scale changes in behaviour from 'commuting' to 'foraging/searching' along routes of straight travel; note visually, it is apparent that tracks of points are at distance from wind turbines.

4.5.4 Random forest classification

The model developed by Shamoun-Baranes et al. (2016) was also transferred to this study to provide a further assessment of behaviour. This was met with partial success; onshore classifications were, in places, dubious with behaviours at some locations classed as 'floating', yet when by visualising, birds were not over water, and likely these were misclassification errors mixing slow commuting activity involving soaring and limited flapping with the more static accelerometer trace of floating. For offshore data, classifications were more robust, however, there still appeared to be instances where floating classes as defined by the accelerometry method, were confused with other slow moving terrestrial classes such as walking or sit-standing. The resultant RF classifications within the area of the Galloper and Greater Gabbard Wind Farms are mapped in Figure 4.13.

(a) Wide wind farm view of mapped behaviours using the RF classifier



(b) Zoomed in view using 2019-2020 fine-scale data

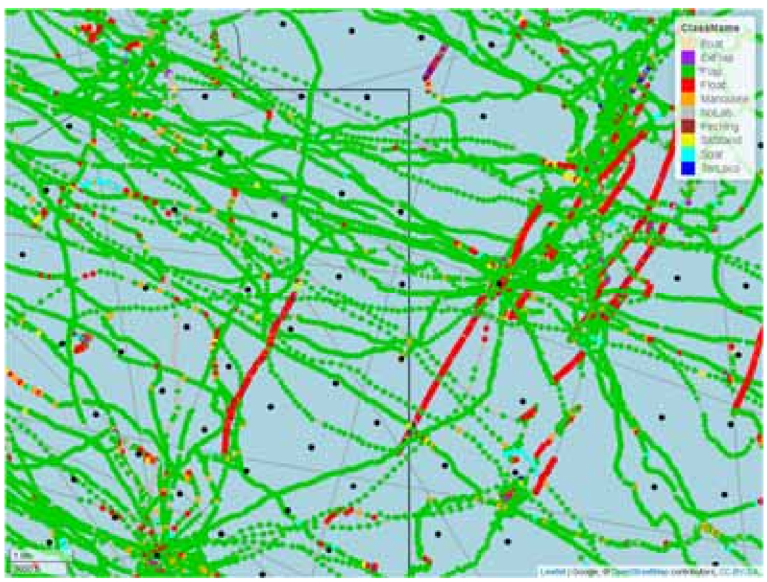


Figure 4.13 Classification of Lesser Black-backed Gull behaviours around the Galloper and Greater Gabbard Wind Farms and cable corridor (black polygons) using RF Models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Top: wider scale extent showing total movements offshore; bottom; local extent around the Galloper and Greater Gabbard Wind Farms and cable corridor (black polygons). Turbines, metmasts and offshore service platforms are shown as black circles; key shows RF classifications (see methods section 3 for more information).

4.5.5 Summarising behaviour within the GWF and Other Offshore Wind Farms

A total of 13 individual birds used offshore areas across 2019 and 2020. Twelve of the 13 birds used offshore areas in 2019, and eight in 2020. Together, the mapped visualisations of behaviours from each classification method reported above revealed a clear commuting band out from the Havergate colony offshore in the direction of the Galloper and Greater Gabbard Wind Farms, with additional stopped, foraging and floating locations used between and beyond the wind farms. A mix of behaviours was evident within the wind farms; by further plotting the behaviours at a finer spatial resolution, it was very apparent that several individuals converged on the offshore service platforms within each wind farm (Figure 3.7). The predominant behaviour at these locations was stopped (Figure 3.8 and Table 3.9), suggesting birds were using the platforms as resting areas, potentially enabling further exploitation of the offshore environment beyond the wind farms.

The proportional time spent in different behaviours within the GWF, Greater Gabbard and other operational/in-construction wind farms is summarised in Tables 4.10-4.12 below, based on the classifications provided by the HMM, EMbC and RF models respectively.

Generally, most time spent within OWFs was spent commuting or searching and less time was spent stopped or floating. This was in contrast to other areas offshore outside OWFs, where generally birds spent most time floating and commuting. Naturally with fewer potential perching opportunities, time budgets of birds offshore outside OWFs contained a lower percentage of time ‘stopped’.

However, there were considerable variations in these patterns, between years and individual OWFs, and further between which classification method was used to summarise behaviours. For example, the time spent floating (as classified by both HMM and EMbC) was lower in 2020 compared to 2019, both within and outside OWFs.

Specifically within the GWF, in the 2019 breeding season, the EMbC classification suggested a more even balance of behaviours, compared to the HMMs, which suggested a greater prevalence of foraging/searching and less frequent time stopped. In contrast, during the 2020 breeding season, the patterns were somewhat more consistent, with both models suggesting that the GWF was used primarily for stopped activities, with the use of offshore service platforms particularly notable. In both years, the percentage of time commuting through the Greater Gabbard Wind Farm was greater than that of GWF, indicating some local differences in how the two wind farms were used. Less time was spent engaged in foraging/searching activities in the Greater Gabbard Wind Farm than in the GWF, particularly in 2019. The differences in behaviour between the sites likely reflects the layout of turbines – in the northerly part of the GWF, birds frequently foraged and rested in between the turbines where there was greater spacing. This area may potentially represent an important foraging habitat, due to oceanographic factors, such as seabed slope and depth.

The above results were based on the five minute dataset that covered all periods of the day and night. Further appraisal of the use of OWFs across the diurnal cycle, and across the breeding season, are provided in Appendix 5, also based on this five minute dataset. However, a different perspective was provided by the RF classification that was based on the 5-10 second dataset, which although allowing a fine-grained inspection of movements of birds around turbines, was restricted to a period of the day between 03:00 and 21:00. This analysis suggested that less time was spent in the wind farm in certain behaviours, and interestingly, this disparity was greatest for stopped or sit-standing activities, highlighting that the use of platforms was greatest at night (when tags recorded only five minute data).

Table 4.10 Proportion of time spent in different behaviours offshore and in offshore wind farms (OWFs), per year and behavioural classification. Both datasets are presented for five minute sub-sampled data, however, the total number of fixes vary between methods, as HMM uses a temporally-interpolated dataset, whereas EMbC uses a filtered dataset based on raw timestamps of the GPS.

(a) 2019

		Floating			Stopped			Commuting			Foraging/searching				Total fixes	
Wind farm	**Method**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n birds**	**n fixes**	**time (hrs)**
Galloper	EMbC	112	9.3	24.1	127	10.6	27.3	130	10.8	28.0	96	8.0	20.6	9	465	38.7
	HMM	86	7.2	18.1	64	5.3	13.5	109	9.1	22.9	216	18.0	45.5	9	475	39.6
G Gabbard	EMbC	70	5.8	17.6	90	7.5	22.7	184	15.3	46.3	53	4.4	13.4	10	397	33.0
	HMM	55	4.6	13.3	78	6.5	18.9	173	14.4	41.9	107	8.9	25.9	10	413	34.4
All OWFs	EMbC	190	15.8	21.4	219	18.2	24.7	322	26.8	36.3	155	12.9	17.5	10	886	73.7
	HMM	145	12.1	15.9	142	11.8	15.5	285	23.8	31.2	342	28.5	37.4	10	914	76.2
Outside OWFs	EMbC	2671	222.6	30.8	1598	133.2	18.4	3048	254.0	35.1	1366	113.8	15.7	12	8683	723.6
	HMM	2061	171.8	22.0	822	68.5	8.8	2830	235.8	30.2	3645	303.8	39.0	12	9358	779.9

(b) 2020

		Floating			Stopped			Commuting			Foraging/searching				Total fixes	
Wind farm	**Method**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n fixes**	**time (hrs)**	**%**	**n birds**	**n fixes**	**time (hrs)**
Galloper	EMbC	8	0.7	5.4	98	8.2	66.2	20	1.7	13.5	22	1.8	14.9	4	148	12.4
	HMM	2	0.2	1.3	94	7.8	60.3	16	1.3	10.3	44	3.7	28.2	4	156	13.0
G Gabbard	EMbC	8	0.7	7.2	32	2.7	28.8	43	3.6	38.7	28	2.3	25.2	4	111	9.3
	HMM	6	0.5	5.5	14	1.2	12.8	42	3.5	38.5	47	3.9	43.1	4	109	9.1
All OWFs	EMbC	16	1.3	6.1	130	10.8	49.4	66	5.5	25.1	51	4.2	19.4	4	263	21.8
	HMM	8	0.7	3.0	108	9.0	40.3	60	5.0	22.4	92	7.7	34.3	4	268	22.4
Outside OWFs	EMbC	179	14.9	12.4	341	28.4	23.5	537	44.8	37.1	392	32.7	27.1	8	1449	120.8
	HMM	118	9.8	7.2	236	19.7	14.5	597	49.8	36.6	678	56.5	41.6	8	1629	135.8

Table 4.11 Proportion of time spent by Lesser Black-backed Gulls from Havergate Island in different behaviours offshore and in offshore wind farms (OWFs) in (a) 2019 and (b) 2020 based on behavioural classification using the RF model. Results are based on the five minute filtered dataset (as also used for EMbC); however, some fixes could not be classified under the RF model whereas they could under the unsupervised EMbC; hence the total number of birds/fixes/hours in 2019 and 2020 for RF data were: 12/8123/677 and 8/1181/98.4, respectively.

(a) 2019

		Galloper			**Gabbard**			**All OWFs**			**Outside OWFs**		
RF class name	**Best matched state (+alternative):**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**
Float	Float	199	16.6	43.4	116	9.7	30.6	325	27.1	37.7	4004	333.7	47.9
Boat	Float	0	0	0	0	0	0	0	0	0	9	0.8	0.1
SitStand	Stop (forage)	13	1.1	2.8	41	3.4	10.8	54	4.5	6.3	623	51.9	7.4
Peck	Stop (forage)	3	0.2	0.7	1	0.1	0.3	4	0.3	0.5	74	6.2	0.9
TerLoco	Float	17	1.4	3.7	2	0.2	0.5	19	1.6	2.2	0	0	0
Flap	Commute (forage)	207	17.2	45.2	202	16.8	53.3	421	35.1	48.9	3297	274.8	39.4
Soar	Commute, forage	8	0.7	1.7	5	0.4	1.3	15	1.2	1.7	144	12.0	1.7
Manoeuvre	Commute, forage	9	0.8	2.0	9	0.8	2.4	18	1.5	2.1	165	13.8	2.0
ExFlap	Commute, forage	2	0.2	0.4	3	0.2	0.8	5	0.4	0.6	48	4.0	0.6

(b) 2020

RF class name	**Best matched state (+alternative):**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**
Float	Float	10	0.8	6.8	8	0.7	7.6	19	1.6	7.5	286	23.8	20.7
Boat	Float	0	0	0	0	0	0	0	0	0	2	0.2	0.1
SitStand	Stop (forage)	86	7.2	58.9	15	1.2	14.3	101	8.4	39.6	234	19.5	16.9
Peck	Stop (forage)	1	0.1	0.7	0	0	0	1	0.1	0.4	8	0.7	0.6
TerLoco	Float	3	0.2	2.1	0	0	0	3	0.2	1.2	0	0	0
Flap	Commute (forage)	42	3.5	28.8	77	6.4	73.3	120	10.0	47.1	805	67.1	58.2
Soar	Commute, forage	2	0.2	1.4	0	0	0	3	0.2	1.2	20	1.7	1.4
Manoeuvre	Commute, forage	2	0.2	1.4	4	0.3	3.8	7	0.6	2.7	23	1.9	1.7
ExFlap	Commute, forage	0	0	0	1	0.1	1.0	1	0.1	0.4	6	0.5	0.4

Table 4.12 Proportion of time spent by Lesser Black-backed Gulls from Havergate Island in different behaviours in offshore wind farms (OWFs) in (a) 2019 and (b) 2020 based on behavioural classification using the RF model. Results are based on the 5-10 second filtered dataset which were primarily collected from 03:00 to 21:00 UTC and so provide a diurnal perspective (rather than a 24 h view as shown by the five minute dataset).

(a) 2019

		Galloper			Gabbard			All OWFs			Outside OWFs		
RF class name	**Best matched state (+alternative):**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**
Float	Float	8163	17.3	49.7	3358	6.0	16.1	11521	23.3	32.3	26808	47.4	35.3
Boat	Float	8	0	0	13	0	0	21	0	0	103	0.2	0.1
SitStand	Stop (forage)	286	0.7	2.0	8249	11.9	32.0	8535	12.6	17.5	1671	3.2	2.4
Peck	Stop (forage)	106	0.2	0.6	279	0.4	1.1	385	0.7	1.0	602	1.1	0.8
TerLoco	Float	290	0.6	1.7	382	0.6	1.6	672	1.2	1.7	1367	2.5	1.9
Flap	Commute (forage)	8227	14.6	42.0	9649	16.7	44.9	17876	31.3	43.4	36859	73.5	54.8
Soar	Commute, forage	222	0.4	1.1	240	0.4	1.1	462	0.8	1.1	942	2.0	1.5
Manoeuvre	Commute, forage	389	0.7	2.0	443	0.8	2.2	832	1.5	2.1	1565	3.3	2.5
ExFlap	Commute, forage	118	0.3	0.9	281	0.4	1.1	399	0.7	1.0	447	0.9	0.7

(b) 2020

RF class name	**Best matched state (+alternative):**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**	**N fixes**	**Time (hrs)**	**%**
Float	Float	430	0.6	9.7	440	0.6	3.8	870	1.2	5.4	2736	5.0	14.1
Boat	Float	6	0	0	3	0	0	9	0	0	24	0.1	0.3
SitStand	Stop (forage)	1430	2.0	32.3	5314	7.5	47.2	6744	9.6	42.9	313	0.5	1.4
Peck	Stop (forage)	34	0	0	92	0.1	0.6	126	0.2	0.9	188	0.4	1.1
TerLoco	Float	55	0.1	1.6	137	0.2	1.3	192	0.3	1.3	230	0.4	1.1
Flap	Commute (forage)	2338	3.3	53.2	4938	7.0	44	7276	10.3	46.0	16677	27.2	76.6
Soar	Commute, forage	75	0.1	1.6	108	0.1	0.6	183	0.3	1.3	462	0.9	2.5
Manoeuvre	Commute, forage	99	0.1	1.6	188	0.3	1.9	287	0.4	1.8	358	0.7	2.0
ExFlap	Commute, forage	27	0	0	52	0.1	0.6	79	0.1	0.4	163	0.3	0.8

4.6 Altitudes of Lesser Black-Backed Gulls Within and Outside the GWF and Other Offshore Wind Farms

Analyses of altitudes and the proportions of fixes within RSZs considered data collected both at five minute and 5-10 second intervals. During periods of offshore movement, data from 13 individuals were recorded at five minute fix rates (number of fixes = 11,365), while 12 individuals provided information for fix rates of 5-10 second (n = 206,750 fixes). Data are combined across the 2019 and 2020 breeding seasons.

Altitudes and the proportions of fixes within the RSZs of the Galloper and Greater Gabbard Wind Farms were calculated based on heights estimated both relative to the actual sea surface and MSL baselines, with differences potentially expected for altitudes based on pressure measurements as they reflect actual sea surface pressure (see section 3.5).

4.6.1 Altitude analysis based on data collected at a five minute fix rate

Tables 4.13-4.15 and 4.16-4.18 display mean GPS and pressure sensor-derived altitudes and the proportions of fixes within RSZs for all periods, the day-time and night-time, based on data collected at a five minute resolution, respectively considering (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2).

Mean altitudes estimated from barometric pressure sensor data collected at a five minute resolution were similar to those provided by GPS altitudes, although with more confined standard deviations (Tables 4.13, 4.16). Altitudes estimated from both the sensors were lower within GWF than those recorded within the Greater Gabbard Wind Farm, and altitudes outside OWFs (Tables 4.13, 4.16). Mean altitudes displayed when birds were within or outside wind farm boundaries were largely similar, however (Tables 4.13, 4.16). Regarding diel patterns, altitudes recorded by both sensors were generally higher during the day (Tables 4.14, 4.17) than at night (Tables 4.15, 4.18) across all OWFs, with the exception of GPS altitudes within GWF. Estimates of the proportions of altitudes within the RSZ were broadly similar across both the sensors (Tables 4.13, 4.16). However, when delineated by diel periods, the proportions of altitudes within the RSZ were consistently higher during the day than at night, across both methods. Visualisations of the altitude distributions are also shown in Figures 4.14-4.17.

Altitudes attributed to both GPS and barometric pressure measurements were 8.91-13.59 m greater when only considering fixes associated with in flight behaviours, while the proportions of fixes within the RSZ were 13.7-17.37% greater (Tables 4.13, 4.16). The disparity varied between the night and day, with in flight only altitudes recorded during the night differing to those based on all fixes to a greater extent than those recorded during the day. Additionally, at night the difference varied between methods, with in flight altitudes attributed to GPS differing from those based on all fixes by 3.19-45.14 m, and those based on barometric pressure by 10.06-12.94 m. In contrast, during the day altitudes only differed by a range of 6.76-10.61 across both methods. This contrast between day and night in the extent of differences between altitudes associated with flight only and all fixes may arise from birds exhibiting greater floating/loafing behaviour at night. This difference is further reflected in the proportions of fixes within RSZs, with the proportions associated with in flight fixes at night being 15.78-24.84% greater than those based on all fixes, compared with 10.07-16.63% for the day.

Table 4.13 Mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	22.91	98.38	504	18.37	31.04	497	32.54	32.54	164	30.78	31.19	153
Galloper	8.91	61.53	612	10.16	23.57	611	17.32	17.32	106	17.02	17.68	104
All OWFs	15.10	79.62	1144	13.79	27.28	1136	23.60	23.60	270	22.62	23.15	257
Outside OWFs	12.98	51.31	9956	14.13	32.91	9997						

Table 4.14 Day-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	27.04	96.47	377	22.08	33.5	370	39.52	39.52	149	35.68	35.95	145
Galloper	8.640	27.52	497	10.70	24.69	496	18.11	18.11	90	16.13	18.55	90
All OWFs	16.37	66.28	902	15.44	29.04	894	26.50	26.50	239	23.71	25.17	235
Outside OWFs	15.98	57.63	7063	17.50	36.39	7031						

Table 4.15 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n	%[1]	%[2]	n[1]
Gabbard	10.66	103.26	127	7.55	18.65	127	11.81	11.81	15	16.54	17.32	21
Galloper	10.04	130.35	115	7.85	17.84	115	13.91	13.91	16	12.17	13.91	14
All OWFs	10.36	116.67	242	7.69	18.23	242	12.81	12.81	31	14.46	15.70	35
Outside OWFs	5.65	29.62	2893	6.14	20.53	2966						

Table 4.16 Mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	30.99	82.30	187	27.45	33.45	182	44.92	44.92	84	45.05	46.70	82
Galloper	22.06	61.41	158	19.78	30.62	157	32.28	32.28	51	34.39	35.03	54
All OWFs	26.63	72.29	358	23.66	31.93	352	37.71	37.71	135	38.64	39.77	136
Outside OWFs	21.46	61.64	2930	24.22	38.73	2915						

Table 4.17 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	34.31	83.28	158	28.84	35.14	153	48.10	48.10	76	45.75	47.06	70
Galloper	17.69	23.67	139	19.64	31.17	138	31.65	31.65	44	34.78	34.78	48
All OWFs	26.23	62.14	310	24.18	33.06	304	38.71	38.71	120	38.82	39.47	118
Outside OWFs	23.22	66.64	2404	26.00	40.12	2386						

Table 4.18 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n	%[1]	%[2]	n
Gabbard	12.94	75.59	29	20.08	21.52	29	27.59	27.59	8	41.38	44.83	12
Galloper	54.01	165.44	19	20.79	27.07	19	36.84	36.84	7	31.58	36.84	6
All OWFs	29.20	119.57	48	20.36	23.59	48	31.25	31.25	15	37.50	41.67	18
Outside OWFs	13.42	28.09	526	16.20	30.47	529						

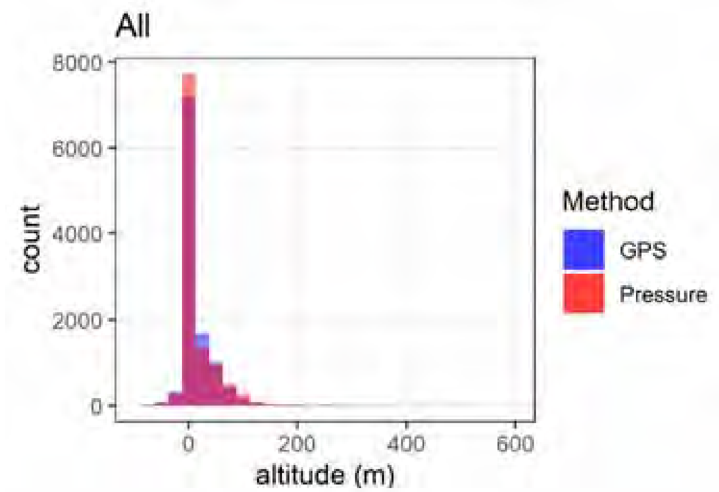


Figure 4.14 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes attributed to all fixes at a fix rate of five minutes.

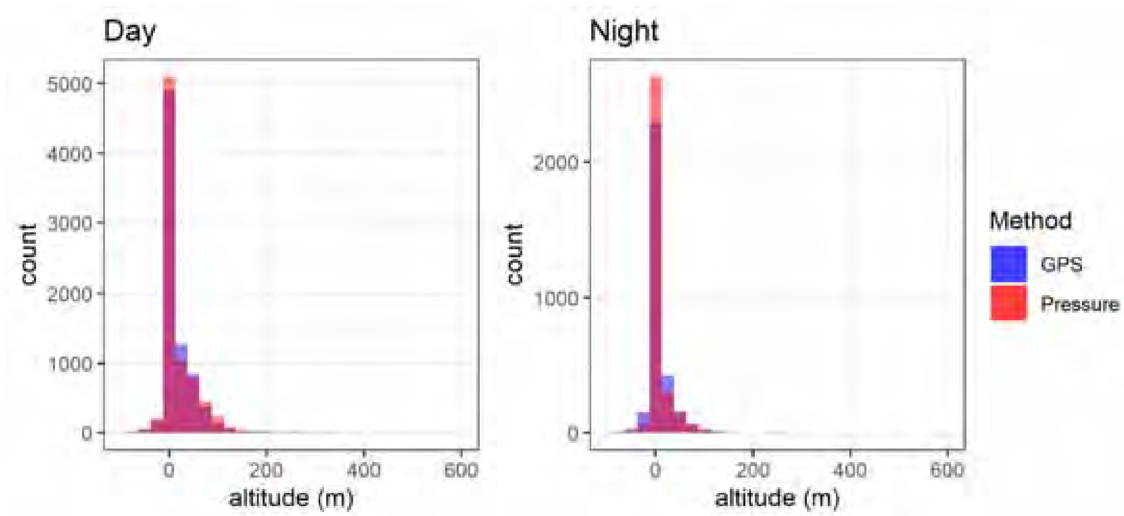


Figure 4.15 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes attributed to all fixes at a fix rate of five minutes, split by day and night.

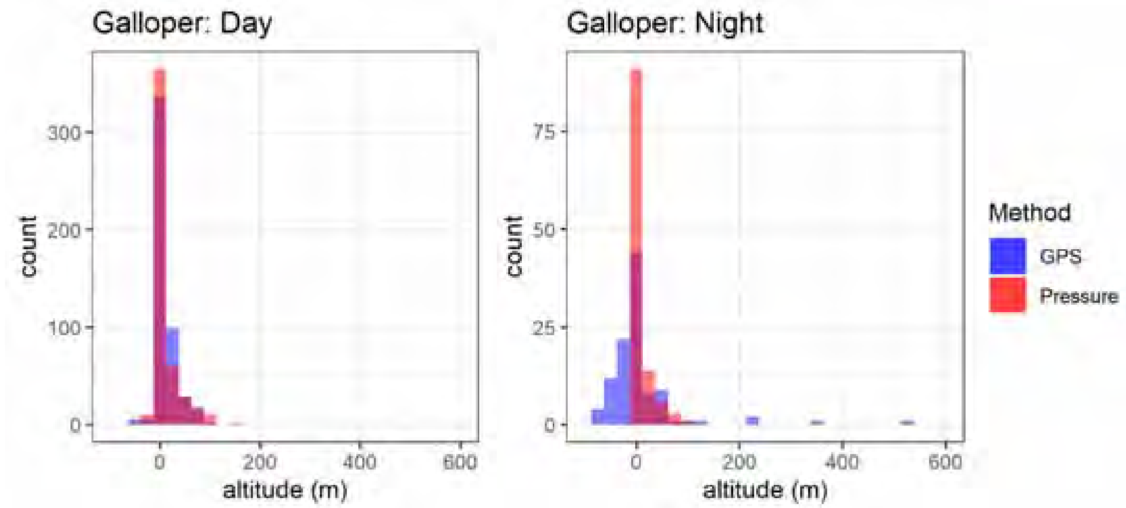


Figure 4.16 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes within the GWF attributed to all fixes at a fix rate of five minutes, split by day and night.

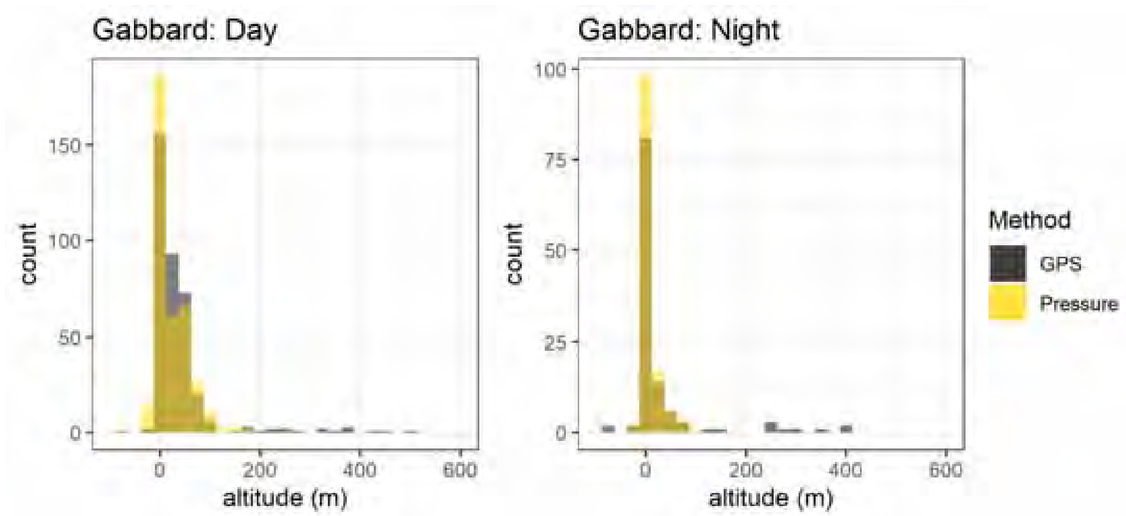


Figure 4.17 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes within the Greater Gabbard OWF attributed to all fixes at a fix rate of five minutes, split by day and night.

4.6.2 Altitude analysis based on data collected at a 5-10 second fix rate

Tables 4.19-4.21 and 4.22-4.24 display mean GPS and pressure sensor-derived altitudes and the proportions of fixes within RSZs for all periods, the day-time and night-time, based on data collected at a 5-10 second resolution, respectively considering (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2). Note, that data collection at this sampling rate was biased to the day-time and hence sample sizes for the night-time period are low.

Altitudes estimated from pressure sensor data recorded at a fix rate of 5-10 seconds were consistently lower than those recorded by GPS. This deviation was maintained across all spatial and temporal categories. Altitudes recorded by both sensors were frequently higher during the day (Table 4.20) than at night (Table 4.21) across all wind farm boundaries, with the exception of GPS altitudes within GWF. Proportionally, altitudes were less likely to be within the RSZ of the Greater Gabbard Wind Farm during periods of night than day. The opposite relationship was apparent for proportions of flights within the RSZ of GWF (Table 4.20 and 4.21). This may be related to differences in the size of the RSZ between the OWFs (see 4.6.3). In both OWF areas, sample sizes were much smaller at night (Table 4.21) than during the day (Table 4.20). This may be related to night roosting behaviour in gulls, which may occur outside the offshore region of the wind farms. The proportion of altitudes within the RSZ were often lower when based on pressure sensor data than GPS. While the degree of overlap was dependent on the RSZ characteristics of the specific wind farm, the greater proportion of overlapping altitudes attributed to GPS may be due to GPS maintaining higher mean altitudes. Visualisations of the altitude distributions are also shown in Figures 4.18-4.21.

Altitudes attributed to both GPS and barometric pressure measurements were 6.36-13.84 m greater when only considering fixes associated with in flight behaviours, while the proportions of fixes within the RSZ were 7.12-22.5% greater (Tables 4.13, 4.16). The disparity varied between the night and day, with in flight only altitudes recorded during the night differing to those based on all fixes to a lesser extent than those recorded during the day (in contrast to altitudes taken at a fix rate of five minutes). In flight altitudes recorded at night differed from those based on all fixes by 1.61-6.10 m, compared with 6.83-14.41 m for the day. This difference is further reflected in the proportions of fixes within RSZs, with the proportions associated with in flight fixes at night being 4.75-8.02% greater than those based on all fixes, compared with 7.21-22.84% for the day.

Table 4.19 Mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	8.76	57.36	9271	8.48	27.08	9183	26.16	26.16	2425	15.35	15.78	1410
Galloper	13.41	24.28	12892	8.54	24.08	12807	23.17	23.17	2987	13.98	13.98	1790
All OWFs	13.33	36.34	37895	8.48	24.24	37538	14.28	14.28	5412	8.52	8.63	3200
Outside OWFs	14.83	36.96	91430	8.71	22.68	90416						

Table 4.20 Day-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	8.35	58.19	8931	8.11	25.58	8844	25.99	25.99	2321	14.94	15.25	1321
Galloper	13.37	24.30	12661	8.33	24.03	12576	22.89	22.89	2898	13.53	13.53	1701
All OWFs	13.31	36.92	36306	8.45	24.09	35950	14.38	14.38	5219	8.41	8.49	3022
Outside OWFs	14.87	38.11	84270	8.71	22.97	83257						

Table 4.21 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n	%[1]	%[2]	n
Gabbard	19.44	25.83	340	18.25	52.11	339	30.59	30.59	104	26.25	29.50	89
Galloper	15.63	23.56	231	19.58	24.34	231	38.53	38.53	89	38.53	38.53	89
All OWFs	13.86	18.68	1589	9.19	27.40	1588	12.15	12.15	193	11.21	11.90	178
Outside OWFs	14.35	18.68	7160	8.69	18.87	7159						

Table 4.22 Mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	17.42	73.95	2548	15.42	32.82	2508	46.08	46.08	1174	27.91	28.91	700
Galloper	27.21	27.54	3112	17.88	33.87	3066	45.95	45.95	1430	28.86	28.73	885
All OWFs	23.52	44.42	10325	15.70	31.63	10136	25.22	25.22	2604	15.64	15.84	1585
Outside OWFs	24.79	43.75	26592	15.07	29.53	26088						

Table 4.23 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						**% in rotor swept zone**					
	GPS			**Pressure sensor**			**GPS**			**Pressure Sensor**		
	Mean	**SD**	**n**	**Mean**	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**	**%[1]**	**%[2]**	**n[1]**
Gabbard	16.96	75.75	2410	15.16	33.35	2370	46.39	46.39	1118	27.55	28.35	653
Galloper	27.45	27.66	3012	17.72	34.12	2966	46.02	46.02	1386	28.35	28.22	841
All OWFs	23.82	45.45	9755	15.91	32.26	9566	25.67	25.67	2504	15.62	15.77	1494
Outside OWFs	25.65	45.68	23814	15.54	30.10	23311						

Table 4.24 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) actual sea surface and (2) Mean Sea Level (MSL) (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						**% in rotor swept zone**					
	GPS			**Pressure sensor**			**GPS**			**Pressure Sensor**		
	Mean	**SD**	**n**	**Mean**	**SD**	**n**	**%[1]**	**%[2]**	**n**	**%[1]**	**%[2]**	**n**
Gabbard	25.46	26.29	138	19.92	21.39	138	40.58	40.58	56	34.06	38.41	47
Galloper	19.78	22.49	100	22.82	24.99	100	44.00	44.00	44	44.00	44.00	44
All OWFs	18.39	19.29	570	12.14	17.87	570	17.54	17.54	100	15.96	17.02	91
Outside OWFs	17.49	19.20	2778	11.16	23.93	2777						

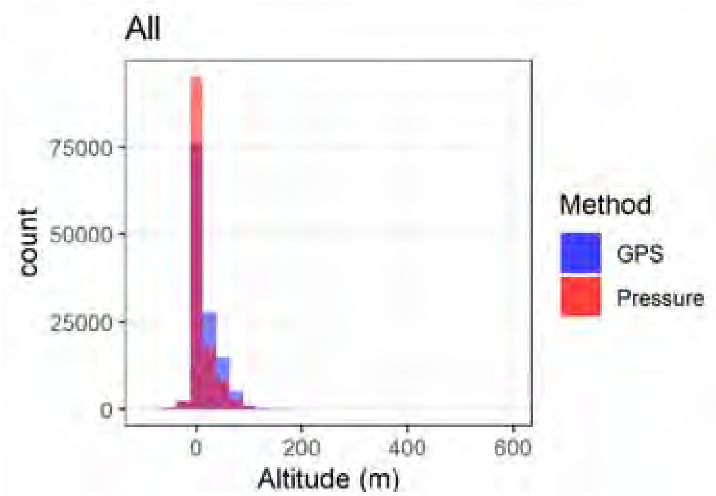


Figure 4.18 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes attributed to all fixes at a fix rate of 5-10 seconds.

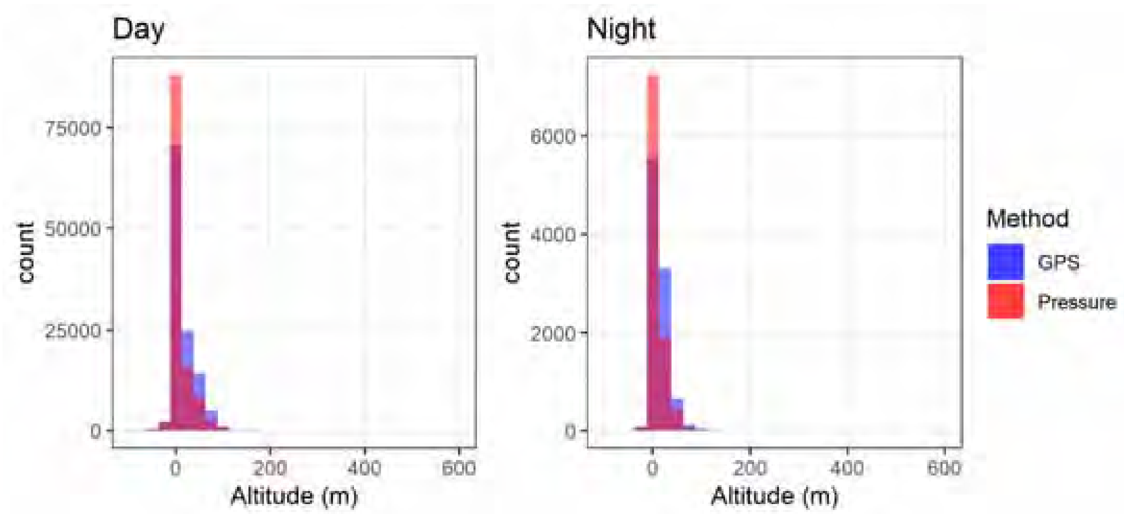


Figure 4.19 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes attributed to all fixes at a fix rate of 5-10 seconds, split by day and night.

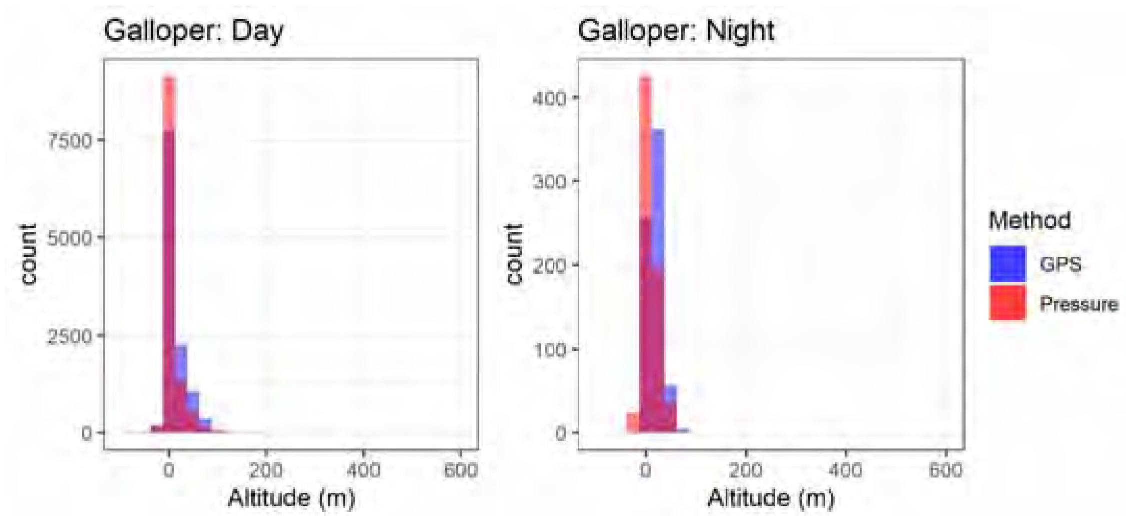


Figure 4.20 Comparison of GPS (blue bars) and pressure sensor (red bars) derived altitudes within the GWF attributed to all fixes at a fix rate of 5-10 seconds, split by day and night.

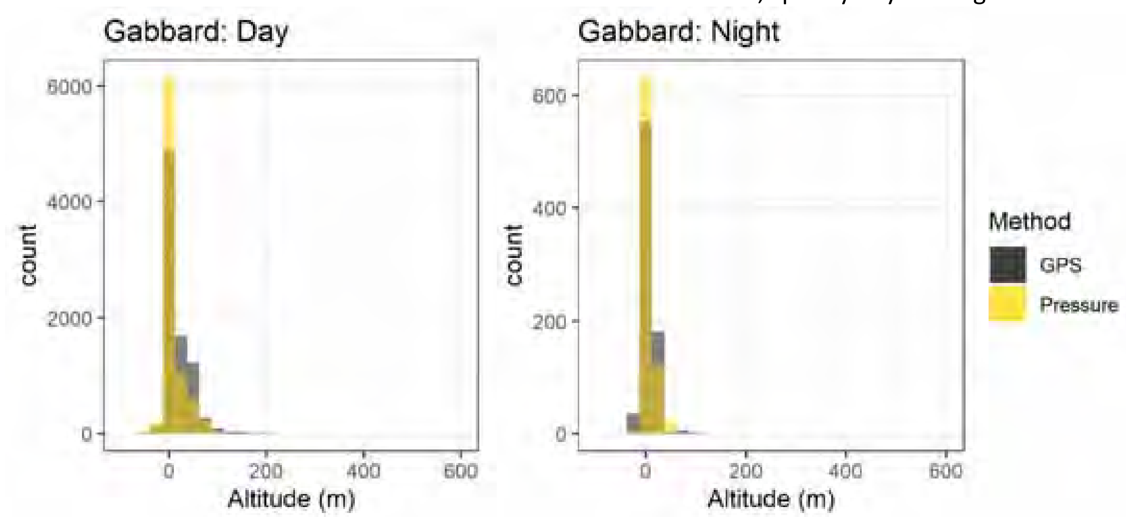


Figure 4.21 Comparison of GPS (black bars) and pressure sensor (yellow bars) derived altitudes within the Greater Gabbard Wind Farm attributed to all fixes at a fix rate of 5-10 seconds, split by day and night.

4.6.3 Altitude recording method and three-dimensional use of wind farms

When examined in a three-dimensional context, and in relation to the RSZ of the GWF (Fig 4.22) and Greater Gabbard Wind Farm (Fig 4.23) turbines, it was apparent some variation was present in both GPS and pressure sensor altitudes. GPS data, collected both at five minute and 5-10 second sampling rates, showed a number of series of positions at higher altitudes within both the Galloper and Greater Gabbard Wind Farms. Some outlying negative altitudes were present within the pressure sensor 5-10 second data within the GWF, representing part of the error distribution in the data (Fig 4.29). In both the Galloper and Greater Gabbard Wind Farms, pressure sensor altitudes generally maintained a tighter distribution than altitudes attributed to the GPS. This is further evidenced by the standard deviation of GPS and pressure sensor altitudes displayed in the tables in sections 4.4.1 and 4.6.2 above. There is a more in depth evaluation of the three-dimensional space use of the GWF and other OWFs in section 4.7.

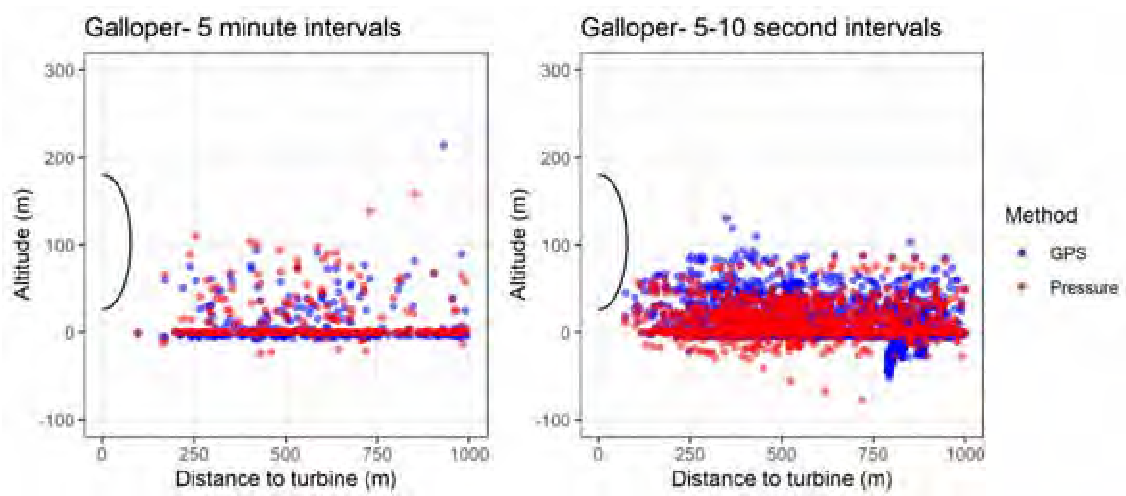


Figure 4.22 Comparison of GPS (blue points) and pressure sensor (red points) derived altitudes in three-dimensional space within the GWF split by fix rates of five minutes and 5-10 seconds. The rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. Note, this depiction does not take into account wind direction and direction turbines then face, hence assuming a precautionary approach of birds approaching at consistent direct angle along the line of rotation.

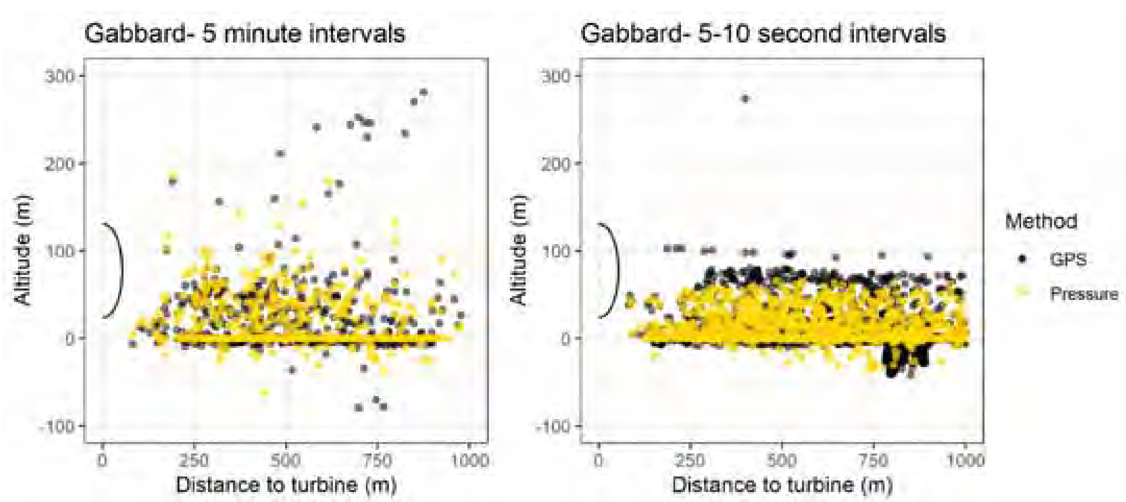


Figure 4.23 Comparison of GPS (black points) and pressure sensor (yellow points) derived altitudes in three-dimensional space within the Greater Gabbard Wind Farm split by fix rates of five minutes and 5-10 seconds. The rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. Note, this depiction does not take into account wind direction and direction turbines then face, hence assuming a precautionary approach of birds approaching at consistent direct angle along the line of rotation.

4.6.4 Pressure sensor error distribution

For each GPS fix taken, a concurrent value of barometric pressure was also recorded. The single pressure value attributed to each fix was derived from a burst of 10 pressure readings recorded at a rate of 10 Hz. To examine the degree of variation within the burst of pressure sensor readings, and the subsequent influence of this variation on comparisons of GPS and pressure sensor altitude, the standard deviation in altitudes attributed to pressure bursts was investigated. It was apparent that altitudes derived from pressure burst data followed normal distributions across both fix rates and between individuals (Fig. 4.24) Within the Galloper and Greater Gabbard Wind Farms altitudes derived from pressure burst data also displayed normal distributions across both fix rates (Fig 4.25). Within the wind farms burst altitudes maintained a mean standard deviation per burst of 0.95-4.56 m (five minute fix rate) (Table 4.25) and 0.89-1.65 m (5-10 second fix rate) (Table 4.26). The mean difference between the GPS and pressure sensor altitudes were of 0.68-23.81 m (five minute fix rate) (Table 4.18) and 0.03-24.00 m (5-10 second fix rate) (Table 4.26). Therefore, standard deviation in pressure error was smaller than the variance between mean GPS and pressure sensor altitudes.

Measurements of altitude in GPS systems may also contain a degree of error. Potential error arises from variation in the speed of receiving of ephemeris and almanac information from satellites, which are used to process positional information, and discrepancies in the atomic time held by the GPS and the satellite (Ross-Smith et al. 2016). Higher sampling frequency (5-10 seconds) may increase altitude accuracy, as the GPS module continually works at maximum capacity to achieve the greatest precision, while at five minute sampling rates the GPS may enter an energy saving mode between fixes, slowing the reception of positional information (Thaxter et al. 2018a). However, in Thaxter et al. (2018a) the precision of altitude information was deemed not to have significantly influenced the outcome of flight height analysis.

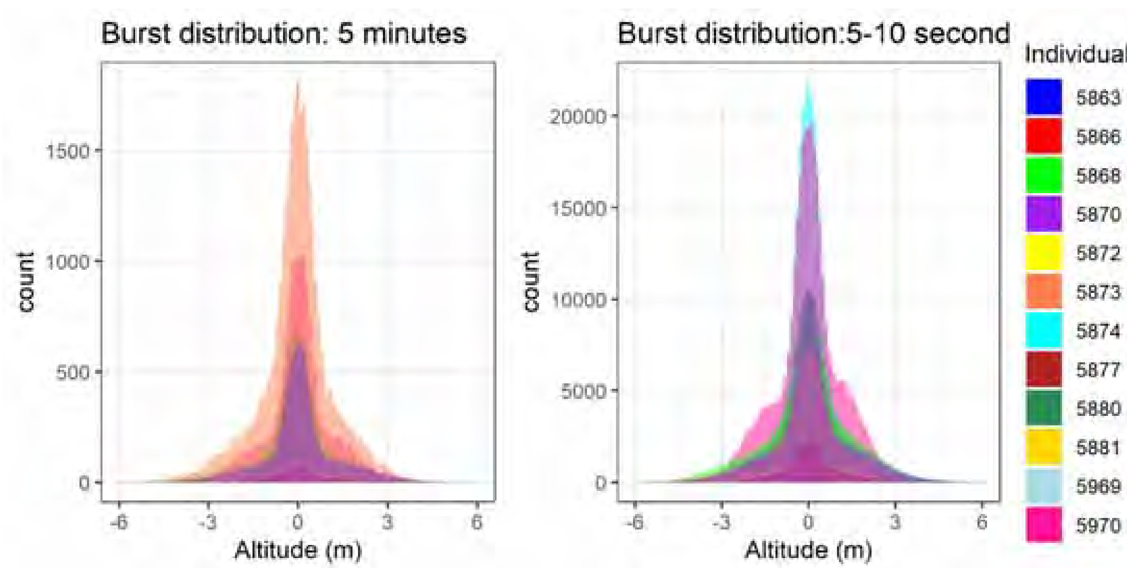


Figure 4.24 Standard deviations of altitudes produced from pressure burst values (10 per fix) in relation to fix rate and tracked individuals.

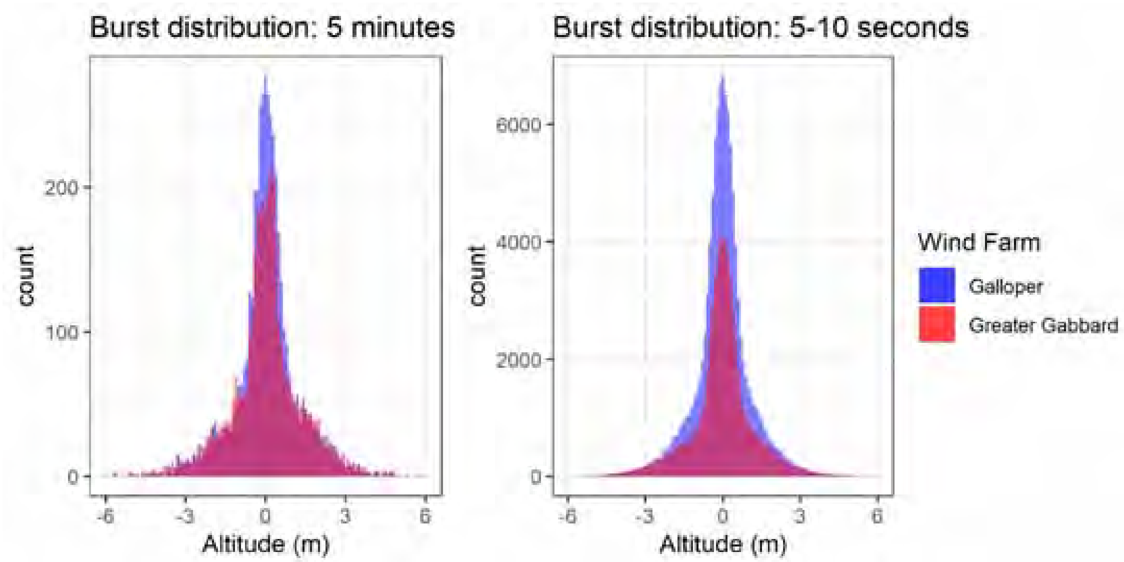


Figure 4.25 Standard deviations of altitudes produced from pressure burst values (10 per fix) in relation to fix rate, for the GWF (blue) and Greater Gabbard Wind Farm (red).

Table 4.25 Mean GPS and pressure sensor derived altitudes, produced from five minute fix rates, in relation to the rotor swept zone (RSZ) of the Galloper and Greater Gabbard Wind Farms. Also displayed is the mean standard deviation of altitudes produced per burst (10 per fix) of pressure sensor recordings.

	Flight Height			
	GPS		**Pressure sensor**	
Wind Farm	**Rotor zone**	**Mean**	**Mean**	**SD**
Galloper	In	50.61	57.91	1.70
	Out	0.64	4.55	0.95
Greater Gabbard	In	52.99	60.57	4.56
	Out	5.99	6.84	1.01
Outside	NA	13.46	14.57	0.98

Table 4.26 Mean GPS and pressure sensor derived altitudes, produced from 5-10 second fix rates, in relation to rotor swept zone (RSZ) of the Galloper and Greater Gabbard Wind Farms. Also displayed is the mean standard deviation of altitudes produced per burst (10 per fix) of pressure sensor recordings.

	Flight Height			
	GPS		**Pressure sensor**	
Wind Farm	**Rotor zone**	**Mean**	**Mean**	**SD**
Galloper	In	52.79	31.21	1.35
	Out	1.09	1.05	0.89
Greater Gabbard	In	51.88	28.07	1.65
	Out	1.38	2.06	1.16
Outside	NA	13.87	7.77	1.20

4.7 Movements Within the GWF and Other OWFs

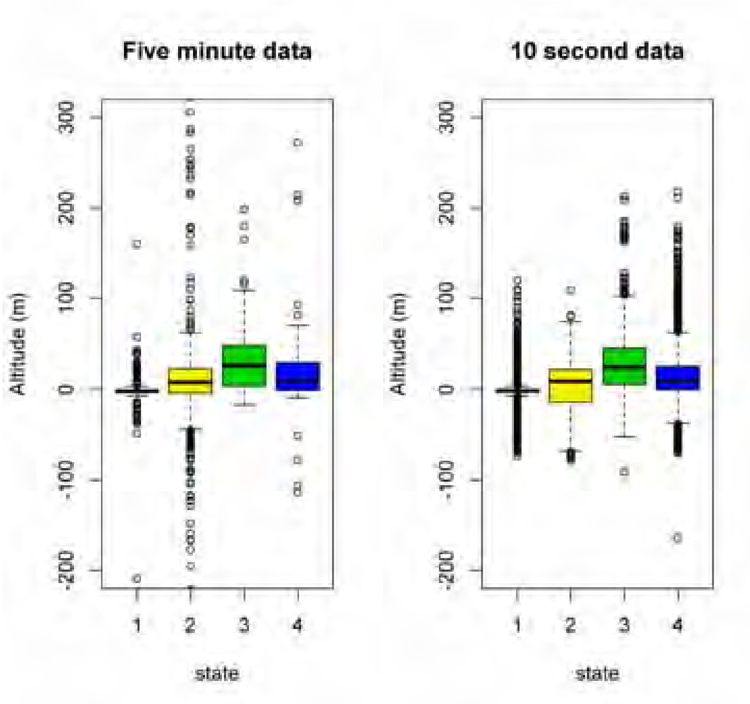
4.7.1 Behaviour, altitude and three-dimensional use of wind farms

The analyses of behaviour and flight heights presented above in sections 4.5 and 4.6 were brought together to assess three-dimensional space within the GWF and other OWFs. These analyses were made using the EMbC and RF behavioural classifications (using the equivalent dataset as the analysis of flight heights in section 4.6). For these investigations, we focused on the classifications from the unsupervised EMbC and RF model that were based on filtered but otherwise non-interpolated data, as the HMM in using an interpolated method for behavioural distinction essentially decouples covariate data from the original GPS fixes, i.e. flight altitude. While covariates could validly be matched to the nearest fix which, this may also introduce some error into the distribution. For this analysis, we also pool 2019 and 2020 for further simplicity.

For each behavioural state, GPS fixes recorded within the Galloper and Greater Gabbard Wind Farms were first plotted in relation to altitude (Fig. 4.26) and, second, both in relation to distance to nearest wind turbine and altitude, thus presenting as a two-dimensional x,y plot representing three-dimensional space (Figs. 4.27-4.30). These plots revealed some interesting patterns. First, there were apparent large variations in the spread of GPS altitudes along the x-axes in all plots, that were mostly associated with stopped or floating activity, thus likely representing error; however, this error was recorded at specific distances from individual turbines. These points were associated with the locations of offshore service platforms, with the nearest platform distance to a turbine being ca. 1500 m within GWF and 800 m within the Greater Gabbard Wind Farm. This error was apparent both in the five minute sampled data (Fig 4.27-4.28) and the fast-sampling 5-10 second dataset (Fig 4.29-4.30, a sampling rate for UvA tags that has been shown to be more precise (Thaxter et al. 2018a) given that the receiver is permanently switched on at these rates, providing further evidence that an external phenomena is likely driving the source of error at service platforms. This error is most likely due to interference with the GPS signal around structures on the platforms. Or alternatively there may have been some other interference with the GPS such as an electromagnetic source, i.e. interference from another UHF signal perhaps; it is noted, however, that birds primarily targeted offshore service platforms rather than standalone metmasts.

More thorough assessment of flight altitudes within OWFs is provided in section 4.6 above, however, simple boxplots revealed higher overall flight heights of Lesser Black-backed Gulls commuting than foraging (Fig. 4.26). The error surrounding stationary points is also apparent in these plots. Of further note was the high proportion of fixes that were classified as floating by the RF model, yet were apparently high above sea level. It is therefore likely the RF model misclassified a proportion of slower commuting fixes. This was particularly true for the faster-sampling 5-10 second dataset.

(a) EMbC



(b) RF

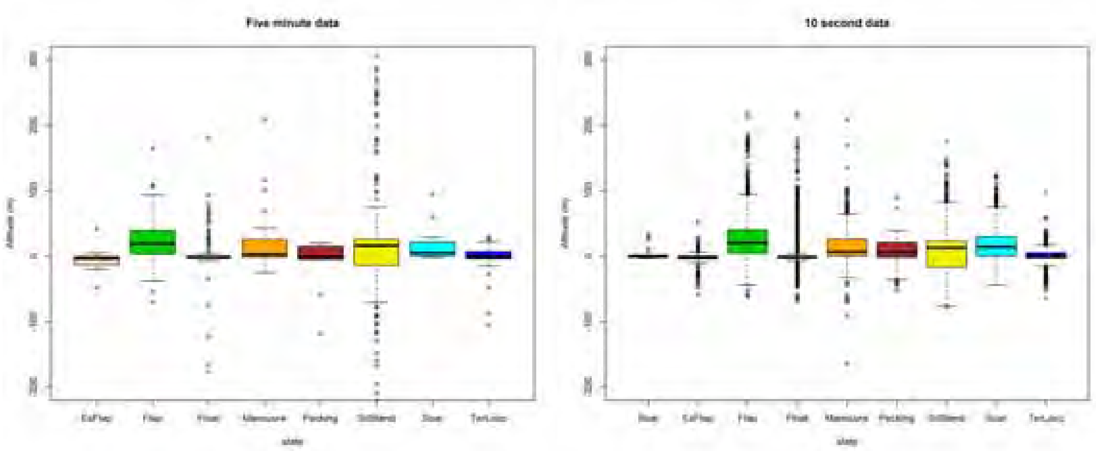


Figure 4.26 Offshore altitude distributions of Lesser Black-backed Gulls, for each behavioural state, based on data collected at a five minute sampling rate in 2019 and 2020, using behavioural classifications from (a) EMbC and (b) the RF model. States in (a) correspond to 1 = floating, 2 = stopped, 3 = commuting, 4 = foraging/searching.

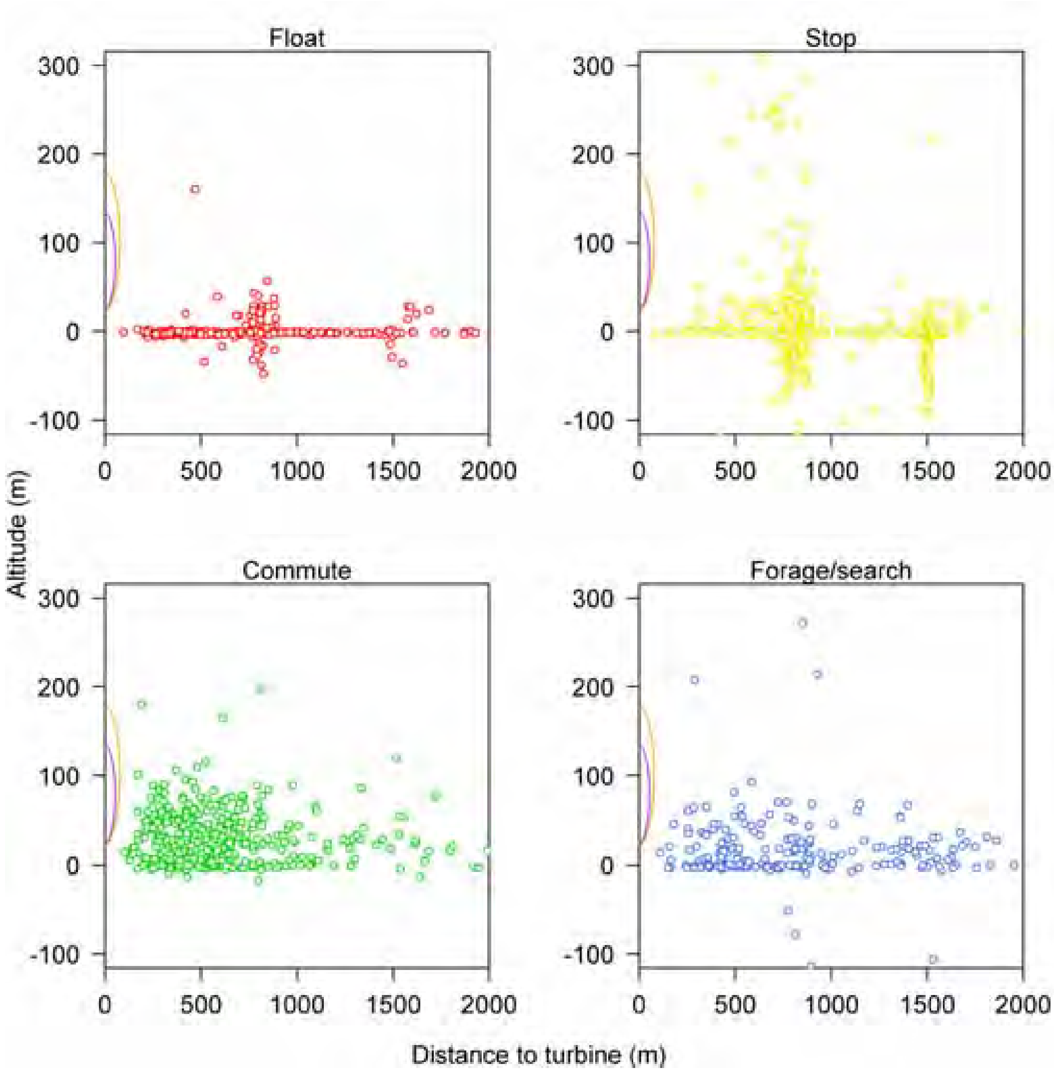


Figure 4.27 GPS fix locations of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a five minute rate, split by EMbC behavioural state. The rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. Note, this depiction does not take into account wind direction and direction turbines then face, hence assuming a precautionary approach of birds approaching at a consistent direct angle along the line of rotation.

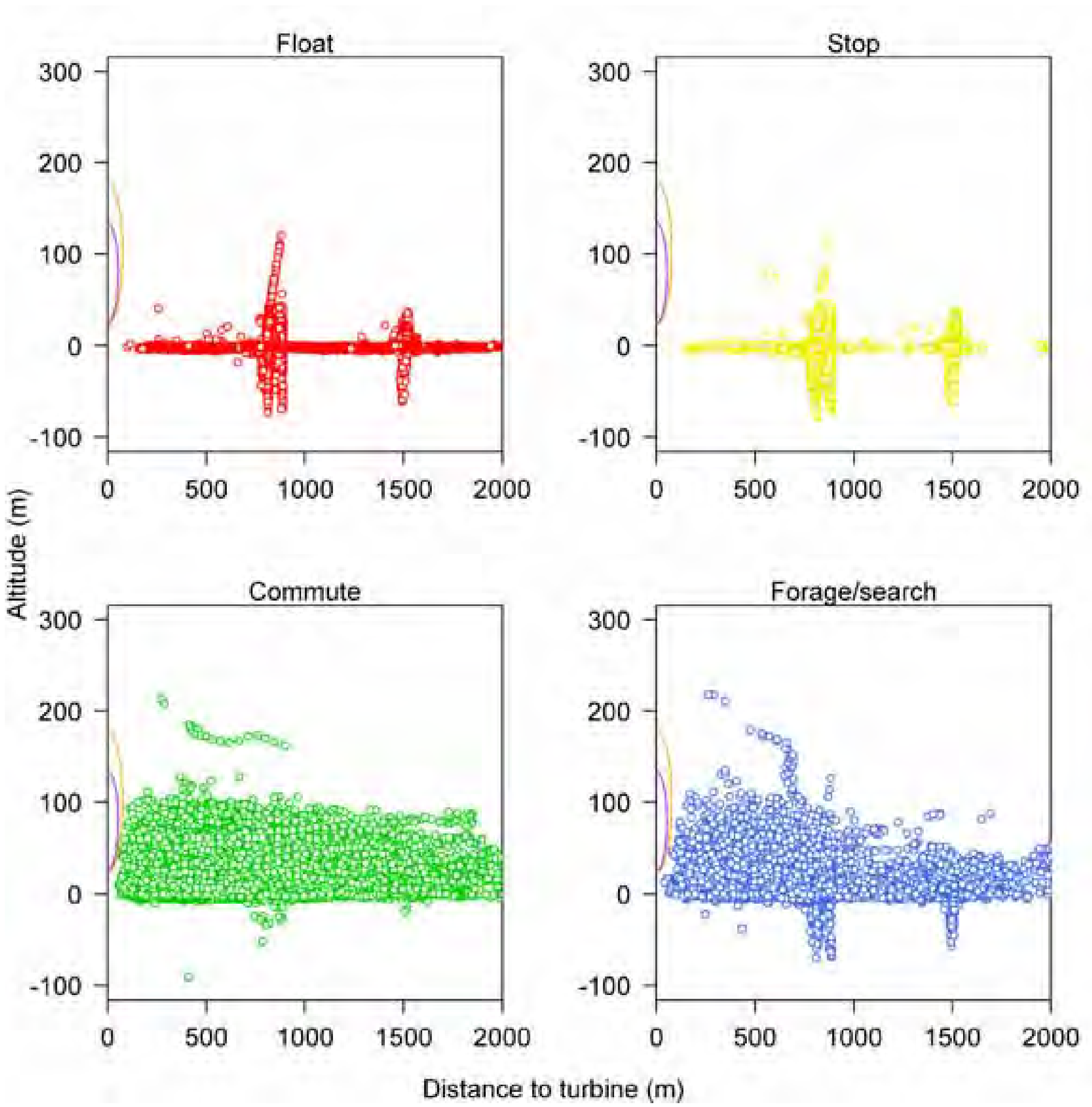


Figure 4.28 GPS fix locations of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a 5-10 second rate, split by EMbC behavioural state. The rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. See Fig 4.33 for more information.

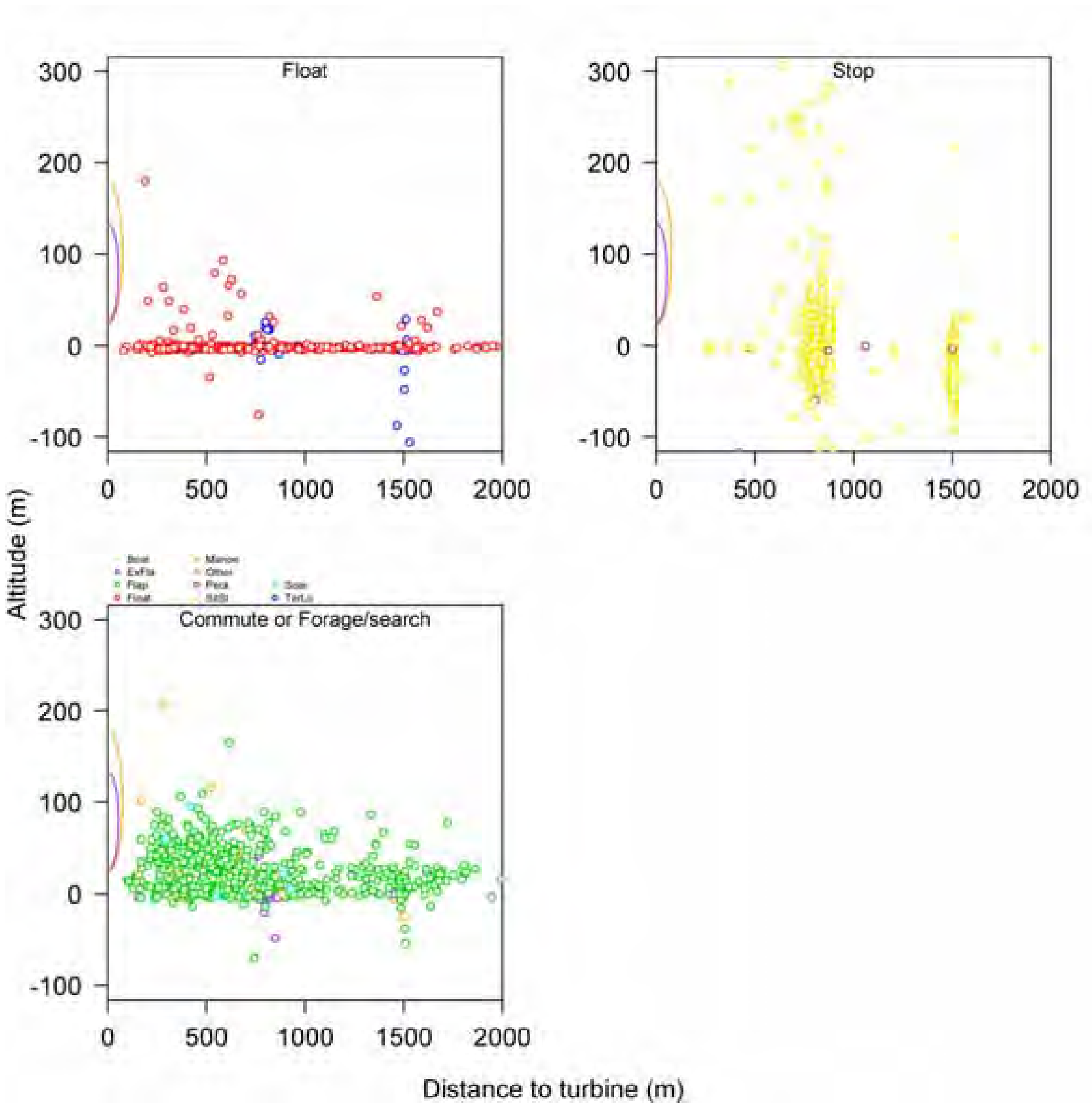


Figure 4.29 GPS fix locations of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a five minute rate, split by behavioural classes from the RF model. Random Forest (RF) classes: top left stopped (RF model, 'SitStand', 'Pecking'), top right floating (RF model, 'Float', 'TerLoco', 'Boat'), bottom left commuting and foraging/searching (RF model, 'Flap', 'Soar', 'Manoeuvre' and 'ExFlap'); the rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. See Fig 4.33 for more information.

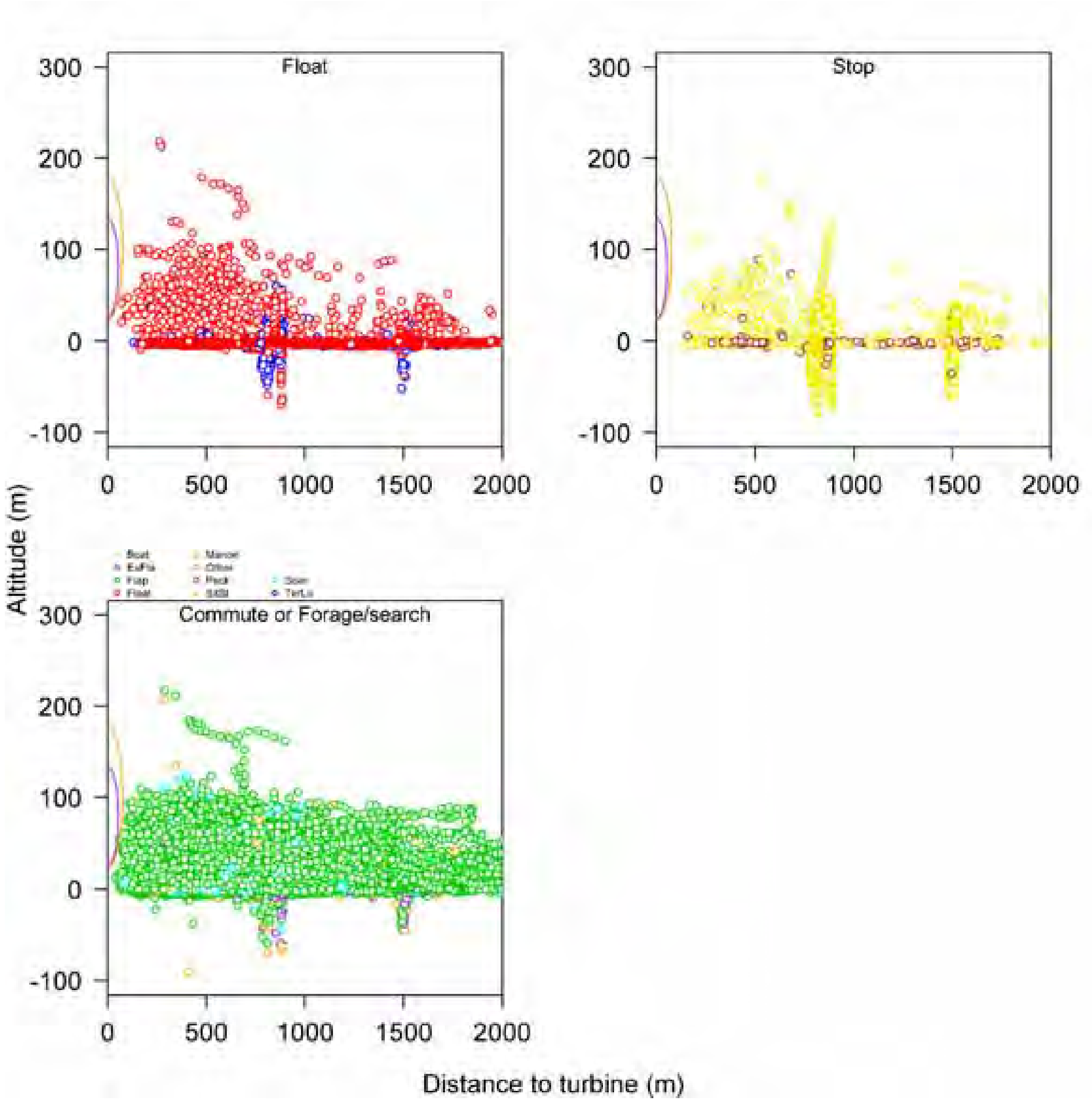


Figure 4.30 GPS fix locations of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a 5-10 second sampling rate, split by behavioural classes from the RF model. RF classes are given as: top left stopped (RF model, 'SitStand', 'Pecking'), top right floating (RF model, 'Float', 'TerLoco', 'Boat'), bottom left commuting and foraging/searching (RF model, 'Flap', 'Soar', 'Manoeuvre' and 'ExFlap'); the rotor swept volume is depicted by semi-circles on the y-axis for dimensions of the turbines in each site. See Fig 4.33 for more information.

Fine-scale avoidance behaviours were initially visualised with the raw tracking data; for example in Fig 4.31 below, which shows behaviours classified by the RF model, the pattern of avoiding turbines is illustrated by one bird (5874) that made a circle of flapping flight around a single turbine, at between >50 m to ca. 100 m distance, and several other individuals (shown within this image) appeared to not venture near to turbines, with some even showing potential deviations in tracks (e.g. potential micro avoidance) on approach.

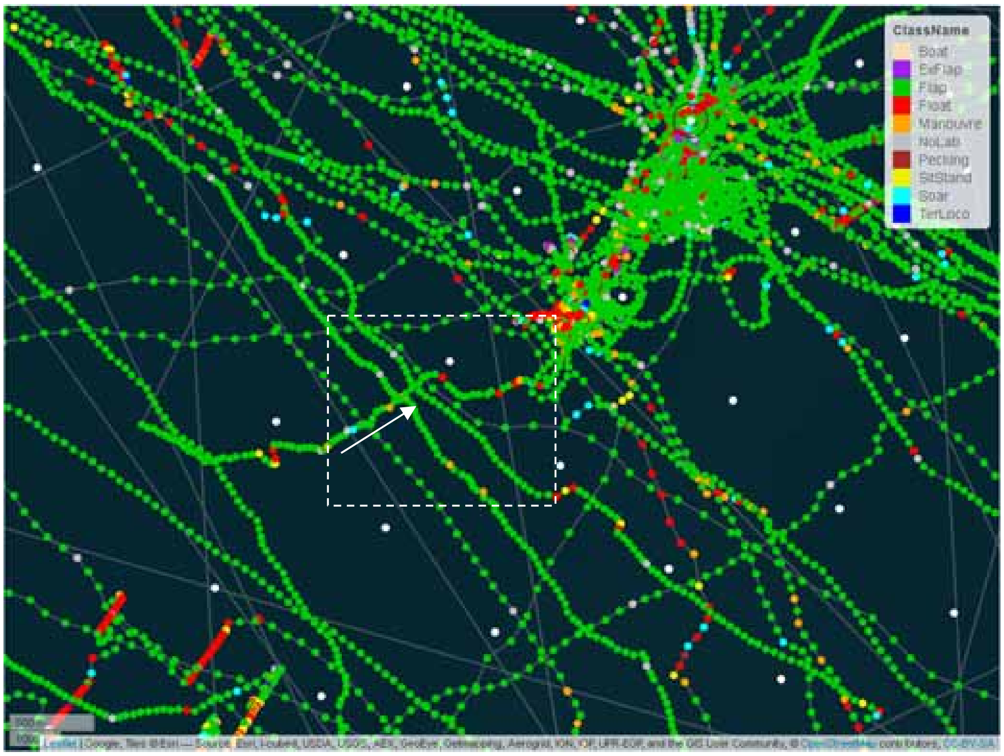


Figure 4.31 Fine-scale behaviour of Lesser Black-backed Gulls around individual wind turbines (white circles), overlain with data collected at 5-10 seconds, delineated by behaviour using the RF model; a black circle shows the offshore platform (not to scale); note potential deviations in some tracks (white square and arrow showing travel direction).

4.7.2 Interaction with the three-dimensional rotor swept volume

The fixes in the three-dimensional distance to turbine and altitude space as summarised above, were further translated into utilisation distributions based on the "in flight" (i.e. commuting and foraging/searching) fixes from the EMbC model.

Visually, these plots indicated very clearly that there was little to no interaction with the three dimensional rotor swept volume in either the Galloper or Greater Gabbard Wind Farms (Fig 4.32-4.33) and, indeed, no fixes in either the five minute or 5-10 second datasets were recorded in this zone. As a result, the distribution of observed fixes within the three-dimensional space was significantly different from a random distributions of points, indicating meso-avoidance, as also found in Thaxter et al. (2018a) and Johnston et al. (2022) ($P < 0.001$). The wide-scale interaction of Lesser Black-backed Gulls with the Galloper and Greater Gabbard Wind Farms nevertheless indicates a lack of a population-level macro-avoidance as also recorded in Thaxter et al. (2018a) and Johnston et al. (2022).

Further (see also the plots in section 4.7.1) birds did not use turbine bases; in fact very few fixes were recorded near to turbines regardless of flight altitude; should turbines have been used for activities such as perching, a group of stopped behaviours should have been visible at the turbine bases; this was not seen here, but has been recorded at other sites in the UK for this species (Clewley et al. 2021). The difference here could feasibly be a question of turbine design between different OWFs, and that within the Galloper or Greater Gabbard Wind Farms, turbines may not offer perching opportunities, and/or alternatively the offshore platforms offer much greater attraction.

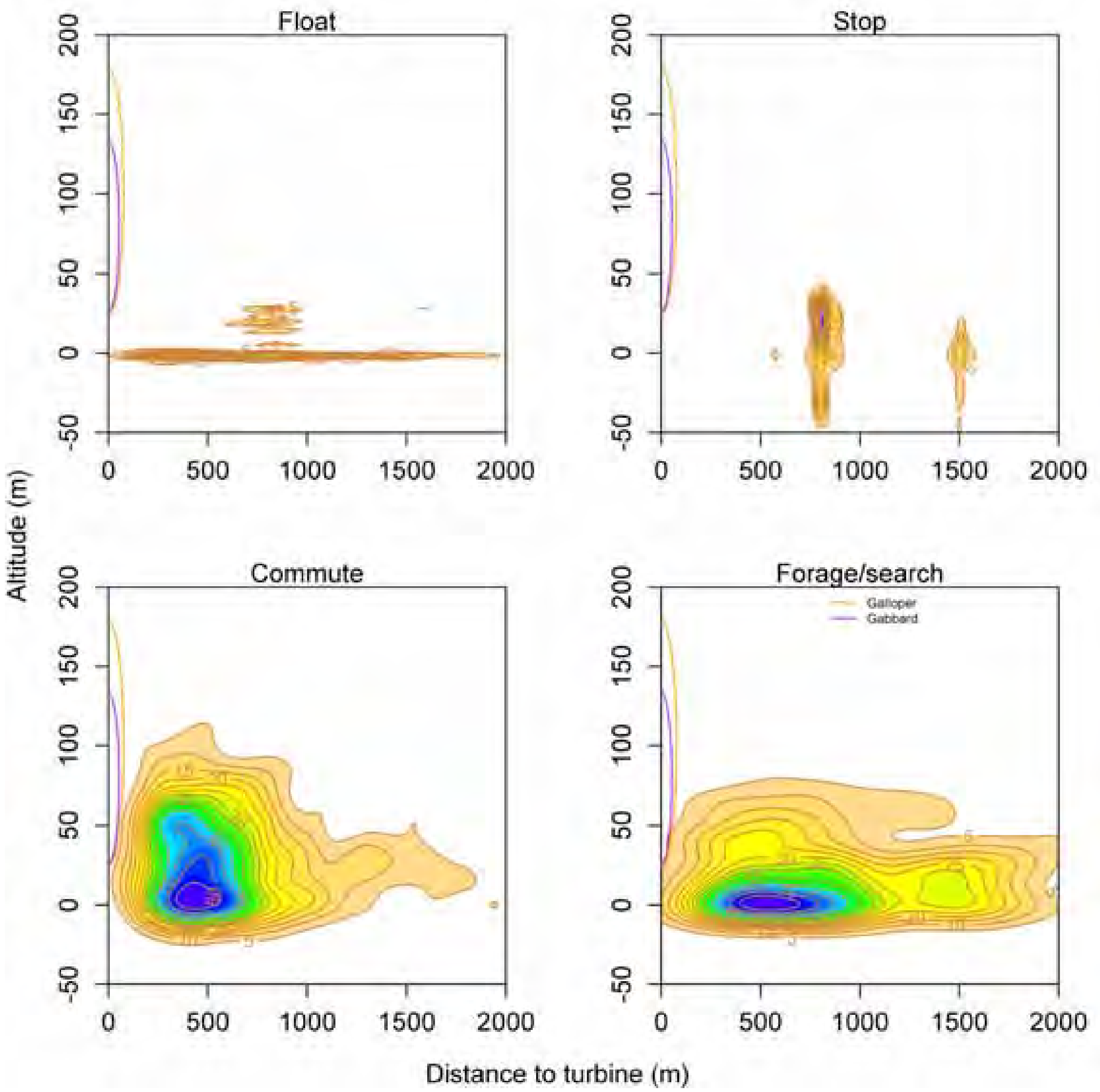


Figure 4.32 Distribution of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a five minute rate, split by EMbC behavioural state, and as assessed through a kernel density estimation. The three-dimensional rotor swept volume is indicated for the Galloper and Greater Gabbard Wind Farms, respectively.

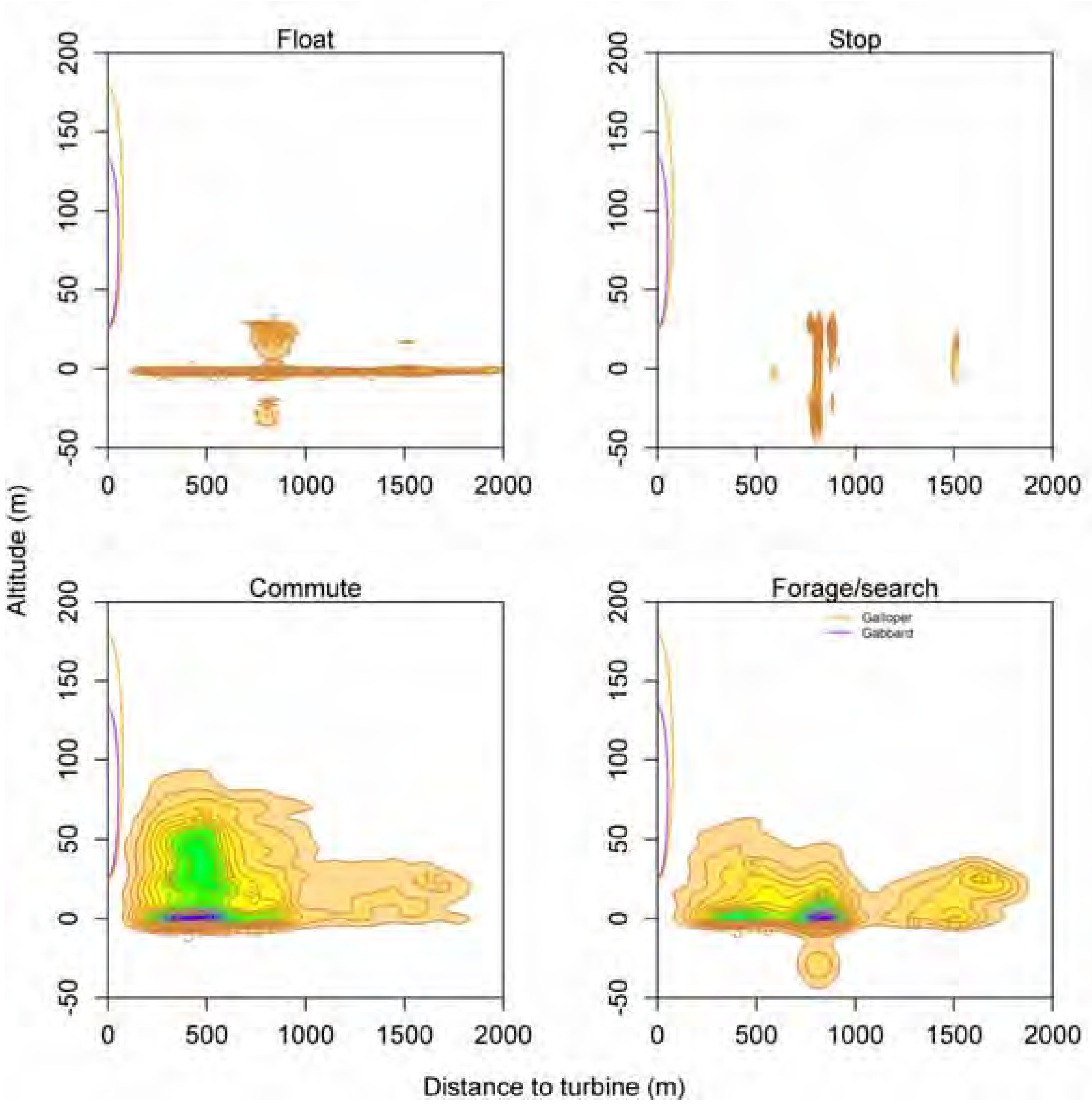


Figure 4.33 Distribution of Lesser Black-backed Gulls within the Galloper and Greater Gabbard Wind Farms in relation to distance from nearest turbine and altitude, based on data collected at a 5-10 second rate, split by EMbC behavioural state, and as assessed through a kernel density estimation. The three-dimensional rotor swept volume is indicated for the Galloper and Greater Gabbard Wind Farms, respectively.

4.7.3 Commuting 'flight' direction

We further investigated the direction of commuting flights within both the Galloper and Greater Gabbard Wind Farms. Given the placement of the wind farms SE of the Havergate colony, we hypothesised there may be differences in flight altitude as birds travelled in a south to south-easterly direction from the colony passing through the wind farms, and then returning back through the wind farms on a more north to north-westerly trajectory; for instance if birds we able to build altitude in flight on land before then commuting out to sea.

Fig 4.34 below, based on the fast-sampling 5-10 second dataset, shows a clear directional bias in flights through the wind farms with instantaneous directional heading at the individual fix level being biased towards southeast (46.5% of data), equating to outward directions, and northwest (26.8%).

This analysis also indicates (in an indirect way) that the travel direction from the breeding colony to the Galloper and Gabbard Wind Farms is likely directionally biased on the outward route of trips, yet on return, birds are more likely to return from a different direction; note however, this is a point-based analysis thus may overlook gradual drift in commuting direction and excludes fixes classified as foraging/searching.

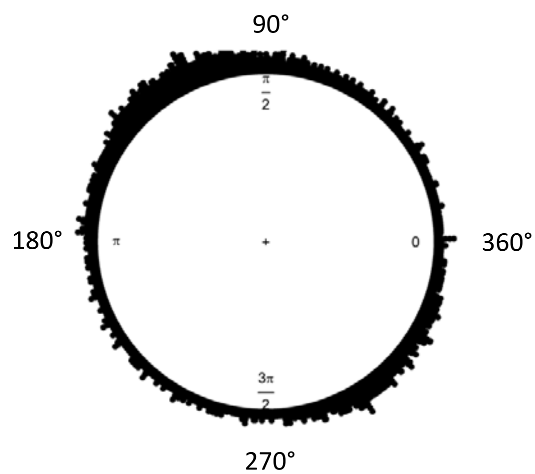


Figure 4.34 Distribution of instantaneous GPS headings for commuting Lesser Black-backed Gulls from Havergate Island, as identified by the EMbC model, based on fast-sampling 5-10 second data within the Galloper and Greater Gabbard Wind Farms

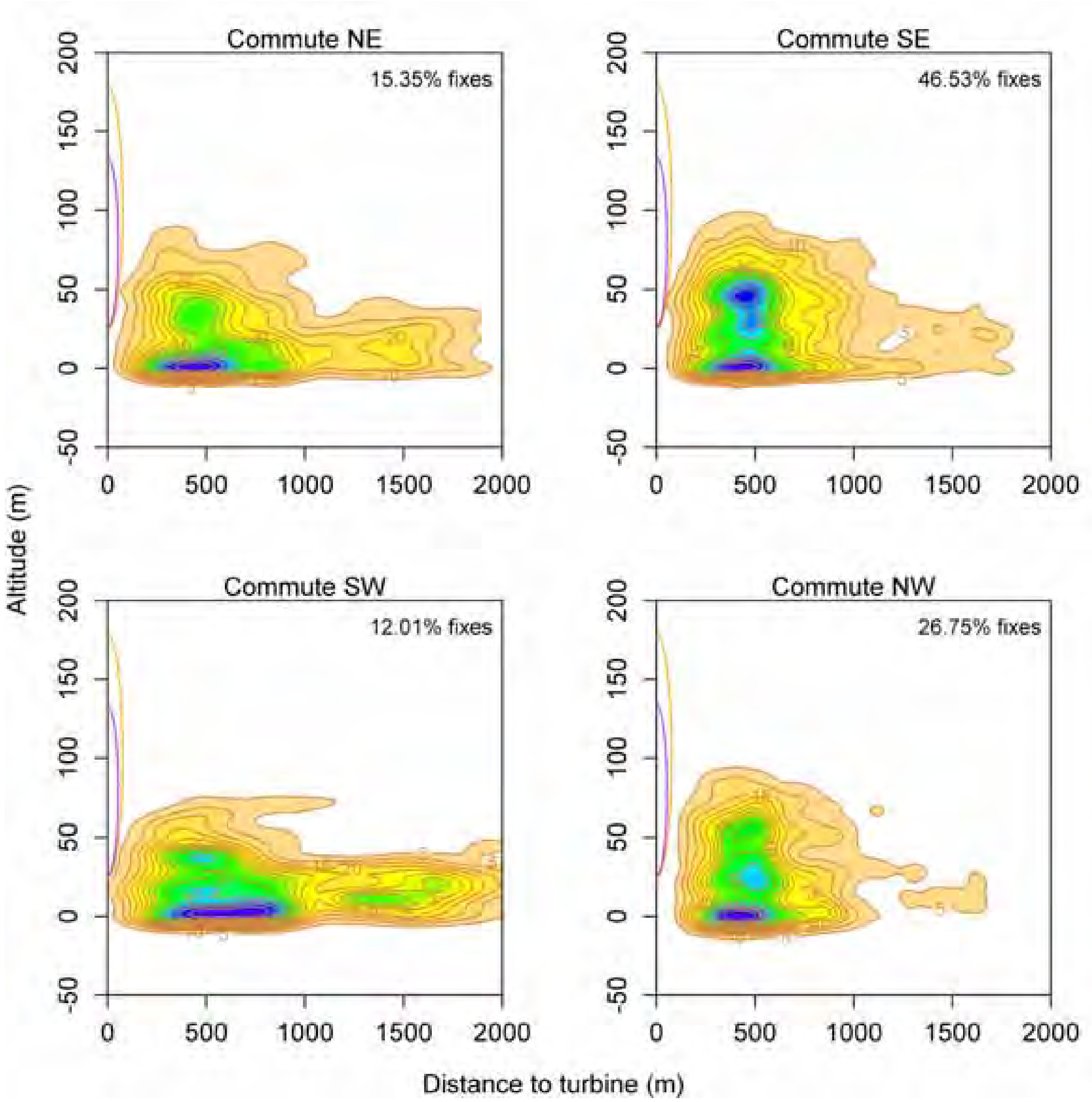


Figure 4.35 Distribution of Lesser Black-backed Gull commuting behaviour within the Galloper and Greater Gabbard Wind Farms, as assessed through a kernel density estimation, indicating distribution of fixes within the three-dimensional space within offshore wind farms when travelling different directions; data plotted using the fast-sampling 5-10 second dataset.

The distribution of the three-dimensional utilisation distribution space within the OWFs also varied according to travel direction (Fig 4.35). Although this is a descriptive assessment and does not take into account other biases such as time of day, weather, etc, there is an indication that commuting flights crossing the wind farms in a NW direction (i.e. likely on return to the colony), were more likely to be at a lower altitude than those likely coming from the colony heading SE.

As with the analysis across all directions above, the greatest concentration of commuting movements was at ca. 400-500 m indicating use of the turbine rows within the wind farms, indicating meso-avoidance across all travel directions.

4.8 Summary of 2019/20 Non-breeding Season Movements

Over-winter movements were also recorded from the GPS tags deployed in 2019, covering periods from when birds were no longer at the colony, to when they subsequently returned the following year. A total of 19 individuals provided data for this phase of the annual cycle (see Fig 4.36), i.e. those that also contributed data during the breeding season of 2020; two further birds (tracked with Movetech GPS-GSM tags) provided data for the near-full non-breeding period, but these birds unfortunately did not return to the colony (see section 4.1, Fig 4.37).

Table 4.27 outlines summary information from the movements outside of the breeding period. Absences from the colony lasted on average 228 days, with data suitable for further analysis (here taken as data with gaps between GPS fixes less than a 24 hours) averaging 202 days per bird. Birds travelled up to 3865 km (straight line distance) from Havergate in 2019/20, seen from one bird that reached Mauritania. Among other destinations, eight birds had a wintering area (defined by more than 10 consecutive days in a location) in Spain, six in Morocco, six in Western Sahara, three in Portugal, one in Mauritania, and only one bird spent the whole of the winter in the UK. This latter finding was interesting given that at other gull colonies, a larger proportion of overwintering birds in the UK has been reported (Thaxter et al. 2019).

Acknowledging that data gaps within the GPS records sometimes prevented a full assessment of total travel distance for some birds, Lesser Black-backed Gulls tracked from Havergate travelled up to 26,745 km (a bird wintering in Western Sahara with good coverage across the GPS record). However, there was no overall correlation between travel distance and maximum distance reached ($F_{1,18}$ = 0.59, P = 0.454), nor any correlation with how long birds were monitored for ($F_{1,18}$ = 1.84, P = 0.192). Gaps in the GPS record were more prevalent for Movetech tags than UvA, with five of the nine birds providing non-breeding data having gaps of over a month (using the 24-hour delineation), although there were no gaps in the dataset for bird 1119 that did not make it back to the colony. There was a maximum gap of 44 days (for bird 5872) for birds fitted with UvA tags.

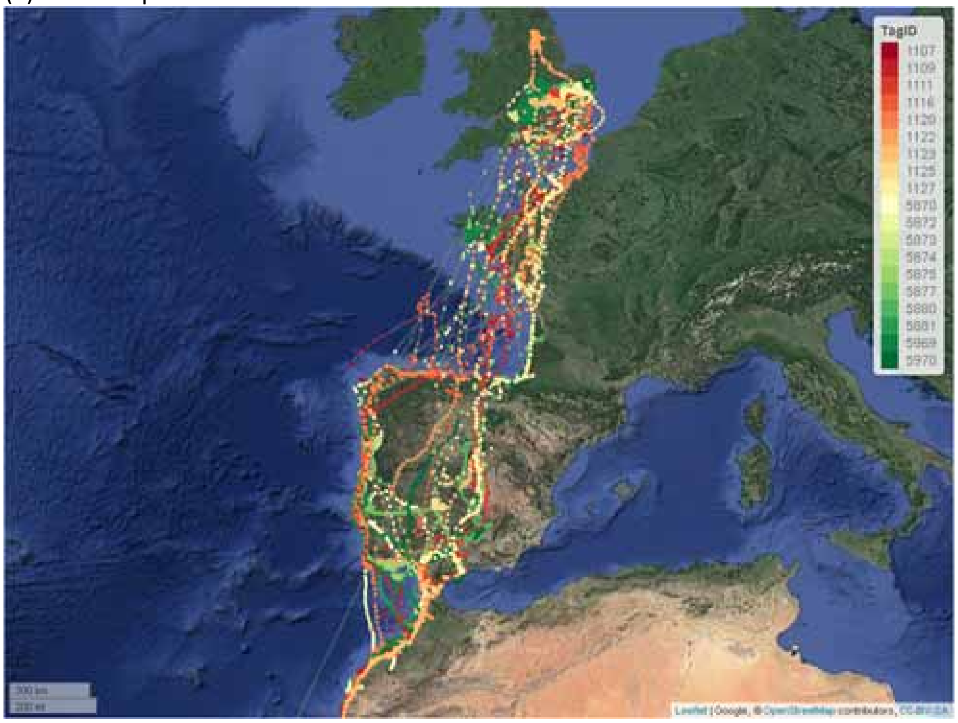
It was also possible to define stopovers and wintering areas by daily travel distance per bird. Here we took a threshold of 5 km/day to delineate stopped and travelling phases; Fig 4.38 shows the areas used by birds (red locations), both on migration, such as along the coasts of northern Spain and Portugal and at other times of winter. A more thorough analysis would be required to assess migration and non-breeding movements, however, the data showed that on average birds had 65.48±17.18% of their days classified as stopped at a stopover or wintering location and 34.52±17.18% travelling. However, this was highly variable per individual, with between 30.00% and 86.12% percentage of days stopped and 13.88% and 70.04% travelling; these calculations were made omitting the birds with more than 38 days of time when the tag was not monitoring due to data gaps, thus being based on 14 birds.

Table 4.27 Data collection periods over the 2019/2020 non-breeding season for Lesser Black-backed Gulls fitted with GPS tags on Havergate Island in 2019. Data came from both Movetech (MT) and University of Amsterdam (UvA) tags; start dates are the last date-time a bird was in the breeding colony, and the end date was the first fix back the following year; key to countries: Spain, Portugal, UK, Western Sahara, Morocco, Mauritania.

Tag ID	Start date	End date	Data duration (days)	Usable data (days)	GPS fixes	Max distance (km)	Total distance (km)	Destination
5870	23/09/2019 05:07	01/05/2020 18:24	221.55	221.55	12545	2249.75	15803.31	Spa/Mor
5872	28/08/2019 02:17	19/04/2020 11:12	235.37	191.13	10403	2443.39	17120.68	Mor
5873	19/08/2019 03:49	06/03/2020 19:40	200.66	200.66	6764	265.75	7275.72	UK
5874	24/07/2019 07:43	12/03/2020 20:38	232.54	227.20	11170	1522.99	11025.86	Por
5875	08/08/2019 03:36	07/03/2020 18:27	212.62	212.62	15584	1881.85	11833.64	Spa
5877	15/09/2019 05:06	28/03/2020 10:10	195.21	195.21	10106	1776.79	16885.35	Spa/Por
5880	02/08/2019 03:56	18/03/2020 19:34	229.65	229.65	13262	1774.22	15110.94	Spa
5881	13/08/2019 03:20	20/04/2020 21:44	251.77	243.04	9850	3699.60	26745.34	W Sah
5969	22/07/2019 03:28	04/04/2020 17:07	257.57	241.44	9930	2245.88	18693.51	Mor
5970	03/08/2019 14:02	20/02/2020 09:40	200.82	184.74	10531	1826.84	14271.80	Spa
1107	19/08/2019 21:04	13/04/2020 02:06	237.21	97.15	1594	3864.85	6063.95	Mau/W Sah
1109	08/08/2019 15:42	16/04/2020 17:48	252.09	238.10	4914	3680.67	15870.76	W Sah
1111	06/08/2019 03:32	05/04/2020 13:56	243.43	137.24	4811	2192.69	11411.71	Spa/Mor
1116	12/08/2019 03:26	30/04/2020 14:16	262.45	256.14	7546	3509.16	13093.69	W Sah
1120	23/08/2019 04:55	23/04/2020 19:59	244.63	238.09	6390	3094.91	10712.86	Mau/W Sah
1122	09/08/2019 03:36	14/03/2020 15:13	218.48	178.18	5753	2004.57	12436.57	Mor
1123	20/08/2019 03:30	06/04/2020 11:26	230.33	185.21	4348	3523.05	10895.08	W Sah
1125	19/08/2019 22:52	24/03/2020 17:42	217.79	180.14	4181	1564.16	10585.81	Spa
1127	31/08/2019 04:53	14/03/2020 15:32	196.44	190.04	4888	1785.14	10093.15	Spa
1108*	26/07/2019 04:41	04/05/2020 17:53	283.55	87.81	1510	2203.59	3913.94	Mor
1119*	01/09/2019 03:29	02/05/2020 18:37	244.63	244.63	4247	1839.14	6077.30	Por
Mean*	**16/08/2019**	**31/03/2020**	**228.45±20.97**	**202.50±39.29**	**8135±3705**	**2363.49 ± 955.56**	**13469.99 ± 4620.76**	
Range*	**22/07 – 23/09**	**20/02 – 01/05**	**195.21-262.45**	**97.15-256.14**	**1594-15584**	**265.75 ± 3864.85**	**6063.95 ± 26745.34**	

*Two birds tracked with Movetech tags recorded near-full non-breeding data but sadly did not make it back to the breeding colony in 2020; these birds are excluded from mean information.

(a) NW Europe



(b) S Europe and W Africa

Figure 4.36 Movements of 19 Lesser Black-backed Gulls over the 2019/2020 non-breeding season and over-winter period, split by individual birds, with focus on (a) the range in north-west Europe, and (b) the southern part of the range in Southern Europe and Africa.

Figure 4.37 Movements of two further Lesser Black-backed Gulls (that did not return to the breeding colony in 2020) over the 2019/2020 non-breeding season and over-winter period, split by individual birds; last known locations en route back to the colony can be seen in northern France where tags ceased transmitting data (being tags using the mobile phone network to communicate).

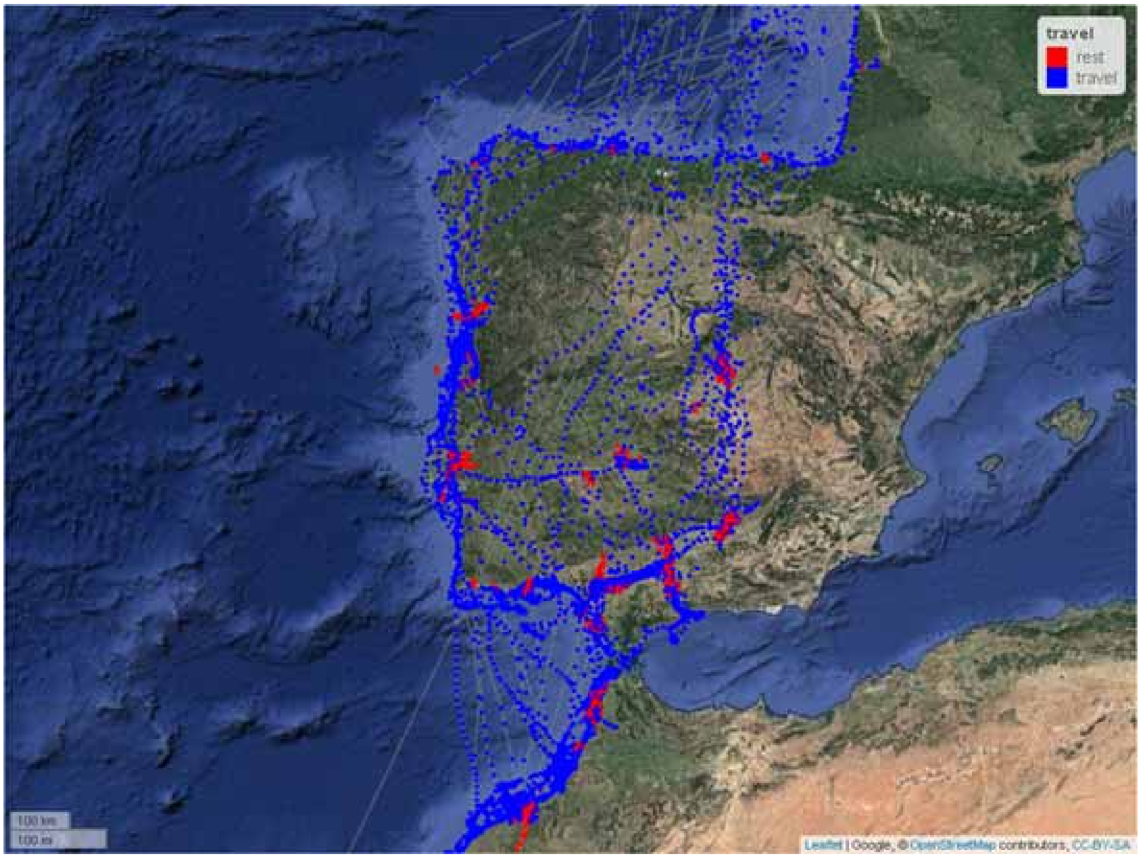


Figure 4.38 Movements of 19 Lesser Black-backed Gulls over the 2019/2020 non-breeding season and over-winter period, with GPS fixes coloured by travel and resting periods (defined by 5 km/day); the map centres on Spain, Portugal and northern Morocco where a majority of birds spent the winter months.

5. COMPARISONS WITH HISTORICAL DATASETS

5.1 GPS Data Collected for Lesser Black-backed Gulls between 2010 and 2015

Data from the 2010-14 BTO study based at Orford Ness undertaken for the BEIS (formerly DECC) OESEA programme (Thaxter et al. 2014b) and a second, shorter RSPB study undertaken in 2010 and 2011 at Orford Ness and Havergate Island (RSPB unpublished) were available to provide a comparison of the trip statistics, connectivity with the GWF and other OWFs, and area use of Lesser Black-backed Gulls from the Alde-Ore Estuary SPA in 2019 and 2020. As tags were deployed with permanent harnesses in the former study, some additional data were available beyond the original lifespan of the project, in 2015, from those tags that were still active.

A total of 234.5, 1535.7, 1455.0 and 846.3 'bird-days' of tracking data were collected at Orford Ness by the BTO study between 2010 and 2013, respectively, of which, respectively, 217.9, 1421.0, 1283.7 and 694.4 days of data were useable for further analysis (i.e. from complete trips – see Chapter 3; see Appendix 7 for further details for individual bird tracking durations (Table 5.1). Although this work was conducted at Orford Ness, at the Lantern Marsh area of the site, following a tidal surge in the winter of 2013, birds were displaced from this area. Those birds with active tags monitored in 2014 and 2015 breeding seasons, relocated to Havergate. Data are therefore treated as being associated with the Havergate colony for three birds in 2014 and two birds in 2015, giving 366.6 and 247.4 bird-days of data, amounting to 249.4 and 241.7 days useable for analysis (Table 5.1).

In 2010, a further sample of birds was tracked by the RSPB using short-lived deployments. A total of 16.8 'bird-days' of tracking data were collected from three birds, two at Orford Ness and one at Havergate, with all but 0.1 days of data available for further analysis. In 2011, a total of 84.4 'bird-days' of data were collected from 13 further birds, 10 at Orford Ness and three at Havergate, all which were useable for further analysis (Table 5.1 – see also Appendix 7 for specific details of data per bird). The 'igotU' tags used in this study were attached via tesa tape to the back feathers and were archival battery powered devices requiring a subsequent recapture of the bird to retrieve the tag and acquire the data. Hence tracking periods were on average less than a week for these tags. The end dates reported reflect the date at which the tag either ceased collecting data, or when the bird was recaptured to download the data from the tag. Data collection was restricted to the late incubation and early chick-rearing periods in June each year.

Table 5.1 Summary of mean tracking durations for Lesser Black-backed Gulls tracked from Orford Ness Island and Havergate during the 2010-2015 breeding seasons from studies undertaken for the BEIS (formerly DECC) OESEA programme (Thaxter et al. 2014b) and by the RSPB, in comparison to data collected for the present project from Havergate during the 2019 and 2020 breeding seasons.

(a) Orford Ness

Study, Year (sample)	Start/tag date	End date	Data duration (days)	Usable data (days)	GPS fixes
BEIS OESEA					
2010 (10)	13/06/2010	07/07/2010	23.5 ± 8.7	21.8 ± 7.9	11809 ± 8378
2011 (19)	08/05/2011	27/07/2011	80.8 ± 26.5	74.8 ± 26.3	11910 ± 4281
2012 (14)	20/03/2012	02/07/2012	103.9 ± 24.1	91.7 ± 36.9	6173 ± 2775
2013 (10)	19/03/2013	11/06/2013	84.6 ± 18.3	69.5 ± 34.0	4232 ± 2195
RSPB					
2010 (2)	09/06/2010	15/06/2010	5.9 ± 2.4	5.7 ± 2.2	4820 ± 1847
2011 (10)	01/06/2011	08/06/2011	6.8 ± 1.2	6.8 ± 1.2	5691 ± 1012

(b) Havergate

Study, Year (sample)	Start/tag date	End date	Data duration (days)	Usable data (days)	GPS fixes
BEIS OESEA					
2014 (3)	17/03/2014	17/07/2014	122.2 ± 70.0	83.1 ± 52.0	3838 ± 2461
2015 (2)	17/03/2015	19/07/2015	123.7 ± 9.3	120.9 ± 5.4	9083 ± 5107
RSPB					
2010 (1)	04/06/2010	09/06/2010	4.9	4.9	4163
2011 (3)	07/06/2011	12/06/2011	2.3 ± 2.4	2.3 ± 2.4	1977 ± 2001
Present					
2019 (30)	22/05/2019	09/08/2019	78.8 ± 27.6	72.9 ± 29.7	17706 ± 17932
2020 (19)	31/03/2020	06/08/2020	128.0 ± 41.5	109.7 ± 50.2	17386 ± 20994

5.2 Trip Statistics for Lesser Black-backed Gulls between 2010 and 2015

Previous tracking data were available for Orford Ness for 24 Lesser Black-backed Gulls tracked from 2010-2013 as part of the BEIS (DECC) OESEA research programme and for 12 further Lesser Black-backed Gulls tracked in 2010 and 2011 by the RSPB. Up to 3,056 foraging trips were recorded in any given year (2011), but amounts of data per year varied given the number of deployments, tracking durations and tag types.

Trip statistics from previous years are summarised in Table 5.2. The mean offshore foraging range of Lesser Black-backed Gulls from Orford Ness was 27.9±28.4 km in 2010, based on data from the BEIS (DECC) OESEA study, but decreased over the following three years to 9.9±9.4 km. Similar foraging ranges were recorded by the RSPB study in 2010 and 2011. Birds were recorded up to 159 km offshore from the colony, however, such trips were likely not associated with breeding activity, occurring post-breeding. As in 2019 and 2020, offshore trips were typically of greater distance than inland trips, but were more similar in 2012 and 2013 when birds did not venture offshore as much. Trip durations for Lesser Black-backed Gulls from Orford Ness were 8.1±15.2 hours in 2010, based on data from the BEIS (DECC) OESEA study, but also declined in the following three years. By contrast, trip durations were just 3.1±7.7 hours in 2010 and 2.7±2.4 hours in 2011, based on the RSPB data; these data were more likely to represent breeding season activity only, covering up to a week of data per bird. The decline in the extent of offshore usage of birds from Orford Ness between 2010 and 2013 was linked to poorer breeding success (Thaxter et al. 2015).

Previous tracking data were available for Havergate for just three Lesser Black-backed Gulls tracked in 2014 and 2015 as part of the BEIS (DECC) OESEA research programme and for four birds tracked in 2010 and 2011 by the RSPB. A maximum of 421 trips were recorded in 2014.

The mean offshore foraging range of Lesser Black-backed Gulls from Havergate was 11.6±9.1 km in 2014 and 15.7±13.2 km in 2015, based on data from three birds from the BEIS (DECC) OESEA study. Interestingly only one trip was recorded offshore from by birds tracked in the RSPB study at Havergate in 2010-2011. This may be because the shorter duration of data collection during breeding did not cover movements birds may have made later in the season offshore, or, alternatively may just represent the substantial individual variation known to occur in this species.

Further details of the trip statistics for individual birds are given in Appendix 7.

Table 5.2 Mean foraging statistics for Lesser Black-backed Gulls tracked from Orford Ness Island and Havergate during the 2010-2015 breeding seasons, based on data from studies undertaken for the BEIS (DECC) OESEA programme (Thaxter et al. 2014) and by the RSPB, in comparison to data collected for the present project from Havergate during the 2019 and 2020 breeding seasons.

(a) Orford Ness

Study, Year (sample)	N trips [incomplete]	N offshore trips [incomplete]	Trip duration (hrs) mean+SD (max)	Foraging range (km) mean+SD (max)	Total distance per trip (km) mean+SD (max)	Offshore foraging range (km) mean+SD (max)	Onshore foraging range (km) mean+SD (max)
BEIS OESEA							
2010 (10)	393 [37]	102 [16]	8.1±15.2 (149.4)	14.6±20.8 (158.8)	47.1±90.7 (801.7)	27.9±28.4 (158.8)	8.8±13.1 (107.4)
2011 (19)	3578 [6]	625 [1]	4.5±6.1 (144.5)	14.9±18.5 (124)	37.1±51.4 (564.5)	27±21.8 (124)	11.4±15.7 (119.1)
2012 (14)	3056 [15]	517 [4]	5.6±10.5 (205.6)	9.2±13.2 (179.9)	22.6±39.7 (675.9)	11.5±15.1 (158.6)	8±12.1 (179.9)
2013 (10)	1650 [25]	129 [7]	6.3±9.6 (143.6)	10.6±14.1 (118.5)	26.7±50.1 (899.8)	9.9±9.4 (42.1)	10.4±14 (118.5)
RSPB							
2010 (2)	24 [1]	7 [1]	3.1±7.7 (37.9)	10.9±14.5 (59.8)	35.2±73.8 (352.2)	24.2±20.0 (59.8)	5.25±5.75 (21.9)
2011 (10)	152 [0]	32 [0]	2.7±2.4 (11.6)	9.2±12.1 (74.5)	24.2±36.0 (197.2)	19.7±21.5 (74.5)	6.15±5.68 (28.2)

(b) Havergate

Study, Year (sample)	N trips [incomplete]	N offshore trips [incomplete]	Trip duration (hrs) mean+SD (max)	Foraging range (km) mean+SD (max)	Total distance per trip (km) mean+SD (max)	Offshore foraging range (km) mean+SD (max)	Onshore foraging range (km) mean+SD (max)
BEIS OESEA							
2014 (3)	421 [0]	45 [0]	7.2±18.5 (211.3)	11±11.7 (108.5)	31±57.9 (517.1)	11.6±9.1 (46.4)	10.8±11.5 (108.5)
2015 (2)	254 [0]	10 [0]	2.4±2.6 (33.7)	7±4.7 (44.9)	14.8±10.4 (97.7)	15.7±13.2 (44.9)	6.5±3.6 (25.9)
RSPB							
2010 (1)	8 [0]	0 [0]	1.8±1.2 (3.9)	11.6±3.5 (16.9)	14.7±9.1 (25.8)	-	11.6±3.5 (16.9)
2011 (3)	60 [0]	1 [0]	1.4±1.5 (6.3)	10.3±3.8 (24.1)	12.2±12.9 (49.0)	9.3	10.3±3.8 (24.1)
Present study							
2019 (30)	4593 [253]	300 [32]	5.2±16.2 (889.9)	12.4±14.5 (178.2)	31.1±47.6 (919.0)	31.5±27.0 (178.2)	10.7±12.1 (154.4)
2020 (19)	4423 [157]	158 [16]	3.6±5.4 (137.2)	8.3±9.8 (103.4)	19.5±26.8 (338.9)	21.3±19.1 (88.7)	7.6±8.8 (103.4)

5.3 Connectivity of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA between 2010 and 2015 with the GWF and Other Offshore Wind Farms

The connectivity of Lesser Black-Backed Gulls breeding at the Alde-Ore Estuary SPA between 2010 and 2015 with OWFs is summarised in Table 5.3.

Figures 5.1-5.3 summarise movements based respectively on data from the BEIS (DECC) OESEA study from Orford Ness between 2010 and 2013, from Havergate in 2014 and 2015, and from RSPB data from Orford Ness and Havergate from 2010 and 2011.

Between 2010 and 2013, up to 50% of the Lesser Black-backed Gulls tracked in the BEIS (DECC) OESEA study from Orford Ness showed connectivity with the area of the GWF, but this was highly variable between years and linked to variations in offshore usage and breeding success (Thaxter et al. 2015), decreasing over time (2011, 47%; 2012, 29%; 2013, 0%). Both birds tracked by the RSPB from Orford Ness in 2010 and 20% of those tracked in 2011 also showed connectivity with the GWF.

Only one of the three birds tracked in the BEIS (DECC) OESEA study from Havergate in 2014 and 2015 and none of the four birds tracked by the RSPB study from Havergate in 2010 and 2011 showed connectivity with the GWF. In comparison, 56% and 58% of birds tracked from Havergate in 2019 and 2020 showed connectivity with the GWF.

Detailed information of the connectivity shown by individual birds is shown in Appendix 7.

Table 5.3 Connectivity (*) between Lesser Black-backed Gulls tracked from (a) Orford Ness and (b) Havergate Island in the Alde-Ore Estuary SPA during the 2010-2015 breeding seasons and offshore wind farms, based on data from studies undertaken for the BEIS (DECC) OESEA programme (Thaxter et al. 2014b) and by the RSPB. Connectivity is here defined as there being a GPS point (p) within the wind farm polygon, or where the straight line (l) route between two points passes over the wind farm polygon. Wind farms are denoted as (1) operational; (2) partial generation/under construction; (3) under construction Wind farms in the pre-planning or planning stages are excluded from this table (i.e. East Anglia Round 3 Zone), however we present (4) GWF for a perspective of pre-construction interactions (*). Totals(5) include all operational sites, those under construction and GWF.

(a) Orford Ness

Study/Year (sample)	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
BEIS OESEA								
2010 (10)	5	5 (3)	1	0	4	0	0	6
2011 (19)	9	7	0	0	6	0	0	10
2012 (14)	4 (1)	4	1	0	0	0	0	5
2013 (10)	0	1	0	0	0	0	0	1
RSPB								
2010 (2)	2	1	0	0	0	0	0	2
2011 (10)	2	2	0	0	0	0	0	2

(b) Havergate

Study/Year	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
BEIS OESEA								
2014 (3)	0	0	0	0	0	0	0	0
2015 (2)	1	(1)	0	0	0	0	0	1
RSPB								
2010 (1)	0	0	0	0	0	0	0	0
2011 (3)	0	0	0	0	0	0	0	0
Present study								
2019 (30)	17	19	1	1	1	1	1	19
2020 (19)	11	11	1	0	0	0	0	11

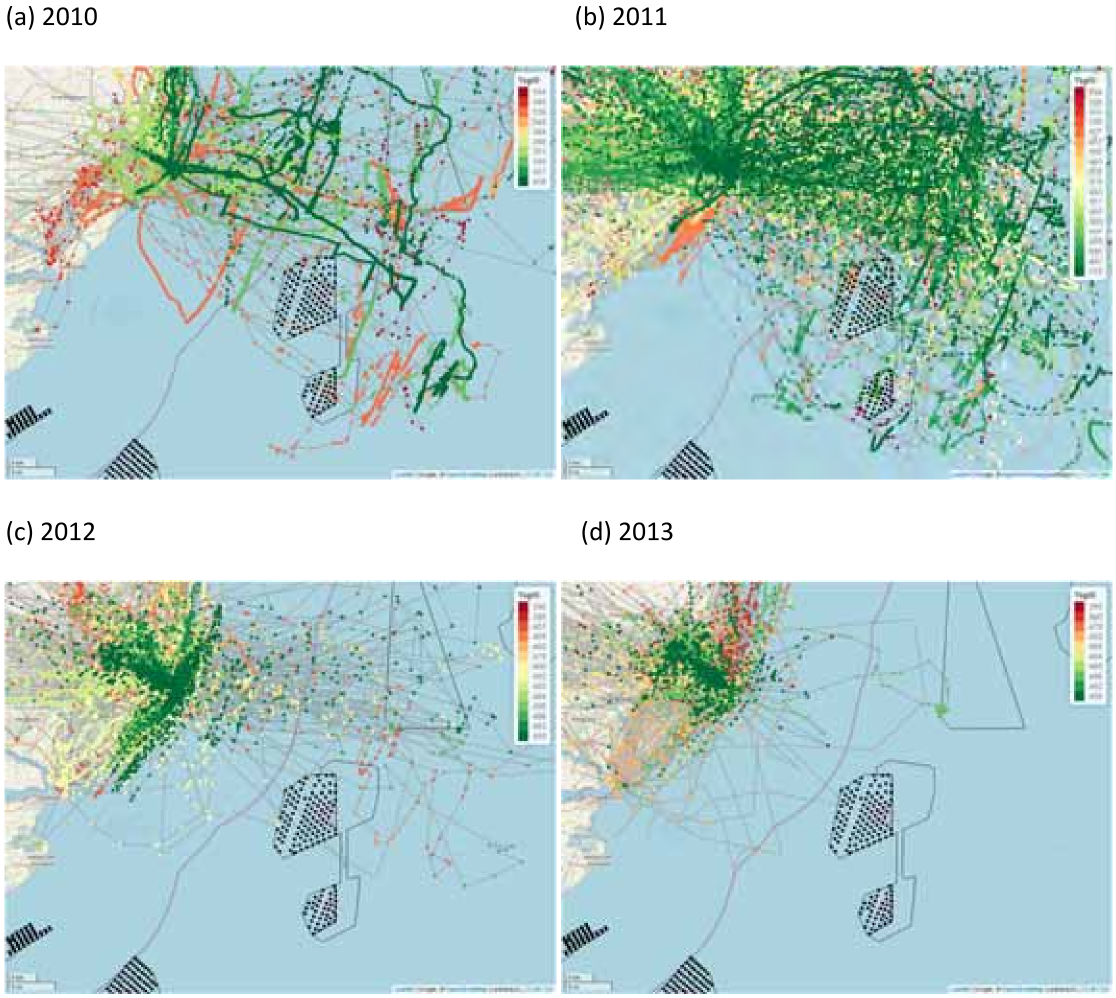


Figure 5.1 Tracking data collected from Lesser Black-backed Gulls from Orford Ness under the BEIS (DECC) OESEA programme, during the 2010-2013 breeding seasons, with a focus on the Galloper and Greater Gabbard Wind Farms.

Figure 5.2 Tracking data collected from Lesser Black-backed Gulls from Havergate Island under the BEIS OESEA programme, during the 2014-2015 breeding seasons, with a focus on the Galloper and Greater Gabbard Wind Farms.

Figure 5.3 Tracking data collected from Lesser Black-backed Gulls from Orford Ness and Havergate by the RSPB, during the 2010-2011 breeding seasons, with a focus on the Galloper and Greater Gabbard Wind Farms. Reproduced by permission of RSPB. © RSPB 2020.

5.4 Area Use of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA between 2010 and 2015

As reported by Thaxter et al. (2015), the offshore area use of Lesser Black-backed Gulls tracked from Orford Ness as part of the BEIS (DECC) OESEA research programme varied between 2010 and 2013 (see Fig 5.1).

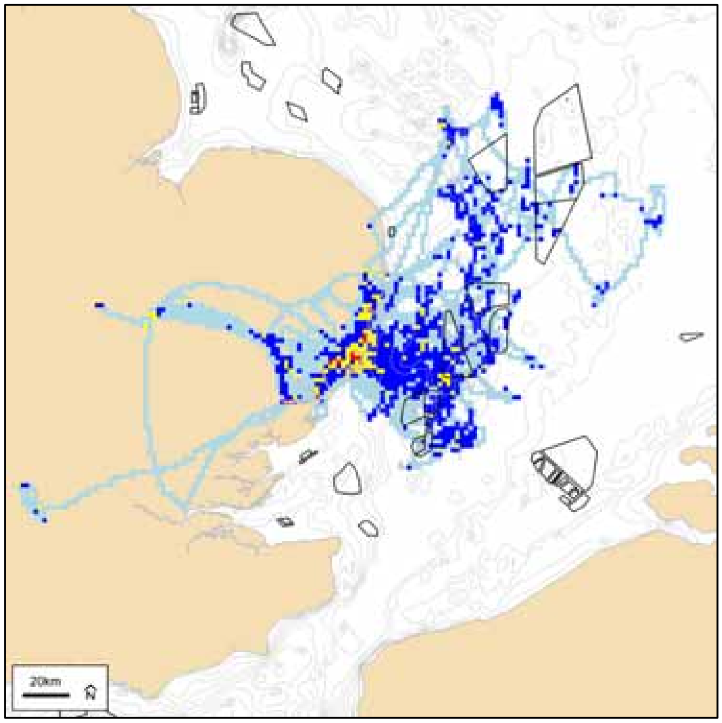
In 2010, 3.24% and 3.35% of the 95% and 100% UDs respectively of birds tracked from Orford Ness as part of the BEIS (DECC) OESEA research programme overlapped with areas of operational, under-construction OWFs or the GWF (Table 5.4). In that year, 1.55% and 1.02% of the 95% and 100% UDs respectively of birds tracked from Orford Ness as part of the BEIS (DECC) OESEA research programme overlapped with the GWF. There was also overlap between the 95% and 100% UDs of birds tracked from Orford Ness and the GWF in 2011, but thereafter overlaps reduced markedly, linked particularly to changes in breeding success. Similar figures were reported for the birds tracked by the RSPB study in 2010 and 2011.

Birds tracked from Havergate in 2010 and 2011 by the RSPB and by the BEIS (DECC) OESEA study in 2014 and 2015 showed negligible use of OWF areas (see Figs 5.5-5.7).

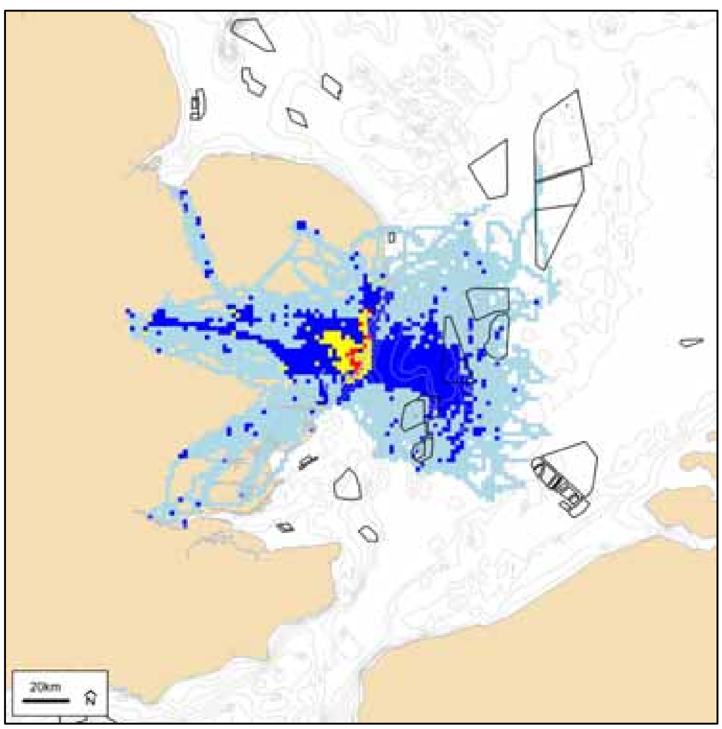
Further details of the area use of individual birds are given in Appendix 7.

Although interactions with OWFs between 2010 and 2015 were limited, birds tracked from Orford Ness did show a level of connectivity and use of the GWF and, to a much lesser extent, the Greater Gabbard Wind Farm. Interestingly, the level of interaction with the GWF (Table 5.4) was comparable to that measured for birds tracked from Havergate in 2019 and 2020 (Table 4.4). Therefore despite the apparent high use of the GWF, as shown by the density of tracks in this area, by birds tracked from Havergate in 2019 and 2020, the overall temporal use of the site was quite similar to that previous recorded for birds from Orford Ness. There are some caveats, however, in this comparison. First, there could be differences in area use for each of the two colonies (Havergate and Orford Ness) within the Alde-Ore Estuary SPA that could result in differences in overall area use and OWF interaction (e.g. Wakefield et al. 2013). Further, while the GWF was not constructed at the time of the 2010-2015 study, the Greater Gabbard Wind Farm was. It is also suspected that birds in both the 2019-2020 study and the previous 2010-2015 work were targeting an area within and around the wind farms characterised by a change in sea-bed slope, that may be highly productive for foraging. Caution is thus required in interpreting reasons for use of the site and potential attraction to the wind farm.

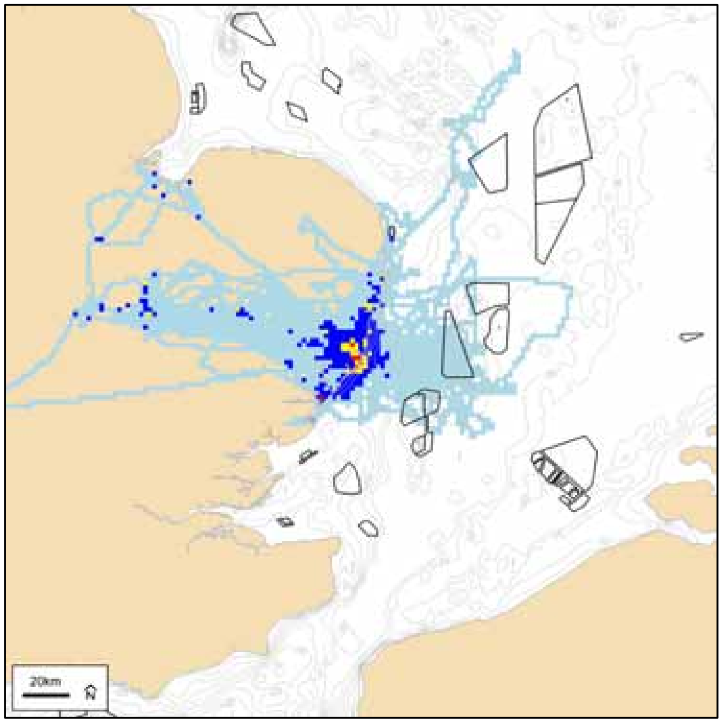
(a) 2010



(b) 2011



(c) 2012



(d) 2013

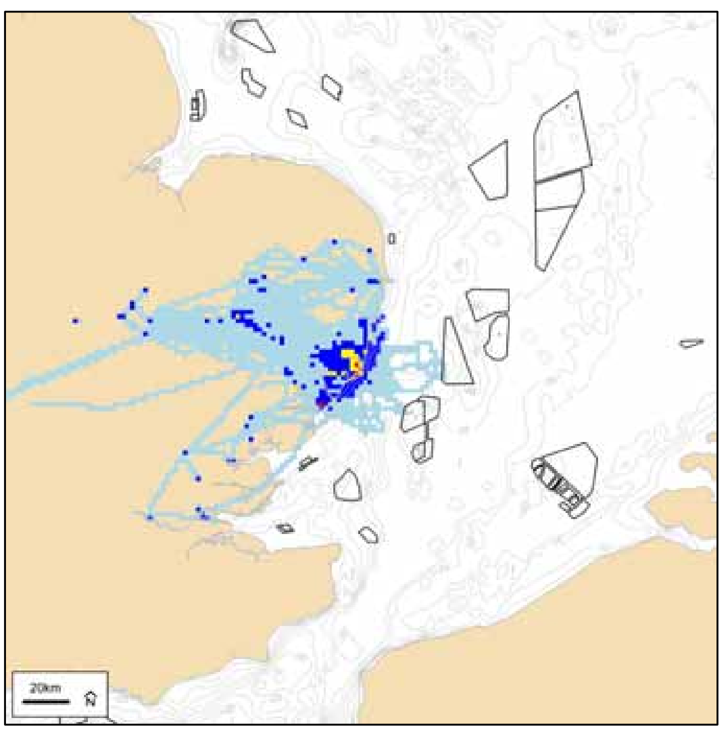
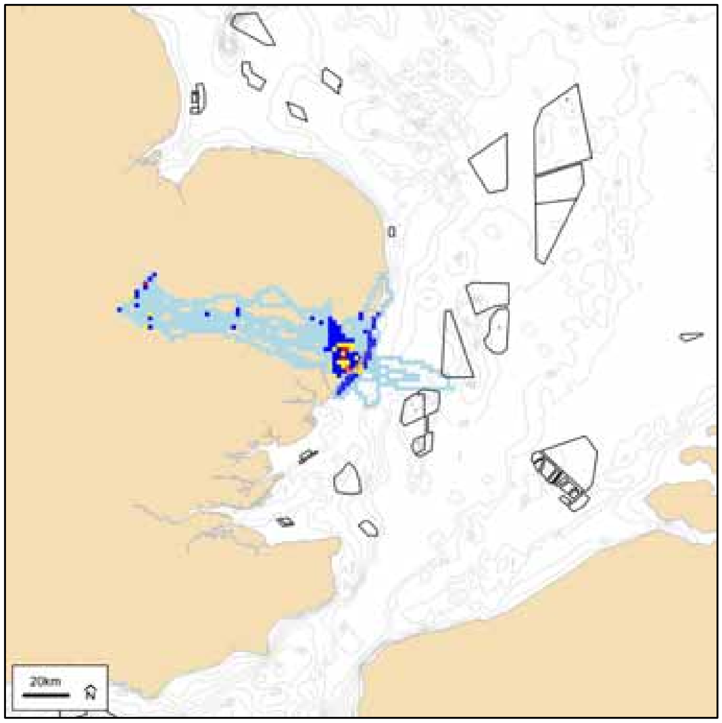


Figure 5.4 Utilisation distributions for all Lesser Black-backed Gulls tracked from Orford Ness in (a) 2010, (b) 2011, (c) 2012, (d) 2013 based on data from the BEIS (DECC) OESEA study. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD.

(a) 2014 (three birds)



(b) 2015 (two birds)

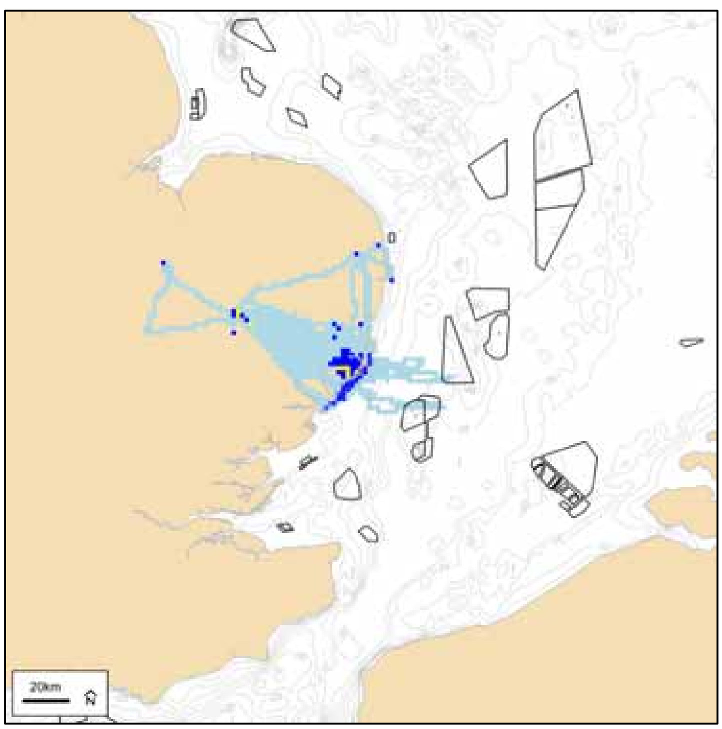
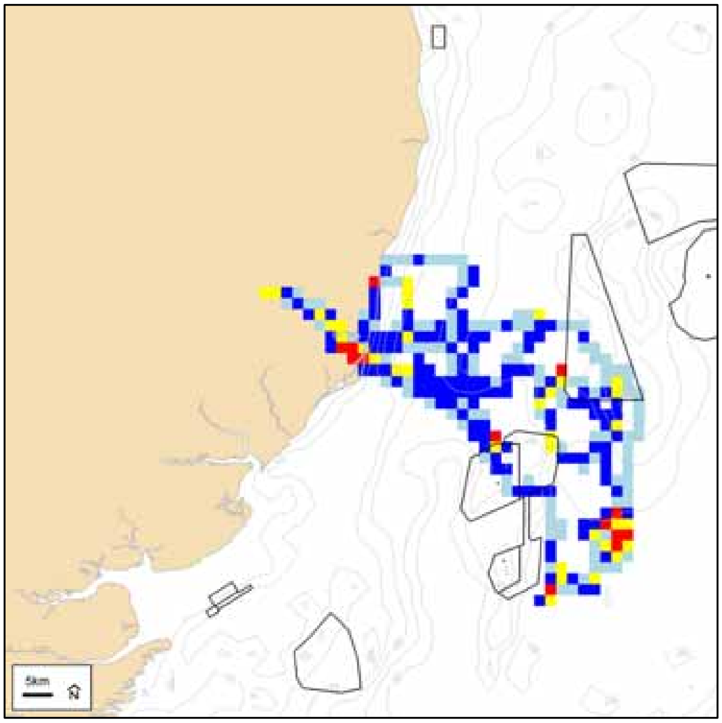


Figure 5.5 Utilisation distributions for all Lesser Black-backed Gulls tracked from Havergate Island in (a) 2014, (b) 2015 based on data from the BEIS (DECC) OESEA study. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD.

(a) 2010 (two birds)



(b) 2011 (10 birds)

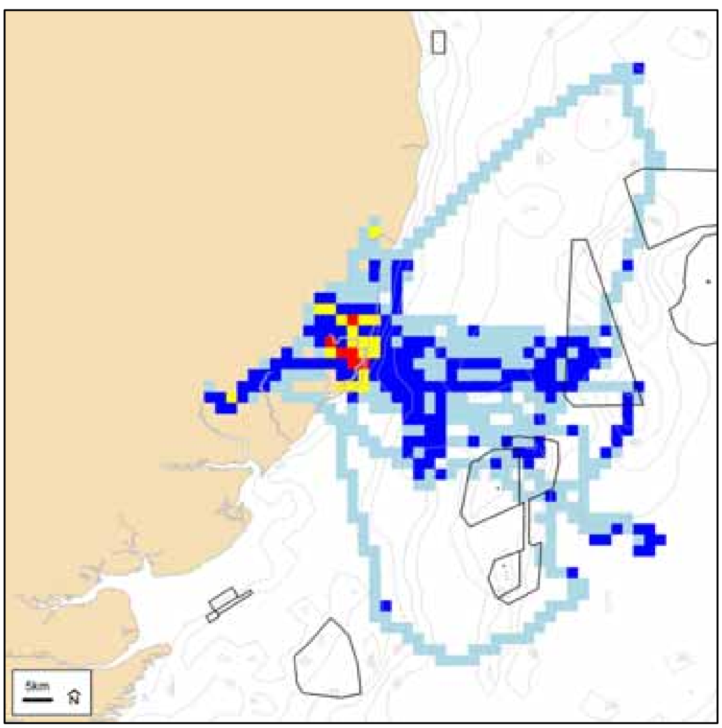
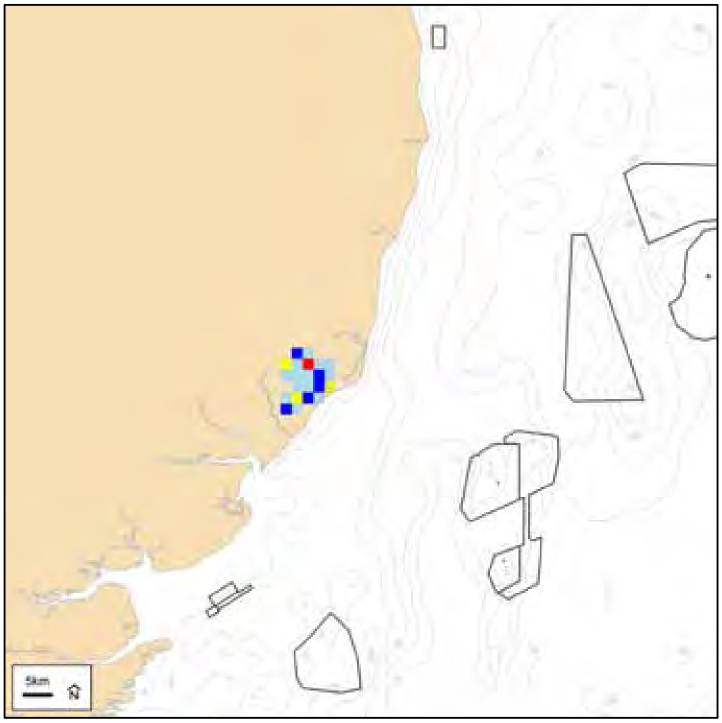


Figure 5.6 Utilisation distributions for all Lesser Black-backed Gulls tracked from Orford Ness in (a) 2010 and (b) 2011 based on data from the RSPB study. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD. Reproduced by permission of RSPB. © RSPB 2020.

(a) 2010 (one bird)



(b) 2011 (three birds)

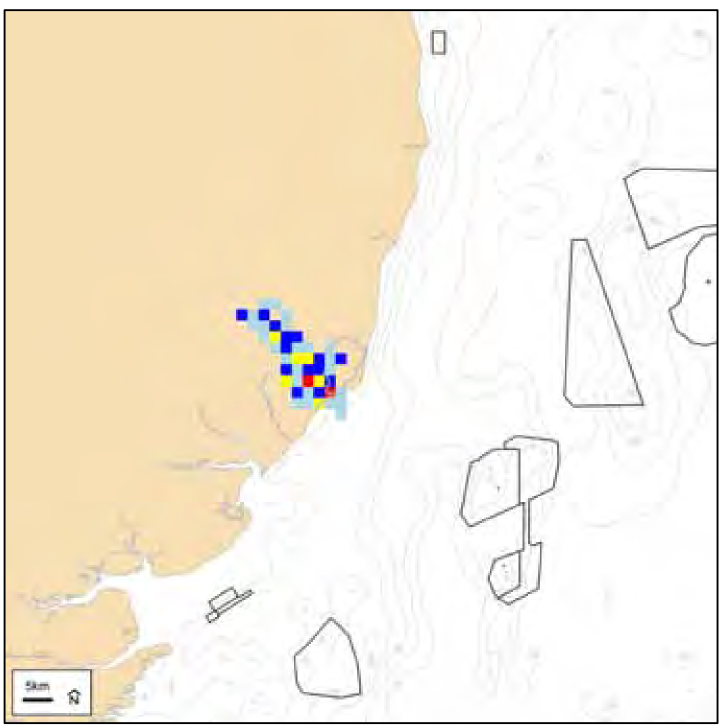


Figure 5.7 Utilisation distributions for all Lesser Black-backed Gulls tracked from Havergate in (a) 2010 and (b) 2011 based on data from the RSPB study. Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD. Reproduced by permission of RSPB. © RSPB 2020.

Table 5.4 Summary of utilisation distribution (UD) analyses for Lesser Black-backed Gulls tracked from (a) Orford Ness and (b) Havergate Island during the 2010-2015 breeding seasons. This summary is based on all observations during trips, including all bird kernel sizes and percentage overlap of the 100% UD (full area use), 95% UD (considered typical of total area use) and 50% UD (representing core area use) with: (1) operational, (2) partial generation/under construction, and (3) under construction wind farms during the period studies. All wind farms in the pre-planning or planning stages are excluded from this table (i.e. East Anglia Round 3 Zone), however we present (4) GWF for a perspective of pre-construction interactions. Totals include (5) all operational, under construction and the GWF pre-construction wind farm area.

(a) Orford Ness

				Overlaps with each UD (%)														
	UD area (km^2)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
BEIS OESEA																		
2010 (10)	56	3620	10492		1.55	1.02		0.42	1.18			0.07		1.27	1.07		3.24	3.35
2011 (19)	68	3592	14444		1.23	0.84		0.17	0.98					0.34	0.97		1.74	2.8
2012 (14)	32	1040	10276			0.64			0.67			0.07						1.39
2013 (10)	20	896	7220						0.12									0.12
RSPB																		
2010 (2)	52	692	1156		2.07	1.65		3.15	2.92								5.22	4.58
2011 (10)	24	776	2224		2.38	2.48		0.78	2.06								3.16	4.54

(b) Havergate

				Overlaps with each UD (%)														
	UD area (km^2)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
BEIS OESEA																		
2014 (3)	36	472	2856			0.06												0.06
2015 (2)	4	296	2952			0.96			1.04									2
RSPB																		
2010 (1)	4	36	88															
2011 (3)	8	88	184															
Present study																		
2019	56	2708	16068		1.87	0.76		2.43	0.91						0.76		4.30	2.66
2020	20	1220	8572		0.33	1.42		0.66	1.71								0.98	3.24

5.5 Altitudes of Lesser Black-backed Gulls Breeding at the Alde-Ore Estuary SPA between 2010 and 2015

Analyses of altitudes based on previous data collected at Orford Ness from 2010-2015 are presented in full in Appendix 8. As with the data for the 2019-2020 tracking period, these analyses considered both (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2). In the latter case, EMbC behavioural classifications indicative of commuting (state3, high speed, low turn angle) and foraging/searching (state 4, high speed, high turn angle) were considered.

Analyses are presented separately for the five minute and 5-10 second data resolutions for both day and night periods. Note that only GPS-derived altitudes were available for this historic dataset.

The data collected at the five minute resolution showed that Lesser Black-backed Gulls had an overall mean altitude of 10.38±29.91 (SD) m above the sea surface within the GWF (and a 19.0% overlap with the RSZ), and that altitudes were higher during the day then at night (Appendix 8). Very few fixes were recorded at night within OWFs during the 2010-2015 period. These altitudes were comparable albeit slight lower than those recorded in the Greater Gabbard Wind Farm that was operational at the time. Considering only fixes in flight, mean 'flight heights' within the GWF were estimated at 21.47±37.54 m above the sea surface (a 36.1% overlap with the RSZ).

Altitude distributions based on the 5-10 second dataset were lower than those recorded at the five minute resolution. Lesser Black-backed Gulls had an overall mean altitude of 6.36±14.72 m within the GWF (and a 16.6% overlap with the RSZ), while mean 'flight heights' within the GWF were estimated at 8.91±14.90 m (a 20.2% overlap with the RSZ). Again, this was largely reflective of daytime activity with very few fixes recorded overnight within OWFs. These altitudes were lower than those recorded in the Greater Gabbard Wind Farm that was operational at the time.

6. DISCUSSION

6.1 Assessment of the Field Programme

The field programme worked very well. An early site visit in April 2019 was sufficient to identify that working on Orford Ness would not be possible, given the lack of ground-nesting Lesser Black-backed Gulls, and the subsequent organisation for catching all 30 birds on Havergate Island was very efficient.

The catching and tagging process also worked efficiently, with one team setting, monitoring and emptying nest traps, then ringing and processing the caught birds, and the other team assessing the size of caught individuals and tagging those birds that were suitable. As a result of the careful preparation and planning, and skills of the field team, 30 Lesser Black-backed Gulls were tagged in four days, and a total of 63 gulls (53 Lesser Black-backed and 10 Herring Gulls) were caught in this time period.

The general performance of both tag types was sufficient to meet the aims of the project, though the UvA tags collected higher-resolution data throughout the breeding season as expected. The data collection rate achievable by the Movetech tags meant that there was an increased probability of there being a gap in the data on trips. However, all data (including those on incomplete trips) were included in the basic analyses, and both types of tags produced sufficient analysable data to meet the aims of the project.

6.2 Connectivity and Area Use of Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA with the GWF and Other Offshore Wind Farms

In 2019, 19 (63%) of the 30 tracked gulls displayed some connectivity with OWFs, of which 17 (57%) interacted with the GWF. In 2020, the connectivity rate was very similar, with 11 (59%) of the 19 tracked gulls showing connectivity with the GWF and other OWFs. A distinct commuting 'belt' was displayed in both years from the breeding colony within the Alde-Ore Estuary SPA to the Galloper and Greater Gabbard Wind Farms.

Area use was assessed through a Time-In-Area approach (TIA), which defines areas representing the birds' 50% (core), 75%, 95% and 100% utilisation distributions (UDs). In 2019, 4.30% of the 95% UD calculated for all birds overlapped with OWFs, and 1.87% with the GWF. In 2020, the percentage overlap was much lower, with 0.98% of the 95% UD for all birds overlapping with OWFs, and just 0.33% with the GWF.

The disparity in the number of offshore trips and time spent offshore between 2019 and 2020 highlights the importance of monitoring inter-annual variation in movements, time budgets and behaviour. It is thought that the lower proportion of offshore activity recorded in 2020, compared to 2019, was a consequence of the low reproductive success of the colony in 2020 (see Appendix 2). It appears most of the gulls breeding on Havergate Island in 2020 failed to fledge chicks. Adults are known to conduct more offshore foraging trips when they are provisioning chicks (Thaxter et al. 2015), and tend to forage onshore for self-provisioning. Therefore, adult gulls such as these tracked birds are less likely to make offshore trips if they do not have chicks to feed.

Comparative analyses were made of the foraging trips, wind farm connectivity and area use of Lesser Black-backed Gulls tracked during pre-construction studies undertaken between 2010 and 2015 (Thaxter et al., 2014b; RSPB, unpublished) at Havergate and Orford Ness. These results indicated that trip metrics, such as foraging distance offshore and trip duration, were similar in these earlier studies, albeit with variation between years and according to the duration of tag deployments (reflecting the different devices used). Further, while data collected in 2019 and 2020 provided evidence of attraction to structures within the Galloper and Greater Gabbard Wind Farms, the overall use of the GWF was also similar in these earlier studies. Overlaps of the 95% UD with the GWF were 1.87% and 0.33% for birds from Havergate in 2019 and 2020 respectively, compared with 1.55% and 1.23% for birds from Orford Ness (based on data from the BEIS (DECC) study) in 2010 and 2011 respectively, but zero overlap in 2013 and 2014, when poor breeding success at the colony resulted in limited use of the offshore environment. (Similar results were seen in the RSPB study in 2010 and 2011, albeit based on a more limited time period.) Use of the Greater Gabbard Wind Farm was less for birds tracked at Orford Ness in these earlier studies, however, overlaps 0.42% of the 95% UD with the site being 0.42% and 0.17% in 2010 and 2011 respectively (again based on data from the BEIS (DECC) study) compared to 2.43% and 0.66% in 2019 and 2020 respectively. This perhaps reflects that the fact that the main concentration of foraging activity was slightly further north for birds tracked from Orford Ness. The similar use of the GWF between these studies appears to reflect use of an area where the seabed slopes and of potential high productivity within the GWF footprint. Behavioural classification of the 2019 and 2020 data (see Figs 4.9 and 4.11) suggests this is an important area for foraging.

6.3 Behaviours of Lesser Black-Backed Gulls Within and Outside the GWF and Other Offshore Wind Farms

Three methods (Hidden Markov Models (HMMs), Expectation Maximisation Binary Clustering (EMbC) and a Random Forest (RF) model) were used to understand behaviour based on data collected at a standard five minute sampling rate and at a fast-sampling rate of 5-10 seconds. These analyses confirmed that all four behaviours defined by the EMbC and HMM classifications – 'perching', 'floating', 'commuting' and 'foraging/searching' – were exhibited within the footprint of the turbines of Galloper and Greater Gabbard Wind Farms. Generally, most time spent within OWFs was spent commuting or foraging/searching and less time was spent stopped or floating, which was in contrast to other areas offshore outside OWFs, where generally birds spent most time floating and commuting. This pattern, however, varied between method of classification used, and year and also between the Galloper and Greater Gabbard Wind Farms. Variation in behaviours across years may have reflected relative breeding success, with birds in 2020 less constrained by central place foraging due to the poor productivity at the Havergate colony.

Three offshore substations/service platforms within the Galloper and Greater Gabbard Wind Farms were used regularly as resting/perching locations, with their use being greatest at night. These offshore substations/service platforms appeared to be focal points which provided structures from which foraging trips to areas within the GWF and beyond it to the south-east could take place. A particular foraging/searching and floating area was identified within the northern section of the GWF, next to the GWF offshore substation/service platform, where two turbine rows were more separated.

6.4 Flight Heights Within and Outside the GWF and Other Offshore Wind Farms

Some variation was apparent in the altitudes estimated from GPS and barometric pressure sensors and according to the sampling rate of the dataset. GPS and barometric pressure sensor data produced similar altitudes based on data collected at a five minute resolution. In contrast, at the 5-10 second resolution, mean altitudes estimated from pressure sensor data were consistently lower than those from GPS. As a consequence, lower proportions of altitudes estimated from the barometric pressure sensor data were within turbine RSZs of the Galloper and Greater Gabbard Wind Farms, based on data collected at the 5-10 second fix rate. Altitudes were higher during the day than at night across both methods.

The degree of variance between the two methods is potentially related to both the accuracy of GPS altitudes, and the calibration process of pressure data. The reliance on behavioural modelling to infer floating behaviour, through which mean sea level pressures were acquired from the observed data, may be a potential source of uncertainty. Similarly, when in flight, estimates of the mean sea level pressures taken from the ERA5 mode also include an inherent degree of uncertainty. The potential error in the pressure sensor estimates was slight, however, when compared to the overall variance displayed in pressure sensor and GPS derived altitudes.

6.5 Movements Within the GWF and Other Offshore OWFs

While Lesser Black-backed Gulls showed little macro-avoidance of the Galloper and Greater Gabbard Wind Farms, and there was evidence of attraction to structures within these sites, analyses of movements within the Galloper and Greater Gabbard Wind Farms suggested significant meso-avoidance of the turbine rows. No GPS fixes were recorded in the turbine rotor sweep volumes and the distribution of observed fixes – both in the overall dataset and filtered to just consider “in flight” (commuting and foraging/searching) fixes using the EMbC classification – within the three-dimensional space was significantly different from a random distributions of points. These results, therefore, closely matched previous results of Lesser Black-backed Gulls tracked at South Walney, NW England (Thaxter et al. 2018b). Interestingly, while birds used offshore service platforms within the wind farms, the spatial visualisation of area use within the three-dimensional space did not reveal use of turbine bases, as has been reported for other wind farms in the UK and elsewhere (e.g. Vanermen et al., 2019, Clewley et al. 2021).

Visualisation of individual flight paths suggested potential (last-second) micro avoidance of individual turbines. In addition, the direction of travel to and from the colony had a slight influence (albeit with high variability) on how birds used the space between turbine rows when commuting.

6.6 Overall Conclusions

The tracking study undertaken in 2019 and 2020 revealed that Lesser Black-backed Gulls from the Alde-Ore Estuary SPA showed significant use of both the Galloper and Greater Gabbard Wind Farms, although overall use of the GWF was similar to pre-construction studies undertaken from 2010-2015. There was evidence of significant attraction to substations/service platforms, which provided focal points from which foraging trips to areas within the GWF and beyond it to the south-east could take place. A particular foraging/searching and floating area was identified within the northern section of the GWF, next to the GWF offshore substation/service platform. Nevertheless, while Lesser Black-backed Gulls showed little macro-avoidance of the Galloper and Greater Gabbard Wind Farms, analyses of movements within the Galloper and Greater Gabbard Wind Farms suggested significant meso-avoidance of the turbine rows, with no fixes recorded within the turbine rotor sweep volumes.

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APPENDICES

Appendix 1 University of Amsterdam Tag Schedule

During the breeding season, we specified a **first geofence around the breeding colony** (Figure 2.1a); this geofence was used to switch fix rates to 900 s, to conserve battery power while birds were within the colony, and we specified a faster communication rate (every 300 s) to facilitate data download while birds were in range of the base station. We specified a **second geofence around the Galloper and Greater Gabbard Wind Farms** (Figure 2.1b) to allow very high sampling fix rates (10 s) in this area; high-resolution data have previously allowed assessment of space use and behaviour in relation to wind farms (Thaxter et al., 2015) and also individual turbines (Thaxter et al., 2018a). These fix rates were prioritised between 03:00 to 21:00 UTC each day, with rates reduced to 300 s overnight. This temporal split was chosen as tags were unable to sustain a high fix rate during darkness when solar recharging of the battery is not possible. Loss of battery power results in gaps in the GPS data whilst the battery recharges, so a coarser night rate was set to avoid this. Also time spent within the wind farm overnight was minimal for this colony, so a fast night rate was unnecessary.

We also specified a 'fallback' option where if the data stored in the tag reached a percentage of the memory capacity (here chosen as 10%), then the tag would revert to different settings; here a fix rate of 300 s in the wind farm, to minimise the chance of over-filling the memory and potentially creating gaps in the GPS records. This was a particular concern ahead of birds departing the colony at the end of the breeding season, after which point they would not be within range of the base-station until the following breeding season, so stored data could not be downloaded, and settings would be fixed.

Outside of these two areas, we specified global settings with a 'standard' fix rate of 300 s, that matched previous studies, with a further 'energy surplus' ('E+') setting of 10 s to allow faster sampling when there was clement weather (sunny conditions), maximising data collection when the battery was at full charge. When birds were away from the colony we specified lower communication rates at 3600 s, as birds were more likely to be out of the range of local communication with the base station. However, as above, we also specified a 'fallback' option for the global settings, for tags to switch to a coarser fix rate of 7200 s once the memory was 10% full, should birds have departed the colony before we had chance to switch tags to non-breeding settings.

During the non-breeding season, we specified **a slightly wider first geofence** around the local area to the colony (Figure 2.1d). A slightly reduced 900 s fix rate, but with a faster 'standard' E+ setting of 300 s provided faster sampling rates for birds that remained around the local area for a time outside the breeding period; we further specified a 'fallback' option for tags to switch to a fix rate of 7200 s should birds remain local for much longer periods during the winter months. Note, given that occasional gaps were recorded overwinter for birds that remained in the UK during the 2019/20 non-breeding period (section 4.8), following the 2020 breeding season settings were changed to 10,800 s (three hours) for subsequent non-breeding data collection (a period not covered by this report). We also specified a faster communication rate of 300 s for this local area, as birds could come within the range of the base station; it was expected, however, that most birds would leave this area during the non-breeding period. We retained the same **second GPS geofence for the Galloper and Greater Gabbard Wind Farms** described above for the non-breeding period (Figure 2.1d), to continue faster sampling should any birds have used the area during this time, this geofence also being nested within the first above. Although this could potentially result in data gaps should use of the wind farm by birds occur within the winter months, previous evidence for birds from the Orford Ness colony within the Alde-Ore Estuary SPA suggests this is unlikely (Thaxter et al., 2019), and so this geofence was most likely to capture movements offshore during the tail end of the breeding season. Outside these geofences, we specified a global fix rate of 7200 s.

A final **third geofence covered potential winter locations in southern Europe and Africa**, where longer winter days and greater sunlight allows tags to collect more frequent data than if birds wintered in the UK. Rates in this area were specified at 1800 s but with an E+ setting of 900 s (Figure 2.1c).

Although complex, these geofences enabled very flexible data collection that benefitted the aims of the project, without compromising on temporal coverage.

Appendix 2 Assessment of Tag Effects

Previous assessments of the potential negative effects of fitting devices using harnesses for Lesser Black-backed Gulls found no differences in breeding success and return rates between tagged and control groups (Thaxter *et al.* 2016). Nevertheless, impacts should not be discounted (e.g. because of differences in study methods and between sites and years) and it is thus important to monitor and assess any potential impacts both with respect to the birds' welfare and as a licence requirement (tags were fitted under licence approval from the independent Special Methods Technical Panel (SMTP) of the BTO Ringing Committee), and also to provide context to results.

The time taken to safely fit the harnesses was c. 20-25 minutes and overall capture, holding and handling time was aimed to be 45 minutes or less. All individuals were observed immediately after release to ensure mobility was not impaired in any way. All birds flew away normally, as expected.

To assess the effects of devices and harnesses on breeding success and return rates, separate control birds and their nests were also monitored. The control sample included 23 further birds captured during the study, and also fitted with a metal ring and a colour-ring, and seven additional birds previously colour-ringed as part of a long-term monitoring study at the site.

A2.1 Productivity Assessment

2019

Regular monitoring of the nests of tagged and control birds was conducted during the 2019 breeding season to determine hatching success. Once chicks are a few days old, they become mobile and leave the nest cup. As a result, it is difficult to monitor nests through to fledging. Therefore, in addition to monitoring apparent chick production at the nests of the tagged and control birds, fledging success was also monitored for the entire colony.

Monitoring began for each nest on the day that adults were captured (20th, 21st, 22nd or 23rd May) and then every nest was checked subsequently on the 28th May, 2nd June, 5th June, 9th June, 15th June and 19th June 2019, with a final check for those nests with eggs remaining on the 25th June 2019. On average, nests were checked every 4.7 ± 1.2 days.

Nest success for 2019 is presented in Table A2.1, as a minimum and maximum estimate of hatching success. The minimum estimate represents the number of chicks from each nest that hatched successfully and were seen simultaneously. The maximum estimate is calculated from the maximum number of eggs that could have hatched from each nest, taking into account known eggs that did not hatch, were predated, were damaged during incubation, or chicks from a nest that were known to die within the first five days. For instance, if all three eggs were present on one visit, but no eggs were present on the subsequent visit six days later, the minimum estimate would be zero, as all eggs could have been predated, and the maximum estimate would be three, as all eggs could have hatched and the chicks moved away from the nest.

The average hatching date of the first egg for each nest is presented in Table A2.2, with minimum and maximum date estimates. These estimates are only presented for nests where at least one egg is known to have hatched, either because at least one egg was found to be hatching, or a chick was found. This sample amounted to 48 nests, of which 25 were nests of tagged birds, and 23 of control bird nests. On average, control birds had a lower hatching success than tagged birds, which suggests that the tagging process did not have an adverse effect on reproductive success and productivity.

In 2019, 1665 pairs of Lesser Black-backed Gulls and 521 pairs of Herring Gulls nested. The combined colony fledging success from both species was 2186 chicks, i.e. an average of 1.00 chicks fledged per nest.

2020

This same level of monitoring was intended for the 2020 breeding season, but the Covid-19 pandemic prevented RSPB staff from accessing the colony during the egg laying and incubation period of the breeding season. Staff were able to return to the island in June and July, and made an assessment of fledging success for the entire colony. A total of 1775 pairs of Lesser Black-backed Gulls and 549 pairs of Herring Gulls nested. The combined colony fledging success from both species was 653 chicks, i.e. an average of 0.28 chicks fledged per nest across the entire island, much lower than in 2019. However, the areas in which tagged gulls nested had particularly low productivity. The southern half of the island, including the Pits, the Ridge and Dovey's, had an average fledging success of 0.15 chicks per pair, compared to the northern half of the island which had 0.39 chicks per pair. The reasons for this difference in fledging success for different parts of the island are unknown.

Table A2.1 A summary of all nest monitoring data collected from 60 Lesser Black-backed Gull nests in 2019. Minimum and maximum hatching rates and first egg hatching dates have been calculated for each nest.

Nest number	Tag / Control	Sub site	Initial clutch size	Number of chicks hatched		Hatching rate (%)		Hatch date of first egg	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	C	Pit	3	0	3	0.0	100.0		
2	T	Pit	3	2	3	66.7	100.0	02/06/2019	02/06/2019
3	C	Pit	3	2	3	66.7	100.0	06/06/2019	08/06/2019
4	T	Pit	3	1	2	33.3	66.7	05/06/2019	05/06/2019
5	C	Pit	3	3	3	100.0	100.0	06/06/2019	08/06/2019
6	C	Pit	3	1	1	33.3	33.3	03/06/2019	05/06/2019
7	T	Pit	3	2	3	66.7	100.0	21/05/2019	26/05/2019
8	C	Pit	3	1	3	33.3	100.0	06/06/2019	08/06/2019
9	T	Dovey's	3	2	3	66.7	100.0	05/06/2019	05/06/2019
10	T	Dovey's	3	2	3	66.7	100.0	29/05/2019	01/06/2019
11	T	Dovey's	3	2	3	66.7	100.0	29/05/2019	01/06/2019
12	C	Dovey's	2	2	2	100.0	100.0	29/05/2019	01/06/2019
13	T	Dovey's	3	0	3	0.0	100.0		
14	T	Dovey's	3	2	3	66.7	100.0	29/05/2019	02/06/2019
15	T	Dovey's	2	1	1	50.0	50.0	29/05/2019	02/06/2019
16	C	Dovey's	3	2	3	66.7	100.0	28/05/2019	28/05/2019
17	C	Dovey's	3	2	3	66.7	100.0	29/05/2019	01/06/2019
18	C	Dovey's	3	2	3	66.7	100.0	02/06/2019	02/06/2019
19	T	Dovey's	3	1	3	33.3	100.0	22/05/2019	07/06/2019
20	T	Dovey's	3	3	3	100.0	100.0	29/05/2019	01/06/2019
21	T	Dovey's	3	1	3	33.3	100.0	03/06/2019	04/06/2019
22	C	Dovey's	2	0	0	0.0	0.0		
23	C	Dovey's	2	1	2	50.0	100.0	23/05/2019	27/05/2019

Nest number	Tag / Control	Sub site	Initial clutch size	Number of chicks hatched		Hatching rate (%)		Hatch date of first egg	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
24	T	Dovey's	3	2	3	66.7	100.0	03/06/2019	04/06/2019
25	T	Dovey's	3	2	3	66.7	100.0	28/05/2019	28/05/2019
26	T	Dovey's	3	2	2	66.7	66.7	29/05/2019	01/06/2019
27	C	Dovey's	3	3	3	100.0	100.0	29/05/2019	01/06/2019
28	T	Dovey's	3	2	3	66.7	100.0	02/06/2019	02/06/2019
29	T	Dovey's	3	0	3	0.0	100.0		
30	T	Dovey's	3	2	3	66.7	100.0	29/05/2019	01/06/2019
31	C	Dovey's	3	1	3	33.3	100.0	06/06/2019	08/06/2019
32	T	Dovey's	3	0	3	0.0	100.0		
33	T	Dovey's	3	1	3	33.3	100.0	02/06/2019	02/06/2019
34	T	Dovey's	3	3	3	100.0	100.0	29/05/2019	01/06/2019
35	T	Dovey's	3	3	3	100.0	100.0	03/06/2019	04/06/2019
36	T	Dovey's	3	2	3	66.7	100.0	29/05/2019	01/06/2019
37	T	Pit	3	0	3	0.0	100.0		
38	T	Ridge	3	3	3	100.0	100.0	06/06/2019	08/06/2019
39	T	Ridge	3	3	3	100.0	100.0	05/06/2019	05/06/2019
40	C	Ridge	3	1	3	33.3	100.0	10/06/2019	14/06/2019
41	C	Ridge	2	0	2	0.0	100.0		
42	T	Ridge	3	3	3	100.0	100.0	03/06/2019	04/06/2019
43	C	Ridge	3	1	3	33.3	100.0	09/06/2019	09/06/2019
44	C	Ridge	3	2	3	66.7	100.0	04/06/2019	08/06/2019
45	T	Ridge	3	0	1	0.0	33.3		
46	C	Ridge	2	0	0	0.0	0.0		
47	T	Ridge	3	1	2	33.3	66.7	29/05/2019	01/06/2019
48	T	Ridge	3	3	3	100.0	100.0	05/06/2019	05/06/2019
49	C	Ridge	3	2	3	66.7	100.0	29/05/2019	01/06/2019

Nest number	Tag / Control	Sub site	Initial clutch size	Number of chicks hatched		Hatching rate (%)		Hatch date of first egg	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
50	C	Ridge	3	3	3	100.0	100.0	29/05/2019	01/06/2019
51	C	Ridge	3	0	2	0.0	66.7		
52	C	Ridge	3	2	3	66.7	100.0	06/06/2019	08/06/2019
53	C	Ridge	3	2	3	66.7	100.0	06/06/2019	08/06/2019
54	C	Pit	3	2	3	66.7	100.0	02/06/2019	02/06/2019
55	C	Pit	3	2	3	66.7	100.0	05/06/2019	05/06/2019
56	C	Pit	3	1	3	33.3	100.0	05/06/2019	05/06/2019
57	C	Pit	3	0	3	0.0	100.0		
58	C	Pit	3	0	3	0.0	100.0		
59	C	Pit	2	1	2	50.0	100.0	04/06/2019	08/06/2019
60	C	Pit	3	2	3	66.7	100.0	10/06/2019	14/06/2019

Table A2.2 A summary of mean productivity metrics for tagged and control birds separately, and all monitored birds combined.

Sample of birds	Initial clutch size mean ± SD	Mean no. of chicks hatched		Mean hatching rate (%)		Mean hatch date of first egg	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Tagged	2.97 ± 0.18	1.70 ± 1.02	2.77 ± 0.57	57.2 ± 33.8	92.8 ± 17.3	31/05/2019	02/06/2019
Control	2.80 ± 0.41	1.37 ± 0.96	2.57 ± 0.86	47.8 ± 33.3	90.0 ± 27.9	03/06/2019	05/06/2109
All	**2.88 ± 0.32**	**1.53 ± 1.00**	**2.67 ± 0.73**	**52.5 ± 33.6**	**91.4 ± 23.1**	**01/06/2019**	**03/06/2019**

A2.2 Return Rate Assessment

The return rates of tagged and control groups were assessed through re-sightings of the colour-ringed birds. RSPB staff where able to undertake re-sightings on Havergate Island until mid-April 2020, after which the Covid-19 pandemic prevented the staff accessing the island until June, when sighting colour-rings was more challenging because of the growth in vegetation. This access restriction reduced the planned time period available to relocate the tagged and control birds, but sufficient sightings were still made to compare return rates between the two groups in 2020.

The number of sightings of each group of gulls made on Havergate Island in 2020 is summarised in Table A2.3. On average, control birds had a lower return rate than tagged birds, which suggests that the tagging process did not have an adverse effect on survival rates.

Table A2.3 A summary of the number of colour-ringed gulls in each study cohort sighted on Havergate Island in 2020. Sightings on Havergate Island were all made by Dave Fairhurst and Mike Marsh (RSPB).

Study cohort	Total in study in 2019	Total seen on Havergate 2020	Percentage return rate to Havergate
Control	30	13	43.3
Tagged	30	18	60.0
Movetech	15	9	60.0
UvA	15	9	60.0

In addition to those tagged birds that were observed at Havergate in 2020, a further 2 birds (1 Movetech, 1 UvA) were known to have returned from the data that were transmitted from their tags, indicating an overall return rate of 66.6%.

One bird (Movetech 1108) conversely was observed at Havergate in 2020, but its tag transmitted no data.

In total, either because they did not return, or because tags had failed, data were not received from 11 birds.

Two birds (Movetech 1119 and UvA 5863) were confirmed to have died. 5863 died of suspected botulism during the 2019 breeding season, and was retrieved by the RSPB staff. 1119 was recovered in Villers-Bocage, Calvados, France on 22th May 2020 on its return migration; it had drowned in a sewage works tank. This bird had originally been ringed on 24th April 2002.

Two birds (Movetech 1112 and 1113) were also suspected to either have died, or their tags became detached earlier than anticipated. 1112 transmitted stationary data points from a reservoir on farmland in Suffolk up until 7th August 2019, but investigations could not relocate the tag or carcass. The tag began transmitting again in August 2020 from the same reservoir, and was retrieved, but no carcass was evident. 1113 transmitted stationary data points from under powerlines in a field in Suffolk between October 2019 and June 2020, but no tag or carcass was retrieved.

One control bird (NHNY), originally ringed as a chick on 29th June 2014, was reported dead on 2nd May 2020.

Appendix 3 Ring, Colour-ring, Biometric and Tag Information Summary.

Table A3.1 A summary of the data associated with the ringing, processing and tagging process of this study, for 60 Lesser Black-backed Gulls caught during this study, or selected to be controls as part of it. Age codes: P = pullus (not yet fledges); A = adult (at least 3 years old). Birds with no 'Tag information' are controls for the study.

			Bird biometrics					Tag information			Original ringing details		
Ring number	**Colour ring**	**Nest location**	**Wing (mm)**	**Total head (mm)**	**Bill length (mm)**	**Gonys depth (mm)**	**Weight (g)**	**Tag type**	**Tag number**	**Tag weight (g)**	**Date**	**Age**	**Location**
GR47965	BWBR	The Pit	411	110.6	50.5	16.7	740	-	-	-			
GR47966	BWBU	The Pit	410	108.5	48.3	15.6	720	-	-	-			
GG78845	LCLW	The Pit	437	115.0	54.8	18.6	938	Movetech	1109	19.04	07/07/2013	P	Havergate
GR27186	NFNT	The Pit	435	124.8	56.9	18.6	1013	Movetech	1120	18.73	12/07/2014	P	Havergate
GR47967	BWBW	The Pit	406	107.5	47.8	16.3	728	-	-	-			
GR47969	BWBZ	The Pit	391	112.5	49.9	16.5	720	-	-	-			
GN32417	BXBA	The Pit	428	123.5	53.9	17.4	948	Movetech	1119	18.54	24/04/2002	A	Ipswich
GR47971	BXBB	The Pit	423	108.4	46.9	16.9	748	-	-	-			
GR47972	BXBC	Dovey's	446	123.4	52.9	18.3	883	Movetech	1108	18.36			
GR47974	BXBD	Dovey's	417	111.7	49.7	15.8	780	Movetech	1118	17.67			
GR47975	BXBF	Dovey's	400	105.7	48.1	15.1	733	UvA	5866	13.7			
GR47976	BXBH	Dovey's	403	111.4	48.7	17.3	773	-	-	-			
GR47977	BXBJ	Dovey's	410	110.0	46.3	16.4	733	UvA	5873	13.8			
GR47978	BXBK	Dovey's	396	112.8	51.0	16.7	790	Movetech	1112	17.98			
GR47979	BXBL	Dovey's	415	111.1	48.9	16.1	808	Movetech	1122	18.27			
GR47980	BXBN	Dovey's	440	117.4	50.8	18.9	883	-	-	-			
GR47981	BXBP	Dovey's	452	119.7	49.9	19.5	948	-	-	-			
GR47982	BXBR	Dovey's	424	119.5	53.9	18.7	893	-	-	-			
GG78339	DCDJ	Dovey's	436	121.1	53.4	17.7	883	Movetech	1111	18.29	01/07/2012	P	Havergate

			Bird biometrics					Tag information			Original ringing details		
Ring number	Colour ring	Nest location	Wing (mm)	Total head (mm)	Bill length (mm)	Gonys depth (mm)	Weight (g)	Tag type	Tag number	Tag weight (g)	Date	Age	Location
GR47983	BXBS	Dovey's	422	121	54.4	17.7	820	Movetech	1116	18.26			
GR47984	BXBT	Dovey's	431	122.2	55.4	16.9	860	Movetech	1123	18.38			
GR47986	BXBU	Dovey's	397	107.9	48.2	16.2	735	-	-	-			
GR47987	BXBV	Dovey's	402	113.3	53.9	16.0	720	-	-	-			
GR47988	BXBW	Dovey's	422	112.2	49.5	16.7	775	UvA	5881	13.57			
GR53107	BXBX	Dovey's	428	122.9	55.3	18.0	920	Movetech	1127	18.53	19/03/2013	A	Milton Tip, Cambs
GR47989	BXBY	Dovey's	396	108.8	49.0	15.9	770	UvA	5970	13.49			
GR47990	BXBZ	Dovey's	413	114.6	48.0	16.6	720	-	-	-			
GR47991	BYBA	Dovey's	434	119.6	52.1	19.0	900	Movetech	1107	18.23			
GR47992	BYBB	Dovey's	424	127.4	54.9	18.6	800	Movetech	1125	18.06			
GR47993	BYBC	Dovey's	439	125.0	55.3	18.8	820	-	-	-			
GR47994	BYBD	Dovey's	442	118.0	51.2	18.5	820	Movetech	1117	18.22			
GR47995	BYBF	Dovey's	423	120.6	53.2	18.5	890	UvA	5876	13.8			
GR47996	BYBH	Dovey's	443	127.1	55.5	19.5	965	Movetech	1113	18.11			
GR47997	BYBJ	Dovey's	391	108.5	45.3	16.2	737	UvA	5868	13.8			
GR47998	BYBK	Dovey's	415	118.0	47.4	18.6	745	UvA	5880	13.85			
GR47999	BYBL	Dovey's	407	111.3	48.9	17.4	740	UvA	5875	13.58			
GR27160	NDNU	Ridge	432	125.1	53.2	19.0	875	UvA	5874	13.59	29/06/2014	P	Havergate
GR55502	BYBN	Ridge	420	104.5	48.9	16.0	740	UvA	5865	13.74			
GR55505	BYBP	Ridge	408	108.7	45.5	16.6	750	UvA	5877	13.57			
GR55506	BYBR	Ridge	421	108.6	44.9	16.1	760	-	-	-			
GR55507	BYBS	Ridge	412	113.3	46.8	17.4	755	-	-	-			
GR55508	BYBT	Ridge	431	123.0	51.4	19.2	960	UvA	5863	13.77			
GR55510	BYBU	Ridge	436	126.5	53.6	19.4	930	-	-	-			

			Bird biometrics					Tag information			Original ringing details		
Ring number	**Colour ring**	**Nest location**	**Wing (mm)**	**Total head (mm)**	**Bill length (mm)**	**Gonys depth (mm)**	**Weight (g)**	**Tag type**	**Tag number**	**Tag weight (g)**	**Date**	**Age**	**Location**
GR55511	BYBV	Ridge	450	121.2	51.6	18.8	970	-	-	-			
GR27392	NUNF	Ridge	438	128.6	50.0	18.9	970	UvA	5870	13.62	12/07/2014	P	Havergate
GR55512	BYBW	Ridge	418	109.2	45.6	15.4	750	-	-	-			
GR55513	BYBX	Ridge	401	110.1	48.8	17.5	750	UvA	5969	13.46			
GR27365	NSNZ	Ridge	427	118.0	54.2	17.1	850	UvA	5872	13.59	02/07/2014	P	Havergate
GR55514	BYBY	Ridge	420	120.6	48.0	18.5	860	-	-	-			
GR55515	BYBZ	Ridge	403	109.3	48.8	16.5	755	-	-	-			
GR55516	BZBA	Ridge	398	107.4	43.9	17.1	670	-	-	-			
GR55517	BZBB	Ridge	444	120.1	53.1	17.9	930	-	-	-	14/07/1996	P	Orford Ness
GR55518	BZBC	Ridge	423	116.4	48.9	17.3	845	-	-	-			
GG78109	BKBH		-	-	-	-	-	-	-	-	11/07/2010	P	Havergate
GG78739	BVBC		-	-	-	-	-	-	-	-	01/06/2013	P	Orford Ness
GG78797	LBLD		-	-	-	-	-	-	-	-	27/06/2013	P	Havergate
GR27359	NSNT		-	-	-	-	-	-	-	-	02/07/2014	P	Havergate
GG78615	DLDX		-	-	-	-	-	-	-	-	08/07/2012	P	Havergate
GR27213	NHNY		-	-	-	-	-	-	-	-	29/06/2014	P	Havergate
GR27384	NTNW		-	-	-	-	-	-	-	-	12/07/2014	P	Havergate

Table A3.2 Numbers of Lesser Black-backed Gulls colour-ringed at Orford Ness and Havergate.

Year	**Orford Ness**			**Havergate**			**Orford Ness/ Havergate combined**		
	pulli	adults	total	pulli	adults	total	pulli	adults	total
1996	419	0	419	0	0	0	419	0	419
1997	643	0	643	0	0	0	643	0	643
1998	286	0	286	0	0	0	286	0	286
1999	645	0	645	0	0	0	645	0	645
2000	581	0	581	0	0	0	581	0	581
2001	314	0	314	0	0	0	314	0	314
2002	308	0	308	0	0	0	308	0	308
2003	323	0	323	0	0	0	323	0	323
2004	321	0	321	0	0	0	321	0	321
2005	398	0	398	0	0	0	398	0	398
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	11	0	11	11	0	11
2008	82	0	82	66	0	66	148	0	148
2009	37	0	37	82	0	82	119	0	119
2010	1	17	18	239	5	244	240	22	262
2011	109	61	170	261	11	272	370	72	442
2012	0	16	16	224	0	224	224	16	240
2013	0	36	36	244	0	244	244	36	280
2014	0	0	0	356	13	369	356	13	369
2015	2	0	2	11	0	11	13	0	13
2016	1	0	1	192	0	192	193	0	193
2017	6	0	6	0	0	0	6	0	6
2018	0	0	0	0	0	0	0	0	0
2019	0	0	0	116	47	163	116	47	163
2020	0	0	0	66	0	66	66	0	66
2021	0	0	0	115	1	116	115	1	116
Total	**119**	**130**	**249**	**1824**	**77**	**1901**	**1943**	**207**	**2150**

Table A3.3 Numbers of colour-ringed Lesser Black-backed Gulls resighted at Orford Ness and Havergate from 2010-2021.

(a) Birds ringed at Orford Ness as pulli.

Year seen	1996-2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
2010	100												100
2011	75	0											75
2012	75	0	1										76
2013	35	0	5	0									40
2014	14	0	5	0	0								19
2015	17	0	4	0	0	0							21
2016	21	0	2	0	0	0	0						23
2017	16	0	3	0	0	0	0	0					19
2018	5	0	3	0	0	0	0	0	0				8
2019	15	0	4	0	0	0	0	0	0	0			19
2020	15	0	2	0	0	0	0	0	0	0	0		17
2021	17	0	2	0	0	0	0	0	0	0	0	0	19

(b) Birds ringed at Orford Ness as adults.

Year seen	1996-2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
2010	0												0
2011	0	13											13
2012	0	11	37										48
2013	0	8	27	4									39
2014	0	4	13	3	5								25
2015	0	3	11	3	4	0							21
2016	0	1	4	1	3	0	0						9
2017	0	2	3	0	2	0	0	0					7
2018	0	2	0	0	0	0	0	0	0				2
2019	0	0	1	0	1	0	0	0	0	0			2
2020	0	0	1	0	1	0	0	0	0	0	0		2
2021	0	1	1	0	3	0	0	0	0	0	0	0	5

(c) Birds ringed at Havergate as pulli.

Year seen	1996-2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
2010	2												2
2011	5	0											5
2012	11	4	0										15
2013	11	11	0	0									22
2014	6	12	7	3	0								28
2015	9	17	10	8	0	0							44
2016	11	21	19	17	7	1	0						76
2017	11	19	12	23	14	17	0	0					96
2018	6	10	11	17	9	14	0	1	0				68
2019	11	19	6	15	13	37	0	8	0	0			109
2020	9	21	13	21	18	41	0	15	0	0	0		138
2021	13	18	15	19	18	45	0	25	0	0	5	0	158

(d) Birds ringed at Havergate as adults.

Year seen	1996-2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
2010	0												0
2011	0	1											1
2012	0	2	3										5
2013	0	2	1	0									3
2014	0	2	1	0	0								3
2015	0	0	1	0	0	9							10
2016	0	3	2	0	0	4	0						9
2017	0	1	3	0	0	4	0	0					8
2018	0	1	1	0	0	3	0	0	0				5
2019	0	0	1	0	0	3	0	0	0	0			4
2020	0	0	3	0	0	3	0	0	0	0	20		26
2021	0	0	2	0	0	2	0	0	0	0	19	0	23

(e) All birds ringed at Orford Ness and Havergate.

Year seen	1996-2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
2010	102												102
2011	80	14											94
2012	86	17	41										144
2013	46	21	33	4									104
2014	20	18	26	6	5								75
2015	26	20	26	11	4	9							96
2016	32	25	27	18	10	5	0						117
2017	27	22	21	23	16	21	0	0					130
2018	11	13	15	17	9	17	0	0	0				82
2019	26	19	12	15	14	40	0	0	0	0			126
2020	24	21	19	21	19	44	0	0	0	0	0		148
2021	30	19	20	19	21	47	0	0	0	0	0	0	156

Table A3.4 Numbers of Lesser Black-backed Gulls colour-ringed at Orford Ness and Havergate resighted in East Anglia, during March-August, 2010-2021.

(a) Local sightings (up to 10 km from Orford Ness/Havergate).

Location	**Number of individuals seen**
Aldeburgh, Suffolk (TM4656)	5
Boyton area, Suffolk	5
Butley/Staverton Park area	73
Gedgrave Marshes, Orford, Suffolk (TM4148)	4
Hollesley Marshes, Hollesley, Suffolk (TM3744)	9
Iken, Suffolk	2
Snape area, Suffolk	100
Blaxhall, Suffolk (TM3557)	1
Sudbourne, Suffolk	7
Sutton area	8
Tunstall, Suffolk	2
Wantisden, Suffolk	5
Woodbridge, Suffolk	3

(b) East Suffolk.

Location	**Number of individuals seen**
Beccles, Suffolk (TM4290)	1
Blythburgh, Suffolk (TM4474)	27
Bromeswell, Suffolk	1
Carlton Colville, Suffolk (TM5091)	2
Easton, Suffolk	1
Elmswell, Suffolk (TL9863)	1
Felixstowe, Suffolk	57
Flixton, Suffolk (TM3086)	1
Ipswich, Suffolk	3
Lowestoft, Suffolk (TM5593)	5
Minsmere, Suffolk (TM4766)	57
Mutford, Suffolk (TM4889)	1
near Woodbridge, Suffolk	1
Palgrave, Suffolk (TM1178)	1
Sizewell, Suffolk (TM4762)	9
Southwold (harbour), Suffolk (TM5074)	2
Walberswick, Suffolk	1
Westleton, Suffolk (TM4469)	3
Wetherden, nr. Stowmarket, Suffolk (TL9962)	2
Wolsey's Creek, near Reydon, Suffolk (TM4776)	1

(c) West Suffolk.

Location	Number of individuals seen
Fakenham Magna, Suffolk (TL9075)	1
Great Livermere area, Suffolk	90
Mickle Mere, Pakenham, Suffolk (TL9369)	1
Tuddenham St Mary, Suffolk (TL7471)	5

(d) Essex.

Location	Number of individuals seen
Alresford, Essex	1
Brightlingsea, Essex	1
Burnham-on-Crouch, Essex	1
Clacton-on-Sea, Essex	2
Hamford Water, Essex (TM2424)	1
Harwich, Essex	1
Holland Haven, Essex (TM2217)	3
Kirkby-le-Soken, Essex	1
Pitsea Landfill Site, Essex (TQ7485)	2
West Mersea, Essex	1

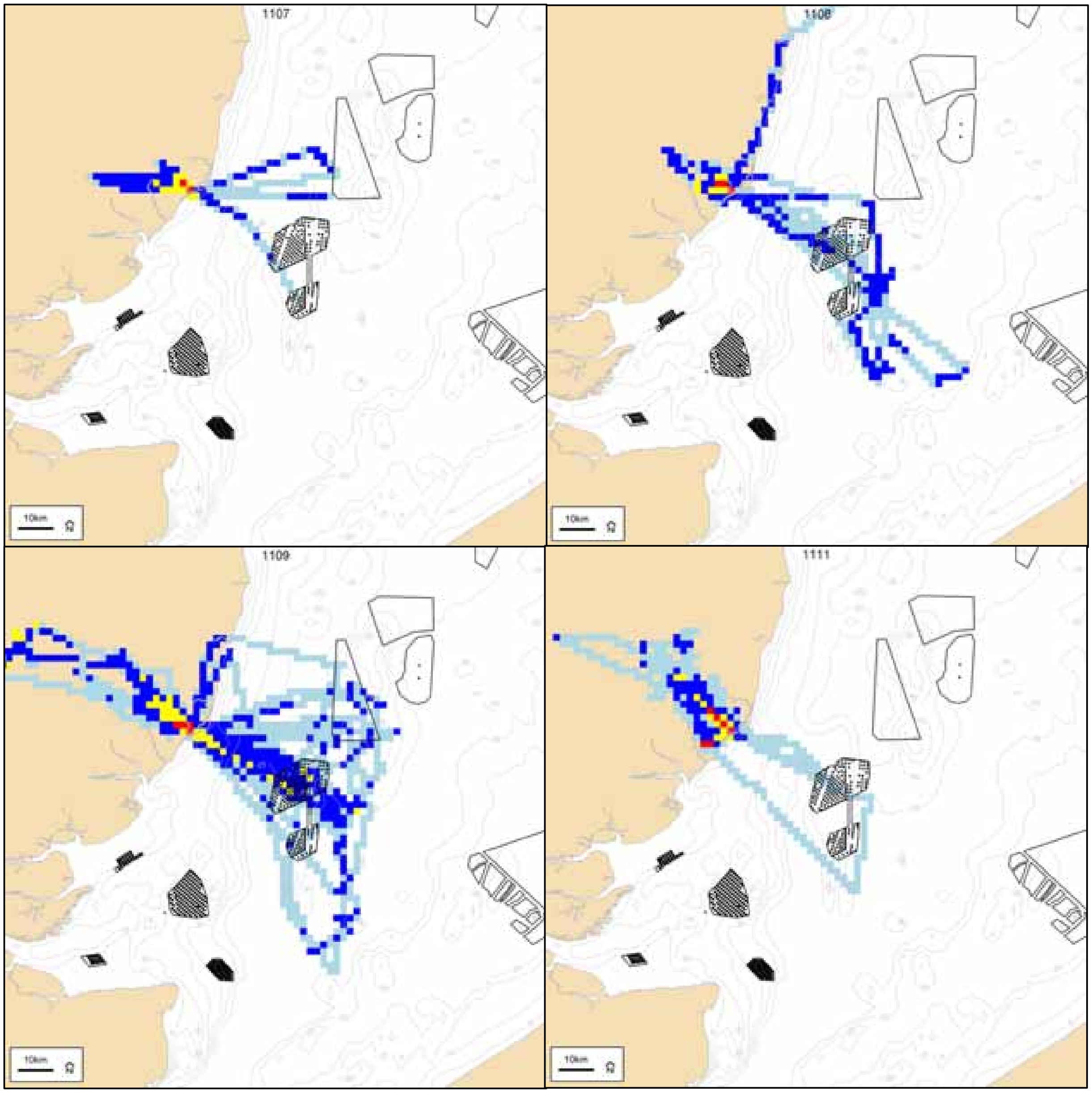
(e) Cambridgeshire.

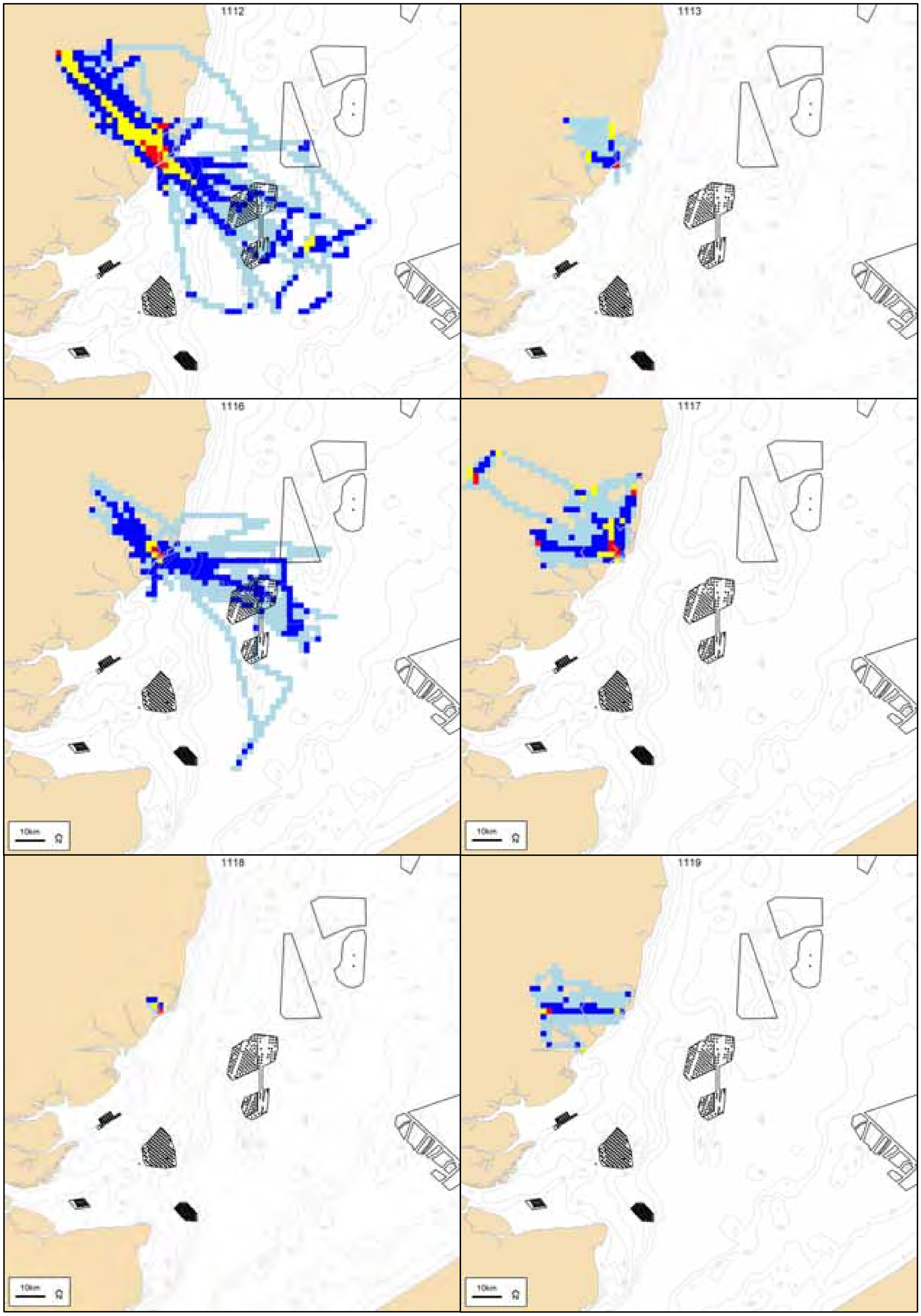
Location	Number of individuals seen
Cottenham Long Drove, Cambridgeshire (TL4869)	1
Godmanchester GP, Cambridgeshire (TL2571)	2
Grafham Water NR, Cambridgeshire	1
Milton tip, near Cambridge (TL4762)	23
near Swavesey, Cambridgeshire	1
Orton Goldhay, Peterborough, Cambridgeshire	1

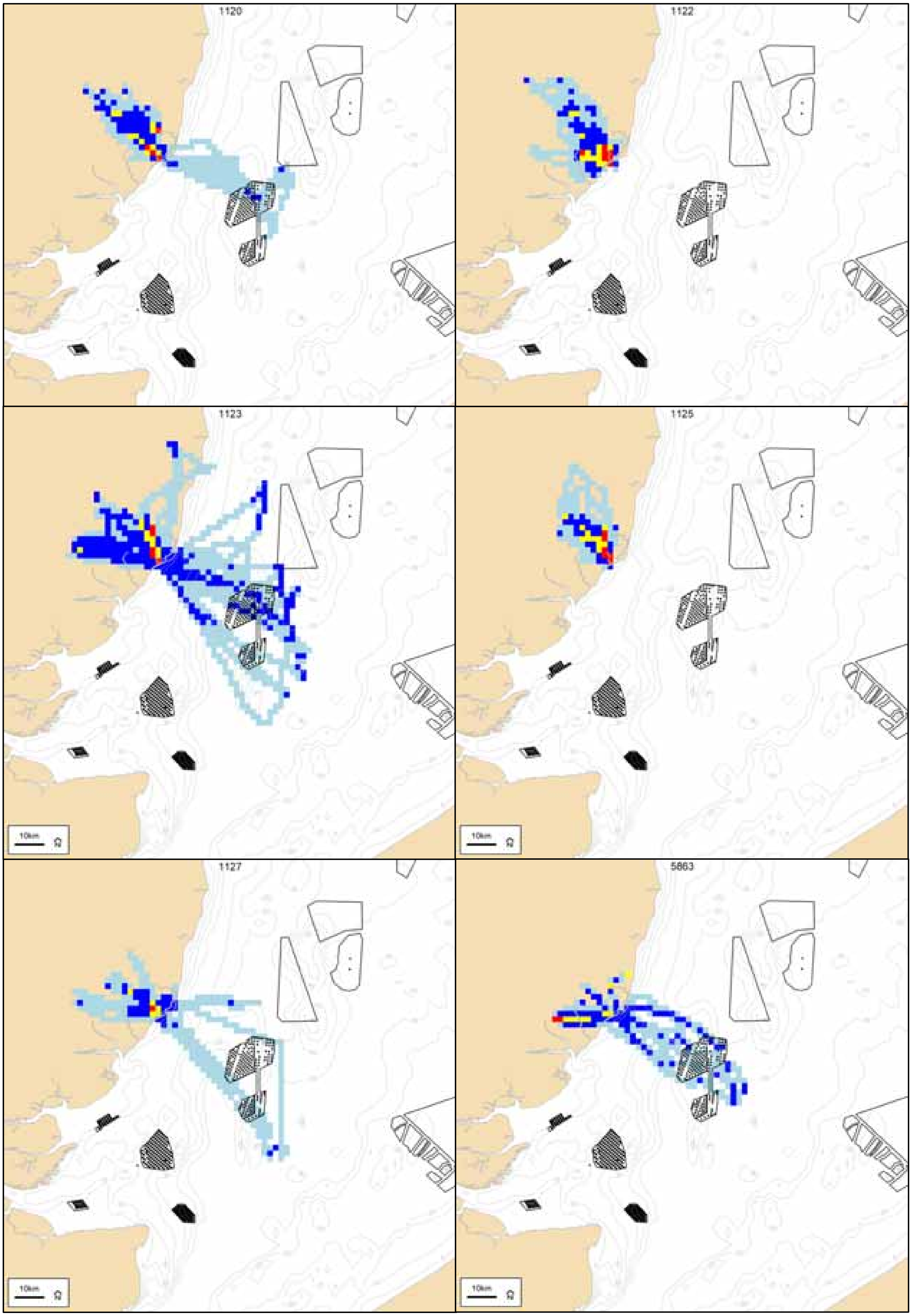
(f) Norfolk.

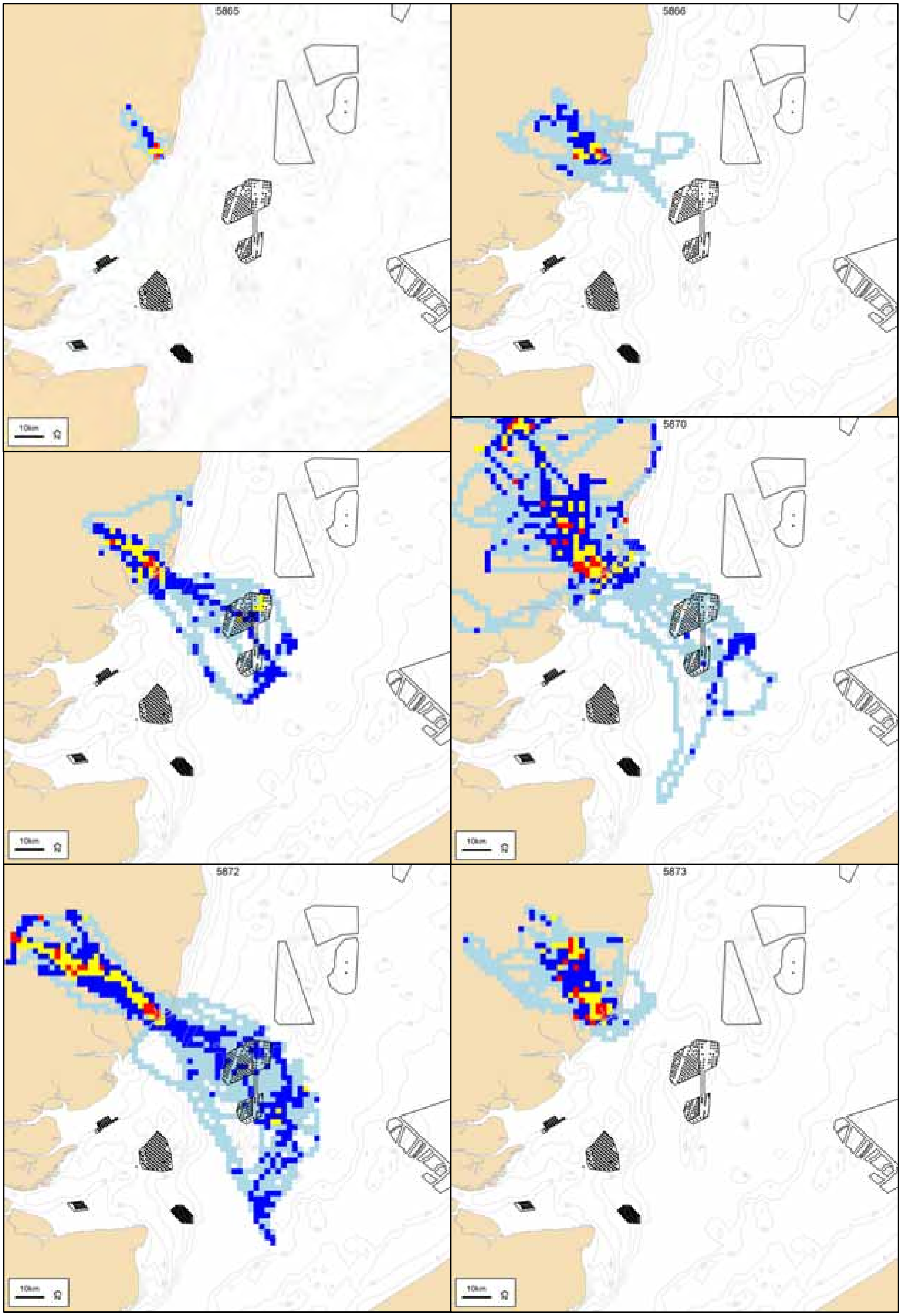
Location	Number of individuals seen
Acle, Norfolk	1
Blakeney, Norfolk (TG0244)	1
Buxton, Norfolk (TG2322)	1
Earsham, Norfolk (TM3088)	19
Feltwell Landfill Site, near Feltwell, Norfolk (TL7492)	2
Great Yarmouth, Norfolk	1
Hemsby, Norfolk (TG5017)	1
Nunney Lakes Reserve, Thetford, Norfolk (TL8781)	1
West Harling, Norfolk (TL9884)	2

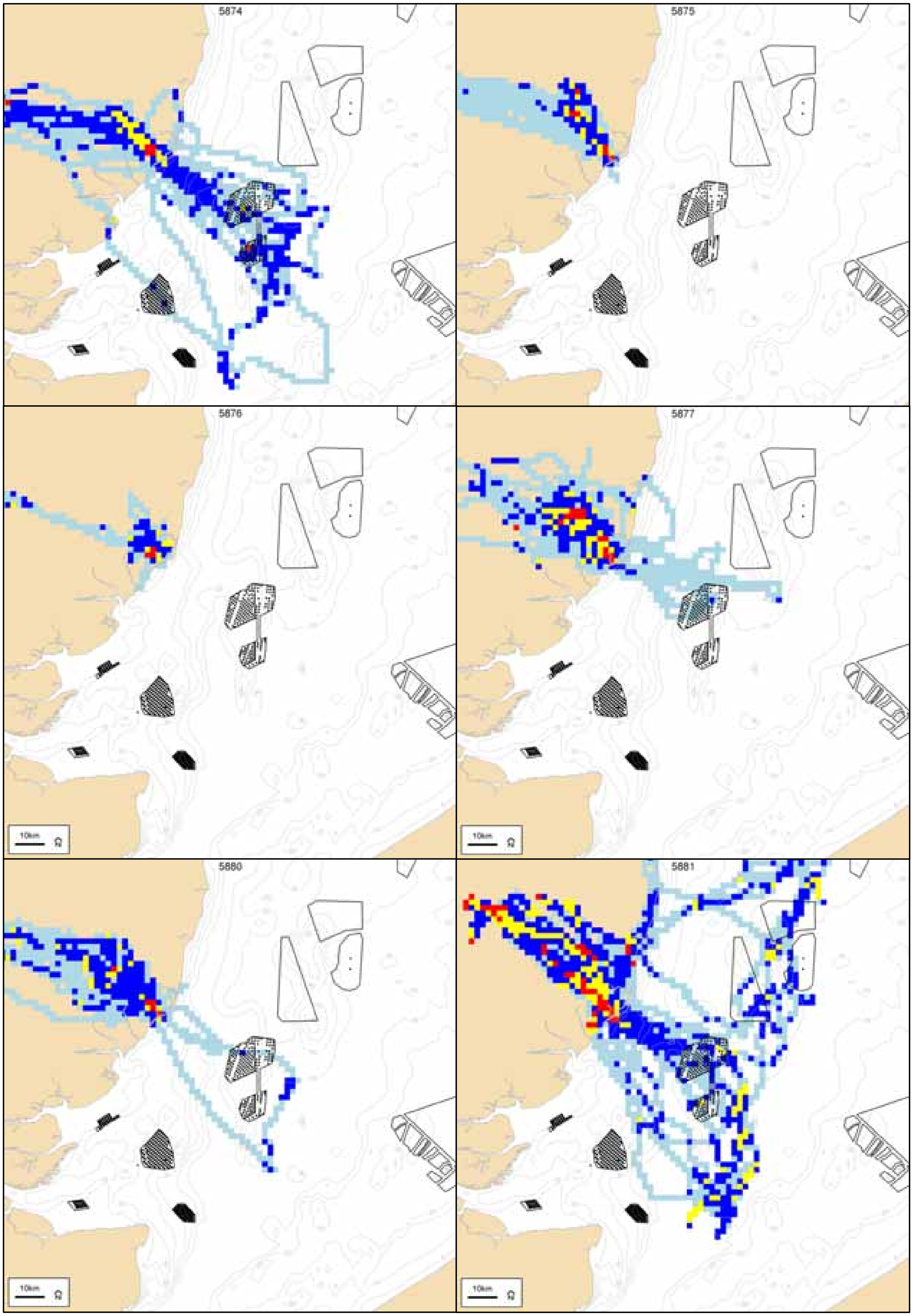
Appendix 4 Time-In-Area Utilisation Distributions for Individual Lesser Black-backed Gulls.




1112
1113
1116
1117
1118
1119
10km


1120
1122
1123
1125
1127
5863
10km
10km
10km
10km


5865
5866
5870
5872
5873
10km


5874
5875
5876
5877
5880
5881
10km
10km
10km
10km

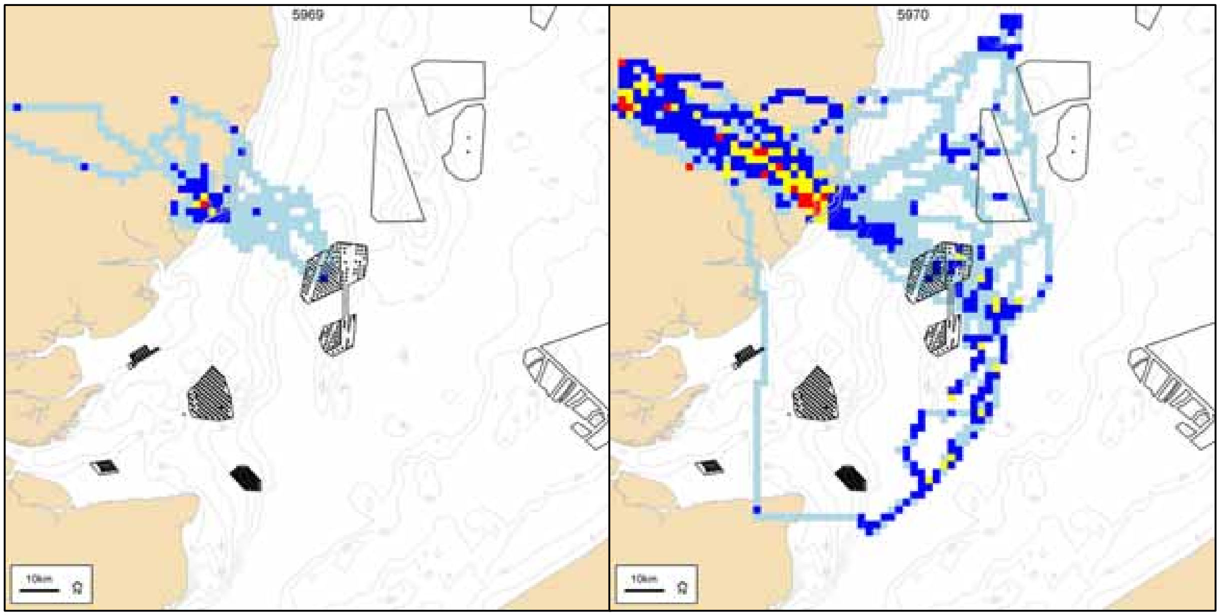
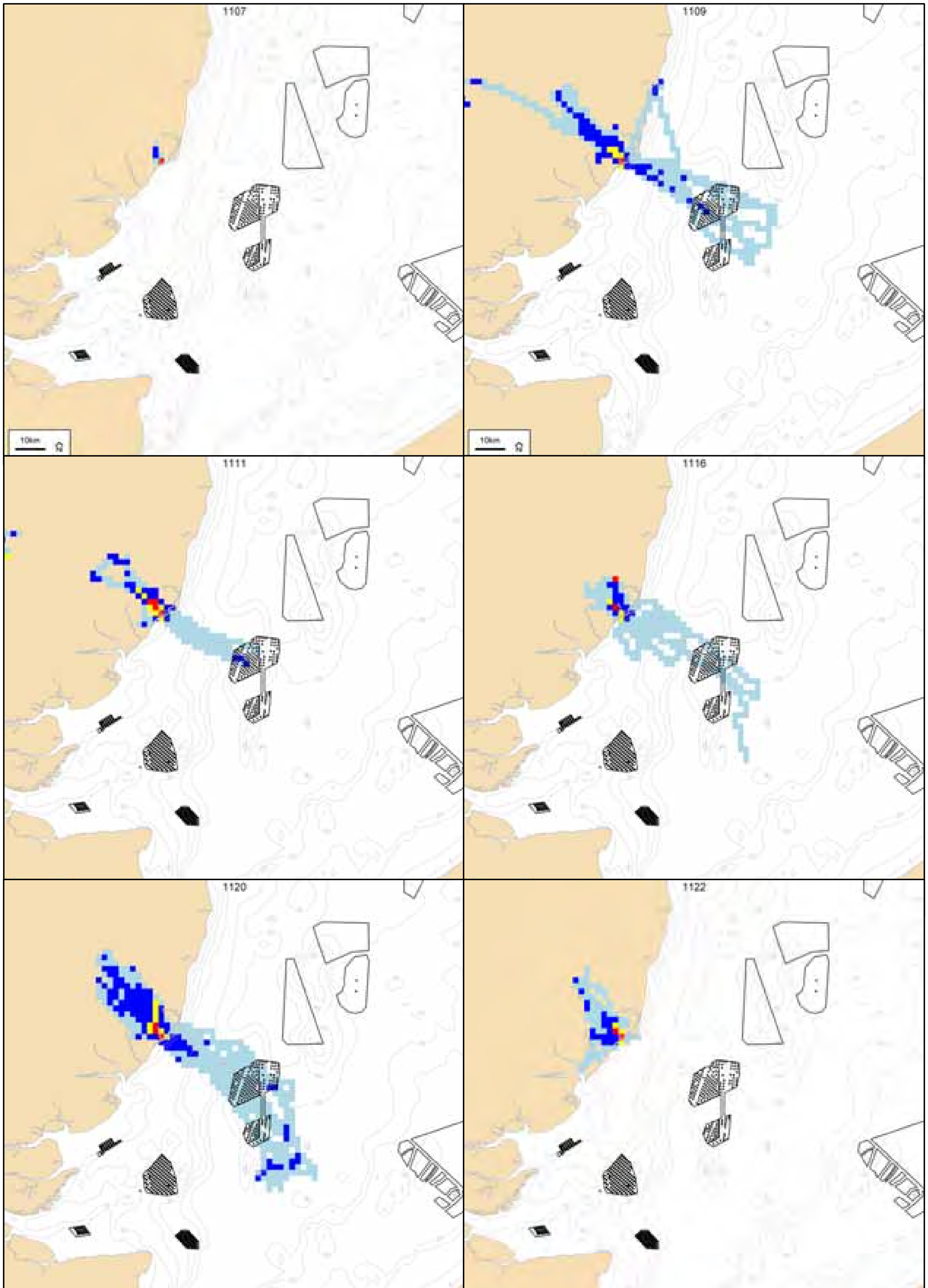
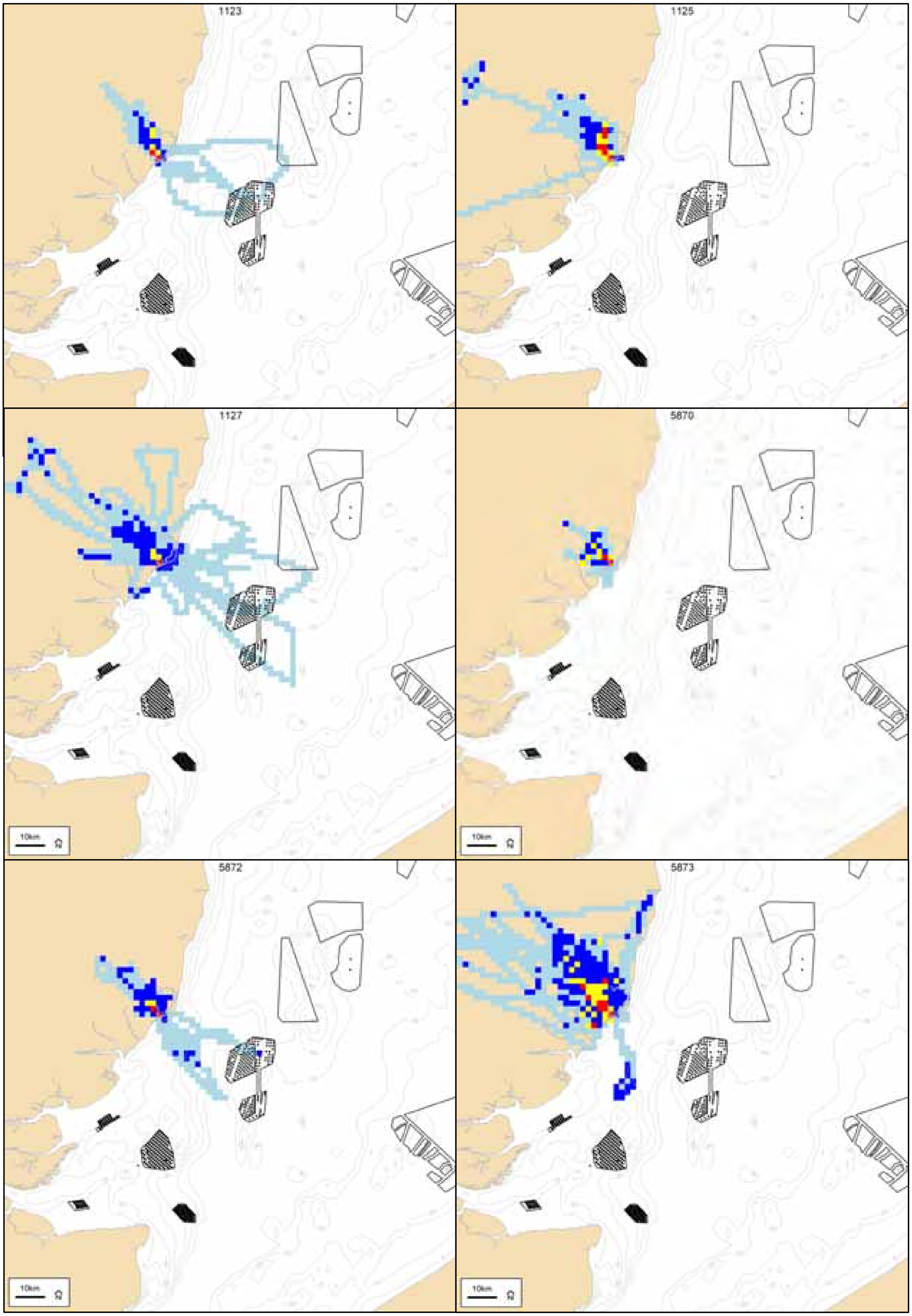
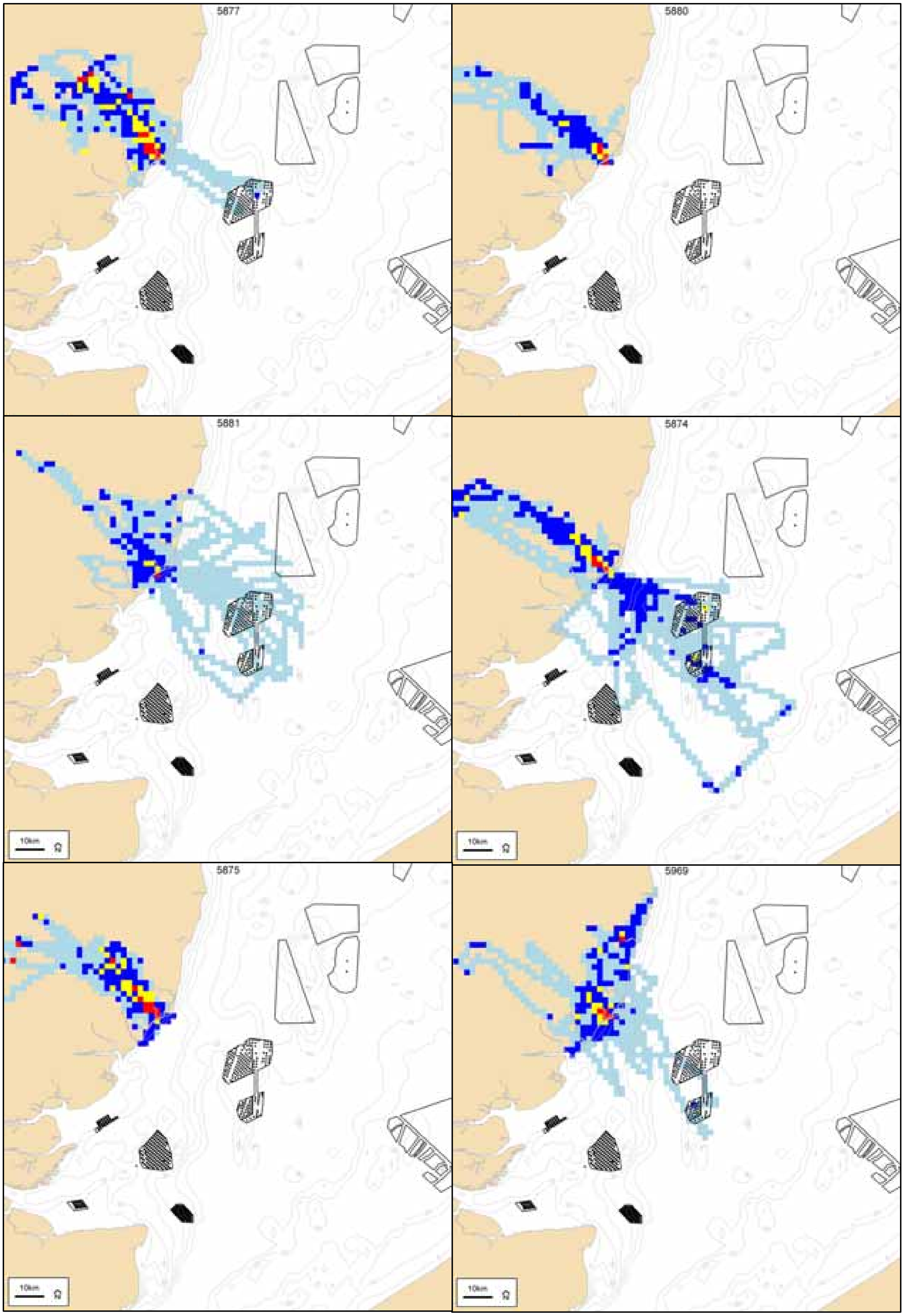


Figure A4.1 Utilisation distributions for individual Lesser Black-backed Gulls tracked in 2019.


1107
1109
1111
1116
1120
1122
10km
10km
10km
10km
10km
10km


1123
1125
1127
5870
5872
5873
10km
10km
10km
10km


5877
5880
5881
5874
10km
10km
5875
5969
10km
10km

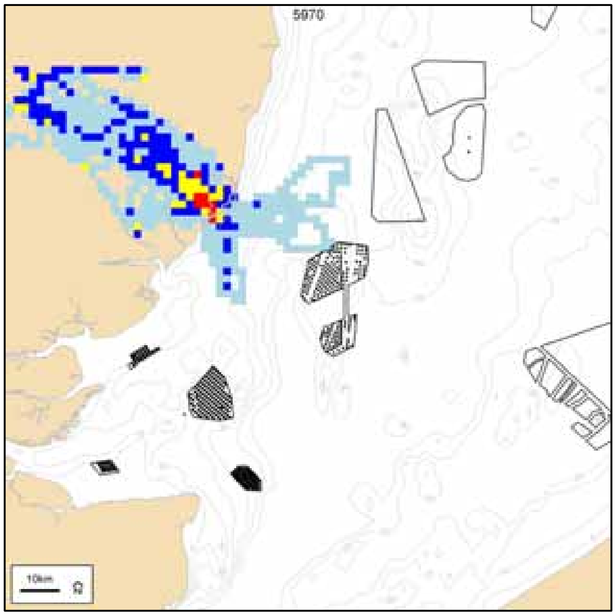


Figure A4.2 Utilisation distributions for individual Lesser Black-backed Gulls tracked in 2020.

Appendix 5 Diurnal and Seasonal Behavioural Assessment

A5.1 Time Budgets and Variation in Activity Across the Day

The behaviours of Lesser Black-backed Gulls in the Galloper and Greater Gabbard Wind Farms described in sections 4.5 and 4.7 was further evaluated with respect to the time of day, using classifications from the EMbC and RF models (Figures A5.1 and A5.2). As noted in those sections, 'stopped' behaviours were observed at offshore platforms within the wind farms, although birds apparently did not use turbine bases.

Time spent stopped at offshore platforms was heavily biased to twilight and overnight periods – this is reflected in the large amount of proportion time spent in stopped activities overnight, for example, in 2019 (Fig. A5.1). Further, it was very clear that Lesser Black-backed Gulls, rarely rested on the sea overnight in the GWF, with birds showing either little to no use of the wind farm during these hours or sitting on the platform structures instead. Some birds rested on the sea overnight in the Greater Gabbard Wind Farm, however. In contrast, floating was by far the predominant behaviour overnight in offshore areas outside of wind farms (Fig. A5.1).

The RF classification (Fig A5.2), indicated that flapping and floating were the dominant behaviours offshore. A cyclical pattern was evident, with an increase in floating and a reduction in flapping in the middle part of the day, potentially linked to the timing of departure and arrival of foraging trips.

A summary of the relative time spent in the Galloper and Greater Gabbard Wind Farms during the day and night, together with the proportion of time spent in flight based on the EMbC behavioural classifications indicative of commuting (state3, high speed, low turn angle) and foraging/searching (state 4, high speed, high turn angle) is provided in Table A5.1.

As in the assessment in section 4.4, based on area use, this summary indicated that birds tended to use OWFs relatively more during the day than on the night. However, this picture was more complex when using raw time values compared to estimates based solely on area use, with sometimes the reverse being true. For example, based on time estimates, the GWF was used more in the day than the night in 2019, but more in the night than in the day in 2020.

Differences between the estimates based on area use and time budgets are due to differences in what each represents. The estimates The estimates based on area use considered the time-in-area (TIA) 95% occupancy contour, which encompasses all lower contours (e.g. 75%, 50%), and is essentially a perimeter around the space used by birds at that contour level i.e. representative of the area where birds spent most of their time. However, the assessment takes no account of the relative time spent in each grid cell within that perimeter. By contrast, the assessment based on time budgets considers the full temporal distribution. An equivalency may be reached if a three-dimensional surface area summed comparison was estimated from the TIA including all contour levels within the full space-time distribution.

The proportion of time spent in flight (as a percentage of the time spent in respective OWFs and offshore areas) was less within OWFs than in other offshore areas. This difference was attributable to the increased time spent perching within OWFs on structures in comparison to offshore areas more generally, where rest activity overnight was far more dominated by floating activities (Figs A5.1 and A5.2). The proportion of time spent in flight was typically greater in the day than in the night, although the opposite was the case for birds within the GWF in 2019. (Table A5.1).

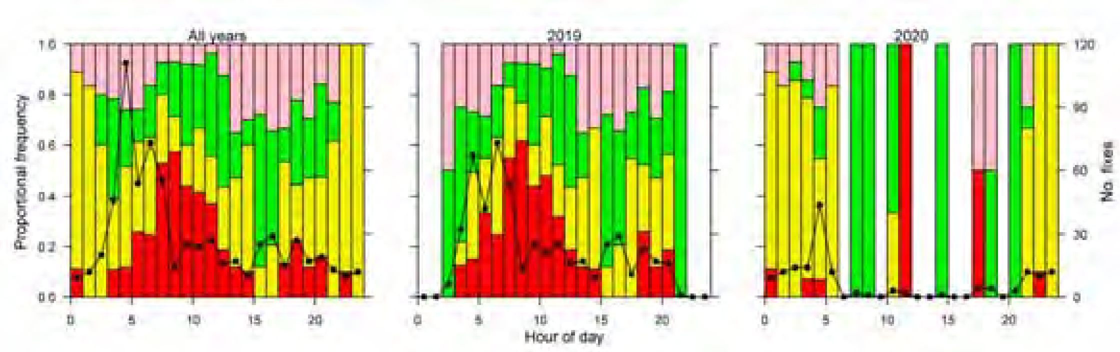
Table A5.1 The relative diurnal to nocturnal time spent in the Galloper and Greater Gabbard Wind Farms by Lesser Black-backed Gulls tracked from Havergate Island during the 2019 and 2020 breeding seasons, together with the time spent in flight. A value greater than 1 = bias to greater diurnal activity, less than 1 = bias to nocturnal activity.

Year	Wind farm	% time in OWFs (%)		Relative diurnal to nocturnal time in OWFS	% time in flight in OWFs (%)		Relative diurnal to nocturnal time in flight in OWFs
		Day	Night		Day	Night	
2019	Galloper	0.62	0.29	2.11	45.69	83.33	0.55
	Gabbard	0.42	0.84	0.50	66.10	38.46	1.72
	All OWFs	1.07	1.14	0.94	54.09	50.00	1.08
	Offshore outside OWFs	8.87	20.35	0.44	58.82	31.33	1.88
2020	Galloper	0.17	0.19	0.90	45.71	14.10	3.24
	Gabbard	0.22	0.05	4.60	69.57	35.00	1.99
	All OWFs	0.40	0.23	1.69	60.24	18.37	3.28
	Offshore outside OWFs	2.31	1.15	2.00	73.76	44.70	1.65

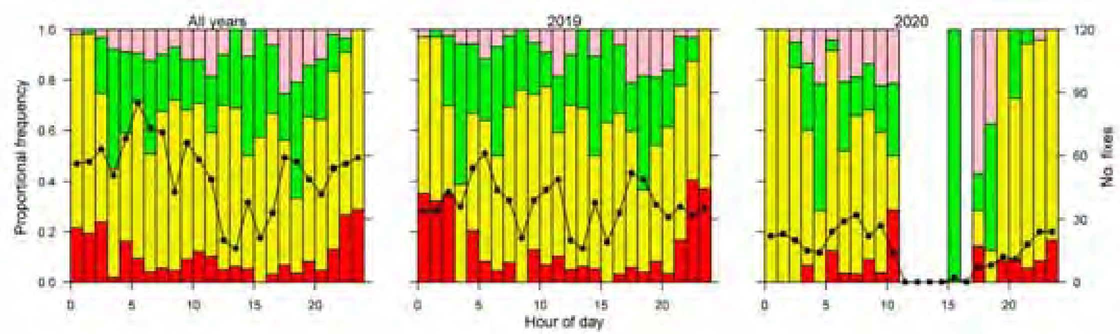
Table A5.2 Summary of number of fixes recorded during the day and night, and in flight (as used to inform the assessment in Table A5.1), in the Galloper and Greater Gabbard Wind Farms for Lesser Black-backed Gulls tracked from Havergate Island during the 2019 and 2020 breeding seasons. 'In flight' values are based on the EMbC behavioural classification at five-minute resolution, using states 3 and 4 for commuting and foraging, respectively.

Year	Wind farm	n fixes in OWFs		n fixes in flight in OWFs		No. fixes 'on trips' away from colony		
						Total	Day	Night
		Day	Night	Day	Night			
2019	Galloper	429	36	196	30	81942	69615	12327
	Gabbard	292	104	193	40	81942	69615	12327
	All OWFs	745	140	403	70	81942	69615	12327
	Offshore outside OWFs	6178	2509	3634	786	81942	69615	12327
2020	Galloper	70	78	32	11	41752	37445	4307
	Gabbard	92	20	64	7	41752	37445	4307
	All OWFs	166	98	100	18	41752	37445	4307
	Offshore outside OWFs	964	481	711	215	41752	37445	4307

(a) GWF



(b) Greater Gabbard Wind Farm



(c) Offshore, outside wind farms

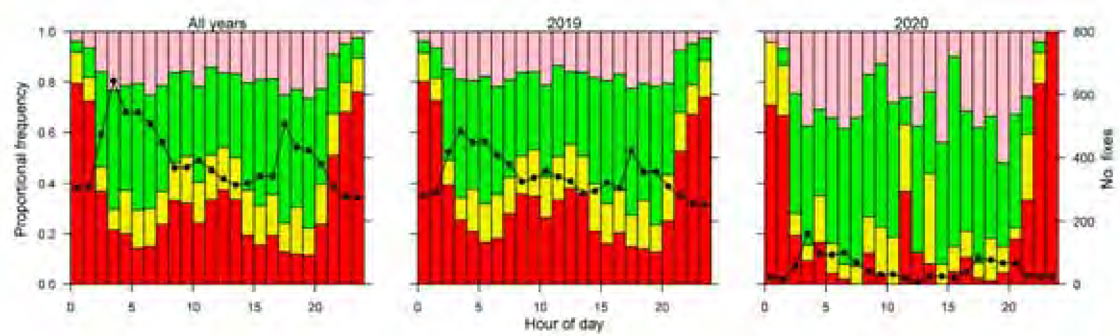


Figure A5.1 Classification of Lesser Black-backed Gull behaviours in (a) the GWF, (b) the Greater Gabbard Wind Farm and (c) other offshore areas outside wind farms plotted over time of day, using EMbC models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Red = float, yellow = stop, green = commute, pink = foraging/search. Black lines and points denotes the number of fixes per hour as a metric of use of the specified areas.

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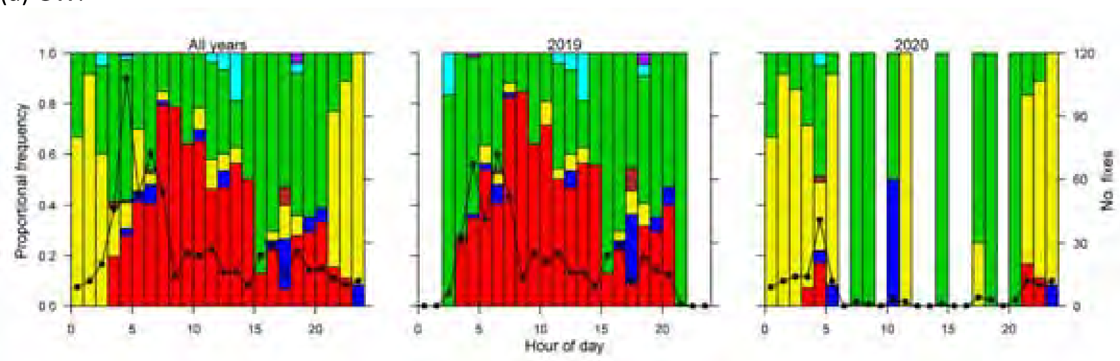
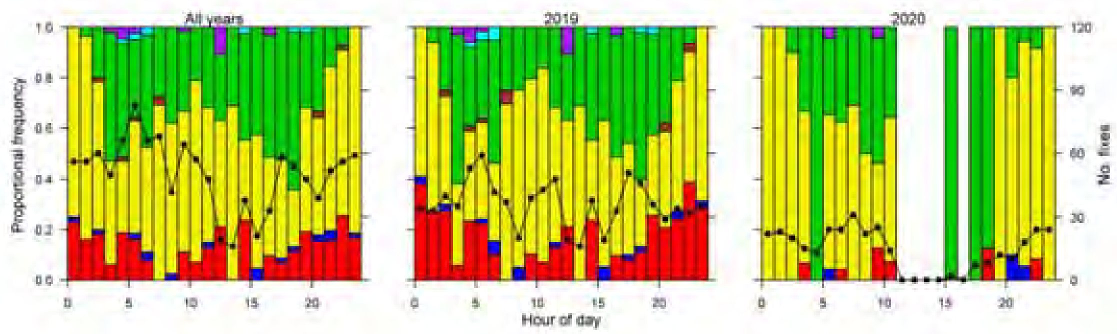
(a) GWF



(b) Greater Gabbard Wind Farm



(c) Offshore, outside wind farms

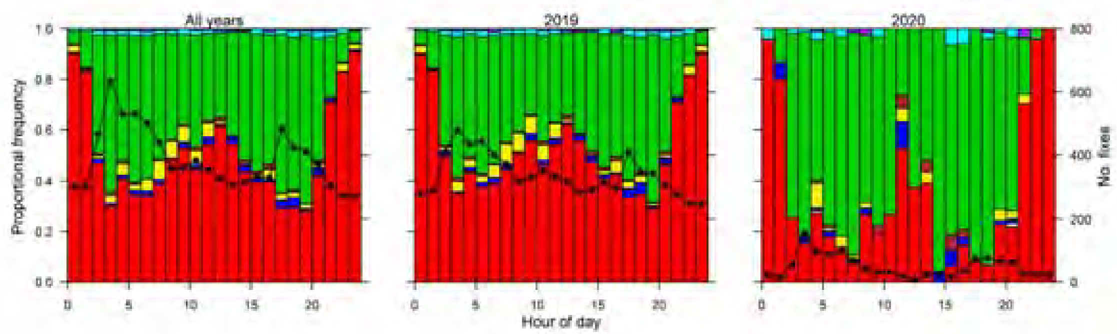


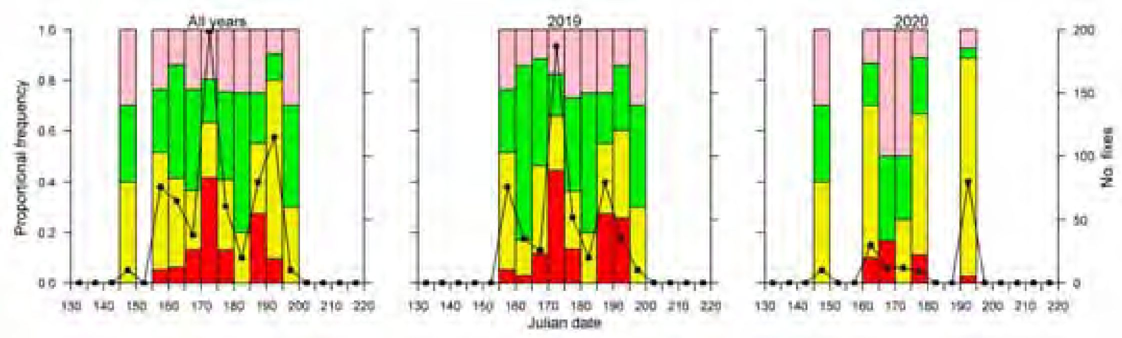
Figure A5.2 Classification of Lesser Black-backed Gull behaviours in (a) the GWF, (b) the Greater Gabbard Wind Farm and (c) other offshore areas outside wind farms plotted over time of day, using RF models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Red = float, yellow = stop, green = commute, pink = foraging/search. Black lines and points denotes the number of fixes per hour as a metric of use of the specified areas.

A5.2 Variation in Activity Across the Breeding Season

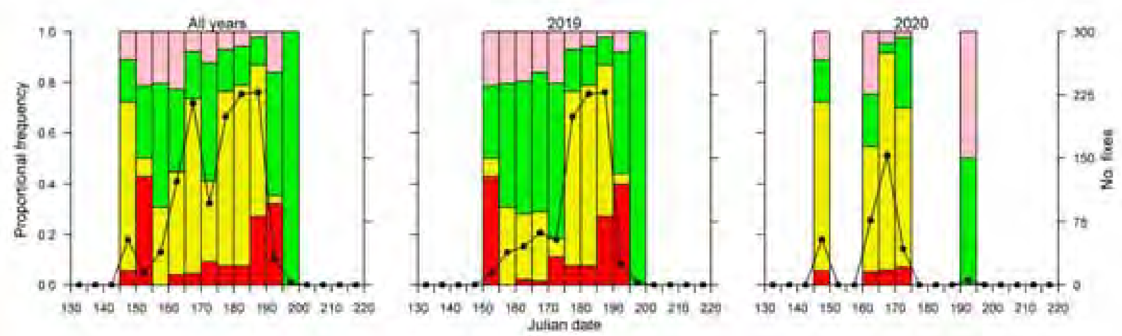
The variation in behaviours of Lesser Black-backed Gulls in the Galloper and Greater Gabbard Wind Farms across the breeding season was also evaluated, again using classifications from the EMbC and RF models (Figures A5.3 and A5.4).

OWFs were primarily used between 10th May and 19th July (Julian dates 130 to 200) However, very occasional use was recorded as early as 5th April. Use of the GWF peaked between ca. 19th and 24th June in 2019 and between ca. 9th and 14th July in 2020. Peak use of the Greater Gabbard Wind Farm was more pronounced (matching the greater total time spent within this wind farm) and occurred between ca. 14th June and 9th July in both years. The use of OWFs also coincided with general greater use of the offshore environment (Figs. A5.3 and A5.4). Of further interest was the correlation, particularly at Greater Gabbard, between greater use of OWFs and the increase in time spent stopped, indicative of greater time spent being driven by perching on platforms.

(a) GWF



(b) Greater Gabbard Wind Farm



(c) Offshore, outside wind farms

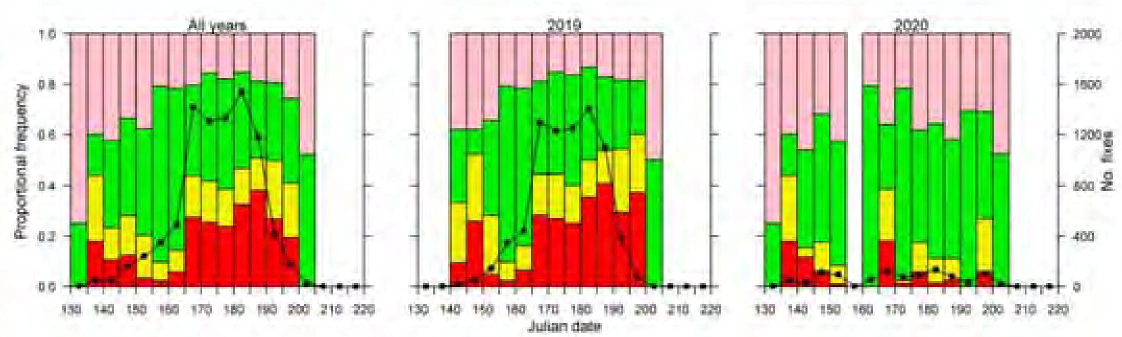
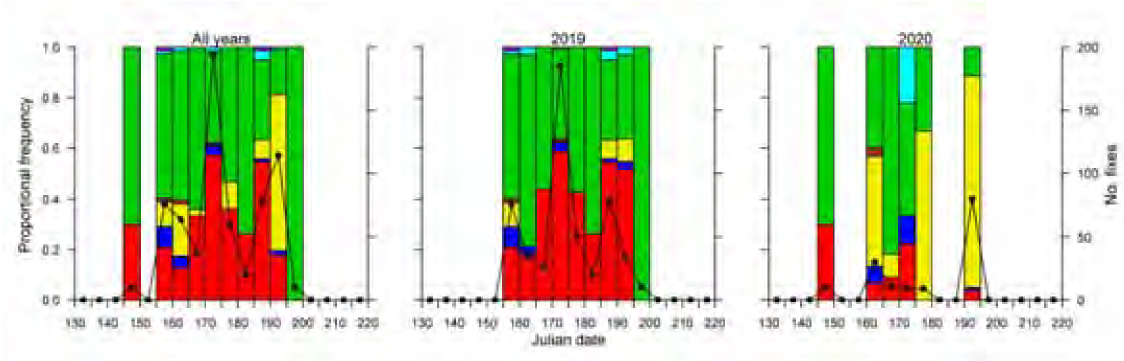
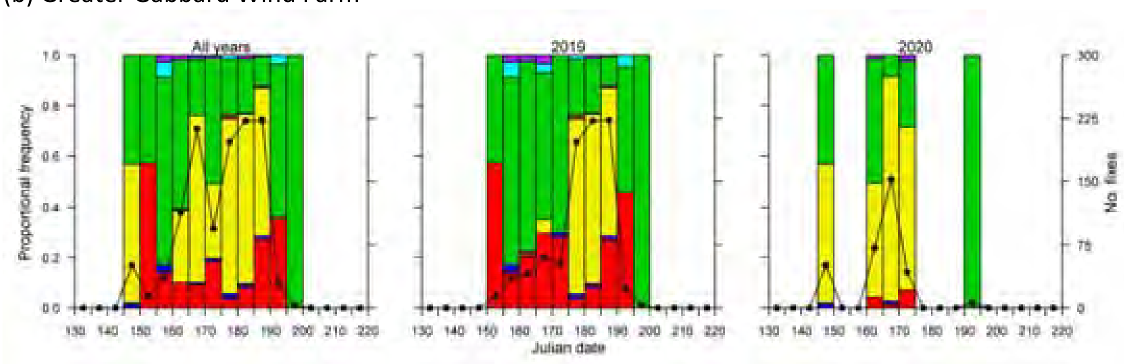


Figure A5.3 Classification of Lesser Black-backed Gull behaviours in (a) the GWF, (b) the Greater Gabbard Wind Farm and (c) other offshore areas outside wind farms plotted Julian date, using EMbC models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Red = float, yellow = stop, green = commute, pink = foraging/search. Black lines and points denotes the number of fixes per hour as a metric of use of the specified areas.

(a) GWF



(b) Greater Gabbard Wind Farm



(c) Offshore, outside wind farms

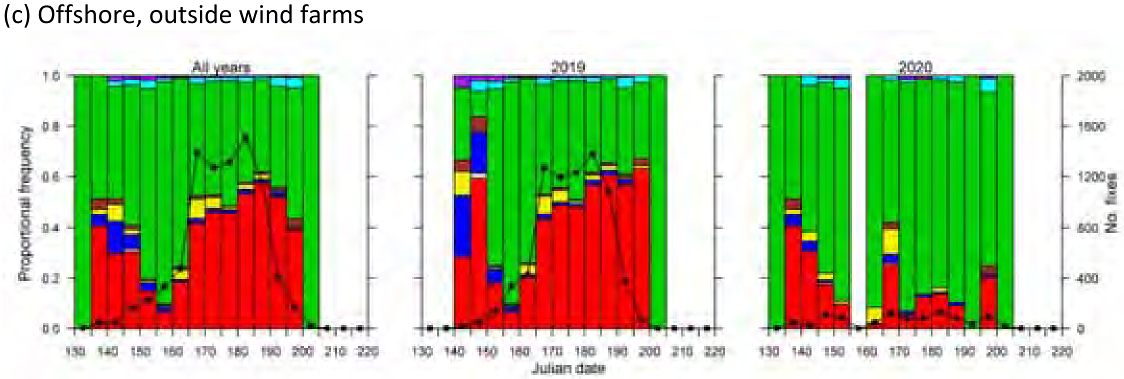


Figure A5.4 Classification of Lesser Black-backed Gull behaviours in (a) the GWF, (b) the Greater Gabbard Wind Farm and (c) other offshore areas outside wind farms plotted Julian date, using RF models, based on five minute resolution data from the 2019 and 2020 breeding seasons. Red = float, yellow = stop, green = commute, pink = foraging/search. Black lines and points denotes the number of fixes per hour as a metric of use of the specified areas.

Appendix 6 Altitudes in relation to a Mean Sea Level (MSL) baseline

A6.1 Altitudes in relation to as Mean Sea Level (MSL) baseline based on data collected at a five minute fix rate

Table A6.1 Mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	**SD**	**n**	**Mean**	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**	**%[1]**	**%[2]**	**n[1]**
Gabbard	22.48	98.26	504	18.37	31.04	497	32.54	32.54	164	31.19	30.78	155
Galloper	8.69	61.44	612	10.16	23.57	611	17.32	17.32	106	17.68	17.02	108
All OWFs	14.80	79.51	1144	13.79	27.28	1136	23.60	23.60	270	23.15	22.62	263
Outside OWFs	12.76	51.28	9956	14.13	32.91	9997						

Table A6.2 Day-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	**SD**	**n**	**Mean**	**SD**	**n**	**%[1]**	**%[2]**	**n[2]**	**%[1]**	**%[2]**	**n**
Gabbard	26.61	96.29	377	22.08	33.5	370	39.52	39.52	149	35.95	35.68	133
Galloper	8.28	27.57	497	10.7	24.69	496	18.11	18.11	90	18.55	16.13	92
All OWFs	16.00	66.18	902	15.44	29.04	894	26.50	26.50	239	25.17	23.71	225
Outside OWFs	15.78	57.6	7063	17.5	36.39	7031						

Table A6.3 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL)and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%¹	%²	n	%¹	%²	n
Gabbard	10.20	103.29	127	7.55	18.65	127	11.81	11.81	15	17.32	16.54	22
Galloper	10.45	130.09	115	7.85	17.84	115	13.91	13.91	16	13.91	12.17	16
All OWFs	10.32	116.54	242	7.69	18.23	242	12.81	12.81	31	15.70	14.46	38
Outside OWFs	5.39	29.55	2893	6.14	20.53	2966						

Table A6.4 Mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%¹	%²	n	%¹	%²	n
Gabbard	31.29	82.41	187	27.45	33.45	182	44.92	44.92	84	46.70	45.05	85
Galloper	22.24	61.44	158	19.78	30.62	157	32.28	32.28	51	35.03	34.39	55
All OWFs	26.85	72.37	358	23.66	31.93	352	37.71	37.71	135	39.77	38.64	140
Outside OWFs	21.66	61.63	2930	24.22	38.73	2915						

Table A6.5 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%¹	%²	n	%¹	%²	n
Gabbard	34.72	83.38	158	28.84	35.14	153	48.10	48.10	76	47.06	45.75	72
Galloper	17.92	23.57	139	19.64	31.17	138	31.65	31.65	44	34.78	34.78	48
All OWFs	26.53	62.21	310	24.18	33.06	304	38.71	38.71	120	39.47	38.82	120
Outside OWFs	23.43	66.62	2404	26.00	40.12	2386						

Table A6.6 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n	%[1]	%[2]	n
Gabbard	12.59	75.46	29	20.08	21.52	29	27.59	27.59	8	44.83	41.38	13
Galloper	53.84	165.74	19	20.79	27.07	19	36.84	36.84	7	36.84	31.58	7
All OWFs	28.92	119.70	48	20.36	23.59	48	31.25	31.25	15	41.67	37.50	20
Outside OWFs	13.60	28.19	526	16.20	30.47	529						

A6.2 Altitudes in relation to as Mean Sea Level (MSL) baseline, based on data collected at a 5-10 second fix rate

Table A6.7 Mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	8.36	57.39	9271	8.48	27.08	9183	26.16	26.16	2425	15.78	15.35	1449
Galloper	12.99	24.22	12892	8.54	24.08	12807	23.17	23.17	2987	13.98	13.98	1791
All OWFs	12.98	36.32	37895	8.48	24.24	37538	14.28	14.28	5412	8.63	8.52	3240
Outside OWFs	14.61	36.93	91430	8.71	22.68	90416						

Table A6.8 Day-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	7.94	58.22	8931	8.11	25.58	8844	25.99	25.99	2321	15.25	14.94	1349
Galloper	12.95	24.23	12661	8.33	24.03	12576	22.89	22.89	2898	13.53	13.53	1702
All OWFs	12.95	36.90	36306	8.45	24.09	35950	14.38	14.38	5219	8.49	8.41	3051
Outside OWFs	14.61	38.09	84270	8.71	22.97	83257						

Table A6.9 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n	%[1]	%[2]	n
Gabbard	19.47	25.57	340	18.25	52.11	339	30.59	30.59	104	29.50	26.25	100
Galloper	15.22	23.58	231	19.58	24.34	231	38.53	38.53	89	38.53	38.53	89
All OWFs	13.71	18.47	1589	9.19	27.40	1588	12.15	12.15	193	11.90	11.21	189
Outside OWFs	14.54	18.59	7160	8.69	18.87	7159						

Table A6.10 Mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	16.97	74.03	2548	15.42	32.82	2508	46.08	46.08	1174	28.91	27.91	725
Galloper	26.81	27.44	3112	17.88	33.87	3066	45.95	45.95	1430	28.73	28.86	881
All OWFs	23.13	44.41	10325	15.70	31.63	10136	25.22	25.22	2604	15.84	15.64	1606
Outside OWFs	24.54	43.75	26592	15.07	29.53	26088						

Table A6.11 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						% in rotor swept zone					
	GPS			Pressure sensor			GPS			Pressure Sensor		
	Mean	SD	n	Mean	SD	n	%[1]	%[2]	n[1]	%[1]	%[2]	n[1]
Gabbard	16.48	75.84	2410	15.16	33.35	2370	46.39	46.39	1118	28.35	27.55	672
Galloper	27.06	27.56	3012	17.72	34.12	2966	46.02	46.02	1386	28.22	28.35	837
All OWFs	23.42	45.44	9755	15.91	32.26	9566	25.67	25.67	2504	15.77	15.62	1509
Outside OWFs	25.33	45.70	23814	15.54	30.1	23311						

Table A6.12 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight, including standard deviation (SD) and sample size (n), for GPS and pressure sensor-derived altitudes recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) Mean Sea Level (MSL) and (2) actual sea surface (although when calculated in relation to GPS altitude mathematically equivalent percentages are produced).

	Altitude						**% in rotor swept zone**					
	GPS			**Pressure sensor**			**GPS**			**Pressure Sensor**		
	Mean	**SD**	**n**	**Mean**	**SD**	**n**	**%[1]**	**%[2]**	**n**	**%[1]**	**%[2]**	**n**
Gabbard	25.52	25.90	138	19.92	21.39	138	40.58	40.58	56	38.41	34.06	53
Galloper	19.25	22.67	100	22.82	24.99	100	44.00	44.00	44	44.00	44.00	44
All OWFs	18.16	19.11	570	12.14	17.87	570	17.54	17.54	100	17.02	15.96	97
Outside OWFs	17.72	19.07	2778	11.16	23.93	2777						

Appendix 7 Detailed Accounts of the Movements of Lesser Black-backed Gulls Tracked between 2010 and 2015

A7.1 GPS Data Collected for Individual Lesser Black-backed Gulls between 2010 and 2015

Table A7.1 Data collection periods over the 2010 and 2015 breeding seasons for Lesser Black-backed Gulls fitted with GPS tags at Orford Ness by the BTO using University of Amsterdam (UvA) tags.

(a) 2010

Nest location	Tag ID	Start/tag date	End date	Data duration (days)	Usable data (days)	GPS fixes
Sizewell B	334	15/06/2010 12:58	01/07/2010 06:12	15.7	15.7	733
Lantern	335	05/06/2010 15:51	07/07/2010 02:36	31.4	31.4	2606
Lantern	336	15/06/2010 12:35	06/07/2010 06:02	20.7	19.5	22067
Lantern	345	05/06/2010 23:07	10/07/2010 01:15	34.1	33.7	2693
Lantern	347	no data	-	-	-	-
Lantern	384	15/06/2010 14:04	21/06/2010 14:03	6.0	6.0	3234
Lantern	388	15/06/2010 13:02	08/07/2010 03:56	22.6	21.7	16385
Lantern	391	15/06/2010 15:03	05/07/2010 05:15	19.6	18.0	16522
Lantern	395	15/06/2010 14:04	18/07/2010 04:09	32.6	24.3	18580
Lantern	407	15/06/2010 15:06	08/07/2010 04:02	22.5	21.4	15957
Lantern	408	15/06/2010 14:35	14/07/2010 22:12	29.3	26.2	19309
Mean ± SD		**13/06/2010**	**07/07/2010**	**23.5 ± 8.7**	**21.8 ± 7.9**	**11809 ± 8378**

(b) 2011

Nest	Tag ID	Start/tag date	End date	Data duration	Usable data	GPS fixes
Sizewell B	334	11/04/2011 19:11	29/07/2011 18:50	109.0	108.6	6188
Lantern	336	27/03/2011 19:13	09/08/2011 02:52	134.3	22.6	1131
Lantern	391	03/04/2011 17:53	28/07/2011 20:20	116.1	114.8	10134
Lantern	395	29/03/2011 07:12	16/07/2011 06:28	109.0	109.0	10332
Lantern	407	20/03/2011 10:56	28/07/2011 05:24	129.8	129.8	14228
Lantern	457	21/05/2011 18:03	20/07/2011 09:36	59.6	59.6	8330
Lantern	459	21/05/2011 19:00	24/07/2011 05:21	63.4	63.4	16769
Lantern	460	21/05/2011 19:22	10/08/2011 06:18	80.5	80.5	11431
Lantern	478	21/05/2011 14:59	02/08/2011 06:06	72.6	71.3	14641
Lantern	479	21/05/2011 15:34	24/07/2011 12:37	63.9	63.9	10450
Lantern	480	21/05/2011 17:11	12/08/2011 04:46	82.5	82.5	15713
Lantern	481	21/05/2011 19:41	11/07/2011 01:28	50.2	50.2	11710
Lantern	482	21/05/2011 18:31	30/07/2011 04:20	69.4	69.4	8758
Lantern	483	21/05/2011 18:37	01/08/2011 11:12	71.7	71.7	14669
Lantern	484	21/05/2011 14:49	28/07/2011 17:08	68.1	68.1	14627
Lantern	485	21/05/2011 16:36	21/07/2011 08:35	60.7	60.7	13934
Lantern	486	21/05/2011 19:13	11/08/2011 16:00	81.9	81.9	18252
Lantern	492	21/05/2011 16:43	30/06/2011 05:33	39.5	39.5	8061
Lantern	493	21/05/2011 15:34	03/08/2011 04:42	73.5	73.5	16928
Mean ± SD		**08/05/2011**	**27/07/2011**	**80.8 ± 26.5**	**74.8 ± 26.3**	**11910 ± 4281**

(c) 2012

Nest	Tag ID	Start/tag date	End date	Data duration	Usable data	GPS fixes
Lantern	336	29/04/2012 14:34	19/08/2012 20:55	112.3	5.9	278
Lantern	395	23/03/2012 07:33	17/06/2012 15:33	86.3	69.8	3477
Lantern	407	13/03/2012 14:00	15/08/2012 19:13	155.2	155.2	9384
Lantern	459	21/03/2012 14:37	21/06/2012 17:07	92.1	92.1	7666
Lantern	460	16/03/2012 05:40	15/07/2012 02:36	120.9	120.9	5913
Lantern	479	26/03/2012 09:22	29/06/2012 04:46	94.8	94.8	8896
Lantern	480	08/04/2012 04:42	07/06/2012 10:53	60.3	60.3	5986
Lantern	482	17/02/2012 07:15	02/07/2012 05:41	135.9	132.7	10762
Lantern	483	19/03/2012 15:14	26/06/2012 03:37	98.5	98.5	7084
Lantern	484	16/03/2012 07:22	15/06/2012 17:03	91.4	91.4	7415
Lantern	485	27/03/2012 18:03	23/06/2012 04:34	87.4	54.6	2727
Lantern	486	24/03/2012 18:36	26/06/2012 13:37	93.8	88.0	4531
Lantern	492	16/03/2012 16:30	23/06/2012 14:43	98.9	98.9	6242
Lantern	493	19/02/2012 11:10	25/06/2012 16:00	127.2	120.6	6055
Mean ± SD		**20/03/2012**	**02/07/2012**	**103.9 ± 24.1**	**91.7 ± 36.9**	**6173 ± 775**

(d) 2013

Nest	Tag ID	Start/tag date	End date	Data duration	Usable data	GPS fixes
Lantern	395	30/03/2013 09:41	26/06/2013 06:35	87.9	86.8	6051
Lantern	460	25/03/2013 19:02	24/05/2013 15:16	59.8	59.8	4010
Lantern	479	26/03/2013 18:44	18/06/2013 03:04	83.3	83.3	3819
Lantern	482	17/02/2013 16:23	18/06/2013 03:34	120.5	108.6	4547
Lantern	483	10/03/2013 17:04	26/05/2013 09:26	76.7	76.7	4910
Lantern	484	27/03/2013 15:10	08/06/2013 13:55	72.9	72.9	5135
Lantern	485	04/04/2013 17:41	05/06/2013 20:48	62.1	9.9	454
Lantern	486	25/03/2013 15:13	21/06/2013 17:59	88.1	88.1	6523
Lantern	492	14/03/2013 09:19	14/06/2013 14:22	92.2	10.1	465
Lantern	493	06/03/2013 06:32	17/06/2013 01:29	102.8	98.2	6406
Mean ± SD		**19/03/2013**	**11/06/2013**	**84.6 ± 18.3**	**69.5 ± 34.0**	**4232 ± 95**

(e) 2014

Nest	Tag ID	Start/tag date	End date	Data duration	Usable data	GPS fixes
Havergate	460	13/03/2014 17:53	09/09/2014 18:55	180.0	62.8	2852
Havergate	479	27/03/2014 05:48	10/05/2014 14:30	44.4	44.4	2023
Havergate	486	11/03/2014 07:13	31/07/2014 11:46	142.2	142.2	6639
Mean ± SD		**17/03/2014**	**17/07/2014**	**122.2 ± 70.0**	**83.1 ± 52.0**	**3838 ± 461**

(f) 2015

Nest	Tag ID	Start/tag date	End date	Data duration	Usable data	GPS fixes
Havergate	460	17/03/2015 17:32	12/07/2015 19:10	117.1	117.1	5471
Havergate	478	17/03/2015 17:48	26/07/2015 00:35	130.3	124.6	12694
Mean ± SD		**17/03/2015**	**19/07/2015**	**123.7 ± 9.3**	**120.9 ± 5.4**	**9083 ± 5107**

Table A7.2 Data collection periods over the 2010 and 2011 breeding seasons for Lesser Black-backed Gulls fitted with 'igotU' GPS tags by the RSPB on Havergate Island and Orford Ness.

(a) 2010

Colony	Tag ID	Start/tagging date	End date	Data duration (days)	Usable data (days)	GPS fixes (n)
Orford Ness	ORF001	03/06/2010 13:11	07/06/2010 17:59	4.200127	4.200127	3514
	ORF010	15/06/2010 15:53	23/06/2010 07:16	7.640891	7.263206	6126
Colony Average		**09/06/2010**	**15/06/2010**	**5.9 ± 2.4**	**5.7 ± 2.2**	**4820 ± 1847**
Havergate	HAV007	04/06/2010 13:50	09/06/2010 12:00	4.923681	4.923681	4163
Colony Average		**04/06/2010**	**09/06/2010**	**4.923681**	**4.923681**	**4163**
Year Average		**07/06/2010**	**13/06/2010**	**5.6 ± 1.8**	**5.5 ± 1.6**	**4601 ± 1360**

(b) 2011

Colony	Tag ID	Start/tagging date	End date	Data duration (days)	Usable data (days)	GPS fixes (n)
Orford Ness	ORF0038	05/06/2011 19:43	12/06/2011 16:49	6.878935	6.878935	5846
	ORF0048	08/06/2011 11:57	15/06/2011 13:24	7.060509	7.060509	5952
	ORF0058	08/06/2011 12:11	15/06/2011 14:22	7.091192	7.091192	5967
	ORF017	22/05/2011 18:06	26/05/2011 13:02	3.788299	3.788299	3173
	ORF020	24/05/2011 18:06	31/05/2011 19:28	7.056667	7.056667	5898
	ORF022	26/05/2011 15:44	02/06/2011 23:54	7.340127	7.340127	6220
	ORF024	01/06/2011 18:39	08/06/2011 13:00	6.764734	6.764734	5654
	ORF026	02/06/2011 16:13	10/06/2011 13:50	7.900266	7.900266	6628
	ORF027	02/06/2011 16:31	08/06/2011 13:20	5.867384	5.867384	4921
	ORF028	04/06/2011 16:29	12/06/2011 14:31	7.917986	7.917986	6651
Colony Average		**01/06/2011**	**08/06/2011**	**6.8 ± 1.2**	**6.8 ± 1.2**	**5691 ± 1012**
Havergate	HAV0030	03/06/2011 15:09	09/06/2011 11:45	5.858819	5.858819	4940
	HAV0040	07/06/2011 16:23	10/06/2011 18:05	3.070961	3.070961	2574
	HAV0094	10/06/2011 14:10	18/06/2011 08:28	7.76228	7.76228	6553
Colony Average		**07/06/2011**	**12/06/2011**	**2.3 ± 2.4**	**2.3 ± 2.4**	**1977 ± 2001**
Year Average		**02/06/2011**	**09/06/2011**	**6.5 ± 1.5**	**6.5 ± 1.5**	**5460 ± 1276**
Total averages						
Orford Ness		**02/06**	**09/06**	**6.6 ± 1.3**	**6.6 ± 1.3**	**5545 ± 1124**
Havergate		**06/06**	**12/06**	**5.4 ± 2.0**	**5.4 ± 2.0**	**4558 ± 1665**

A7.2 Individual trip Statistics of Individual Lesser Black-backed Gulls between 2010 and 2015

Table A7.3 Foraging statistics for Lesser Black-backed Gulls tracked from Orford Ness Island during the 2010-2015 breeding seasons; totals are calculated across all trips and all birds. For 2010 and 2011, bird 334 nested at Sizewell B so trips are calculated from this as a the central place (†); further in 2014 and 2015 (post winter 2013 coastal inundation) birds were based at Havergate not Orford Ness, so trips were assessed from there; bird 336 in 2011 and 478 in 2015 were excluded from total calculation across birds in 2011 due to likely non-breeding and scant data (*).

(a) BEIS (DECC) OESEA data

Colony/Year	Tag ID	N trips	N offshore trips	Trip duration (hrs)	Foraging range (km)	Total distance per trip	Offshore foraging range	Onshore foraging range
Orford Ness								
2010	334†	19 [0]	10 [0]	9.0±9.6 (33.0)	24.9±23.1 (81.5)	77.9±84.7 (311.9)	40.3±20.9 (81.5)	9.6±9.5 (29.9)
	335	50 [0]	9 [0]	12.1±26.8 (149.4)	10.0±9.0 (41.5)	39.9±79.2 (450.4)	8.4±13.3 (32.8)	9.7±9.1 (41.5)
	336	43 [6]	19 [3]	7.8±8.7 (41.1)	18.2±18.7 (66.3)	58.8±67.3 (227.2)	29.5±20.1 (66.3)	6.8±5.1 (25.5)
	345	58 [2]	10 [0]	9.5±18.1 (113.6)	17.4±26.2 (107.4)	55.9±100.4 (519.6)	21.7±24.2 (60.1)	15±25.1 (107.4)
	384	8 [0]	1 [0]	7.8±8.3 (23.3)	10.5±11.5 (35.6)	26.8±32.2 (102.2)	0.4	10.5±11.5 (35.6)
	388	35 [3]	1 [1]	7.2±8.2 (42.5)	7.0±6.1 (22.7)	20.8±22.5 (96.2)	6.4	7.0±6.1 (22.7)
	391	61 [8]	10 [0]	2.9±2.8 (14.1)	9.9±9.3 (39.3)	24.3±26.2 (111.4)	21.4±10.8 (39.3)	6.1±6.4 (34.9)
	395	53 [11]	7 [6]	4.2±3.3 (13.5)	7.5±8.7 (32.2)	17.6±22.0 (85.6)	25.4±7.3 (32.2)	3.7±1.9 (6.6)
	407	16 [2]	10 [1]	19.8±24.7 (78.4)	43.5±52.9 (158.8)	185.4±281.5 (801.7)	53.9±59.7 (158.8)	19.7±20.8 (67.6)
	408	50 [5]	25 [5]	8.5±13.3 (75.0)	18.1±22.0 (99.8)	55.4±77.4 (325.2)	25.9±26.2 (99.8)	6.6±8.8 (31.6)
All birds		**393 [37]**	**102 [16]**	**8.1±15.2 (149.4)**	**14.6±20.8 (158.8)**	**47.1±90.7 (801.7)**	**27.9±28.4 (158.8)**	**8.8±13.1 (107.4)**
2011	334†	195 [1]	50 [0]	6.9±7.2 (41.8)	21.5±25.6 (109.5)	54.7±67.2 (273.3)	28.2±21.8 (74.7)	16.5±23.8 (109.5)
	336*	5 [1]	2 [0]	42.5±40.3 (97.9)	13.0±9.3 (23.0)	104±120.5 (274.4)	5.7±7.5 (11.0)	13.0±9.3 (23)
	391	372 [0]	8 [0]	2.6±2.4 (11.7)	6.8±6.0 (43.3)	14.5±13.6 (96.8)	10.1±12.7 (36.2)	6.6±5.7 (43.3)
	395	258 [0]	7 [0]	4.2±4.9 (47.3)	5.9±6.9 (46.0)	13.6±18.0 (109.2)	21.5±12.6 (36.3)	5.4±6.2 (46.0)
	407	217 [0]	94 [0]	8.8±12.4 (144.5)	13.3±15.9 (119.1)	37.8±57.6 (564.5)	14.3±17.8 (93.1)	10.7±13.1 (119.1)
	457	222 [0]	39 [0]	2.7±2.4 (14.9)	15.0±16.3 (98.4)	36.1±43.4 (218.1)	37.3±16.9 (71.2)	9.6±11.3 (98.4)
	459	173 [0]	44 [0]	4.9±4.9 (33.8)	23.6±26.6 (109.3)	58.0±68.0 (301.3)	21.2±19.1 (90.9)	20.7±26.3 (109.3)
	460	170 [0]	31 [0]	5.6±6.3 (51.7)	9.4±8.6 (39.7)	23.4±26.1 (133.4)	18.4±10.4 (39.7)	8.1±6.7 (21.6)
	478	128 [5]	32 [1]	6.7±8.1 (71.0)	15.8±17.3 (99.8)	46.5±66.3 (360.6)	24.0±20.0 (72.6)	13.1±14.8 (99.8)
	479	229 [0]	31 [0]	2.6±2.6 (13.2)	11.2±13.7 (80.2)	27.5±38.8 (266.2)	35.1±22.4 (80.2)	7.5±6.2 (57.5)
	480	213 [0]	14 [0]	5.2±6.2 (40.0)	17.1±20.6 (118.2)	40.0±48.0 (281.9)	18.8±20.6 (58.8)	16.9±20.6 (118.2)
	481	165 [0]	15 [0]	2.8±2.1 (13.4)	10.6±8.0 (49.8)	26.1±23.6 (125.2)	17.8±15.4 (49.8)	9.6±6.7 (32.6)
	482	195 [0]	58 [0]	3.2±3.4 (18.2)	14.7±18.3 (80.0)	38.6±56.5 (365.3)	33.6±23.5 (80.0)	6.1±5.8 (30.3)
	483	184 [0]	17 [0]	3.3±3.2 (18.8)	24.6±29.0 (99.7)	52.1±61.4 (220.3)	9.2±6.2 (22.0)	23.8±29.5 (99.7)
	484	228 [0]	1 [0]	3.5±3.5 (28.4)	10.6±13.3 (98.5)	24.7±32.4 (221.2)	5.4	10.6±13.3 (98.5)
	485	118 [0]	15 [0]	5.8±12.3 (116.6)	17.1±16.7 (98.9)	44.2±57.6 (445.9)	18.8±13.9 (46.7)	16.1±16.6 (98.9)
	486	196 [0]	55 [0]	6.4±6.0 (32.3)	26.8±19.0 (118.8)	73.7±62.0 (328.2)	42.8±17.2 (90.2)	15.9±15.8 (118.8)
	492	76 [0]	20 [0]	5.2±5.0 (28.9)	9.1±8.9 (51.4)	23.5±25.2 (128.8)	10.4±12.1 (51.4)	8.1±7.3 (34.5)
	493	239 [0]	94 [0]	4.4±4.1 (24.3)	22.3±23 (124)	57.1±69.6 (406.9)	37.9±24.0 (124)	9.5±13.9 (82.8)

Colony/Year	Tag ID	N trips	N offshore trips	Trip duration (hrs)	Foraging range (km)	Total distance per trip	Offshore foraging range	Onshore foraging range
All birds*		**3578 [6]**	**625 [1]**	**4.5±6.1 (144.5)**	**14.9±18.5 (124)**	**37.1±51.4 (564.5)**	**27±21.8 (124)**	**11.4±15.7 (119.1)**
2012	336	3 [1]	1 [1]	2.3±1.1 (3.1)	2.2±0 (2.2)	4.7±0.5 (5.0)	0.4	2.2±0 (2.2)
	395	191 [4]	2 [0]	3.8±4.1 (31.7)	3.6±2.5 (14.9)	7.6±7.2 (40.0)	2.6±1.5 (3.6)	3.6±2.5 (14.9)
	407	219 [0]	61 [0]	12.3±24.2 (205.6)	13.1±20.1 (158.6)	41.1±80.9 (675.9)	14.9±24.9 (158.6)	10.5±16.5 (143.4)
	459	193 [0]	24 [0]	5.6±5.6 (35.7)	9.8±10.7 (100.7)	23.7±29.3 (272.3)	11.8±20.6 (100.7)	9.2±8.5 (41.3)
	460	313 [0]	78 [0]	4.5±9.5 (123.7)	7.0±6.7 (47.8)	16.6±20.8 (214.4)	9.0±10.9 (47.8)	5.5±4.6 (21.7)
	479	310 [0]	18 [0]	3.7±3.7 (31.6)	10.0±8.3 (63.2)	23.6±21.9 (148.6)	10.2±11.1 (35.8)	9.7±8.0 (63.2)
	480	137 [0]	19 [0]	6.9±7.4 (52.8)	7.3±14.6 (125.8)	16.8±33.1 (280.9)	5.9±6.2 (16.1)	6.9±14.6 (125.8)
	482	285 [1]	61 [1]	8.5±9.9 (90.5)	8.9±9.4 (56.5)	24.8±31.5 (257.3)	14.1±11.7 (56.5)	7.7±8 (27.3)
	483	252 [0]	35 [0]	3.8±3.6 (19.7)	12.9±18.9 (99.6)	27.5±39.9 (217.7)	6.6±5.1 (23.9)	12.4±19 (99.6)
	484	225 [0]	45 [0]	5.9±5.5 (35.0)	6.0±6.6 (43.8)	14.1±18.0 (119.1)	7.9±7.5 (39.1)	5.2±6.4 (43.8)
	485	89 [6]	32 [2]	9.8±17.3 (122.2)	14.9±16.6 (98.2)	42.0±66.8 (415.6)	8.2±12.6 (49.2)	14.3±17.0 (98.2)
	486	257 [1]	33 [0]	3.4±3.3 (18.3)	8.9±10.1 (67.0)	19.8±22.9 (165.8)	17.8±19.1 (67)	6.9±6.9 (45.8)
	492	213 [0]	39 [0]	4.5±6.9 (74.4)	8.4±17.3 (179.9)	19.2±39.8 (405.0)	7.0±8.3 (47.9)	7.9±17.1 (179.9)
	493	369 [2]	69 [0]	4.8±13 (143.1)	10.1±16.0 (121.2)	25.2±51.4 (510.2)	17.3±16.9 (71)	7.7±14.4 (121.2)
All birds		**3056 [15]**	**517 [4]**	**5.6±10.5 (205.6)**	**9.2±13.2 (179.9)**	**22.6±39.7 (675.9)**	**11.5±15.1 (158.6)**	**8±12.1 (179.9)**
2013	395	291 [1]	4 [0]	3.8±3.4 (15.7)	6.7±4.5 (35.3)	14.8±10.9 (74.3)	13.3±9 (20.3)	6.5±4.4 (35.3)
	460	187 [0]	31 [0]	4.2±3.7 (16.3)	6.9±5.1 (22.8)	15.5±12.5 (60.0)	5.7±6.3 (22.8)	6.7±5.0 (22.0)
	479	238 [0]	4 [0]	5.6±6.6 (51.8)	9.9±7.9 (73.9)	23.4±24.5 (254.4)	9.9±8.1 (20.3)	9.9±7.9 (73.9)
	482	139 [4]	30 [4]	16.3±14.2 (65.7)	13.7±9.5 (34.2)	43.9±38.1 (190.7)	15.1±9.4 (34.2)	13.4±9.3 (30.6)
	483	172 [0]	10 [0]	7.5±9.7 (61.6)	20.9±27.9 (118.5)	46.8±69.0 (464.7)	5.5±6.8 (19.3)	20.8±27.9 (118.5)
	484	134 [0]	11 [0]	6.1±6.5 (52.8)	8.1±12.8 (98.6)	19.1±33.4 (224.5)	9.5±11.6 (32.5)	7.9±12.7 (98.6)
	485	21 [4]	0 [0]	4.1±2.9 (8.7)	4.9±3.4 (11.5)	9.7±7.8 (25.4)	-	4.9±3.4 (11.5)
	486	215 [0]	16 [0]	5.2±5.7 (43.8)	11.8±14.8 (111.7)	28.2±34.1 (234.7)	10.5±10.6 (38.1)	11.5±14.7 (111.7)
	492	20 [14]	5 [2]	7.2±4.3 (10.2)	8.8±6.4 (18.7)	23.3±18.6 (48.4)	8.0±7.5 (18.7)	3.6±4.0 (11.1)
	493	233 [2]	18 [1]	6.3±16.4 (143.6)	10.2±15.2 (108)	33.8±99.3 (899.8)	10.3±10.6 (42.1)	10.0±15.2 (108)
All birds		**1650 [25]**	**129 [7]**	**6.3±9.6 (143.6)**	**10.6±14.1 (118.5)**	**26.7±50.1 (899.8)**	**9.9±9.4 (42.1)**	**10.4±14.0 (118.5)**
Havergate								
2014	460	107 [0]	24 [0]	9.2±15.5 (106.6)	13.3±15.1 (108.5)	37.5±56.9 (352.0)	12.1±8.4 (39.5)	13.1±15.2 (108.5)
	479	72 [0]	12 [0]	12.7±33.2 (211.3)	9.7±8.2 (59.8)	41.0±88.6 (517.1)	8.9±2.3 (13.7)	9.7±8.2 (59.8)
	486	242 [0]	9 [0]	4.6±12.2 (133.7)	10.4±10.7 (104.6)	25.1±45.0 (496.1)	14.0±15.0 (46.4)	10.2±10.4 (104.6)
All birds*		**421 [0]**	**45 [0]**	**7.2±18.5 (211.3)**	**11±11.7 (108.5)**	**31±57.9 (517.1)**	**11.6±9.1 (46.4)**	**10.8±11.5 (108.5)**
2015	460	254 [0]	10 [0]	2.4±2.6 (33.7)	7.0±4.7 (44.9)	14.8±10.4 (97.7)	15.7±13.2 (44.9)	6.5±3.6 (25.9)
	478*	17 [11]	3 [8]	446.5±784.6 (2034.6)	43.8±36.3 (99.0)	1301.6±1847 (4878.4)	41.1±23.0 (60.6)	43.8±36.3 (99.0)
All birds*		254 [0]	10 [0]	2.4±2.6 (33.7)	7.0±4.7 (44.9)	14.8±10.4 (97.7)	15.7±13.2 (44.9)	6.5±3.6 (25.9)

(b) RSPB data

Colony/Year	Tag ID	N trips [incomplete]	N offshore trips [incomplete]	Trip duration (hrs) mean+SD (max)	Foraging range (km) mean+SD (max)	Total distance per trip (km) mean+SD (max)	Offshore foraging range (km) mean+SD (max)	Onshore foraging range (km) mean+SD (max)
Orford Ness								
2010	ORF001	6 [0]	3 [0]	7.45±14.98 (37.94)	18.36±23.99 (59.75)	78.34±137.55 (352.17)	31.79±29.36 (59.75)	5.28±6.30 (14.79)
	ORF010	18 [1]	4 [1]	1.62±1.16 (4.82)	8.28±9.05 (29.90)	20.03±25.18 (81.01)	18.53±11.33 (29.90)	5.24±5.75 (21.9)
All birds		**24 [1]**	**7 [1]**	**3.14±7.67 (37.94)**	**10.91±14.52 (59.75)**	**35.24±73.8 (352.17)**	**24.21±20.04 (59.75)**	**5.25±5.75 (21.9)**
2011	ORF0038	12 [0]	9 [0]	4.70±2.73 (9.56)	41.54±18.01 (74.46)	111.36±58.8 (197.18)	46.73±18.00 (74.46)	11.89±12.61 (28.23)
	ORF0048	17 [0]	3 [0]	3.06±2.64 (9.37)	7.65±5.48 (20.95)	19.66±16.58 (60.38)	9.95±9.84 (20.95)	6.94±5.15 (15.98)
	ORF0058	15 [0]	6 [0]	4.12±3.72 (11.55)	11.69±12.39 (37.17)	35.89±46.53 (144.27)	17.83±16.43 (37.17)	7.58±6.25 (25.80)
	ORF017	5 [0]	0 [0]	1.02±1.03 (2.81)	2.28±0.81 (3.69)	4.69±4.56 (12.70)	-	2.28±0.81 (3.69)
	ORF020	14 [0]	1 [0]	2.83±1.85 (6.16)	3.75±1.60 (6.18)	9.80±6.05 (21.33)	0.82	3.97±1.41 (6.18)
	ORF022	27 [0]	11 [0]	2.13±1.93 (5.80)	3.54±2.43 (9.37)	7.66±6.84 (24.11)	4.59±3.15 (9.37)	2.42±1.55 (6.10)
	ORF024	14 [0]	0 [0]	2.29±2.08 (8.33)	5.71±2.36 (9.72)	13.76±8.34 (33.43)	-	5.71±2.36 (9.72)
	ORF026	17 [0]	1 [0]	1.09±0.69 (2.56)	6.15±4.49 (20.85)	13.81±11.54 (49.15)	20.85	4.96±2.66 (9.60)
	ORF027	18 [0]	0 [0]	3.10±2.55 (9.84)	4.66±3.39 (13.80)	13.02±14.52 (54.97)	-	4.66±3.39 (13.80)
	ORF028	13 [0]	1 [0]	2.23±0.94 (3.50)	12.65±3.56 (14.50)	33.68±12.12 (52.63)	0.93	12.60±3.75 (14.50)
All birds		**152 [0]**	**32 [0]**	**2.69±2.41 (11.55)**	**9.19±12.12 (74.46)**	**24.18±35.98 (197.18)**	**19.7±21.51 (74.46)**	**6.15±5.68 (28.23)**
Havergate								
2010	HAV007	8 [0]	0 [0]	1.83±1.20 (3.90)	11.56±3.45 (16.92)	14.71±9.11 (25.80)	-	11.56±3.45 (16.92)
All birds		**8 [0]**	**0 [0]**	**1.83±1.20 (3.90)**	**11.56±3.45 (16.92)**	**14.71±9.11 (25.80)**	**--**	**11.56±3.45 (16.92)**
2011	HAV0030	20 [0]	1 [0]	1.52±1.70 (5.36)	9.67±2.42 (16.30)	10.20±9.62 (29.93)	9.27	9.60±2.45 (16.30)
	HAV0040	14 [0]	0 [0]	1.09±1.16 (2.99)	10.50±4.64 (24.07)	11.91±16.46 (49.02)		10.50±4.64 (24.07)
	HAV0094	26 [0]	0 [0]	1.46±1.56 (6.30)	10.69±4.16 (23.71)	13.86±13.12 (48.74)		10.69±4.16 (23.71)
All birds		**60 [0]**	**1 [0]**	**1.39±1.51 (6.30)**	**10.30±3.76 (24.07)**	**12.19±12.85 (49.02)**	**9.27**	**10.28±3.77 (24.07)**

A7.3 Connectivity of Individual Lesser Black-Backed Gulls breeding at the Alde-Ore Estuary SPA between 2010 and 2015

This section provides further details of the interactions between individuals tracked under the BEIS (DECC) OESEA and RSPB research programmes at Orford Ness and Havergate and OWFs.

Table A7.4 Connectivity (*) between individual Lesser Black-backed Gulls tracked from (a) Orford Ness and (b) Havergate Island in the Alde-Ore Estuary SPA during the 2010-2015 breeding seasons and offshore wind farms, based on data from studies undertaken for the BEIS (DECC) OESEA programme (Thaxter et al. 2014b) and by the RSPB. Connectivity is here defined as there being a GPS point (p) within the wind farm polygon, or where the straight line (l) route between two points passes over the wind farm polygon. Wind farms are denoted as (1) operational; (2) partial generation/under construction; (3) under construction Wind farms in the pre-planning or planning stages are excluded from this table (i.e. East Anglia Round 3 Zone), however we present (4) GWF for a perspective of pre-construction interactions (*). Totals(5) include all operational sites, those under construction and GWF.

(a) Orford Ness

Study/Year	Tag ID	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
BEIS OESEA									
2010	334	lp	l			lp			**2 (1)**
	335								**0**
	336	lp	lp			lp			**3**
	345	lp	l			lp			**2 (1)**
	384								**0**
	388								**0**
	391								**0**
	395	lp	lp						**2**
	407			lp					**1**
	408	lp	lp			lp			**3**
	All	**5**	**5 (3)**	**1**	**0**	**4**	**0**	**0**	**6**
2011	334	lp	lp			lp			**3**
	336								**0**
	391								**0**
	395								**0**
	407	lp							**1**

Study/Year	Tag ID	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
	457	lp	lp			lp			**3**
	459	lp				lp			**2**
	460								**0**
	478	lp							**1**
	479	lp	lp						**2**
	480								**0**
	481								**0**
	482	lp	lp			lp			**3**
	483								**0**
	484								**0**
	485		lp						**1**
	486	lp	lp			lp			**3**
	492								**0**
	493	lp	lp			lp			**3**
	All	**9**	**7**	**0**	**0**	**6**	**0**	**0**	**10**
2012	336								**0**
	395								**0**
	407	lp	lp	lp					**3**
	459	lp							**1**
	460	l	lp						**2 (1)**
	479								**0**
	480								**0**
	482		lp						**1**
	483								**0**
	484								**0**
	485								**0**
	486	lp	lp						**2**
	492								**0**
	493								**0**
	All	**4 (1)**	**4**	**1**	**0**	**0**	**0**	**0**	**5**
2013	395								**0**

Study/Year	Tag ID	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
	460								**0**
	479								**0**
	482		lp						**1**
	483								**0**
	484								**0**
	485								**0**
	486								**0**
	492								**0**
	493								**0**
	All	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**
RSPB									
2010	ORF001	lp							**1**
	ORF010	lp	lp						**2**
	All	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**2**
2011	ORF0038	lp	lp						**2**
	ORF0048								**0**
	ORF0058	lp	lp						**2**
	ORF017								**0**
	ORF020								**0**
	ORF022								**0**
	ORF024								**0**
	ORF026								**0**
	ORF027								**0**
	ORF028								**0**
	All	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**

(b) Havergate

Year	Tag ID	Galloper[4]	Greater Gabbard[1]	Scroby Sands[1]	Gunfleet Sands[1]	East Anglia One[2]	Seamade (Mermaid)[3]	Borssele 3 & 4[3]	Total[5]
BEIS OESEA									
2014	460								
	479								
	486								
	All	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2015	460	lp	l						**2 (1)**
	478								**0**
	All	**1**	**(1)**	**0**	**0**	**0**	**0**	**0**	**1**
RSPB									
2010	HAV007								
	All	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2011	HAV0030								
	HAV0040								
	HAV0094								
	All	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

A7.4 Area Use of Individual Lesser Black-Backed Gulls Breeding at the Alde-Ore Estuary SPA

Table A7.5 Summary of utilisation distribution (UD) analyses for individual Lesser Black-backed Gulls tracked from (a) Orford Ness and (b) Havergate Island during the 2010-2015 breeding seasons, based on all observations during trips, including all bird kernel sizes and percentage overlap of the 100% UD (full area use), 95% UD (considered typical of total area use) and 50% UD (representing core area use) with: (1) operational, (2) partial generation/under construction, and (3) under construction wind farms during the period studies. All wind farms in the pre-planning or planning stages are excluded from this table (i.e. East Anglia Round 3 Zone), however we present (4) GWF for a perspective of pre-construction interactions. Totals include (5) all operational, under construction and the GWF pre-construction wind farm areas.

(a) Orford Ness

					Overlaps with each UD (%)															
		UD area (km^2)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**Tag ID**	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
BEIS OESEA																			
2010	334	148	1096	1820		0.28	0.39							5.41	4.06	4.92	5.41	4.34	5.31
	335	12	184	860															
	336	32	1124	2404		4.03	2.99		1.85	2.34					1.17	0.82		7.05	6.15
	345	12	1296	3324		1.72	1.34		0.03	1.29					1.03	0.52		2.79	3.15
	384	8	112	276															
	388	12	84	228															
	391	12	352	900			0.08												0.08
	395	24	908	2536		2.77	1.97		1.63	1.60								4.40	3.57
	407	224	2500	4340								0.13	0.18					0.13	0.18
	408	92	1384	2636		1.33	1.39		1.1	1.24					1.73	1.81		4.16	4.44
	All	**56**	**3620**	**10492**		**1.55**	**1.02**		**0.42**	**1.18**			**0.07**		**1.27**	**1.07**		**3.24**	**3.35**
2011	334	72	2876	6292		2.46	1.60		0.27	1.15					0.97	0.96		3.70	3.72
	336	4	100	308															
	391	8	128	884															
	395	8	112	1036															
	407	56	932	4244			0.72			0.19									0.91
	457	36	1540	3624		1.05	1.42		0.63	1.50						0.51		1.68	3.44

					Overlaps with each UD (%)															
		UD area (km^2)			**Galloper[1]**			**Greater Gabbard[1]**			**Scroby Sands[1]**			**East Anglia One[3]**			**Total[4]**		
Study/Year	**Tag ID**	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
	459	52	2180	4792			0.49								0.18	0.97		0.18	1.46
	460	16	204	1272			0.14												0.14
	478	52	1180	3284		0.62	1.31											0.62	1.31
	479	20	1096	2944		2.19	2.01			1.15								2.19	3.16
	480	48	1164	3320															
	481	24	368	1460			0.10			0.13									0.24
	482	56	1900	3708		0.7	1.9		0.98	3.41					1.79	2.51		3.47	7.81
	483	48	644	1352															
	484	16	420	1976															
	485	52	816	2860		0.09	0.06			0.65								0.09	0.71
	486	92	2288	5188		2.50	1.92		0.95	2.38					0.36	0.28		3.81	4.58
	492	20	200	824															
	493	200	3200	6492		1.28	1.29		0.16	0.46			0.01		0.22	1.36		1.67	3.11
	All	**68**	**3592**	**14444**		**1.23**	**0.84**		**0.17**	**0.98**					**0.34**	**0.97**		**1.74**	**2.8**
2012	336	4	12	24															
	395	8	48	152															
	407	40	1112	5772		0.70	0.17			0.10		0.38	0.13					1.09	0.39
	459	16	364	1464			2.12												2.12
	460	20	184	1220			0.33			2.03									2.36
	479	20	208	1428															
	480	12	204	1144															
	482	16	428	1632						0.27						0.01			0.28
	483	24	504	1480															
	484	16	248	1136															
	485	32	548	2108															
	486	20	356	1840			2.06			2.81									4.87
	492	36	324	1996															

					Overlaps with each UD (%)														
		UD area (km²)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**Tag ID**	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
	493	28	1096	4000															
	All	**32**	**1040**	**10276**			**0.64**			**0.67**			**0.07**						**1.39**
2013	395	4	88	484															
	460	12	176	400															
	479	12	192	1212															
	482	12	364	1384						0.63									0.63
	483	16	908	2968															
	484	4	192	1380															
	485	4	68	184															
	486	12	316	2200															
	492	16	668	1560															
	493	20	988	3476															
	All	**20**	**896**	**7220**						**0.12**									**0.12**
RSPB																			
2010	ORF001	40	440	744		1.63	1.08											1.63	1.08
	ORF010	20	360	576		1.98	1.93		7.17	5.86								9.15	7.79
	All	**52**	**692**	**1156**		**2.07**	**1.65**		**3.15**	**2.92**								**5.22**	**4.58**
2011	ORF0038	196	1380	1880	2.04	2.99	2.39		1.99	2.44							2.04	4.98	4.83
	ORF0048	12	100	232															
	ORF0058	28	356	680		3.60	2.97		0.57	0.30								4.18	3.27
	ORF017	4	12	16															
	ORF020	4	20	28															
	ORF022	8	48	80															
	ORF024	8	24	56															
	ORF026	8	88	172															
	ORF027	12	44	112															

					Overlaps with each UD (%)														
		UD area (km^2)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**Tag ID**	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
	ORF028	4	48	84															
	All	**24**	**776**	**2224**		**2.38**	**2.48**		**0.78**	**2.06**								**3.16**	**4.54**

(b) Havergate

					Overlaps with each UD (%)														
		UD area (km^2)			Galloper[1]			Greater Gabbard[1]			Scroby Sands[1]			East Anglia One[3]			Total[4]		
Study/Year	**Tag ID**	**50%**	**95%**	**100%**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**	**50**	**95**	**100**
BEIS OESEA																			
2014	460	24	364	1676															
	479	4	196	688															
	486	40	396	1812			0.10												0.10
	All	**36**	**472**	**2856**			**0.06**												**0.06**
2015	460	16	108	644			4.41			4.75									9.17
	478	4	304	2684															
	All	**4**	**296**	**2952**			**0.96**			**1.04**									**2.00**
RSPB																			
2010	HAV007	4	36	88															
	All	**4**	**36**	**88**															
2011	HAV0030	4	44	92															
	HAV0040	12	80	132															
	HAV0094	8	56	124															
	All	**8**	**88**	**184**															

Appendix 8 Assessment of Altitude Distributions of Lesser Black-Backed Gulls between 2010 and 2013

A8.1 Introduction

This annex provides an additional assessment of the altitude distributions of Lesser Black-backed Gulls tracked during the 2010-14 BTO study based at Orford Ness undertaken for the BEIS (formerly DECC) OESEA programme (Thaxter et al. 2014b; see Chapter 5 of the main report). The analysis was performed to understand the pre-construction altitude distribution of Lesser Black-backed Gulls within the GWF.

A8.2 Methods

The data have been run through the same processes as in the main report. The same filtering rates – five minutes and 5-10 seconds – have been used, although for the historical BEIS (DECC) OESEA dataset only GPS-derived altitudes were available. Results are presented using data from 2010-2013 only, when birds occupied the Orford Ness colony within the Alde-Ore Estuary SPA; no five minute data (or faster) were collected for birds post-2014, i.e. at the time when birds were treated as "Havergate" birds – see main report. This is because by 2014, tags could not sustain faster rates and so were set to a 30 min resolution.

In keeping with the main report, assessment is made with the 2D RSZ with turbine dimensions relative to LAT (Greater Gabbard, hub: 77.5 m, max blade tip: 131 m, rotor diameter 107 m; Galloper, hub: 103.5, max blade tip: 180.5 m, rotor diameter: 154m) and considers all behaviour, i.e. including time likely spent on the sea surface or perched offshore as well as those in flight. The GWF was not constructed at the time of these data collection, whereas the Greater Gabbard Wind Farm was, so results represent a pre-construction scenario for the former. Results are provided for all data, and day-time and night-time data separately, based on both the five minute and 5-10 second filtering rates. In keeping with the main report, we also present information for the Greater Gabbard Wind Farm, other operational wind farms, and for all areas offshore outside of OWFs.

We also follow the same approach used in the main report for adjusting GPS altitude for tides using information from the National Oceanographic Centre for 2010-2013 for Harwich. GPS altitudes from the bird datasets are measured relative to a geoid approximating MSL. These bird data were therefore first corrected to height above the sea surface using the tidal dataset. In keeping with this new "baseline" measure relative to the actual sea surface rather than MSL or LAT, the RSZs were also adjusted to be relative to the sea surface. Tidal data are measured relative to LAT and, thus, subtracting date-time specific LAT elevation from the fixed RSZs, ensured that all bird height measurements and assessment within the RSZs were made relative to the same tidal-varying sea-surface baseline.

A8.3 Results

A8.3.1 Summary of data availability and day-time and night-time altitude distributions

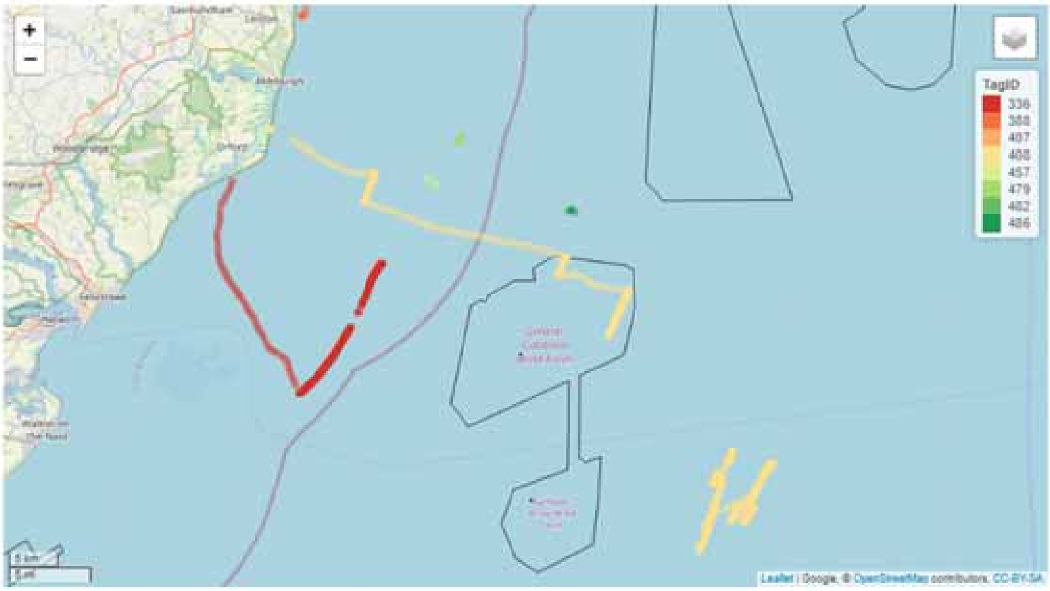
Table A8.1 presents a summary of the number of tagged Lesser Black-backed Gulls providing data at the two different sampling rates used (five minute and 5-10 second), also split between diel periods of day-time and night-time, for all areas for all offshore locations, and for the Galloper and Greater Gabbard Wind Farm areas. Generally fewer data were available for offshore areas at night-time than during the day for both sampling rates used. For the five minute sampling rates, these data reflect overall usage of birds in different areas being unbiased by time of day in sampling effort, hence the lower numbers of birds within wind farms at night-time likely reflected lower overall usage. For 5-10 second rates, however, data were collected opportunistically when the tag's battery could sustain such rates, thus being biased to day-time. These data are mapped in Fig. A8.1 below showing that of eight birds that provided 5-10 second data during the night-time offshore (Fig. A8.1a), only one used the GWF (Fig. A8.1b), within none using the Greater Gabbard Wind Farm.

Fig. A8.2 further shows histograms of the day-time and night-time altitude distributions, based on the five minute and 5-10 second rate datasets, for the Galloper and Greater Gabbard Wind Farms in comparison to all data offshore outside of wind farms, with RSZs displayed for the respective wind farms.

Table A8.1 Sample sizes (max 24 birds)

Area	Rate	All times	Day-time	Night-time
Galloper	5 min	11	11	7
	5-10 s	5	5	1
Gabbard	5 min	8	8	5
	5-10 s	3	3	0
All offshore	5 min	22	22	19
	5-10 s	20	20	8
All locations	5 min	23	23	23
	5-10 s	21	21	15

(a)



(b)

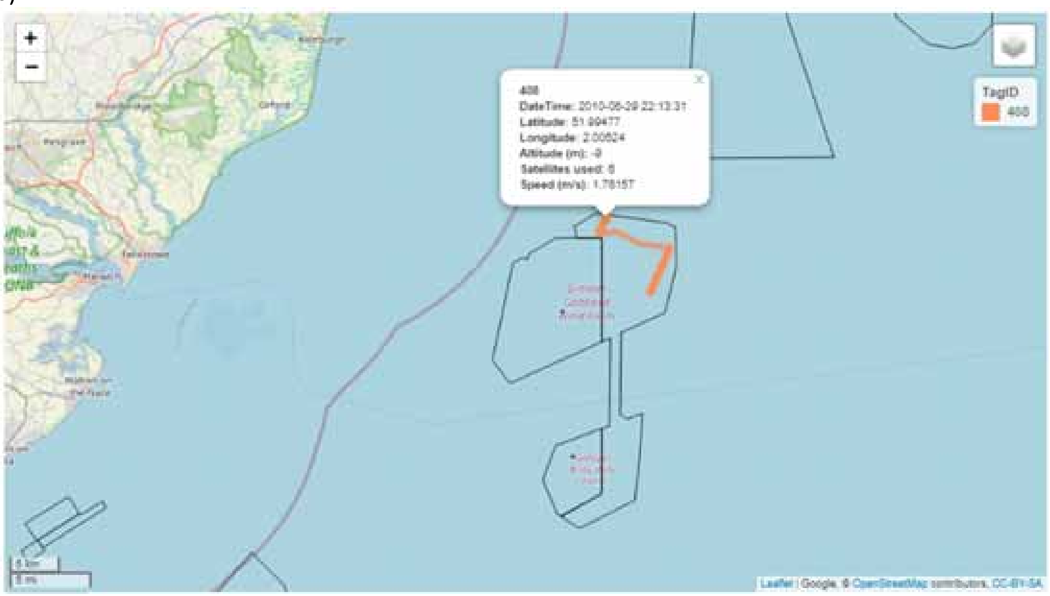


Figure A8.1 Night-time dataset filtered to 5-10 s: (a) all movements offshore and (b) all movements within the GWF.

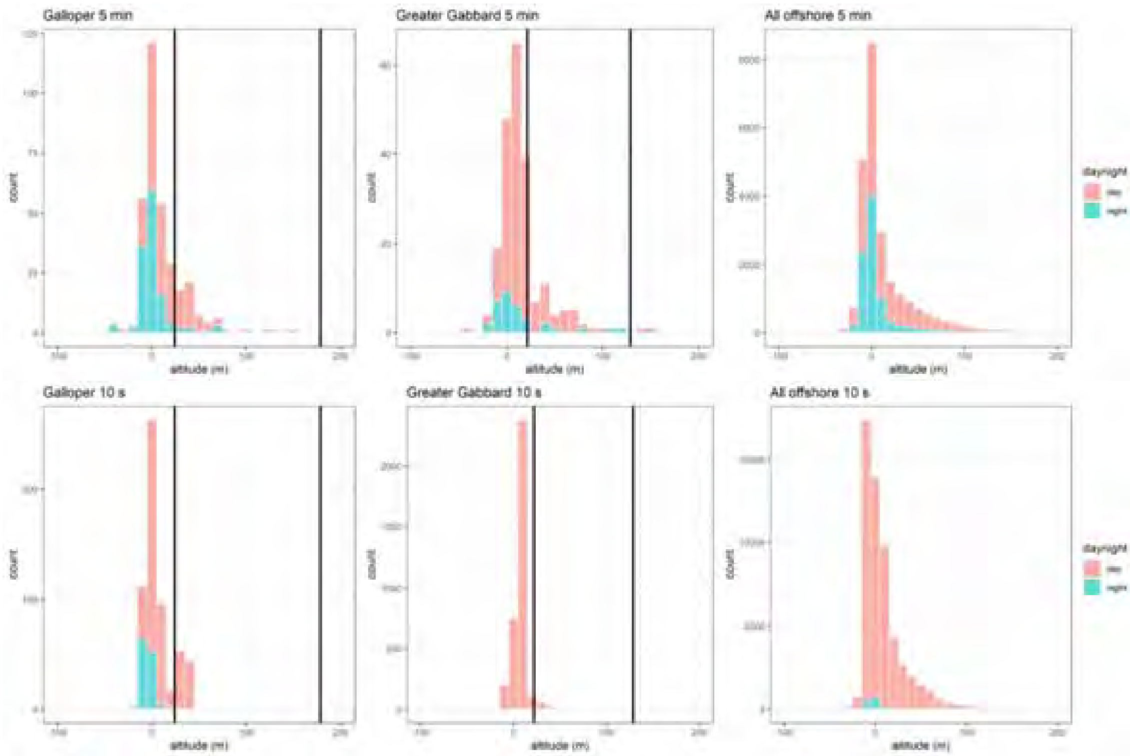


Figure A8.2 Histograms of day and night-time altitude distributions within the Galloper and Greater Gabbard Wind Farms; black lines indicate the lower and upper rotor sweep zones specific to each wind farm but note, these are plotted as relative to MSL for visual clarity; in calculations zones were measured relative to the sea surface and thus varied by a tidal variation of ±2.2 m from those presented in the figure; also shown is the distribution for all data offshore outside OWFs.

A8.3.2 Altitude analysis based on data collected at a five minute fix rate

Tables A8.2-A8.7 display mean GPS altitudes and the proportions of fixes within RSZs for all periods, the day-time and night-time, based on data collected at a five minute resolution from 2010-2013, respectively considering (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2).

Table A8.2 Mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (although in practice the calculations resulted in mathematically equivalent percentages); altitude values are in relation to the sea surface with mean sea level baseline values given in parentheses.

	Altitude			% in rotor swept zone		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	16.79 (16.71)	25.80 (25.84)	209	21.10	21.10	44
Galloper	10.38 (10.65)	29.91 (29.76)	311	19.00	19.00	59
All OWFs	13.09 (13.22)	28.62 (28.52)	521	20.00	20.00	104*
Outside OWFs	13.66 (13.59)	38.44 (38.44)	21743			

*Note one fix was recorded in RSZ of another wind farm (Scroby Sands).

Table A8.3 Day-time mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			% in rotor swept zone		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	16.87 (16.89)	24.41 (24.39)	177	20.30	20.30	36
Galloper	17.43 (17.32)	34.14 (34.25)	188	27.10	27.10	51
All OWFs	17.34 (17.29)	29.93 (29.99)	366*	24.00	24.00	88*
Outside OWFs	19.55 (19.64)	45.08 (45.04)	13648			

*Note one fix was recorded at another wind farm (Scroby Sands).

Table A8.4 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			% in rotor swept zone		
	Mean	SD	n	%[1]	%[2]	n[1]
Gabbard	16.11 (15.70)	32.96 (33.23)	32	25.00	25.00	8
Galloper	-0.06 (0.46)	16.72 (16.75)	123	6.50	6.50	8
All OWFs	3.28 (3.61)	21.98 (21.97)	155	10.30	10.30	16
Outside OWFs	3.41 (3.39)	19.60 (19.58)	8095			

Table A8.5 Mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			% in rotor swept zone		
	Mean	SD	n	%[1]	%[2]	n[1]
Gabbard	25.09 (25.09)	35.11 (35.13)	97	42.30	42.30	41
Galloper	21.47 (27.73)	37.54 (37.40)	147	36.10	36.10	53
All OWFs	23.16 (23.31)	36.67 (36.60)	245	38.80	38.80	95
Outside OWFs	27.25 (27.17)	47.99 (48.02)	11518			

Table A8.6 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			% in rotor swept zone		
	Mean	SD	n	%[1]	%[2]	n[1]
Gabbard	28.91 (28.71)	35.18 (35.30)	67	49.30	49.30	33
Galloper	24.59 (24.46)	40.03 (40.17)	113	39.80	39.80	45
All OWFs	26.50 (26.35)	38.37 (38.51)	181	43.60	43.60	79
Outside OWFs	30.02 (30.08)	51.47 (51.43)	9064			

Table A8.7 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of five minutes, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	17.45 (17.00)	33.65 (33.94)	30	26.70	26.70	8
Galloper	12.01 (12.65)	24.33 (24.47)	34	23.50	23.50	8
All OWFs	14.46 (14.69)	28.96 (29.13)	64	25.00	25.00	16
Outside OWFs	16.58 (16.40)	30.06 (30.09)	2454			

A8.3.3 Altitude analysis based on data collected at a 5-10 second fix rate

Tables A8.8-A8.13 display mean GPS altitudes and the proportions of fixes within RSZs for all periods, the day-time and night-time, based on data collected at a 5-10 second resolution from 2010-2013, respectively considering (i) all fixes, whether birds were in flight or on the sea, and (ii) only those fixes when birds were in flight (foraging, commuting), as based on behavioural classifications produced by the EMbC models (see section 3.4.2). Note, that data collection at this sampling rate was biased to the day-time and hence sample sizes for the night-time period are low (see section A8.3.1 and Figure A8.2). Further, during the night-time, birds were likely resting on the sea surface only, with estimates below zero reflecting error biases in the GPS-derived altitude measure.

Table A8.8 Mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	9.76 (8.82)	7.62 (7.49)	3507	2.91	2.91	102
Galloper	6.36 (5.95)	14.72 (14.59)	579	16.60	16.60	96
All OWFs	9.28 (8.41)	9.05 (8.91)	4086	4.85	4.85	198
Outside OWFs	11.40 (10.95)	40.31 (40.35)	50379			

Table A8.9 Daytime mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 s, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	9.76 (8.82)	7.62 (7.49)	3507	2.91	2.91	102
Galloper	9.21 (8.70)	15.04 (14.97)	461	20.80	20.80	96
All OWFs	9.69 (8.81)	8.81 (8.69)	3968	4.99	4.99	198
Outside OWFs	11.71 (11.26)	40.76 (40.80)	49105			

Table A8.10 Night-time mean altitude, including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 s, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	-	-	-	-		-
Galloper	-4.77 (-4.79)	4.85 (5.01)	118*	0	0	0
All OWFs	-4.77 (-4.79)	4.85 (5.01)	118*	0	0	0
Outside OWFs	-0.44 (-0.94)	8.10 (8.29)	1274**			

* Note, likely behaviour on sea surface, biased to one individual; ** eight birds, again biased to likely sea surface activity.

Table A8.11 Mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	6.94 (6.50)	11.19 (11.22)	1008	10.00	10.00	101
Galloper	8.91 (8.40)	14.90 (14.83)	476	20.20	20.20	96
All OWFs	7.58 (7.11)	12.53 (12.52)	1484	13.30	13.30	197
Outside OWFs	22.55 (22.15)	48.73 (48.76)	30305			

Table A8.12 Day-time mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Gabbard	6.94 (6.50)	11.19 (11.22)	1008	10.00	10.00	101
Galloper	9.40 (8.87)	15.05 (14.99)	454	21.10	21.10	96
All OWFs	7.71 (7.23)	12.56 (12.55)	1462	13.50	13.50	197
Outside OWFs	22.62 (22.23)	48.60 (48.89)	30119			

Table A8.13 Night-time mean altitude of birds classified by the EMbC behavioural classification as in flight (states 3 and 4), including standard deviation (SD) and sample size (n), for GPS-derived altitudes from data collected at Orford Ness and Havergate (2010-2013); recorded at a fix rate of 5-10 seconds, split by offshore wind farm (OWF) boundaries. Also displayed is the proportion of altitudes (%) within the rotor swept zone (RSZ) for the Galloper and Greater Gabbard Wind Farms, based on (1) altitude in relation to the sea surface and (2) mean sea level (see Table A8.2 for more details).

	Altitude			**% in rotor swept zone**		
	Mean	**SD**	**n**	**%[1]**	**%[2]**	**n[1]**
Galloper	-1.02 (-1.14)	5.46 (5.47)	22	0	0	0
All OWFs	-1.02 (-1.14)	5.46 (5.47)	22	0	0	0
Outside OWFs	9.83 (9.73)	13.56 (13.49)	186			

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Assessing movements of Lesser Black-backed Gulls using GPS tracking devices in relation to the Galloper Wind Farm.

A programme of Lesser Black-backed Gull *Larus fuscus* tagging and tracking work was initiated within the Alde-Ore Estuary Special Protection Area during the 2019 breeding season, and continued throughout the 2020 breeding season, in order to fulfil requirements of the Galloper Wind Farm Ornithological Monitoring Programme and test key predictions of the Environmental Statement. The results from both the 2019 and 2020 breeding seasons of tracking are summarised within this report.

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