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Measuring the interaction between marine features of Special Protection Areas with offshore wind farm development zones through telemetry: first breeding season report

Authors

**Chris B. Thaxter[1], Viola H. Ross-Smith[1], Nigel A. Clark[1], Greg J. Conway[1],
Mark. M. Rehfisch[1], Willem Bouten[2] and Niall H.K. Burton[1]**

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

1. The UK government has a commitment to obtain 15% of the UK's electricity from renewable sources by 2020, of which wind energy is likely to form a major part (DECC 2009). Consequently many wind farms are currently under construction and more developments are proposed (e.g. Round 3 zones, Scottish Territorial Waters sites and Extensions to Round 1 and Round 2 sites). There is, however, much concern as to the effects that offshore wind developments may have on seabird populations.

2. Many seabirds designated as feature species of Special Protection Areas (SPAs) might potentially be affected by these developments, as their breeding season foraging ranges and migratory routes may overlap with wind farm sites. The effect of wind farms on particular species is likely to be influenced by altitude at which birds fly, and the avoidance behaviour they might show.

3. This study uses the latest tracking technology to investigate the movements of two seabird species that are features of SPAs. The aims of this study are threefold:
   i. To understand the connectivity of these feature species with the areas of consented wind farms (i.e. those which have already been constructed or are under construction) and proposed wind farm development zones;
   ii. To understand the extent to which these feature species use the areas of wind farms which have already been constructed or are under construction;
   iii. To provide an assessment of the flight altitudes of these feature species that could usefully inform collision risk modelling.

4. In summer 2010, GPS tags were fitted to 11 Lesser Black-backed Gulls at Orford Ness, part of the Alde-Ore Estuary SPA, and four Great Skuas on the Foula SPA in Shetland (out of a total of 25 of each species to be tagged in the project). All individuals tagged were members of breeding pairs, and were caught on the nest. No adverse effects of tagging were observed (although there were high levels of nest failure for the gulls, this was typical for the colony as a whole).

5. Sufficient data for analysis were obtained for ten Lesser Black-backed Gulls and two Great Skuas. Movements away from the colony, many of which were presumed to be for foraging, were classified as 'trips'. Seventy of the 352 trips recorded for Lesser Black-backed Gulls contained a marine component. The maximum distance from the colony that a bird travelled was 159 km. There was variation in the sites visited by individuals, with some never venturing offshore, while others spent more than half their time away from the colony at sea. Eighty-eight trips were recorded for Great Skuas, with a maximum distance of 219 km travelled from the colony. As only a small quantity of data was available for Great Skuas, only limited analyses are presented.

6. For the Lesser Black-backed Gulls that spent substantial periods of time at sea, there was considerable temporal and spatial overlap with consented Round 1 and 2 wind farms (in this case, sites which are under construction), as well as with the proposed Extensions and Round 3 development sites. No such overlap was recorded for Great Skuas as there are no consented or proposed wind farms in the vicinity of Foula. However, this does not preclude Great Skuas interacting with wind farms outside the breeding season on their migrations.

7. The GPS tags deployed also record altitude. Here we provide a preliminary assessment of the precision of altitude measurements (i.e. in the error around the mean) and their accuracy (i.e.

whether the mean value obtained is correct). Results suggest that both Lesser Black-backed Gulls and Great Skuas frequently fly at altitudes where they might be vulnerable to disturbance by wind turbines.

8. The data presented here on the overlap of home ranges and time budgets with consented and proposed wind farms and flight altitudes show the value of GPS tagging data in assessing both connectivity and potential interactions between SPA features and offshore wind farms. A relatively small amount of data is presented from only one breeding season. However, a further 35 tags will be deployed in the 2011 breeding season (14 on Lesser Black-backed Gulls and 21 on Great Skuas) and plans for this forthcoming breeding season and completing the project are discussed. The complete dataset will provide a much clearer understanding of the extent to which these SPA features use the areas of offshore wind farms. The data will also provide a fuller assessment of flight altitudes that could be used to inform collision risk modelling.

1. INTRODUCTION

1.1 Background

The UK government has a commitment to obtain 15% of the UK's electricity from renewable sources by 2020, of which wind energy is likely to form a major part (DECC 2009). Consequently many wind farms are currently under construction and more developments are proposed (e.g. Round 3 zones, Scottish Territorial Waters sites and Extensions to Round 1 and Round 2 sites). There is, however, much concern as to the effects that offshore wind developments may have on seabird populations.

Potential areas for development of offshore wind farms include locations that may hold large numbers of seabirds, seaduck and other waterbirds. Both consented and proposed development zones within the North Sea may also overlap the foraging areas of seabirds that are features of protected sites. Offshore wind farms may potentially impact these bird populations through four main effects: (1) displacement due to the disturbance associated with developments; (2) the barrier effect posed by developments to migrating birds and birds commuting between breeding sites and feeding areas; (3) collision mortality; (4) indirect effects due to changes in habitat or prey availability. When assessing the potential effects of proposed wind farms on local bird populations, it is important to establish not only the use that birds make of the proposed wind farm area, but also in the assessment of collision risk, whether they are likely to come into contact with the turbines. The latter is largely determined by the height at which the birds fly, and any avoidance behaviour that they may show towards the turbines.

Before construction is consented, an Environmental Impact Assessment (EIA) is required to identify the possible risks posed by a development. As part of this process, where a 'likely significant effect' upon a Natura 2000 site (Special Protection Area, SPA, or Special Area of Conservation, SAC[1]) is identified, an Appropriate Assessment (AA) needs to be conducted, to understand and predict the effects on the feature species found at those sites. SPAs are designated under the European Bird's Directive (79/409/EEC), which protects sites within the European Union of international importance for breeding, wintering, feeding, or migrating vulnerable bird species. Wind farms have the potential to affect breeding seabirds or wintering waterbirds that are features of SPAs if they forage in areas where wind farms are proposed, or pass through these areas on migration. Thus, it is important to understand the connectivity between features of SPAs with development regions.

1.2 Project aims

This study uses the latest tracking technology to investigate the movements of two seabird species that are features of SPAs. The aims of this study are threefold:

i. To understand the connectivity of these feature species with the areas of consented wind farms (i.e. those which have already been constructed or are under construction) and proposed wind farm development zones;
ii. To understand the extent to which these feature species use the areas of wind farms which have already been constructed or are under construction;
iii. To provide an assessment of the flight altitudes of these feature species that could usefully inform collision risk modelling.

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[1] http://www.naturalengland.org.uk/ourwork/conservation/designatedareas/spa/default.aspx

Here, we present initial findings of this two-year study covering tracking undertaken during the 2010 first breeding season.

1.3 Tagging birds to understand interactions

1.3.1 Breeding season movements

At-sea data collected from boat or aerial surveys are important tools for assessing the interaction of particular species with offshore wind farms during breeding. However, crucially, these methods cannot establish the origin of birds recorded during surveys, and whether the individuals observed are linked to specific breeding sites. Such an understanding is necessary to assess the impacts of wind farms on the numbers of each feature species from breeding colony SPAs or other protected sites. Radar studies can provide individual tracks of birds in the vicinity of wind farms, but are often unable to identify birds to species level (Walls *et al*. 2009), and it can be difficult to follow individuals near to the turbines due to a "shadow" effect. The tagging of birds within a breeding population can thus help resolve these issues by providing direct data on the movements of individuals from specific sites, and may therefore be very helpful in refining our understanding of potential wind farm impacts and in making better-informed assessments (Walls *et al*. 2009).

If the species in question have been subject to tracking studies in other areas, the resulting findings on their foraging ranges could serve as useful information when considering the likely effects of wind farm developments on nearby breeding populations, hence informing potential connectivity between developments and breeding populations (Thaxter *et al*. in review). However, considerable variation has been shown in foraging area usage between colonies and both within and between breeding seasons for several seabird species (Thaxter *et al*. in review). Differences in the foraging ranges of Northern Gannets *Morus bassanus* between colonies (Lewis *et al*. 2001; Hamer *et al*. 2001), for example, likely reflect the effects of differences in prey availability and intra-specific competition on the distances required to find food. Furthermore, the locations of important foraging habitats, and thus seabird distributions, may be ephemeral, because of links to fluctuating habitat features such as oceanographic fronts (Daunt *et al*. 2006; Camphuysen *et al*. 2006; Skov *et al*. 2008), thus giving rise to large inter-annual variability. There also may be considerable variation in the types of marine systems in which birds forage, and in the prey species available, the capture of which may require a range of foraging tactics. Given such differences in foraging behaviour, it is very important to collect data where wind farms are suspected to have potential impacts on nearby breeding populations. Only with this detailed assessment will the true connectivity between wind farms and protected breeding populations be fully understood.

1.3.2 Non-breeding season movements

Most tracking studies of seabird species have focussed on understanding the movements of species during the breeding season (e.g. Votier *et al*. 2004, 2006). However, seabirds may make use of different areas at different times of year, and hence the true impact of a wind farm development can only be understood through a complete temporal and spatial assessment. There is thus a need to determine distributions separately for the breeding, over-wintering and migration periods. Previous shortcomings of most telemetry methods have prevented accurate long-term monitoring of movements at sea, either because of the expense of tracking devices, or weight increment restrictions for particular species. However, new devices and methods are now available that allow seasonal movements to be monitored for a wider range of species. New GPS tags, such as those developed by the University of Amsterdam and used in this study, have been used to study the movements of Lesser Black-backed Gulls *Larus fuscus* breeding in the Netherlands (e.g. Shamoun-Baranes *et al*. 2011). The combination of technological advances are now allowing a greater range of species to be tracked (at lighter weights e.g. < 20 g), at better spatial resolutions and for longer periods.

1.3.3 Flight altitudes of birds

To be able to assess the collision risk posed by proposed offshore wind farms, information is needed not only on the numbers of birds using the area, but also the proportions of birds flying at heights that expose them to potential collision with the turbine rotor blades (e.g. Band 2000). Flight altitudes of different species are typically assessed during boat surveys that are undertaken to inform the baseline of the EIA. Few precise assessments of flight altitudes exist, though radar studies have begun to provide useful information (e.g. Krijgsveld *et al.* 2005). However, new developments in GPS technology have given rise to systems that collect data over very short sampling intervals (down to 3 seconds), resulting in improved precision and accuracy[2] in altitude measurements.

Altitudes given by GPS may still be inaccurate both in terms of their precision (i.e. in the error around the mean) and their accuracy (i.e. whether the mean value obtained is correct). These errors arise due to the shape of the earth, the number of satellites available for a given location, position dilution of precision (pdop), and other variables such as tidal state, temperature, humidity and pressure. The precision for altitude readings produced by the GPS systems currently available is *ca*. 15 m (Ens *et al*. 2008), which may be regarded as acceptable in relation to offshore wind farms, given that the diameter of turbine rotors may vary from 80 m to 150 m, and turbine heights may range from ca. 107 m – 134 m above mean sea level to the uppermost blade tip. However, taking account of such sources of error may yield great improvements in flight altitude measurements with a precision of 2-3 m, therefore giving information in unprecedented detail, which would be extremely useful for collision risk assessment.

1.4 Focal species

Many seabird species are included as features of breeding colony SPAs, and travel large distances at sea. Although recent work has been conducted on some coastal species that are considered sensitive to developments, such as terns and divers, certain pelagic seabird species may also be sensitive, such as Lesser Black-backed Gulls and Great Skuas *Catharacta skua* (Garthe & Hüppop 2004), but have received less attention. Other species include Northern Gannet (*Morus bassanus*), Razorbill (*Alca torda*) and Atlantic Puffin (*Fratercula arctica*). However, both Lesser Black-backed Gulls and Great Skuas are thought to fly at a height that puts them at risk of interaction with offshore wind farms (Garthe & Hüppop 2004; Banks *et al*. 2005; Shamoun-Baranes & van Loon 2006; Vanermen & Stienen 2009).

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[2] For clarity, the terms "accuracy" and "precision" used throughout this document are defined. Accuracy refers to how closely a measured value agrees with the correct value (a count of 55 birds is accurate but a count of 103 is not if in reality 56 birds are present). Precision refers to the range of an estimate (an estimate of 56 to 57 birds is precise, but an estimate of 1 to 100 birds is less precise). An estimate can be more precise but less accurate than another; if 56 birds are present, an estimate of 92 to 93 birds is more precise but less accurate than an estimate of 50 to 60 birds.

1.4.1 Lesser Black-backed Gulls

The Lesser Black-backed Gull (the UK sub-species of which is *L. fuscus graellsii*) is a qualifying feature of several five breeding colony SPAs in England, two in Scotland and one in Wales (SPA Review: Stroud *et al*. 2001; SNH SPA extensions[3]). At-sea data have been used to investigate the species' distributions and habitat associations, for instance in the German North Sea (Schwemmer & Garthe 2005), and placement within multi-species feeding associations (Camphuysen & Webb 1999). Research has also focused particularly on general breeding biology, diet, and kleptoparasitism (Camphuysen 1995; Calladine 1997; Galván 2003; Kubetzki & Garthe 2003; Kim & Monaghan 2006). However only recently has the species been tracked, in a study of birds breeding in the Netherlands (Shamoun-Baranes *et al*. 2011), and hence limited data are available concerning foraging movements. Previous information suggests that Lesser Black-backed Gulls may forage up to 180 km offshore during the breeding season (Ens *et al*. 2008; Shamoun-Baranes *et al*. 2011, Thaxter *et al*. in review). Hence, there is potential for birds to forage in areas of both consented and proposed offshore wind farms, and AAs have previously evaluated the potential effects of proposed developments on SPA populations where this species is a feature.

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

1.4.2 Great Skuas

The UK holds 60-70% of the world population of Great Skuas, and whilst their breeding distribution is restricted to northern Scotland, the species has been highlighted as being potentially affected by wind farm developments elsewhere while on migration. Key SPAs where Great Skuas are qualifying features are located in Shetland and northern Scotland (Stroud *et al*. 2001; SNH SPA extensions[2]).

Previous information suggests this species may forage more than 100 km from colonies during the breeding season, with distances of up to 60 km being typical (Thaxter *et al*. in review). However, individual Great Skuas can be either offshore generalist opportunistic omnivores feeding, for instance, on fisheries discards (e.g. far offshore), or specialist foragers that focus activity on predating seabirds near to breeding colonies, at distances of up to 13 km (Votier *et al*. 2004; 2006; Thaxter *et al*. in review). Wind farms are less likely to be a major issue during the breeding season for Great Skuas than for Lesser Black-backed Gulls, because no wind farms exist or are proposed within the representative foraging range of important breeding populations. However, the migrations of Great Skuas down the eastern side of the UK (Cramp & Simmons 1977; Furness *et al*. 2006) may take them through the areas of consented and proposed offshore wind farms. Detailed information on the heights that Great Skuas fly at may thus be useful during the assessment process.

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

2. METHODS

2.1 Field sites

During 2010, fieldwork for Lesser Black-backed Gulls was conducted at a large mixed colony of Lesser Black-backed Gulls and Herring Gulls *Larus argentatus* at Orford Ness, Suffolk, UK (52°4'N, 1°33'E). This colony is part of the Alde-Ore Estuary SPA that supported 21,700 pairs of breeding Lesser Black-backed Gulls at the time of designation. After expansion from the late 1960s, the Orford Ness colony has recently reduced in size from over 5,000 apparently occupied nests (AONs) in 1998-2002 (Mitchell *et al*. 2004) to around 1,000 AONs in 2010 (M. Marsh pers. comm.), possibly due to mammalian predation.

Fieldwork for Great Skuas was conducted at Foula SPA, Shetland, UK (60°8'N, 2°5'W) at a colony of *ca*. 2,300 breeding Great Skuas (Mitchell *et al*. 2004, figure for 1998-2002). The colony has reduced in size by 8% since 1982, but during 1998-2002 held 24% of the Great Britain and Ireland total of this species, although the population at the site is thought to have decreased slightly since this time. This site has been well studied in the past (e.g. Hamer & Furness 1991; Votier *et al*. 2007; 2008), and the population has potential to interact with areas of offshore development during non-breeding periods.

2.2 The GPS system

The GPS devices used in this study were developed by the University of Amsterdam. Each consisted of a GPS sensor, a microcontroller with ≥ 4Mb flash-memory, a pressure sensor, an accelerometer, a solar panel, a battery, a battery charger, and a radio transceiver, with a total weight of 19 g (< 3% body mass, in this study: Lesser Black-backed Gull, mean: 851 ± 85 g, range: 710 – 955 g; Great Skua, mean 1303 ± 52; range 1240-1350 g). These devices therefore allowed for continual data collection, potentially over long periods (e.g. up to 2 years). The devices also included two way wireless VHF data communication to ground stations. Thus, once deployed, communication thereafter was with a central base station where GPS locational data were downloaded to a field-based laptop. Communication was facilitated by external relay antennae that amplify the range of the signal. In this study, we used a field relay mounted on a scaffold pole to allow data transmission to the base-station located *ca*. 3 km away. Once tagged birds come within range of the 'network', data from the tags were automatically downloaded. Furthermore, new sampling rate settings and communication intervals were uploaded remotely through the network. An onboard local clock also synchronised with the GPS time once a GPS fix was made.

2.3 Capturing and attaching devices

Fifteen tags per species were available for deployment in the 2010 season. Through agreement with DECC, the remaining 35 devices will be deployed in the 2011 breeding season.

Eleven incubating Lesser Black-backed Gulls were captured on the 5 June 2010 and 15 June 2010 with wire mesh traps placed over nests (Bub 1991) (Table 1). A total of four Great Skuas were caught, also during the incubation period, between 20 June 2010 and 24 June 2010 using a remotely-controlled nest snare trap (Furness *et al*. 2006) (Table 1).

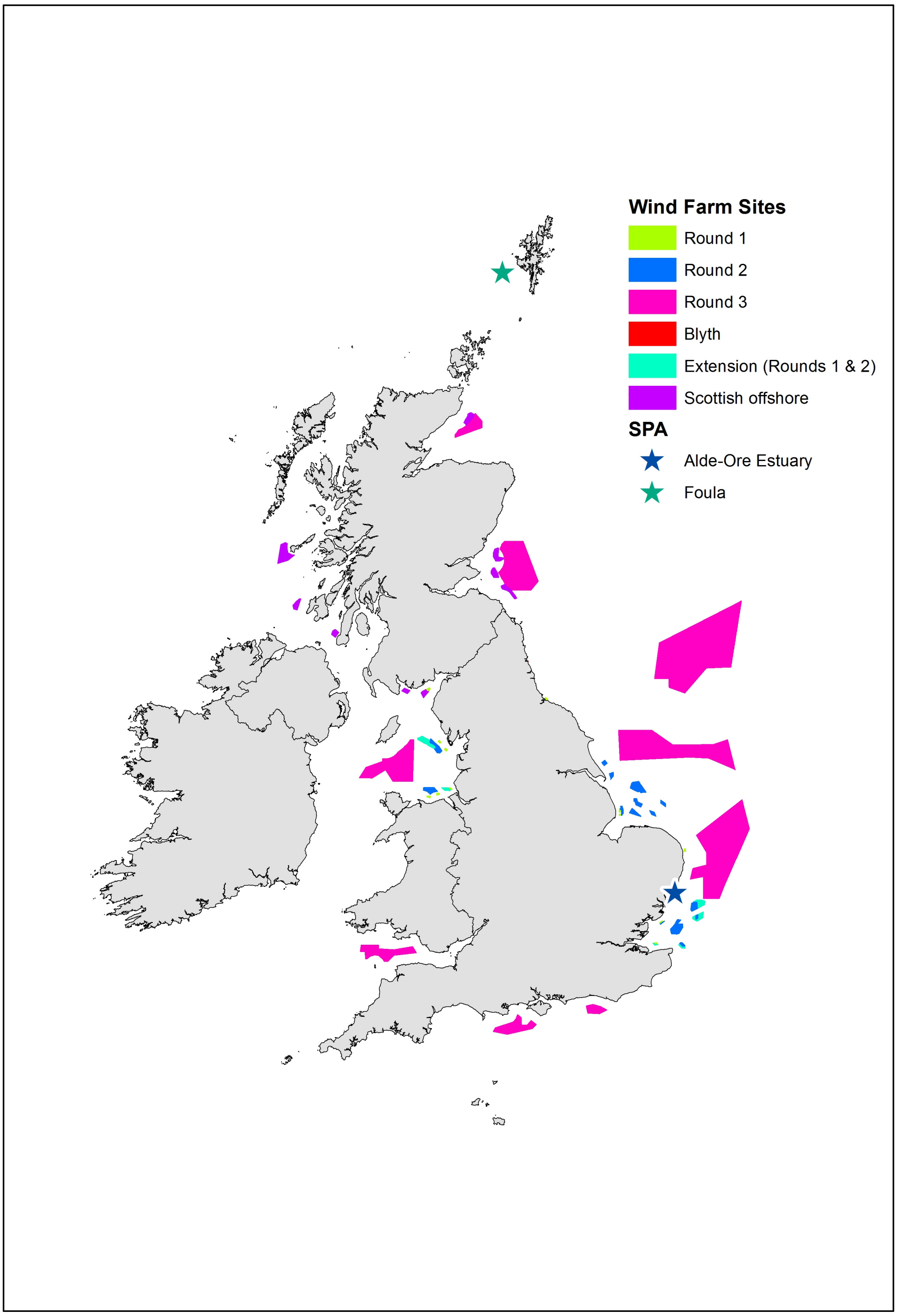

Figure 1 Location of all wind farm sites in the UK in relation to study colonies at Orford Ness and Foula

Table 1 Deployment periods for tags on (a) Lesser Black-backed Gulls and (b) Great Skuas; all Lesser Black-blacked Gulls had functioning tags after the breeding season with the exception of 347 which lost its tag immediately after capture, and 384 for which the solar panel malfunctioned

(a) Lesser Black-backed Gull

Tag	Released	Latest data downloaded[4]	Last recorded at colony	Length of data (days)	Harness
336	15/06/2010 12:16:00	10/07/2010 17:45:49	05/08/2010	25.23	wing
334	15/06/2010 12:30:00	18/07/2010 22:56:11	18/07/2010	33.43	wing
407	15/06/2010 14:05:00	12/07/2010 20:03:26	17/07/2010	27.25	wing
408	15/06/2010 14:24:00	14/07/2010 22:12:11	18/07/2010	29.33	wing
388	15/06/2010 12:45:00	11/07/2010 22:28:33	25/07/2010	26.41	body
384	15/06/2010 13:45:00	21/06/2010 14:03:57	05/07/2010	6.01	body
395	15/06/2010 14:00:00	21/07/2010 06:02:27	21/07/2010	35.67	body
391	15/06/2010 14:42:00	02/07/2010 02:07:20	23/07/2010	16.48	body
345	05/06/2010 11:05:00	10/07/2010 01:15:07	18/07/2010	34.59	leg-loop
335	05/06/2010 13:48:00	07/07/2010 02:36:30	07/07/2010	31.53	leg-loop
347	05/06/2010 13:35:00				leg-loop

(b) Great Skua

Tag	Released	Latest data downloaded	Length of data (days)	Tag lost	Harness
340	21/06/2010 17:07:00	24/06/2010 01:21:22	2.34	24/06/2010	leg-loop
349	22/06/2010 11:10:00	28/07/2010 10:57:18	35.99	28/07/2010	leg-loop
342	22/06/2010 13:35:00	23/06/2010 18:38:34	1.21	23/06/2010	leg-loop
348	23/06/2010 15:35:00	08/07/2010 01:21:36	14.41	08/07/2010	leg-loop

To study the movements of the birds, a GPS logger was attached to the back of the bird using a permanent harness that has been successfully applied in previous studies on other species. For three individual Lesser Black-backed Gulls and all four Great Skuas, we used a Rappole-Tipton (Rappole & Tipton 1991) leg-loop harness, which was previously developed for passerines but has since been used successfully on Dunlin *Calidris alpina*, and South Polar Skuas *Catharacta maccormicki* (Sanzenbacher *et al*. 2000; Mallory & Gilbert 2008). For four Lesser Black-backed Gulls we fitted a back-pack body harness, used previously on raptors, and for the remaining four gulls we used a modified back-pack wing harnesses (Shamoun-Baranes *et al*. 2011). The use of these different methods was agreed by the national Ringing Scheme's Unconventional Marks Panel and their success will be used to inform attachment methods used in 2011.

Leg-loops were constructed from a specialised Elastic cord (1.5 mm) thread housed within flexible Silastic tubing, to loop around the thighs of either side of the bird (e.g. Sanzenbacher *et al*. 2000; Mallory & Gilbert 2008). A layer of neoprene rubber was placed underneath the tag to improve the bird's comfort. For the other back-pack configurations, straps of Teflon thread were fed around the

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[4] At the time of analysis, i.e. excluding most recent data from non-breeding periods.

body or under the wings, and attached to the eyes of the tag, secured with glue. Each tag was deployed only once per bird.

Birds were handled for a maximum of 45 minutes, during which time biometric measurements were taken, and the tag was attached. Lesser Black-backed Gulls were also fitted with an unique combination of plastic colour-rings to enable their subsequent identification as individuals in the field. For Great Skuas, we also measured the egg length, width, and weight on a separate visit to the nest, for subsequent calculation of egg density, which was used to infer likely hatching dates (Furness & Furness 1980).

After tagging, birds were released and resumed normal incubating behaviour. Of the 11 Lesser Black-backed Gulls tagged, one bird (with a leg-loop attachment) subsequently lost its tag immediately after release (the remaining two birds with leg-loops retained their devices). Additionally, one device (no. 384) failed to work properly after a few days of deployment, believed to be due to solar panel damage, but the data obtained are still included here.

Of the four Great Skuas tagged, two birds removed their tags soon after deployment (340 and 342) (Table 1). The remaining two birds (348 and 349) also lost their tags, but at later stages after valuable data had been collected. Therefore, the materials and attachment technique were not robust enough for this species, and thus will need to be revised before the next breeding season.

2.4 Monitoring the potential effects of devices

2.4.1 Lesser Black-backed Gulls

After release tagged Lesser Black-backed Gulls either returned immediately to the nest or its vicinity, or fed around the colony in nearby fields. Tagged Lesser Black-backed Gulls were re-sighted behaving normally on several occasions around the gull colony, and observed roosting nearby at neighbouring estuarine locations. Tags also stopped communicating with the system at a time when all birds departed the colony, thus showing normal post-breeding dispersal. One gull (336), was seen again twice after leaving the colony outside the UK – in northern Spain (43°32’N 08°18’W) on 22 August 2010, and again in southern Spain (37°08’N 06°52’W) on 11 September 2010, indicating apparently normal migration behaviour for this species (see http://www.sovon.nl). Another individual, bird 408, was recorded on 4 February 2011 in Oualidia, Morocco (32°44’N 09°02’W). Five individuals, birds 334, 336, 391, 395 and 407, have now returned to the breeding colony with their tags intact, giving a stretch of data right across the non-breeding period. All these birds left the UK between late July and late November, and all birds migrated as far south as Morocco, although 336 spent most of its winter in Spain. All returned to Orford Ness in March and April 2011 (see Appendix 2 for an example from bird 407). 335, 345 and 347 have also been sighted back at the colony, but have lost their tags, all of which were attached with leg-loop harnesses. We suspect that these tags were removed directly by the birds, in a similar fashion to that of the Great Skuas. Bird 384, with the tag that malfunctioned, has also returned to the Orford Ness colony. Therefore, at the time of writing (22 May 2011), nine birds (334, 335, 336, 345, 347,384, 391, 395 and 407) out of eleven tagged have been recorded back in the breeding colony at Orford Ness, at a time when non-tagged colour-ringed birds are also typically observed (M. Marsh pers. comm.). We therefore believe that the tags did not affect the normal behaviour and movements of birds during the period of study.

Nests were monitored during the breeding season to check whether the fitting of tags to birds affected the likelihood of nest failure. As an additional check on the breeding behaviour of tagged birds, we also set up two nest cameras on 15 June 2010 on two nests of Lesser Black-backed Gulls. These were for monitoring birds immediately after tagging, and were used for birds 408 and 395. The fate of all nests is summarised in Table 2a.

The eggs of bird 408 failed the day after tagging, due to conspecific predation. This nest was initially disturbed during the capture of one member of the breeding pair at 15 June 2010 at 13:45. This bird was tagged and released by 15 June 2010 at 14:24. Thereafter, the tagged bird stayed local to the colony and nest. Although this bird did not directly return to its territory until the following morning (16 June 2010 at 03:55), its mate returned to the nest (15 June 2010 at 17:27) to incubate after the departure of the tagging team. Upon its return, this un-tagged mate consumed two eggs at a nearby unattended nest. The bird then departed for a short trip, and immediately thereafter a neighbouring gull destroyed the eggs in the pair's nest. Whether this attack was carried out by a member the pair whose nest was predated beforehand is uncertain, but may have been due to a pay-back mechanism, as previously reported elsewhere (e.g. Davis & Dunn 1976). However, other individuals were spotted the following day walking around other nests, apparently actively searching for unattended eggs in view of the camera, breaking eggs, drinking the yolk and eating whole eggs. Such behaviours have been reported before, especially later in the season, in Lesser Black-backed Gulls and other gull species (e.g. Davis & Dunn 1976, Schoen & Morris 1984, Spaans *et al*. 1987).

The data for bird 408's nest indicate that it failed after the tagging team had departed, and given that independent control nests also suffered the same fate, we do not believe that the 408's nest failure was a result of tagging or disturbance effects, but rather due to naturally arising conspecific predation by birds of neighbouring nests. The Orford Ness gull colony also suffered apparent mammalian predation, with foxes spotted on the site, and thus breeding failures may have been compounded by the two sources of nest predation.

The other nest that had a camera (that of bird 395) suffered no apparent ill effects following tagging, and continued successfully until 2 July 2010, at which point the nest failed, although the cause of this failure could not be determined.

2.4.2 Great Skuas

The fate of Great Skua nests is summarised in Table 2b. The two birds that lost tags soon after fitting (340 and 342) were subsequently spotted back at their nests behaving normally with their mate, and thus adverse effects of the tagging process were not apparent. The remaining Great Skuas (348 and 349) were monitored at the nest until the 28 June 2010, and during all this time the birds concerned behaved normally.

Immediately after tagging, all Great Skuas went to a nearby pool to bathe, after which time birds returned directly to the nest. A mean period of 1.7 ± 0.4 hrs (max 2.2 hrs) elapsed between a bird's release and its return to the territory or nest.

Table 2 Fate of all (a) Lesser-black Backed Gull and (b) Great Skua nests in this study (one bird tagged per nest). Numbers denote the number of eggs (e) or chicks (c); h = hatching; JDate = Julian date.

(a) Lesser Black-backed Gull

Deployment date	**JDate**	**Tag number**									
		345	**335**	**395**	**384**	**408**	**336**	**334**	**388**	**391**	**407**
05/06/2010	156	2e	3e								
07/06/2010	158	2e									
08/06/2010	159	2e									
11/06/2010	162	2e									
15/06/2010	166	1c	3e	3e	3e	3e	2e	3e	2e	2e	3e
16/06/2010						0					
17/06/2010	168			3e	3e						
23/06/2010	174	0				0	0				
02/06/2010	183	0	0	0	1e	0	0	3e	0	0	3e
11/06/2010	192	0	0	0	0	0	0	0	0	0	0

(b) Great Skua

Deployment date	**JDate**	**Tag number**			
		340	**349**	**342**	**348**
21/06/2010	172	2e			
22/06/2010	173	2e	2e	1e	
23/06/2010	174	2e	2e	1e	2e
24/06/2010	175	2e	2e	1e	2e
28/06/2010	179	1e(1h)	2e	1e	2e

Table 3 Estimated hatching dates of eggs of Great Skua tagged in this study.

Tag number	Date eggs measured	Estimated hatching date	
		Egg 1	**Egg 2**
340	22/06/2010	28/06/2010	27/06/2010
349	22/06/2010	18/07/2010	23/06/2010
342	22/06/2010	22/06/2010	No egg
348	24/06/2010	04/07/2010	02/07/2010

No monitoring data were obtained for Great Skuas past 28 June 2010. For the two birds whose harnesses failed early on, the data collected can be considered to correspond to incubation and foraging.

We calculated Great Skua egg density following Hoyt (1979), and then use a published relationship for Great Skuas on Foula (Furness & Furness 1980) to estimate the likely hatching date.

In particular, these data show that egg 2 of 349 is likely to have failed given that the estimated hatching date was 23/06/2010, and yet on 28/06/2010 the egg was still unhatched. We also cannot say for certain that birds 348 and 349 were definitely incubating, chick-rearing, or were in fact failed birds beyond 28/06/2010. The repeated central place foraging trips of 348 and 349, however, showed no change in duration and distance from the colony in the days post-tagging (see below), suggesting that birds were most likely still incubating or rearing chicks.

2.5 Data collection protocols, post-processing, and analyses

Within the colony area, devices were set to sample on a 30 minute rate to reduce data collection when birds were essentially less active, in a predictable place, and not foraging. However, at-sea data were collected at a variety of sampling intervals: 3 s, 1 min, 5 min, 15 min and 30 min. These rates were initially chosen to assess the performance of the tags and battery consumption. Sampling rates were all numeric multiples to allow filtering of more frequent data to coarser rates as required for fuller investigation of movements.

We initially explored the individual foraging trips for each bird, considering the total distance travelled (total distance between consecutive GPS locations), foraging range (maximum distance from the individual nest site), and trip duration (time of departure to time of return). We also calculated a bearing from the nest to the furthest point visited on each foraging trip (sine transformed). Gaps within the data for foraging trips occurred under more intensive sampling schedules due to greater battery use. Subsequently, the battery was allowed to recharge as the sampling rate was increased. These incomplete trips were excluded from analyses presented here.

In our descriptive statistics, we pooled information for all trips under different sampling regimes, with the caveat that trips under a 30 minute regime have the largest error (± 15 minutes in trip duration). Devices that were attached to birds with the leg-loop methods (345 and 335) suffered some disruption because the feathers of the birds' mantle overlapped with the solar panel, therefore preventing maximum solar charging and influencing our choices of sampling rates for the GPS. We thus selected either 15 or 30 minute rates for these individuals. New parameters can automatically be uploaded to the tags after the tag has been deployed on the bird. Of particular value in this study, was the use of two user-defined latitude-longitude points representing the top-right and bottom-left of a rectangle or 'parameter fence' which can be set around the breeding colony. This 'parameter fence' (of approximately 200 m x 200 m) was used to automatically switch the sampling rate of the tag from quicker rates to one GPS measurement every 30 minutes, and thus helped conserve battery power when the bird was at the nest, This same area was taken to indicate when birds were within and outwith the colony.

2.5.1 Connectivity with the areas of proposed and consented wind farms

In order to understand the connectivity between these features of SPAs investigates, and both consented (i.e. those either already constructed or under construction) and proposed wind farms sites, we examined both the number of birds showing connectivity (here defined as at least one trip showing spatial overlap with the wind farm), and the number of trips made by birds overlapping wind farm zones. These were also expressed in relation to the total number of trips made by birds, both for trips with a marine component, and solely inshore or coastal trips. These interactions were then quantified by spatial and temporal overlap with wind farm zones (see 2.5.2).

2.5.2 Overlap of home ranges with consented and proposed wind farms

2.5.2.1 Spatial overlap

To investigate the overlap of areas the gulls used at sea with consented (i.e. those either already constructed or under construction) and proposed wind farms sites, we used kernel analysis (Worton 1989) to define the foraging 'home ranges' of individual birds during late incubation, and periods following breeding failure. These analyses were carried out twice, firstly using all locations visited by the bird concerned, and secondly including just those that were offshore.

We initially attempted least-squares cross validation (LSCV) for this process, as previously used in kernel analyses for other seabird species (Hamer *et al*. 2007, Thaxter *et al*. 2009, 2010). However, well-known problems with convergence for LSCV were encountered. We followed recommendations to address this issue by introducing random noise into the data, correcting for repeated points being very close together in space that may often be the cause of convergence. However, the kernels produced under this approach with LSCV were not suitable (see Appendix 1 for full details and examples). The reference method (h-ref, or also known as the 'ad-hoc' method), can also be highly biased when used with multi-modal data, the type of data considered here. Therefore we also investigated another method: Brownian Bridge Movement Models (BBMM) (Horne *et al*. 2007), which is based on a random walk between successive locations and is suitable for auto-correlated clustered data. Data were analysed in R version 2.12.1 (R Core Development Team 2010), using additional packages BBMM (Nielson *et al*. 2011), and adehabitat (Calenge 2006). We also produced utilisation distributions for BBMM (see Appendix 1 for full details and examples). While the BBMM approach worked reasonably well, large over-predictions were recorded for two birds in the 95% kernel density estimate (KDE), which produced spurious overlaps with wind farms not encountered by these individuals. Thus, within-bird and within-method variation was apparent.

While each of the methods utilised here had advantages and disadvantages for the data in question, and the ad-hoc smoothing employed can be considered slightly biased, for the purposes of overlap analyses we prioritised this method. Under all methods, the 50% KDEs produced included more than 50% of the total points making up the dataset in question, and therefore may have overestimated the core 50% home range of animals. This issue is especially pertinent for birds where fewer data points were available. This lack of data is also a potential problem, which we acknowledge up-front as a caveat to these analyses. We present the 50% and 95% kernel to represent the core, and total area usage respectively, with a 75% kernel also given. GPS locations were filtered to 5 minutes, 15 minutes and 30 minutes from faster sampling rates to allow progressively more data to be included for assessment in foraging movements. However, final kernels presented here are based on 30 minute data, in order to include data from all foraging trips.

A further 'home range' assessment was also made of the areas of the marine environment where birds may have actively foraged. Following Shamoun-Baranes *et al*. (2011), flight speed was used to categorise periods during which birds were stationary (< 1 km/h), floating or walking (1-4 km/h), or flying (> 4 km/h). These thresholds have previously been supported by measured altitudes in combination with speed (in general, measured altitude < 20 m above ground level and speed < 4 km/h related to 'non-flight') (Shamoun-Baranes *et al*. 2011), suggesting that such speeds would be too low to sustain flight (Shamoun-Baranes & van Loon 2006, Pennycuick 2008). For this 'foraging' analysis, we combined the first two categories above (i.e. excluding flight). This decision, whilst subjective, allows a separate assessment of foraging area usage in relation to offshore wind farms.

2.5.2.2 Time budgets of birds

To further investigate the importance of wind farm zones to birds, we assessed the overall time spent within the wind farm zones as a percentage of the time budgets of individual birds. The number and frequency of trips within each environment were also quantified for each individual. We then assessed the average number of trips across all birds and those that were overlapping with wind farm zones.

2.5.3 Flight altitudes

The GPS tags deployed also record altitude. However, the data on altitude obtained may be limited both in terms of its (1) accuracy (i.e. whether the mean value obtained is correct) and (2) precision (i.e. in the error around the mean). With most GPS systems, the precision of x-y location is considerably better (generally 1.5 times) than that of altitude (possibly up to 15 m error, Ens *et al*. 2008), for the most precise positions. Much of this error is related to the satellite position, which influences the degree of signal distortion between the satellite and the GPS device. This can be quantified through a measurement known as dilution of precision (dop), which is calculated in several different planes. Positional dop (pdop) gives an overall rating of precision for altitude, latitude and longitude. Typically pdop values of less than ten are thought suitable for x-y location (the lower the pdop value, the greater the precision), and thus altitude accuracy follows suit. Pdop values are generally good when there are a large number of evenly distributed satellites in the sky.

However, the earth cannot be described by a simple mathematical shape; GPS manufacturers use models to estimate altitude relative to the modelled earth, from which it is not possible to produce a perfect fit. This produces an accuracy error, i.e. accuracy with reference to a known point, in this case the sea surface. This variation in accuracy can reach up to 40 m below zero in places. Corrections for this bias for known locations can be used to refine this procedure.

In order to assess the altitude at which birds flew offshore, we thus investigated data from the GPS at known altitude in the field. This was achieved in two ways:

(1) Firstly, on 10 December 2010 we conducted a ground-truthing test of a sample tag (not used for tagging in the study) at Orford Ness to assess sampling rates at known altitudes. We tested the sampling parameters used (3 s, 1 min, 5 min, 15 min and 30 min). This test, however, was slightly confounded, as when the GPS calculates position (and altitude), it uses information from previous measurements because positions of satellites are stored in its memory. Theoretically, this means that the shorter the interval between measurements the more accurate the measurement. However, as soon as there is a gap of more than 2 hours between two valid measurements, the satellite information is discarded and the process starts anew. The same issue is encountered when the device is 'reset', and thus loses stored information for the next fixes. Magnets are used to force the tag to communicate with the system, which impel the logger to upload new parameters. This frequently occurred during the trial. Thus, the first measurements (approximately 15 minutes) are less accurate, and were thus removed before further processing. Further ground-truthing will also be carried out during 2011 at both Foula and Orford Ness.

(2) Secondly, we investigated the altitudes recorded during periods of time when birds registered speeds at sea of less than 4 km/hr, which were indicative of birds not thought to be in flight (Shamoun-Baranes *et al*. 2011).

Accuracy here suggests the amount by which flight altitudes would need to be corrected by, or calibrated by, to match to known sea level. Thus for both Lesser Black-backed Gulls and Great Skuas, we initially assessed flight altitudes distributions with histograms and looked for any biases in the peaks therein.

We also undertook a descriptive investigation into the precision of the GPS tags, reflected in the remaining uncertainty we have around the distribution. We firstly removed apparently "less precise" measurements from the dataset. Less precise measurements were filtered out according to their "vertical accuracy" (distinct to our definition of distribution accuracy above), the number of satellites available for fixes (the larger number of which increases the precision of the altitude measurement), and the position of the satellites in the sky, as assessed by pdop. Appropriate cut-off points in these variables were obtained by individual histogram plots, generally selected as: vertical accuracy ≤ 5 m, pdop ≤ 2.0, and ≥ 5 satellites for a fix (although this was investigated as ≤ 10 m vertical accuracy and pdop ≤ 3.0 for Great Skuas, due to slight differences in appropriate cut-offs in the distributions). We were therefore able to examine distributions of altitude recorded in relation to known sources of error (see below), and also evaluate these distributions at different sampling rates.

2.5.4 Formal statistical tests

For formal tests, we used generalized linear models (GLMs) for data with normal errors, and generalized linear mixed-effects models (GLMMs) for those with Poisson or binomial error distributions. To account for repeated foraging trips made by individual birds, 'bird identity' (BirdID) was included as a random effect. All GLMs used F-tests and GLMMs used χ^2 tests to assess the significance of effects and interactions, with the most significant variables selected through step-wise forward selection. General additive mixed-effects models (GAMMs) were also used to represent relationships in the data that were non-linear (foraging range and trip duration). Values are given as the mean ± 1 SD unless otherwise stated. All analyses were performed using R Version 2.12.0 (R Development Core Team 2010).

3. RESULTS

3.1 Descriptive trip statistics

3.1.1 Lesser Black-backed Gull

Descriptive data for Lesser Black-backed Gulls are shown in Table 4. We recorded a total of 352 trips from ten Lesser Black-backed Gulls, of which 70 contained a marine component (i.e. foraging at sea) and 282 were solely terrestrial. These terrestrial trips, however, included many short trips just outside the colony to nearby fields, so may have comprised some loafing behaviours. The maximum distance from the colony recorded was during a marine trip, at 159 km (bird 407). During this trip, bird 407 covered 801 km in 98 hours. However, this bird experienced nest failure by this time, and was therefore no longer constrained by central place foraging.

Trips of Lesser Black-backed Gulls increased in both trip duration (linear tweedie model with Julian date fixed, birdID random: $\beta = 0.095 \pm 0.011$, $t_{358} = 8.869$, $P < 0.001$) and distance reached from the colony as the season progressed ($\beta = 0.054 \pm 0.011$, $t_{358} = 4.998$, $P < 0.001$). This pattern could have been because birds failed, and thus were no longer constrained to a central place. We had a reduced dataset with which to test this assertion (N = 44 active trips; N = 102 failed trips), however we detected no significant difference between active and failed nests after controlling for Julian Date and whether trips included offshore habitat use, for either foraging range reached ($\beta = 0.333 \pm 0.392$, $t_{133} = 0.850$, $P = 0.397$), or trip duration ($\beta = 0.717 \pm 0.477$, $t_{133} = 1.503$, $P = 0.135$). Indeed one bird whose nest failed near the start of deployment (408), did make significantly longer and more distant trips over Julian date (negative binomial GLM for trip duration accounting for marine/terrestrial trips: $\beta = 0.095 \pm 0.022$, Deviance explained$_{1,55}$ = 22.442, $P < 0.001$; negative binomial GLM for distance: $\beta = 0.060 \pm 0.027$, Deviance explained$_{1,55}$ = 6.116, $P = 0.013$). However, some birds such as 395, did not show any trends after they failed (all tests, $P > 0.05$).

Trips that included a marine component were also longer in duration ($\beta = 0.824 \pm 0.174$, $t_{358} = 4.724$, $P < 0.001$), and to regions farther from the colony ($\beta = 1.427 \pm 0.154$, $t_{358} = 9.278$, $P < 0.001$), than those that were solely terrestrial. These differences were apparent after controlling for Julian date, since a significant increase in the number of marine trips were made as the season progressed (binomial GLM: $\beta = 0.084 \pm 0.022$, $t_{359} = 3.856$, $P < 0.001$). Interestingly however, an increasing number of marine trips were also made after birds failed ($\beta = 2.433 \pm 0.777$, $t_{135} = 3.132$, $P = 0.002$), albeit assessed from a reduced dataset.

Most birds made at least three trips to sea. However, the proportion of these offshore trips varied significantly between birds (binomial GLM birdID as fixed effect: Deviance explained$_{9,360}$ = 62.560, $P < 0.001$). The birds with most offshore trips were: 334 (50%), 336 (47%), 408 (32%), and 407 (24%), whereas two individuals (birds 384 and 388) made no offshore trips.

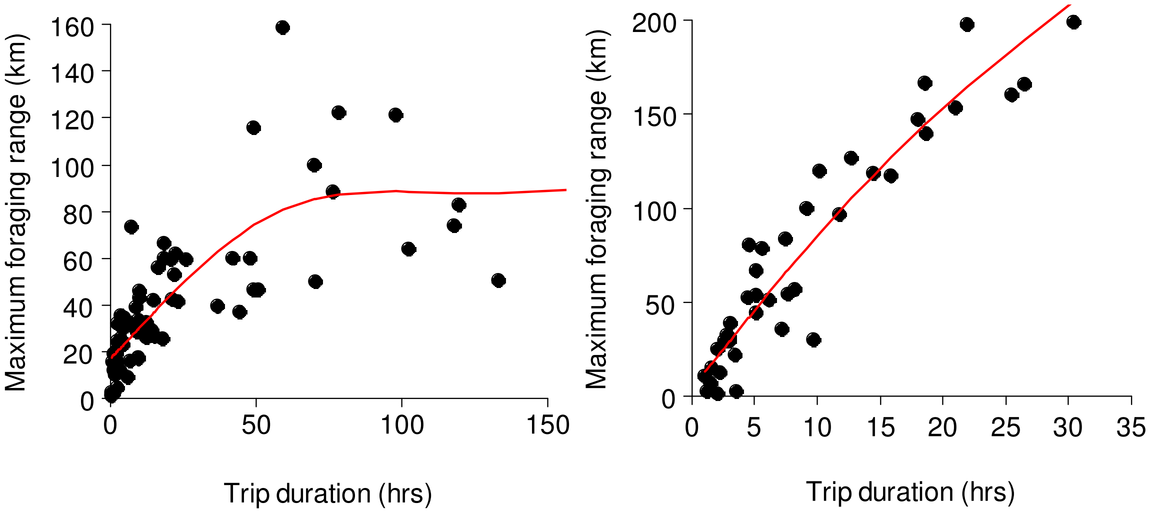
In this study we tagged seven males and two females, with the sex of the remaining bird uncertain, but likely female (one other male 347 was tagged but the device did not remain on the bird – see methods). Although the sample size is not sufficient to draw firm conclusions, we detected no sex differences in maximum distance reached ($t_8 = 1.078$, $P = 0.313$), nor total trip duration ($t_8 = 0.943$, $P = 0.373$).

For all marine trips (from both failed and active nests), there was also a significant relationship between trip duration and distance reached per trip from the colony ($\beta = 0.017 \pm 0.001$, df = 359, F = 15.726, $P < 0.001$). A mixed effect GAMM gave an improvement to this relationship (Res.Df = 66.438, df = 1.562, F = 16.347, $P < 0.001$). There appears to be a likely maximum constraint on foraging range of around 85 km for Lesser Black-backed Gulls from the GAM, though a broken stick model (Daunt *et al*. 2002) may yield a more precise upper maximum. Compared to Great Skuas, much longer trip durations were recorded, although this could be because we have included Lesser Black-backed Gulls trips where birds were not tied to central place foraging (after nest failure). However, the data highlight that gulls still returned to the colony even after failure, and in doing so appeared to have a maximum foraging range from the breeding colony (Figure 2a). However, the pattern of their movements at this time may also be constrained by their post-breeding migration towards Southern Spain and beyond, which is in the opposite direction to their breeding season trips to the North Sea.

Table 4 Descriptive trip statistics for Lesser Black-backed Gulls for (a) all trips combined, (b) marine trips and (c) terrestrial trips. Mean here denotes the mean maximum of all trips.

(a)	No.	Foraging range (km)		Total distance travelled (km)		Trip duration (hrs)		
Bird	Trips	Max	Mean+SD	Max	Mean+SD	Max	Mean+SD	Mean bearing
334	14	88.56	32.6±34.71	677.9	208.35±269.54	133.2	39.37±50.55	-0.41±0.63
335	28	41.34	13.61±10.56	450	62.16±100.85	149.4	18.16±34.83	-0.09±0.71
336	38	66.29	18.88±19.34	302.6	65.93±77.59	70.33	10.18±14.21	-0.03±0.7
345	39	107.5	19.86±29.93	732.6	83.03±153.9	166.7	14.7±29.34	-0.14±0.74
384	10	35.69	6.59±10.58	102.2	18.59±30.74	23.29	6.59±8.31	-0.37±0.78
388	39	22.6	5.28±6.24	97.91	18.49±23.81	46.52	7.73±9.9	0.05±0.75
391	70	39.24	7.34±9.12	108.6	19.31±25.32	11.58	2.72±2.63	0.14±0.73
395	26	32.18	6.74±8.86	86.71	19.57±27.46	73.89	7.47±14	-0.1±0.62
407	33	158.6	22.47±43.55	801	99.17±223.94	98.16	12.26±23.82	-0.12±0.66
408	55	99.57	13.49±20.08	513.1	46.02±89.63	102.4	8.03±16.9	-0.16±0.72
(b)								
334	7	88.56	63.88±18.11	677.9	414.21±241.94	133.2	75.55±49.78	-0.55±0.33
335	2	41.34	26.79±20.57	172.2	99.53±102.82	23.43	12.31±15.72	-0.19±1.12
336	18	66.29	33.35±19.21	302.6	120.46±82.32	70.33	15.59±17.25	-0.21±0.49
345	5	107.5	58.75±31.71	732.6	338.33±251.22	166.7	62±61.8	0.15±0.72
391	9	39.24	23.61±8.53	108.6	64.04±28.2	8.77	3.66±2.81	-0.07±0.9
395	3	32.18	29.82±2.81	86.3	79.36±6.07	15.16	9.46±6.29	0.03±0.93
407	8	158.6	83.47±53.85	801	388.9±319.04	98.16	42.31±34.48	0±0.38
408	18	99.57	31.54±25.73	513.1	119.64±128.42	102.4	17.8±27.19	-0.07±0.77
(c)								
334	7	2.89	1.33±1.05	6.01	2.5±2.2	6.06	3.19±2.06	-0.28±0.83
335	26	35.35	12.6±9.41	450	59.29±102.18	149.4	18.61±36.02	-0.09±0.7
336	20	17.7	5.85±4.65	74.39	16.84±17.49	39.91	5.32±8.62	0.13±0.83
345	34	98.46	14.14±25.44	363.3	45.49±91.09	58.81	7.74±11.8	-0.18±0.74
384	10	35.69	6.59±10.58	102.2	18.59±30.74	23.29	6.59±8.31	-0.37±0.78
388	39	22.6	5.28±6.24	97.91	18.49±23.81	46.52	7.73±9.9	0.05±0.75
391	61	34.8	4.94±6.36	89.86	12.71±16.93	11.58	2.58±2.6	0.17±0.7
395	23	10.26	3.73±2.51	86.71	11.77±17.39	73.89	7.22±14.79	-0.12±0.6
407	25	25.4	2.94±6.78	57.72	6.46±15.46	15.77	2.65±3.57	-0.16±0.73
408	37	22.25	4.7±7.06	48.15	10.21±15.28	12.15	3.28±2.86	-0.21±0.7

Figure 2 Relationship between trip duration and foraging range for (a) Lesser Black-backed Gulls, and (b) Great Skuas for marine trips only.



3.1.2 Great Skua

We recorded a total of 88 trips from four Great Skuas (Table 5). However, the amount of data per bird varied considerably, ranging from only 1.21 days for one bird (342) to 36 days for another (349). The first bird tagged bird (340) made a trip out to sea of 117 km, but lost its tag thereafter.

Most data came from the tags of birds 348 and 349 (Table 5), with a maximum distance of 219 km from the colony recorded. These birds were targeting an offshore continental shelf mid-way between Shetland and the Faroe Islands. All breeding season trips were focused towards the north-west of the colony, but some excursions at the colony were also recorded, with some loafing / bathing, where absences of 1 hour were typical.

Colony-focused trips by Great Skuas were much shorter than offshore trips (Table 5). Excluding colony trips to focus on those offshore trips, albeit with a low sample size, did not show any increasing tendency for longer duration (GLMM with Poisson error: $t_{1,37}$ = -0.236, P = 0.815) or maximum foraging range (GLMM with Poisson error: $t_{1,37}$ = 0.214, P = 0.832) as the season progressed (most data from bird 349).

Not surprisingly, more distant trips were also much longer in duration (GLMM: $\beta = 0.071 \pm 0.006$, $t_{1,37} = 11.141$, $P < 0.001$). However there appeared to be no maximum constraint on this relationship. From the relatively few data we present here, we also tried fitting this relationship as a mixed effects GAMM, which gave a superior model fit compared to a linear model (F = 6.336, Res.Df = 38.202, df = 0.798, P = 0.022) (Figure 2b).

Table 5 Descriptive trip statistics for Great Skuas for (a) marine trips and (b) trips away from the nest at the colony (e.g. for loafing, bathing). Mean here denotes the mean maximum of all trips.

(a)	No. trips	Foraging range (km)		Total distance travelled (km)		Trip duration (hrs)		Mean bearing
Bird		Max	Mean+SD	Max	Mean+SD	Max	Mean+SD	
340	1	117.01	117.01	259.43	259.43	15.85	15.85	-0.94
348	15	126.43	49.88±35.53	274.27	106.15±76.88	12.74	4.78±3.18	0.07±0.70
349	25	218.68	92.38±69.82	579.14	211.37±166.52	30.45	12.26±9.45	-0.01±0.75
(b)								
340	4	1.26	0.84±0.50	2.53	1.68±1.00	1.51	1.14±0.25	0.20±0.75
342	4	1.49	0.8±0.55	3.08	1.42±1.25	1.56	1.15±0.27	0.45±0.95
348	10	1.34	0.95±0.36	2.70	1.90±0.72	1.58	1.08±0.24	-0.53±0.51
349	29	1.39	0.78±0.28	2.79	1.56±0.58	1.18	0.90±0.18	-0.36±0.51

3.2 Connectivity with the areas of proposed and consented wind farms

3.2.1 Lesser Black-backed Gull

Overall, six out of the ten Lesser Black-backed Gulls for which we had data showed connectivity with offshore wind farms (see Table 7 later for full details). Across all birds, an average of 3.2 ± 3.4 trips were made that showed overlaps with offshore wind farms, which was relatively few considering the total average number of 35.2 ± 17.8 made by all birds. However, many of this total number were smaller trips just outside the colony. Of these six birds, all showed connectivity with the East Anglia Round 3 Zone, four with Round 2 zones, one (407) with Round 1 zones, and four with Extensions to Round 1 or 2. These are quantified further in terms of time budgets in section 3.4.

3.2.2 Great Skua

Great Skuas showed no connectivity to any consented or proposed wind farms during the breeding season.

3.3 Overlap of home ranges with consented and proposed wind farms

3.3.1 Spatial overlap

3.3.1.1 Lesser Black-backed Gull

Analysis of the offshore foraging range of gulls (see above) indicated that several consented and proposed wind farm zones were within foraging range of the Orford Ness colony. These included both consented Round 1 and Round 2 wind farms, as well as proposed Extensions to Round 1 and Round 2 sites, and the East Anglia Round 3 Zone.

Table 6 provides example details of kernel 'home range' overlaps for four individual birds in relation to Round 1, Round 2, Extensions, and Round 3 zones. Kernels for both total offshore use and foraging (< 4 km/h) movement speeds are also shown. For foraging area distributions, initial histograms for movement ground speeds for each individual are shown in Figure 2 for Lesser Black-backed Gulls. These also give further weighting to use of the chosen cut-off for distinguishing flight (> 4 km/h), from resting or foraging (< 4 km/h). We combined different sampling units for this assessment because there was no apparent difference in the distribution of speeds from different sampling regimes (i.e. comparing 3 s to 60 s to 5 mins etc) (all Kolmogorov-Smirnov tests of proportional distributions: P > 0.1). Thus we are confident that the kernels produced are representative of the foraging distribution.

Figure 3 Comparison of flight speeds under different sampling rates from Lesser Black-backed Gull 407, as justification for pooling together filtered 'foraging' data at the 30 minute level for kernel analysis.

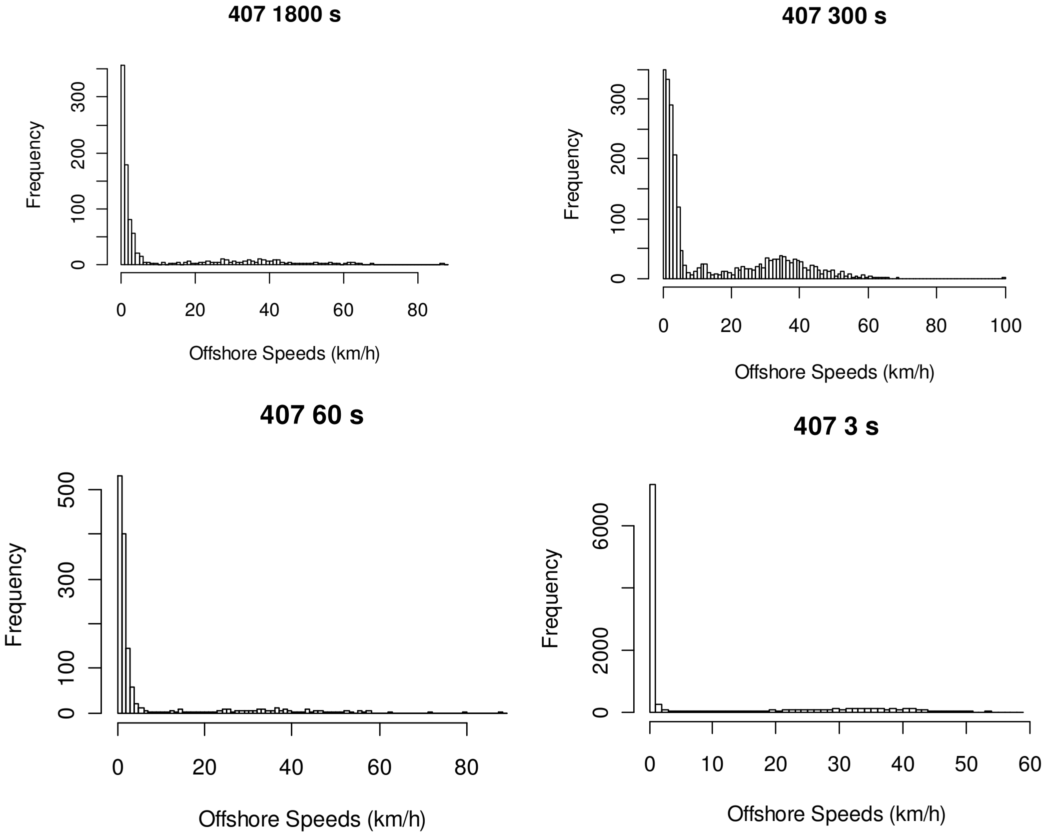


Table 6 provides example details of the percentages of the 50% (core), 75% and 95% (total) kernel density estimates (KDEs) for four offshore-foraging Lesser Black-backed Gulls that overlapped with offshore wind farm zones. Figure 3 provides the associated maps for this subset of birds that foraged offshore. Of the ten birds contributing data, only four showed sufficient overlap to warrant valid kernel analyses; these were birds 334, 336, 407, and 408 (Figure 3). The remaining birds either did not forage at sea at all (384, 388) or made too few trips to reliably assess use of marine areas (335, 345, 391, 395). Thus use of space by the gulls was highly variable.

The areas of Round 1, Round 2, and Extension wind farms (8.8 km^2, 146.5 km^2, 174.8 km^2) in the vicinity of the colony were much smaller than the area of the nearby East Anglia Round 3 Zone (6036.8 km^2).

Of the four birds for which offshore data are presented, the largest overlaps were for tagged birds 407 and 408, with 48.5% and 46.7% of bird 408's "offshore" and "foraging area" 95% KDEs respectively overlapping the East Anglia Round 3 Zone (Table 6). As a result of the smaller overall areas of the other wind farms (Round 1, Round 2, and Extensions), their percentage inclusion in individual bird KDEs was much lower than for the Round 3 Zone (Table 6).

Table 6 Example details of the percentage of the 50% (core), 75% and 95% (total) kernel density estimates (KDEs) for four offshore-foraging Lesser Black-backed Gulls that overlapped with offshore wind farm zones. Data were assessed for both total offshore use, and 'foraging' use, that latter encompassing areas used more intensively (see text for details).

Tag number	Round	Offshore KDE overlap (%)			Forage KDE overlap (%)		
		50	75	95	50	75	95
334	Round 1						
	Round 2	0.62	1.84	2.22	0.69	2.34	2.38
	Round 3	24.90	18.58	29.33	23.85	26.70	31.13
	Ext	7.33	4.70	2.57	7.66	5.30	2.68
336	Round 1						
	Round 2	0.97	5.22	3.21	4.49	5.34	3.04
	Round 3	11.31	18.79	23.95	24.85	26.18	25.24
	Ext	10.26	6.26	3.83	10.77	6.37	3.63
407	Round 1			0.07			0.07
	Round 2						
	Round 3	39.82	53.04	33.24	9.57	51.66	36.57
	Ext						
408	Round 1						
	Round 2			1.47			1.10
	Round 3	26.18	47.94	48.48	37.15	49.63	46.69
	Ext		0.93	1.78		1.18	1.67

Figure 4 Example offshore foraging distributions of Lesser Black-backed Gulls in relation to offshore wind farms, using (a) all data, and (b) 'foraging' area (encompassing resting and foraging). Purple = Round 2 zones, light blue = Extensions and Round 3 zones, blue= Round 1 zones.

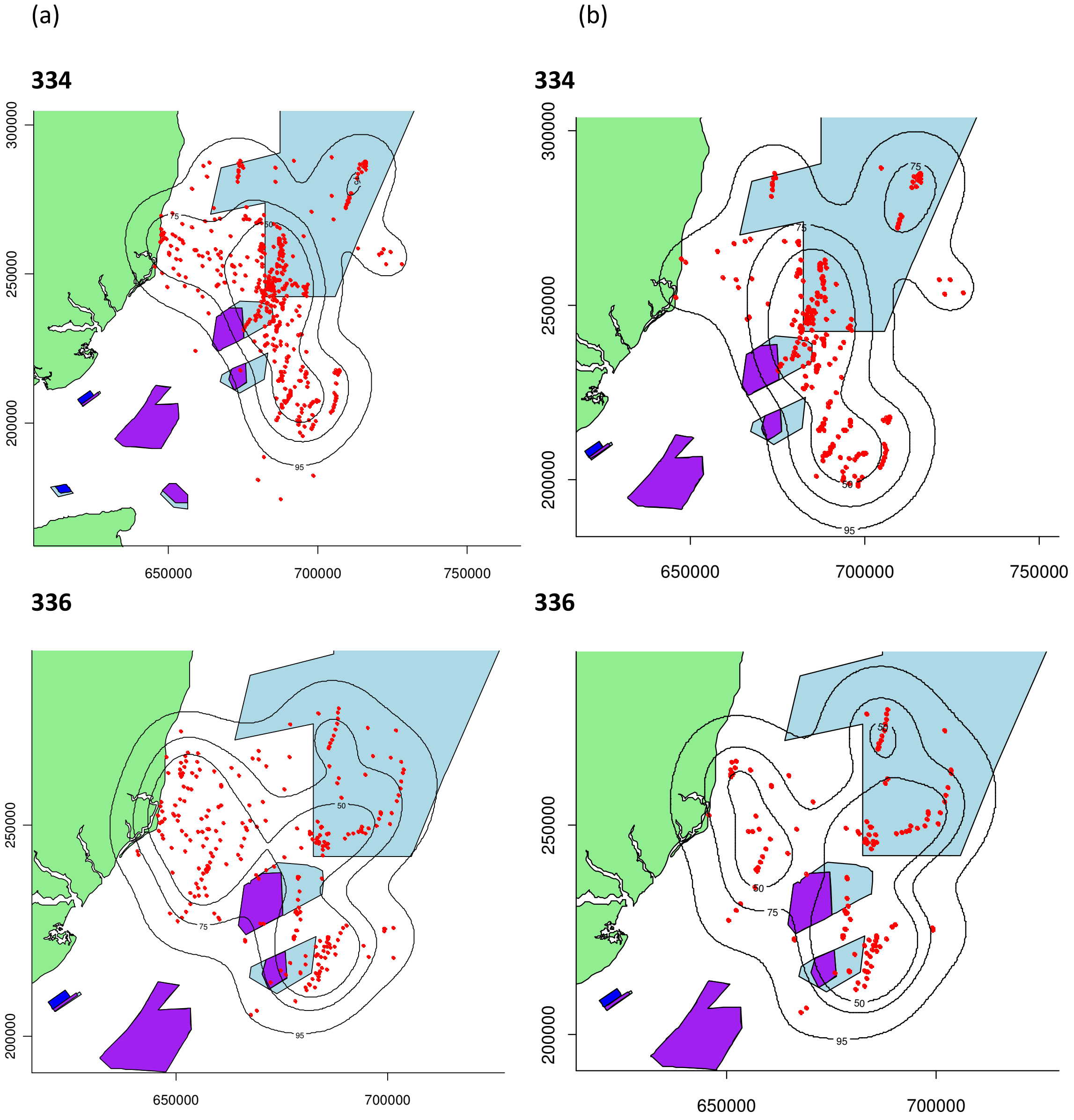
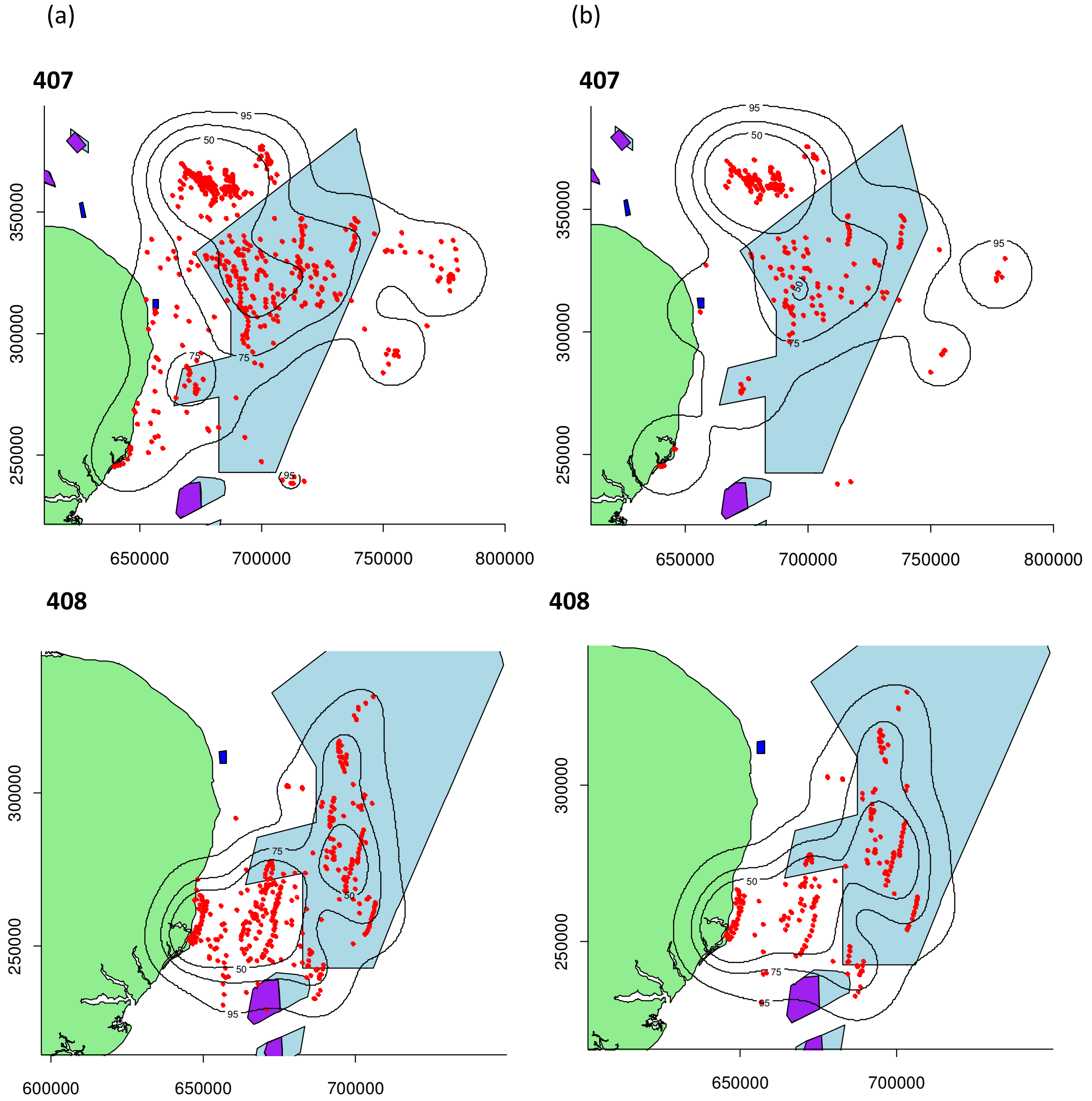


Figure 4 cont. Example offshore foraging distributions of Lesser Black-backed Gulls in relation to offshore wind farms, using (a) all data, and (b) 'foraging' area (encompassing resting and foraging). Purple = Round 2 zones, light blue = Extensions and Round 3 zones, blue= Round 1 zones.



3.3.1.2 Great Skua

We used the same speed criteria to distinguish foraging/resting behaviours from likely flight for Great Skuas as Lesser Black-backed Gulls, with the same cut-off point of 4 km/h in the data being apparent. However, there were no wind farms of any Round located within the vicinity of breeding season foraging locations, and therefore no overlap was detected (Figure 5). All birds tagged in 2010 were believed to have lost their tags prior to migration and thus the movements of these birds through offshore wind farm zones elsewhere can not be ascertained. However, it is hoped that data from birds to be tagged in 2011 will reveal more about their movements.

For comparison with the results for Lesser Black-backed Gulls, we produced kernels for the two Great Skuas around the colony for which sufficient data were obtained. These descriptive data highlight how Great Skuas focused foraging activity in an area west of Shetland into deeper waters on the edge of the Faroe-Shetland Channel towards the oceanic trench (Figure 4), with birds also making repeated trips to similar locations (Figure 6).

Figure 5 Summary of all Great Skua data (four birds) in relation to seabed topography and location of the Faroe Islands**.**

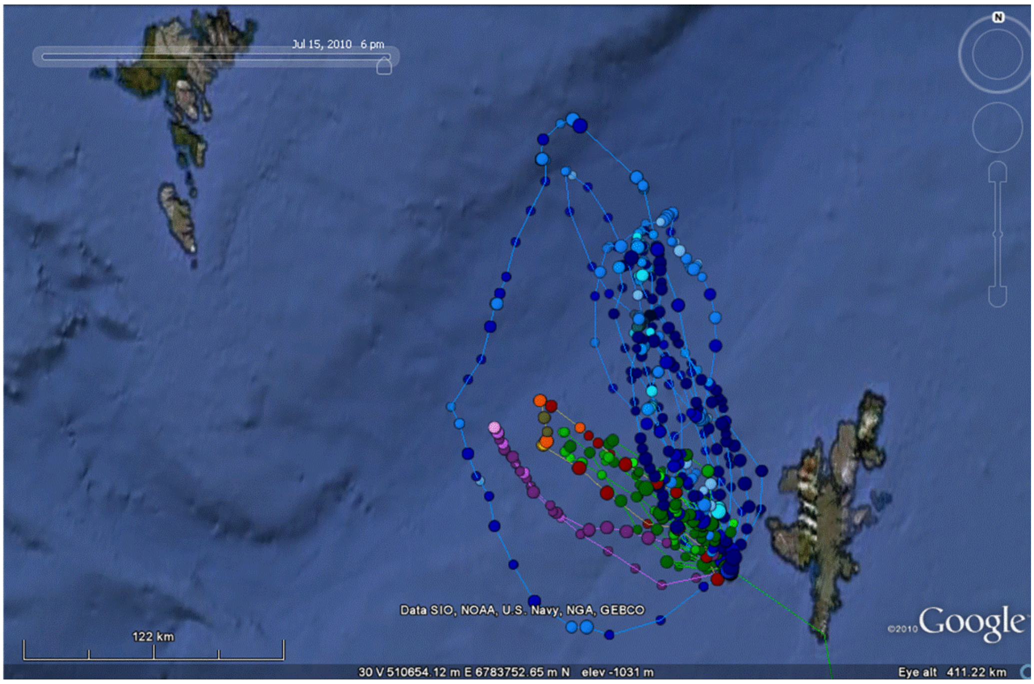
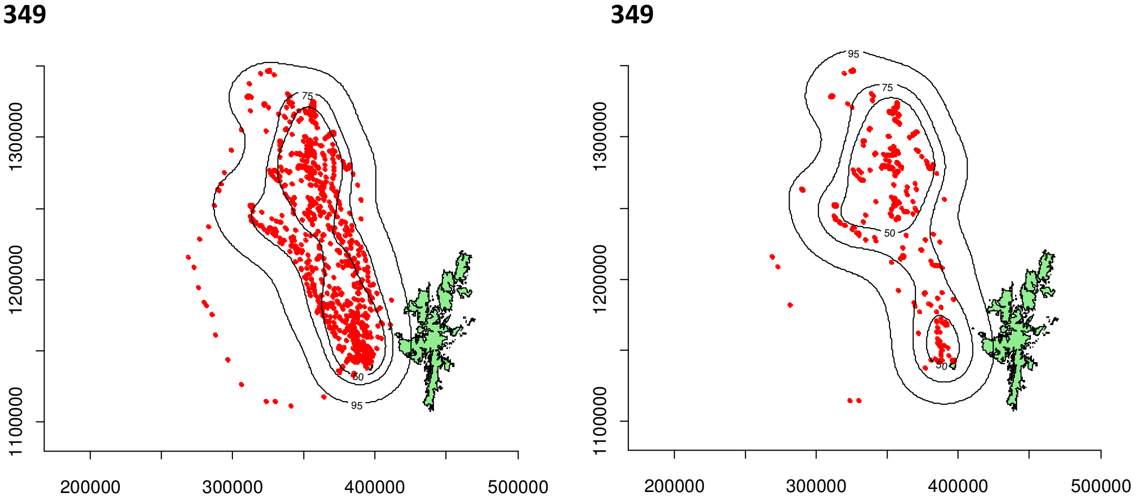


Figure 6 Example kernel analysis for two Great Skuas (348 and 349) with adequate data for (a) all data, and (b) 'foraging' area (encompassing resting and foraging).

(a)



(b)

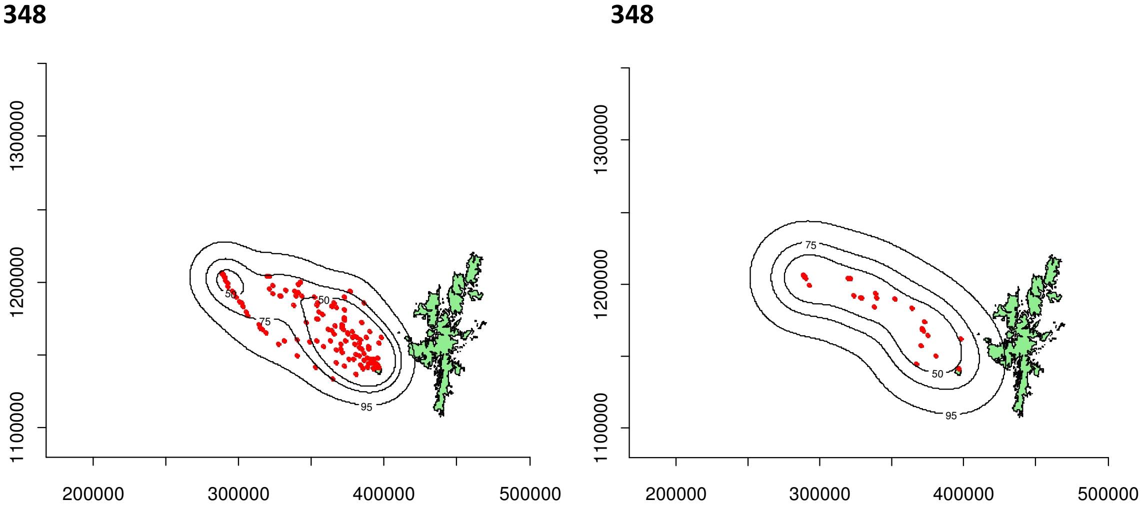
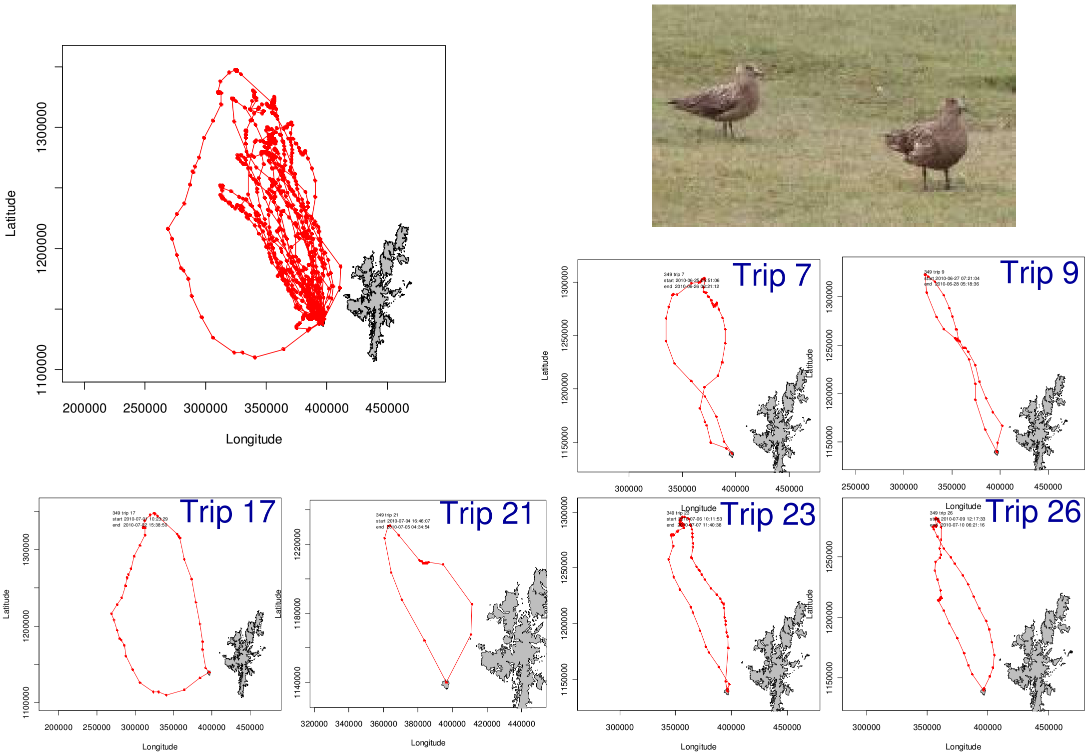


Figure 7 Example foraging area fidelity for Great Skua 349 showing repeated long trips to the northwest of the colony.



3.3.2 Time budget analysis

3.3.2.1 Lesser Black-backed Gull

Of the ten birds for which we obtained data, we recorded 352 complete foraging trips. Of these ten birds, six made foraging trips that interacted with wind farm zones (Table 7). Note, the data presented here encompasses the birds' entire time budgets and thus the results reported are not directly comparable with the spatial overlap analysis which considered only offshore foraging trips.

Not surprisingly, the greatest degree of overlap in the time spent by Lesser Black-backed Gulls on trips away from the nest with offshore wind farm zones was with the large East Anglia Round 3 Zone. The largest amount of overlap per bird was 7.49% for bird 407 (Table 7). Across all birds that showed overlaps, 3.6 ± 2.9% temporal overlap was shown for this Round 3 zone. Across all birds, less than 1% of time was spent in Round 1, Round 2, and Extensions zones combined, related to the smaller area of these zones (Table 7).

Examining the same data for just time spent away from the nest gave a higher temporal percentage overlap: for Round 3: 13.8 to 26.2% (mean 11.4 ± 9.8%), for Round 2: 0.1-0.5% (mean 0.3 ± 0.2%), for Round 1: < 0.01%, and for Extensions: 1.8 to 2.0% (mean 1.1 ± 1.0%).

Table 7 Time spent by Lesser Black-backed Gulls on trips away from the nest in offshore wind farm (WF) zones in relation to the overall time budget of the bird. Data were assessed separately for each round of wind farms and Extensions.

Tag no.	No. trips	No trips in WF	Time at sea and nest	Time in WF (hrs)				Time budget in WF (%)			
				Round 1	Round 2	Round 3	Ext	Round 1	Round 2	Round 3	Ext
334	14	7	1428.7		1	76.3	10.9		0.07	5.34	0.76
335	28	0	1382.8								
336	38	7	1148.9		1.8	34.2	6.8		0.16	2.98	0.59
345	39	3	1535.4		0.5	10.9	1.9		0.03	0.71	0.12
384	10	0	341.6								
388	39	0	1241.9								
391	70	1	891.3			0.6				0.07	
395	26	0	580.7								
407	33	6	1412.0	0.1		105.8		0.01		7.49	
408	55	8	1511.9		0.9	76.9	0.8		0.06	5.09	0.05
Mean	35.2	3.2	1147.5	0.1	1.1	50.8	5.1	0.0	0.1	3.6	0.4
SD	17.8	3.4	412.7		0.5	41.8	4.7		0.1	2.9	0.3

3.3.2.2 Great Skua

For Great Skuas, there were no wind farms located within the vicinity of foraging locations, and therefore no overlap was detected.

3.4 Altitude

We evaluated altitude data obtained from the GPS tags in terms of both (1) accuracy, and (2) precision of the data. This preliminary assessment of the altitude data is presented using results from a trial at the breeding colony at Orford Ness, for two example Lesser Black-backed Gulls that foraged offshore, and a single Great Skua for which most data were available.

3.4.1 Test tag at Orford Ness

These tests were conducted through the tide cycle but resultant data encompassed mainly the mid-tide period. The tag was taken to particular points at the shore and in the gull colony itself (both at known 'zero' altitude). An example of one of the locations, where the tag was set at a 3 s sampling rate is shown below in GoogleEarth© – note here the details for the point selected (typical of others at that location). This was at a time when it was mid-tide, but the apparent altitude given was 7 m below sea level (Figure 7).

Figure 8 Example of 3 s sampling rates at a location along the shore.

Table 8 Tides on 10 December 2010 for the testing of GPS tag, with tide heights and estimated mid-tide height based on the mid-point of high and low. Note mid-tide here is *ca*. 1 m above low tide.

Tide	Time	Height (m)
High	01:07	2.5
Low	07:19	0.3
Mid	09:58	**1.0**
High	14:07	2.3
Mid	16:46	**0.7**
Low	19:25	0.9

The GPS provides altitude measurements relative to mid tide, and in essence takes this point as zero. Thus the device was actually measuring relative to 1 m above low tide (Table 8). Retaining mid-tide as a reference and observing birds through high tide would have meant correcting by 2.3-1.0 = 1.3 m, i.e. at high tide the tag would register an altitude 1 m lower than reality. In this experiment, however, the majority of measurements were taken at mid-tide and thus require negligible correction. A summary of the data are shown in Table 9.

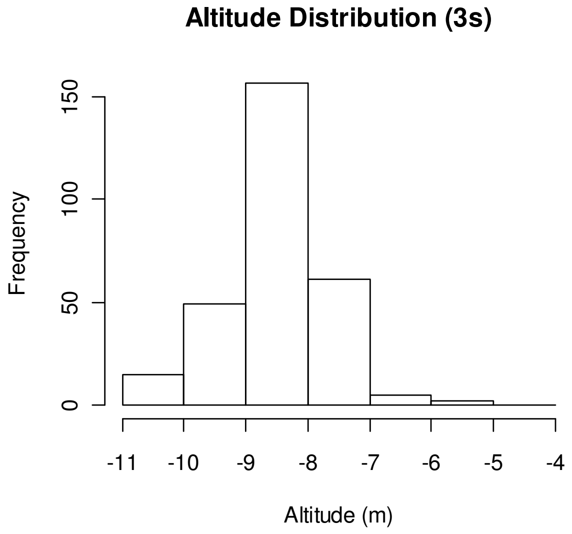
Table 9 Total number of trial GPS fixes available for assessment.

Tag location	3 s	60 s	300 s	1800 s	TOTAL
Gull colony		4	1	2	7
In transit	197	9		1	207
At shore	289	7			296
TOTAL	486	20	1	3	510

Data for 60 s rates often did not store altitude information, most likely related to the resetting issue. The total number of fixes available for use was 510 (Table 9). Of these, the majority were set at a 3 s sampling interval (95%, n = 486), and of the 3 s rates 289 fixes (60%) were at a location at the shore on the ground (34% all fixes in the test).

The test tag taken to Orford Ness therefore provided data restricted mainly to a 3 s rate (theoretically the most accurate rate for altitude) (Figure 8). The distribution for the data in Figure 8 showed a rather small error: -8.00 ± 0.85 m (range -11 to -5 m), with a maximum of ± 3 m surrounding the 3 s distribution. The result suggests a high confidence in the precision of these data, but that a correction would be needed to allow for the discrepancy from zero. The data underlying Figure 6, were also accurate in terms of both pdop (2.77 ± 1.02, range: 1.7-5.3) and number of satellites (7.62 ± 0.73, range: 6-9).

Figure 9 Histogram of altitude for fixes at the 'accurate' 3 s rate when the tag was at the shore, and the tag had been active for at least 10 minutes after the last magnet reset (total of 289 fixes).



3.4.2 Species altitude data: Lesser Black-backed Gull

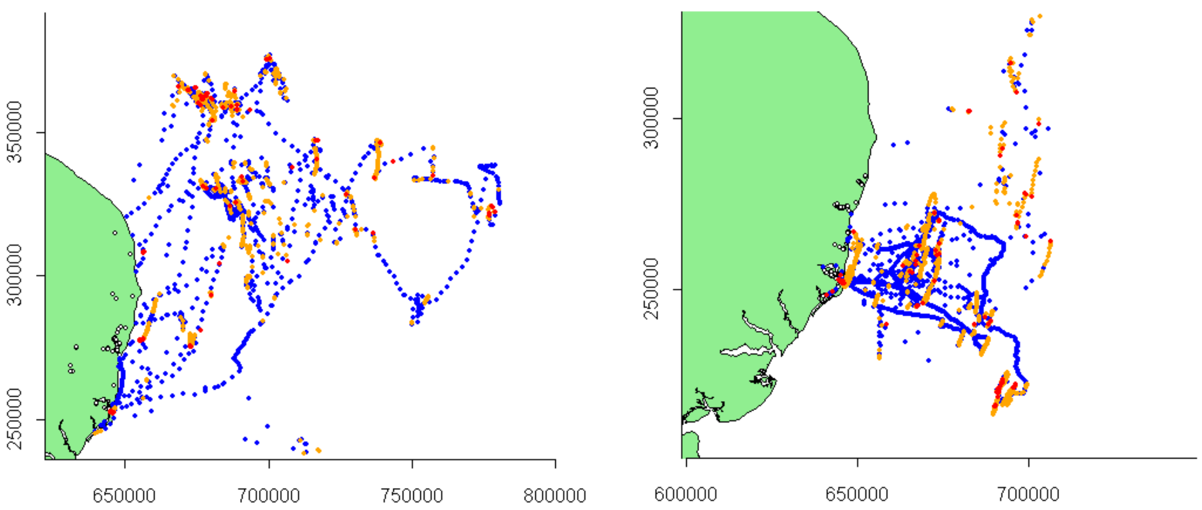
A substantial amount of data was collected for Lesser Black-backed Gulls during the breeding season. Data for numerous foraging tracks recorded at a fast-sampling rate were also available. Figure 9 shows tracks of a bird (391) foraging both offshore and inland. A closer look at particular foraging areas reveals the detail that it is possible to capture, whereby the bird was clearly seen building altitude and dropping altitude at sea. This foraging trip looks clear cut, but nevertheless, we also recorded numerous tracks where negative altitudes were also recorded at sea.

Figure 10 Example of raw altitude data obtained from Lesser Black-backed Gull 391.

3.4.2.1 Accuracy

Here, we present example information for two offshore-foraging birds to show the merit of the altitude data recorded from the GPS devices. We also filtered the data for offshore points, and then investigated the subset of points that corresponded to when the bird was stationary, slowly moving (i.e. swimming), and in faster transit (i.e. flight). These distinctions were plotted for the two birds tested here in Figure 10 below.

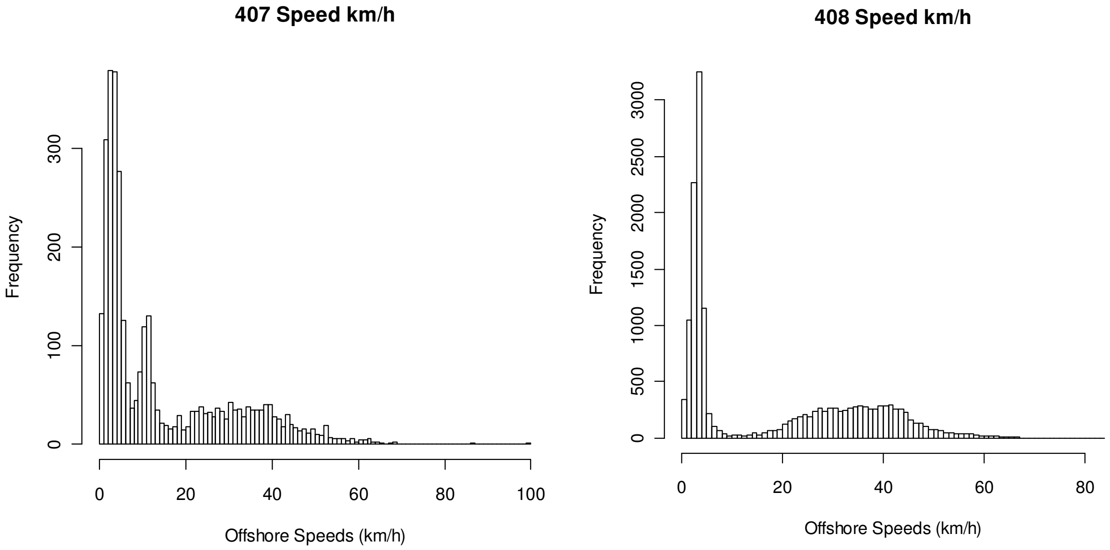
Figure 11 Offshore fixes for Lesser Black-backed Gulls (a) 407 and (b) 408 subdivided by likely activity. Blue (> 4 km/h) flight, orange (1-4 km/h) resting/walking/swimming, and (red) < 1 km/h, most likely resting only; inshore points are shown as white circles.


(a)

(b)

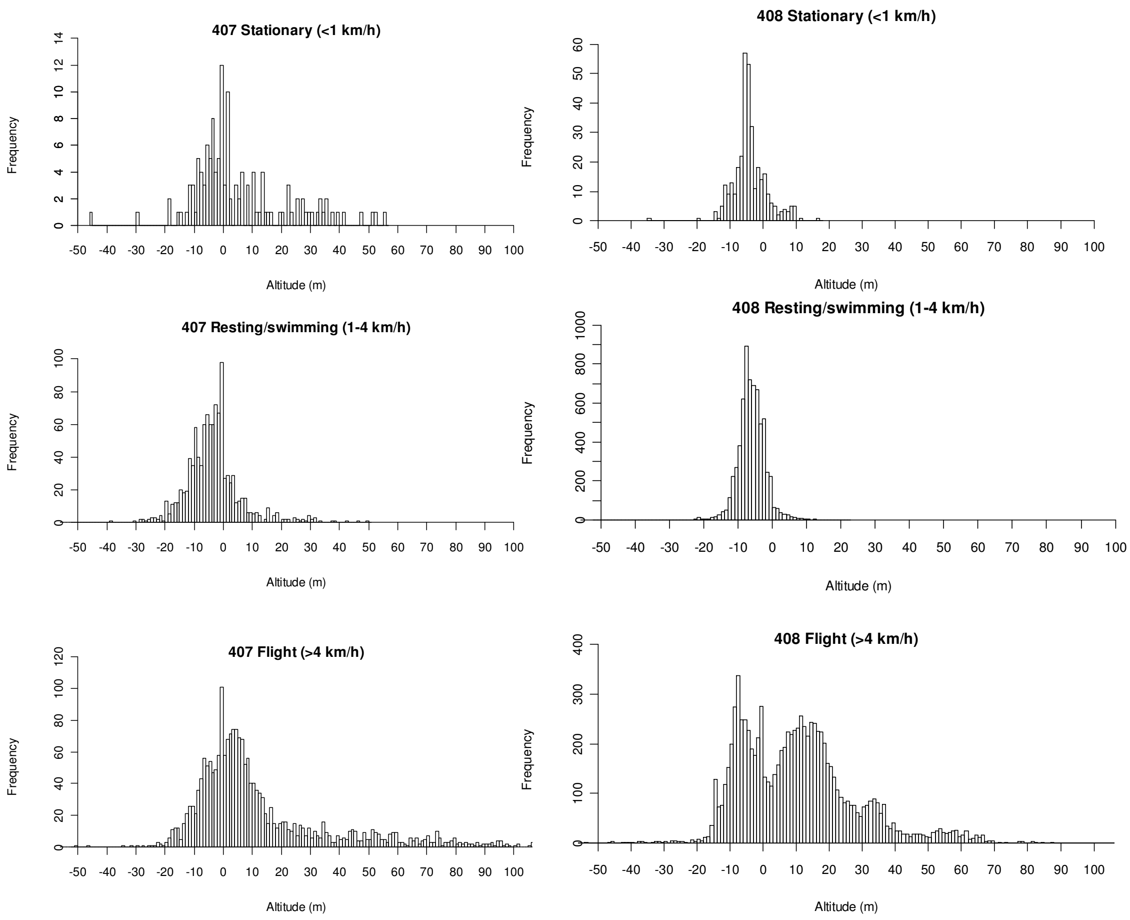
Some slight differences were evident between these two birds in their speed distributions offshore (Figure 11). However, both clearly had a substantial peak < 6 km/h, similar to the cut-off of Shamoun-Baranes *et al*. (2011) who used 4 km/h to distinguish sitting/resting from flight. The speeds for bird 408 however, showed a secondary peak at 12 km/h, whereas those for bird 408 did not. Data for both birds showed a second peak between 20-60 km/h, which may be attributable to flight. Some caution is needed in this interpretation, however, as some birds could be sat on ships travelling at > 10 km/h.

Figure 12 Offshore speeds of Lesser Black-backed Gulls 407 and 408.



The data for altitudes (split by speed categories) showed a relatively similar picture between the birds (Figure 12), although there was also some variation. Altitudes for birds 407 and 408 both exhibited negative peaks in their distributions at speeds below 4 km/h, which are likely to be locations on the sea surface. For flight behaviours, peaks at or below zero were also apparent, which were likely attributable to the bird flying close to the sea surface. However, a long tail in the distribution was also seen for both birds at heights of up to 60-100 m, indicating soaring flight.

Figure 13 Histograms of offshore altitude for two Lesser Black-backed Gulls (407 and 408) by categories of speed.



3.4.2.2 Precision

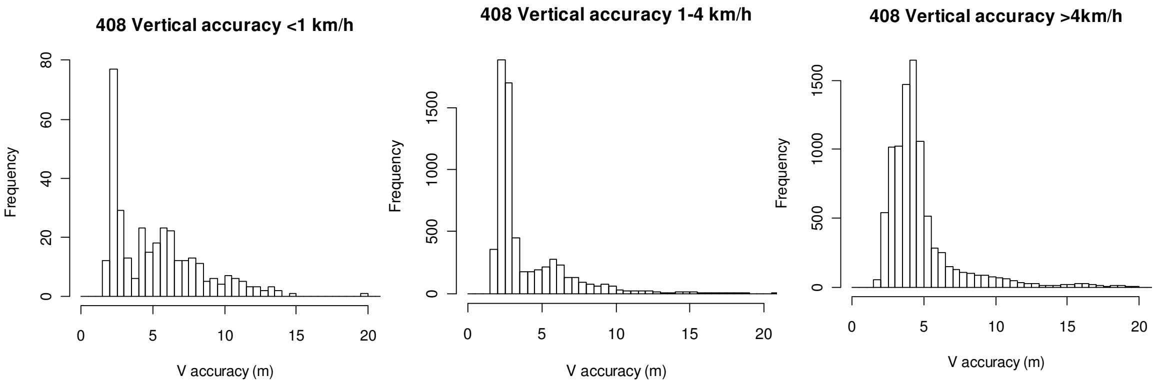
The error associated with GPS fixes can be quantified through a measurement known as dilution of precision (dop), which is calculated in several different planes. Table 10 provides a summary of altitude data for Lesser Black-backed Gulls 407 and 408.

Table 10 Summary of altitude data for Lesser Black-backed Gulls 407 and 408.

Speed	Variable	407	408
< 1 km/h	pdop	4.47±2.76	3.46±2.12
	nsats	5.33±0.98	6.43±1.21
	Altitude (m)	4.61±15.07	-3.53±5.22
1-4 km/h	pdop	4.04±2.16	2.71±1.28
	nsats	5.59±0.98	7.26±1.33
	Altitude (m)	-3.04±9.23	-5.55±4.11
4 km/h	pdop	3.67±1.93	2.74±1.3
	nsats	5.63±0.89	7.03±1.17
	Altitude (m)	14.04±26.67	10.79±18.22

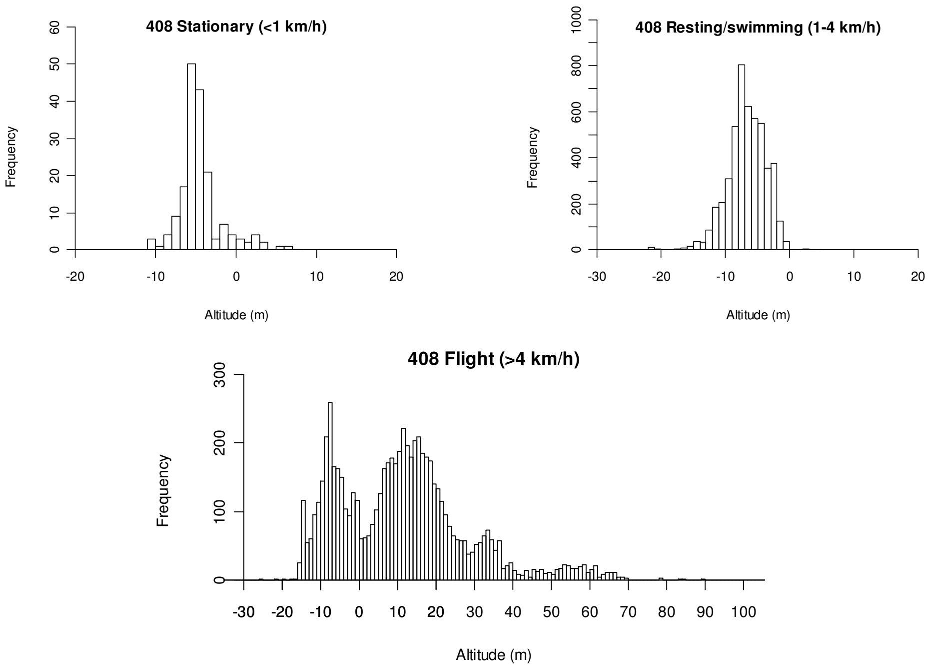
In the data output from the GPS devices, several sources of error are provided relating to precision of the altitude measurement. A measure of “vertical accuracy” (m) is provided that allows an initial assessment of the quality of individual fixes. “Vertical accuracy” values are shown below for bird 408 (Figure 13) as an example (for each speed split using offshore data).

Figure 14 “Vertical accuracy” for Lesser Black-backed Gull 408 for offshore locations.



For bird 408, stripping out the least accurate points (i.e. with > 5 m error), gave a mean altitude for stationary points as: -4.01 ± 2.66 m; and 1-4 km/h points: -6.23 ± 3.05 m. Altitude peaks for points recorded for speeds of > 4 km/h were still bimodal for bird 408 after removing the less precise altitudes (Figure 14). Comparing the standard deviations (Table 10) obtained after stripping out the least accurate points (> 5 m error), suggests a slight narrowing of the spread of the altitude distribution.

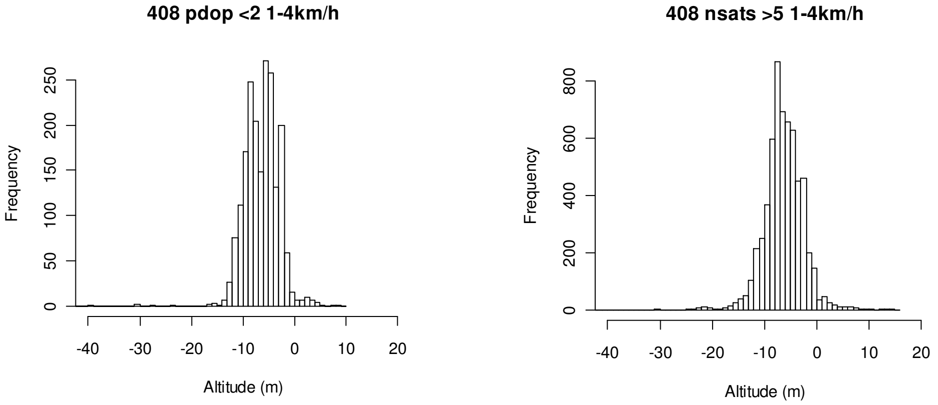
Figure 15 Post-corrected altitude measurements for Lesser Black-backed Gull 408 using the most precise (< 5 m "vertical accuracy") individual GPS measurements.



For the same 408 bird, examining values at 1-4 km/h (Figure 15), the mean altitude using pdop values of less than 2 (the best quality), was -5.87 ± 3.47 m. Again, the standard deviation obtained using pdop values of less than 2 (the best quality) was lower than that in Table 10. Thus filtering the data to use most accurate altitudes appears preferable.

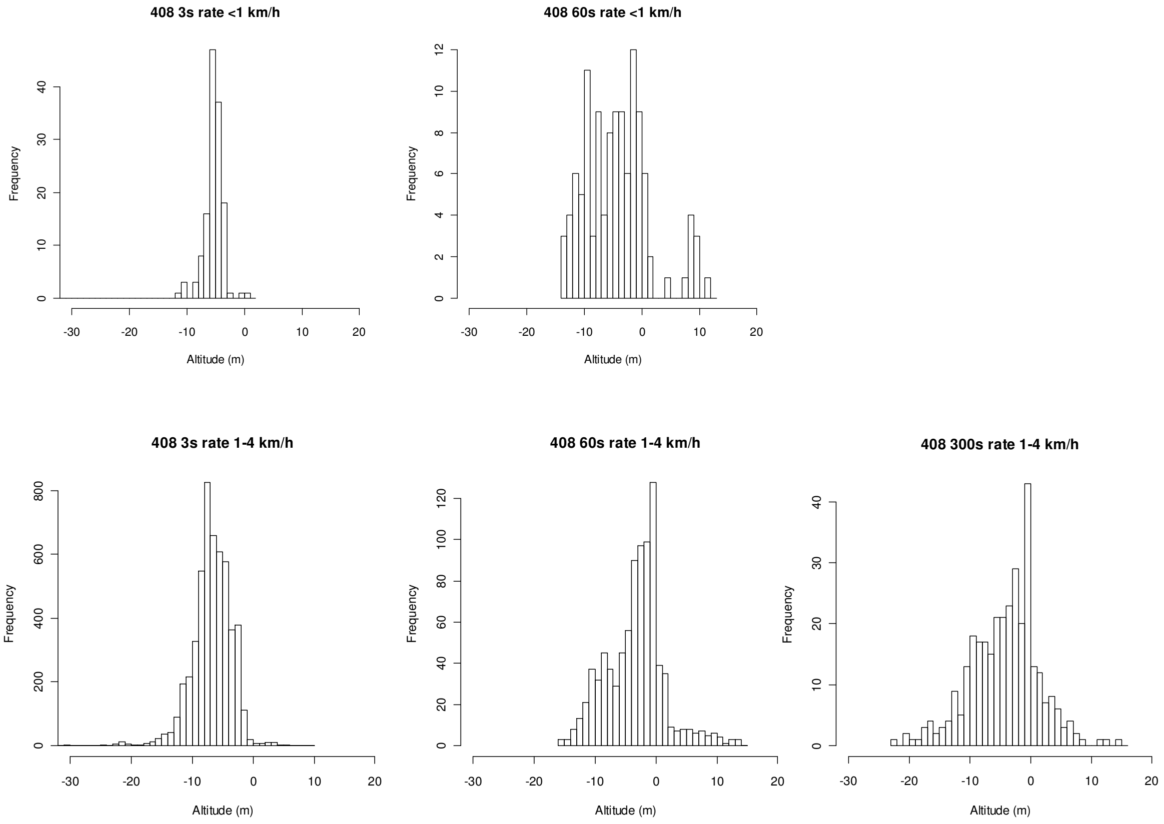
The spread of error around altitudes obtained for bird 408 was approximately ± 10 m, with similar peaks compared to the tag test experiment conducted at the colony.

Figure 16 Post-corrected altitude measurements for Lesser Black-backed Gull 408 using the most precise (< 2.0 pdop value and more than 5 satellites for the GPS fix) individual GPS measurements.



Further sub-dividing the data into those data collected at different sampling rates, appears to also give a slight improvement in the altitude data for bird 408 (Figure 16). Examining non-flight locations at sea (i.e. for speeds of < 4 km/h), the mean altitude for bird 408 at speeds < 1 km on the fastest (3 s) sampling rate was -5.04 ± 3.05 m, and for 1-4 km/h: -6.30 ± 3.53 m.

Figure 17 Test of effects of different sampling rates on altitude distributions for Lesser Black-backed Gull 408 using all GPS measurements.



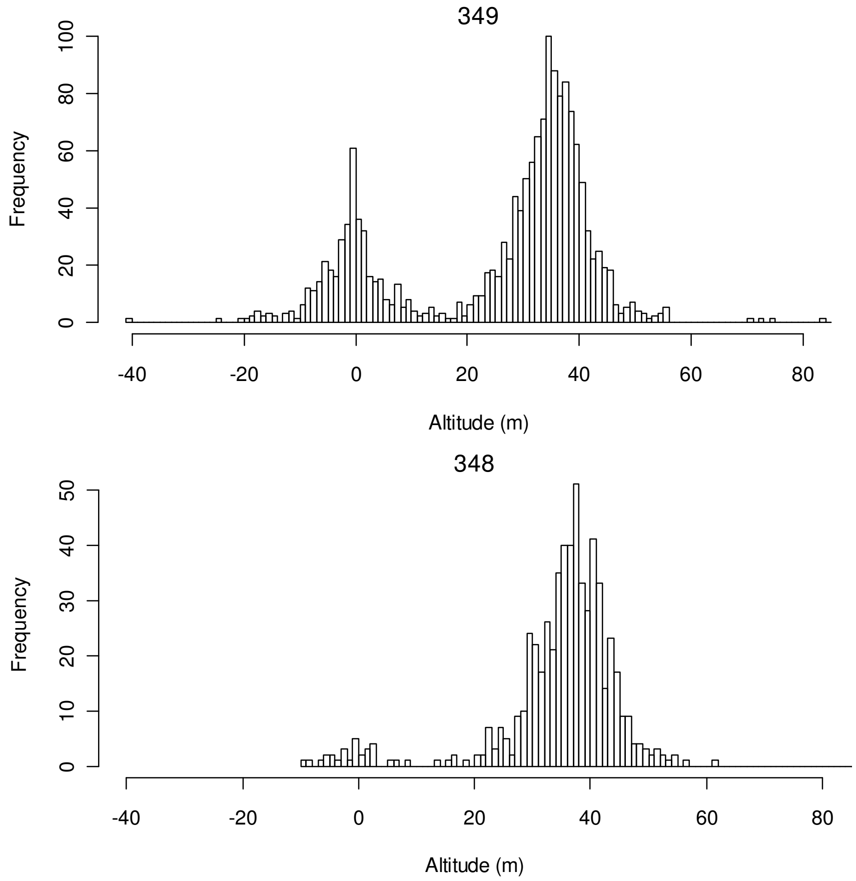
3.4.3 Species altitude data: Great Skua

3.4.3.1 Accuracy

In a similar approach to that taken with the Lesser Black-backed Gulls, we assessed a subset of data for Great Skuas, concentrating on the two birds that gave the most data (348 and 349).

For bird 349, the distribution of offshore flight speeds was bi-modal. Further investigation revealed that the second peak coincided with the apparent altitude of the colony (Figure 17), which is *ca.* 38 m.

Figure 18 Histogram of altitude for Great Skuas 348 and 349 using speeds of < 1 and 1-4 km/h to show differing accuracy peaks in the two distributions.



Altitude measurements for Great Skua 348 also showed the same peak in altitude relating to points at the nest, and with similar error surrounding the distribution (thus giving a reduced likelihood of tag biases in these assessments). However, for bird 348 the initial peak near zero was much reduced. This pattern arose because bird 348 only made two short trips to sea spanning the hours of midnight (max 5.18 hrs), one starting at 23:56 returning 05:04, and one the following day starting at 19:44 returning at 00:55 (8% of all trips, n = 2/25). During nocturnal periods, many seabirds are relatively inactive since visual perception plays an important role in their foraging. Therefore, periods of darkness are related to more ‘stationary’ periods, i.e. here defined as < 1 km/h. In contrast, bird 349 made many more trips to sea that spanned overnight periods (20% of all trips, n = 11/54), thus creating a bigger initial peak in flight altitudes near zero, and a bigger sample size for which to assess the accuracy of the devices at-sea.

3.4.3.2 Precision

Coefficients of variation for Great Skua 349 were generally reduced when more accurate data (< 10 m vertical error, < 3 pdop, and > 5 satellites) were selected, compared to using all data combined (Figures 18, 19 & 20). The at-sea error from bird 349 therefore appears to be ± 10 m, similar to the gulls, with a peak just below zero (-1 to 0 m). The difference here in the bias to the gulls may be due to the inherent error in the GPS algorithm applied by the manufacturers of the devices, i.e. the model reflecting the proper sea level at Foula better than at Orford Ness.

Figure 19 Histograms of offshore altitude for Great Skua 349 split by categories of speed.

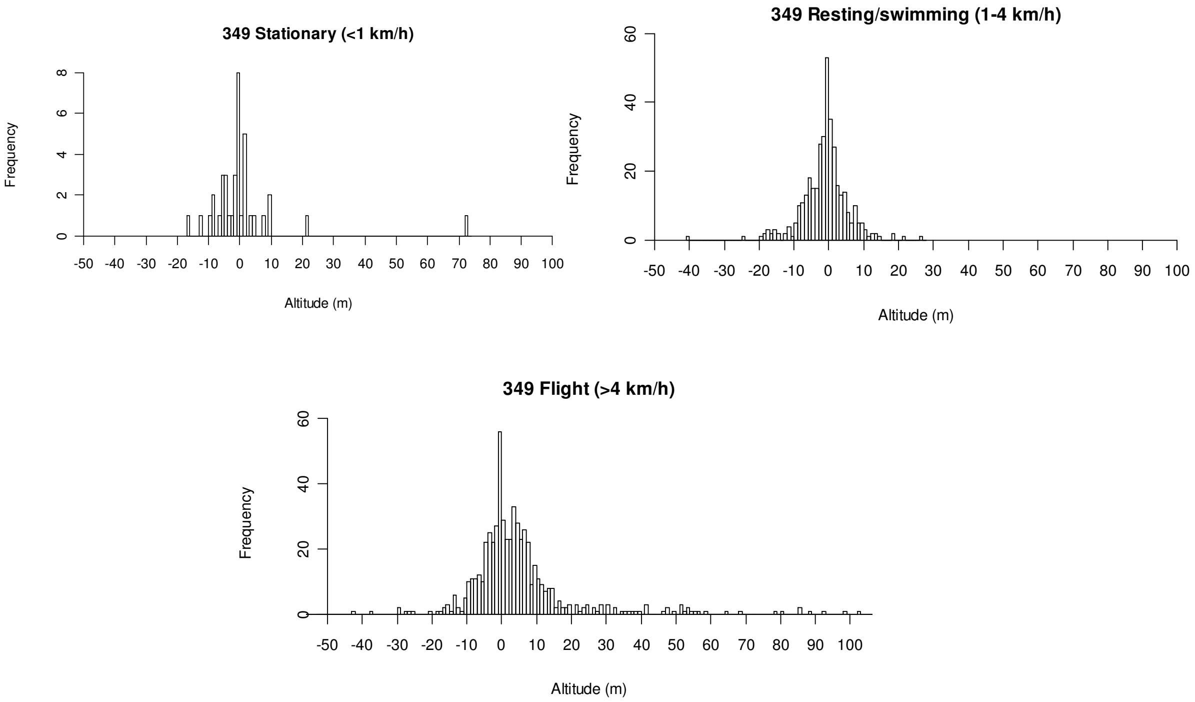


Figure 20 Post-corrected altitude measurements for Great Skua 349 using the most accurate (< 5 m error) individual GPS measurements.

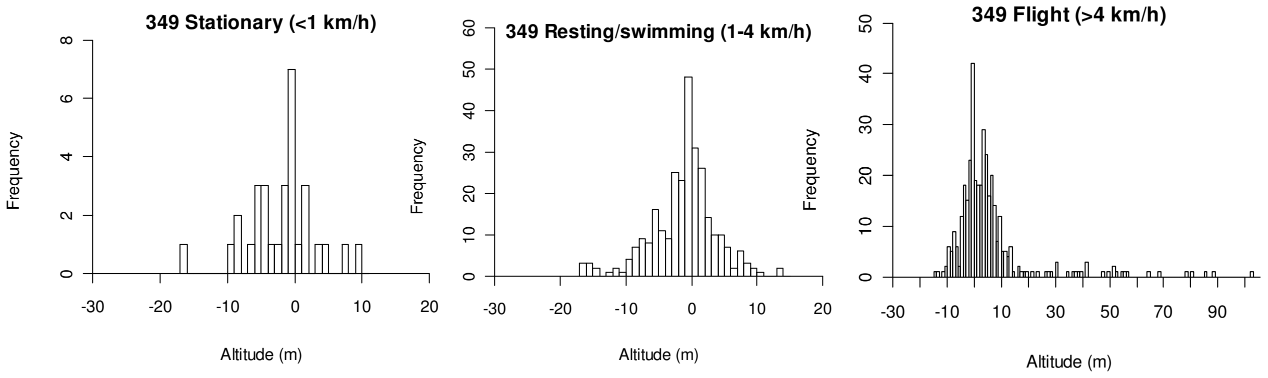
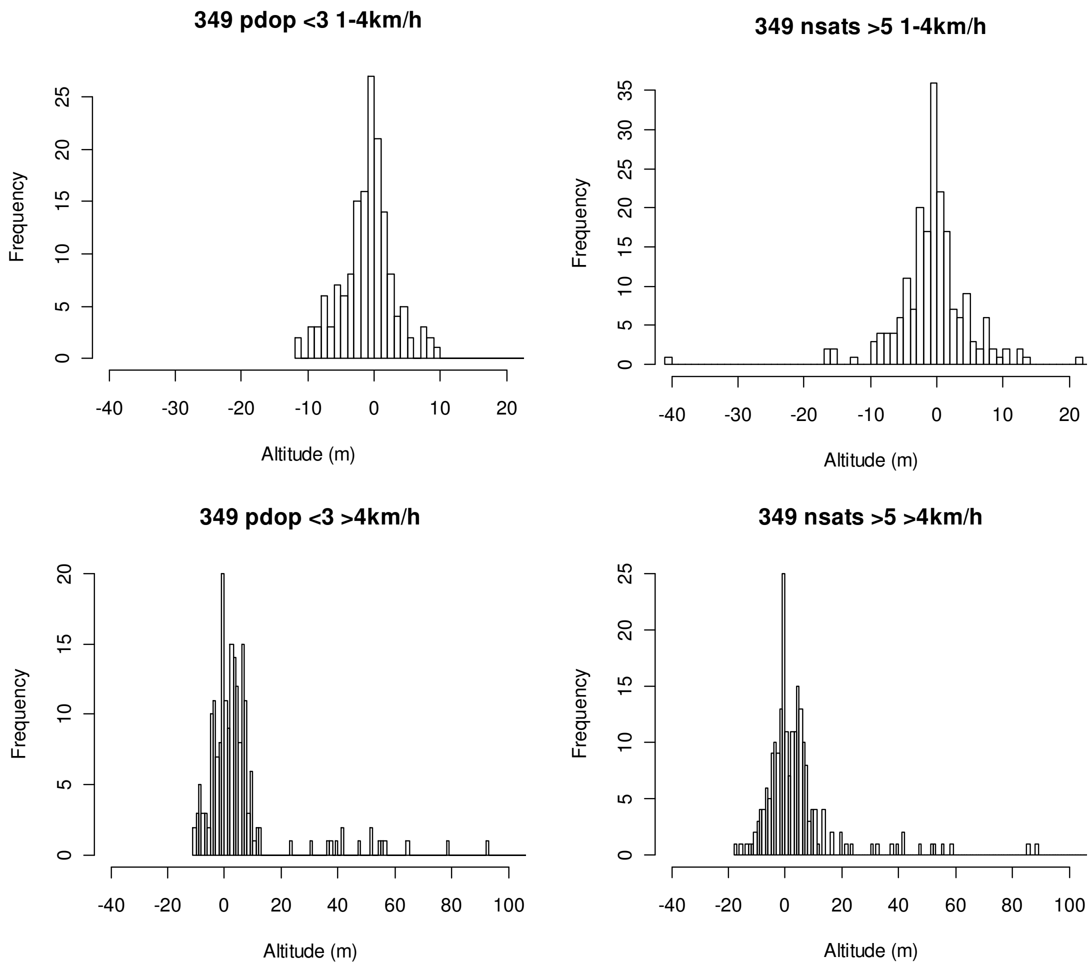


Figure 21 Post-corrected altitude measurements for Great Skua 349 using the most precise < 3.0 pdop value and more than 5 satellites used for the GPS fix) individual GPS measurements.



4. DISCUSSION

The aims of this project were:

i. To understand the connectivity of these feature species with the areas of consented wind farms (i.e. those which have already been constructed or are under construction) and proposed wind farm development zones;
ii. To understand the extent to which these feature species use the areas of wind farms which have already been constructed or are under construction;
iii. To provide an assessment of the flight altitudes of these feature species that could be useful to inform collision risk modelling.

The study used a range of statistical procedures to investigate these three key themes, which are discussed further below.

4.1 Caveats in the current data

In common with the majority of nests at Orford Ness, the nests of the Lesser Black-backed Gulls tagged in this study failed due to predation. The Orford Ness colony therefore seems to be suffering high predation at present. This is not uncommon for gulls, but some colonies are much more stable, such as those on the Severn Estuary or the Wash (Mitchell *et al*. 2004; Burton *et al*. 2010)). While we conducted regular monitoring of the Lesser Black-backed Gull nests, the exact dates of nest failure were largely unknown. Thus for the majority of trips, tagged birds were categorised as ‘probably incubating’. The descriptive data presented here for gulls combines data from both breeding and failed birds across all periods of the season. Therefore, more information is needed about the times when birds were definitely incubating or chick-rearing. Later in the season, foraging trips increased in both duration and maximum distance reached from the colony, which was likely linked to breeding failures. However, when birds’ nests fail they are no longer constrained to a central place, and thus need separate consideration. Birds at this stage still returned to the colony, but sometimes foraged and roosted elsewhere at the coast, before foraging again the next day. These could be considered as two trips.

4.2 Connectivity with the areas of proposed and consented wind farms

Only Lesser Black-backed Gulls used areas of consented and proposed wind farms during the period of the current study. Connectivity here was assessed through whether birds made trips that ventured into wind farms. These data suggested a clear potential for interaction to occur with the large Round 3 zones as six out of the ten lesser Black-backed Gulls for which we obtained data showed connectivity with the East Anglia Round 3 Zone. The consented wind farm zones that are nearby to the colony were also visited, with four showing connectivity with Round 2, one with Round 1, and four with Extensions to Round 1 or 2. These interactions were then quantified further in terms of (1) spatial overlap (section 4.3) and (2) temporal overlap (section 4.4). Further investigation into the deviation of flight paths will be investigated for the forthcoming 2011 season.

4.3 Overlap of home ranges with consented and proposed wind farms

4.3.1 Spatial overlap

Four of the ten Lesser Black-backed Gulls foraged extensively offshore. For these four birds, it was therefore possible to characterise their foraging areas using kernel analyses. For these birds 24.0-48.5% and 25.2-46.7% of the 95% KDE (here used to represent total home range) for all offshore locations and “foraging” locations alone respectively overlapped the East Anglia Round 3 Zone. Thus, while some variations were evident between birds, the East Anglia Round 3 Zone area is clearly an important foraging site. The areas of Round 1, Round 2, and Extension wind farms (8.8 km^2, 146.5 km^2, 174.8 km^2) in the vicinity of the colony were much smaller than the area of the nearby East Anglia Round 3 Zone (6036.8 km^2). Therefore, the percentages of the birds’ home ranges that overlapped these zones were considerably less.

The method used for kernel overlap analyses here was the ad-hoc method. We carried out extensive tests of other methods: LSCV and BBMM, but favoured the ad-hoc method for its convergence, suitability of a smoothing parameter, and lack of over-estimating bias for the 95% KDE. However, the ad-hoc method is itself considered biased for multi-modal distributions, and some of the birds tracked in this study had such area distributions. Thus, results should be interpreted with caution, and more work is needed to establish the most suitable methods for these data.

4.3.2 Temporal overlap

Between 0.07 and 7.49% (mean = 3.6 ± 2.9%) of the birds’ total time budgets (trips + time at the nest) were within the East Anglia Round 3 Zone. As with the spatial analyses, analyses of temporal overlap revealed that, proportionally, little time was spent within the Round 1 or 2 sites or Extensions to Round 1 or 2 sites. The data presented on temporal overlap with offshore wind farm zones encompasses the birds’ entire time budgets and thus the results reported are not directly comparable with the spatial overlap analysis which considered only offshore foraging trips. If only the time spent at sea is considered, there is a higher percentage overlap with the zones; for instance, between 13.8 and 26.2% (mean = 11.4 ± 9.8%) of the birds’ total time budgets were within the East Anglia Round 3 Zone.

4.4 Assessment of the flight altitudes

We assessed both the accuracy and precision of the altitude information obtained from the tags. These are discussed below.

4.4.1 Accuracy

Negative altitudes were frequently recorded at both Foula and Orford Ness, thus accuracy was biased below zero. We believe these biases arose because of the inaccuracy of the initial assumption used when altitude is originally calculated, that the world is a perfect sphere. Similar findings were also recorded by Ens *et al*. (2008).

More negative values for overall accuracy were seen at Orford Ness where the apparent bias was *ca.* -6 m, when the tag should have been reading a value of zero. Therefore for *Lesser Black-backed Gulls during the breeding season, we would recommend correcting the flight altitude information by*

6 m, when producing final flight altitude information. We conducted a descriptive field test of a sample tag at Orford Ness, and found a similar accuracy bias to measurements from the birds themselves, although the test was only reliable for 3 s sampling rates.

At Foula, the accuracy bias was *ca.* -1 m (albeit tested on fewer data), where the tag should've been reading a true zero altitude at sea level. *For Great Skuas, we would therefore recommend correcting the flight altitude information by 1 m*, when producing final flight altitude information.

While both gulls and skuas foraged over large areas during breeding, the likelihood of the accuracy bias itself changing across space is likely to be relatively small. However, for non-breeding season flight altitudes, further location-specific analyses would have to be conducted to check for apparent biases in the accuracy across space (e.g. perhaps assessing altitude by 25 km squares), that could then be used to correct flight altitudes. Tide variations at both Orford Ness and Foula were only ca. 2 m between high and low tide, and thus had only minimal influence on the overall distribution accuracy. When assessing migration flight heights tide information from different locations will also need to be investigated rigorously.

4.4.2 Precision

The Orford Ness field test revealed that the apparent precision error for known mid-tide sea-level locations was 3 m (total error spread around the peak). However, further tests on both Lesser Black-backed Gulls and Great Skuas for locations on the sea-surface and at the colony, revealed likely biases in precision of 10-15 m for both species. Therefore, *having accounted for the biases due to accuracy above, one can currently expect up to 10-15 m precision error around the flight altitudes*.

For both species, we found small improvements in the precision of the distributions using the "most precise" data (here assessed through "vertical accuracy", pdop, and the number of satellites used in individual GPS fixes). Furthermore, faster sampling rates gave similar improvements for the gulls. However, further statistical analyses will be required to assess the effects of these sources of precision error more rigorously. There may also have been some variation in temperature or humidity, which could have given rise to as yet un-quantified error in altitude measurements.

Leg-loop harnesses were used for Great Skuas, which prevented adequate solar charging of the device because the birds' mantle feathers overlapped with, and partially concealed the solar panel. This meant that we could not obtain the fastest sampling rates for Great Skuas in the 2010 season (rates of 15 to 30 minutes were used). Thus, in theory, precision may be improved with faster sampling; such rates will be obtained for Great Skuas during 2011 by using tag attachment techniques similar to those used on the Lesser Black-backed Gulls.

4.4.3 Flight altitudes

We used the flight speed categories used in Shamoun-Baranes *et al*. (2011) to approximately characterise various behaviours. However, these distinctions are not definitive, and thus there may be some overlap between the three categories. However, for assumed flight data (> 4 km/h) from offshore locations, Lesser Black-backed Gull 407 showed altitudes from near zero (i.e. birds flying close to the sea surface) up to and perhaps beyond 70 m, even after filtering out the less precise data measurements (> 5 m vertical accuracy, > 2.0 pdop value, < 5 satellites). Adding the 6 m bias would therefore shift the distribution up to 76 ± 10-15 m. However, generally Lesser Black-backed

Gulls mostly appeared to fly up to 15 ± 10-15 m above sea level. These results match previous altitude information on Lesser Black-backed Gulls from radar and boat studies; estimates suggest that 22% birds fly above 20 m (Innogy 2002; Banks *et al*. 2005; Krijgsveld *et al*. 2005; N Power Renewables 2005; Centrica Energy 2007, 2008, 2009; DONG Energy 2006, 2009; ; Parnell *et al*. 2005; Scira Offshore Energy Ltd. 2006; Shamoun-Baranes & van Loon 2006; IECS 2007; Environmentally Sustainable Systems Ltd. 2008; ECON 2009; RPS 2005, 2008; Vanermen & Stienen 2009; Walls *et al*. 2009).

For Great Skuas, most flight altitudes for bird 349 appear clustered near to zero (thus being 1 ± 10-15 m after the accuracy correction), with a tail in the offshore distribution stretching up to and beyond 50 ± 10-15 m after accounting for the least precise individual measurements (> 10 m vertical accuracy, > 3.0 pdop value, < 5 satellites). These results also concur with previous radar and boat studies - Banks *et al*. (2005) found that 96% birds (N = 179) flew at altitudes less than 20 m, and Vanermen & Stienen (2009) suggested 10% of birds (N = 133) were within turbine height, supported by information from Environmental Impact Assessments (Innogy 2002; N Power Renewables 2005; IECS 2007; RPS 2008; Vanermen & Stienen 2009).

4.5 Future study: winter 2010/11 and the 2011 breeding season

This report summarises data collected on birds caught during the 2010 breeding season. However, a further 35 tags will be deployed in the 2011 breeding season (14 on Lesser Black-backed Gulls and 21 on Great Skuas). These tags will provide further data on the overlap of home ranges and time budgets with consented and proposed wind farms, and flight altitudes in that breeding season. Data should also be obtained on the birds' migrations and winter movements, which will be particularly important for Great Skua, since this is the time when individuals will potentially interact with offshore wind farms. Currently deployed tags should give us information on movements of Lesser Black-backed Gulls in the 2010/11 non-breeding period.

While we tested several kernel approaches here (LSCV, ad-hoc, and BBMM), we aim to obtain a more refined approach to kernel methods for utilisation distributions, having presently selected ad-hoc methods that are also known to be biased for unimodal distributions. We also intend to include further information on the exact location of the wind farm turbines, which are needed for thorough assessment of interactions, and would also allow for an assessment of avoidance behaviour.

For flight altitudes, further work is required. More work in particular is needed in relation to location specific tidal and accuracy biases, as well as assessing both accuracy and precision of altitude information more thoroughly for vertical accuracy, pdop, and number of satellites, as well as in relation to other sources of error such as temperature and humidity. Modelling, in particular, could be used to provide a greater understanding, and one could then theoretically test whether birds are more or less likely to fly in particular bands above the sea surface. Such information would be valuable to collision risk assessment, and ultimately it would be useful to assess locations at sea where flight altitudes correspond to turbine height (as a risk-map). We will also seek to conduct further field tests of the tags at both Orford Ness and Foula. For the final assessment of flight altitude data, the influence of wind speed and direction could also be investigated, potentially with the use of coastal weather station data.

4.6 Concluding comments

The data presented here on the overlap of home ranges and time budgets with consented and proposed wind farms and flight altitudes show the value of GPS tagging data in assessing both connectivity and potential interactions between SPA features and offshore wind farms. A relatively small amount of data is presented from only one breeding season. The complete dataset will provide a much clearer understanding of the extent to which these SPA features use the areas of offshore wind farms. The data will also provide a fuller assessment of flight altitudes that could be used to inform collision risk modelling.

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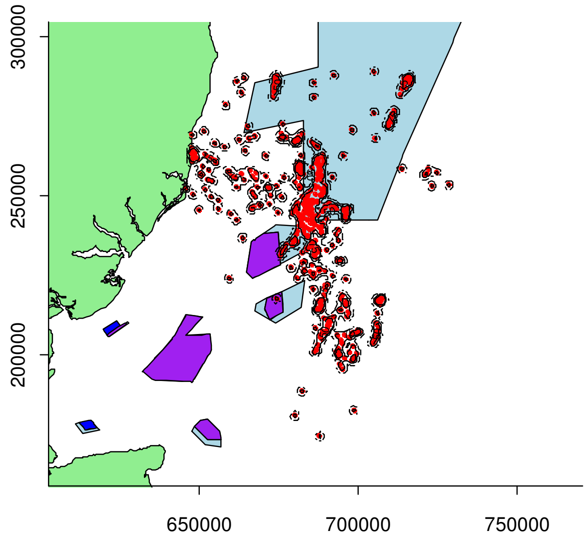
Appendix 1 Examples of kernel utilisation distributions: LSCV, ad hoc and Brownian Bridge.

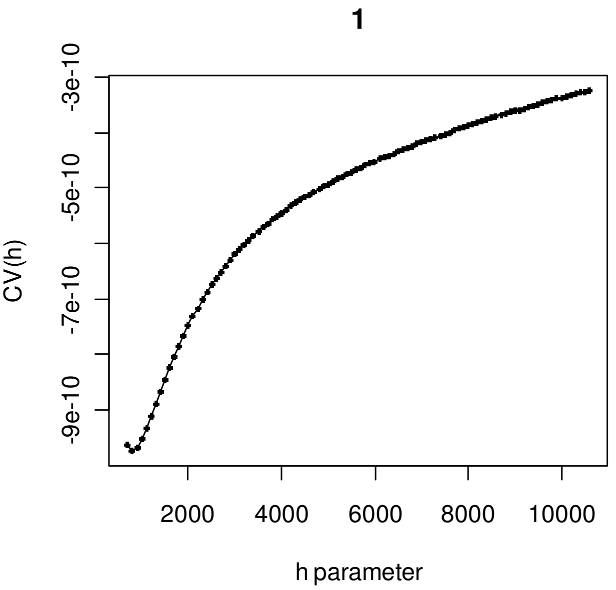
There are well-known problems with estimating a smoothing parameter for kernel analyses. A robust approach previously recommended is to use Least Squares Cross Validation (LSCV), used successfully in other species (Hamer *et al*. 2007; Thaxter *et al*. 2009, 2010). However, when estimating utilisation distributions of animals, the cross-validation criterion cannot be minimised in some cases, which is a statistical problem that still requires further attention (Seaman & Powell 1998). The choice of 'h' in this study obviously has a large bearing on the final overlap of the utilisation distribution with the wind farm zones.

For analyses here, using R 2.12.0 and package (adehabitat), we encountered these well-known problems when using LSCV as a smoothing parameter in the estimation of utilisation distributions. Using function kernelUD() which estimates the utilisation distribution (within the adehabitat package), the algorithm tries to minimise the value of 'h' (i.e. hlim), to then use as the kernel smoothing parameter, but had convergence problems in estimating the value. This happens in the majority of cases for this function, and occurred in all tests we carried out. See http://lists.faunalia.it/pipermail/animov/2006-May/000137.html for more information.

Clément Calenge the author of this R package, has recommended using an additional solution to add a little noise to the data prior to estimating the kernel, so that multiple observations no longer have the same coordinates. Indeed in our data, some points may have been overlapping and repeated at the same locations, or extremely close together, possibly causing the problem. Therefore we followed recommendations and used the function jitter() before the use of kernelUD(). An example output is shown for bird 334 for offshore foraging locations.

```
### including jitter random points to increase convergence
dd=Out3 [,1:2]
dd[[1]]<- jitter(dd[[1]], factor=1, amount=3)
dd[[2]]<- jitter(dd[[2]], factor=1, amount=3)
ud_1003<-kernelUD(dd,h = "LSCV", grid=175)
ud <- getvolumeUD(ud_1003)
unlist(lapply(ud, function(x) sum(x$UD) * (attr(x$UD, "cellsize") ^2)))
res <- lapply(1:length(ud), function(i) {
  uu <- ud[[i]]$UD
  uu[ud[[i]]$UD>98] <- NA
  uu <- getascattr(ud[[i]]$UD,uu)
  return(uu)
})
plotLSCV(ud_1003)
```

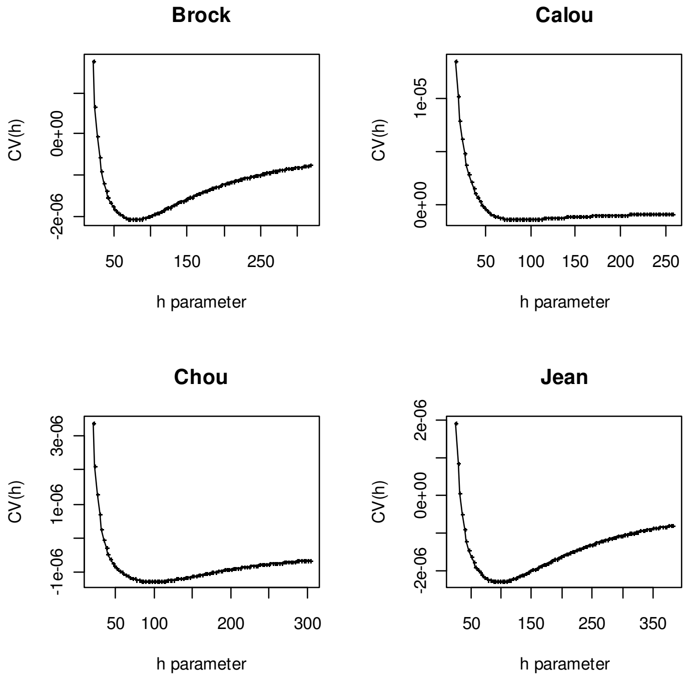




In this example (334), the smoothing parameter of ‘h’ (hlim) was given as 805 – (right-hand plot). However, this parameter is clearly too small given the output of the kernels, because the parameter choice resulted in clusters around individual points and would not have been acceptable as a final kernel.

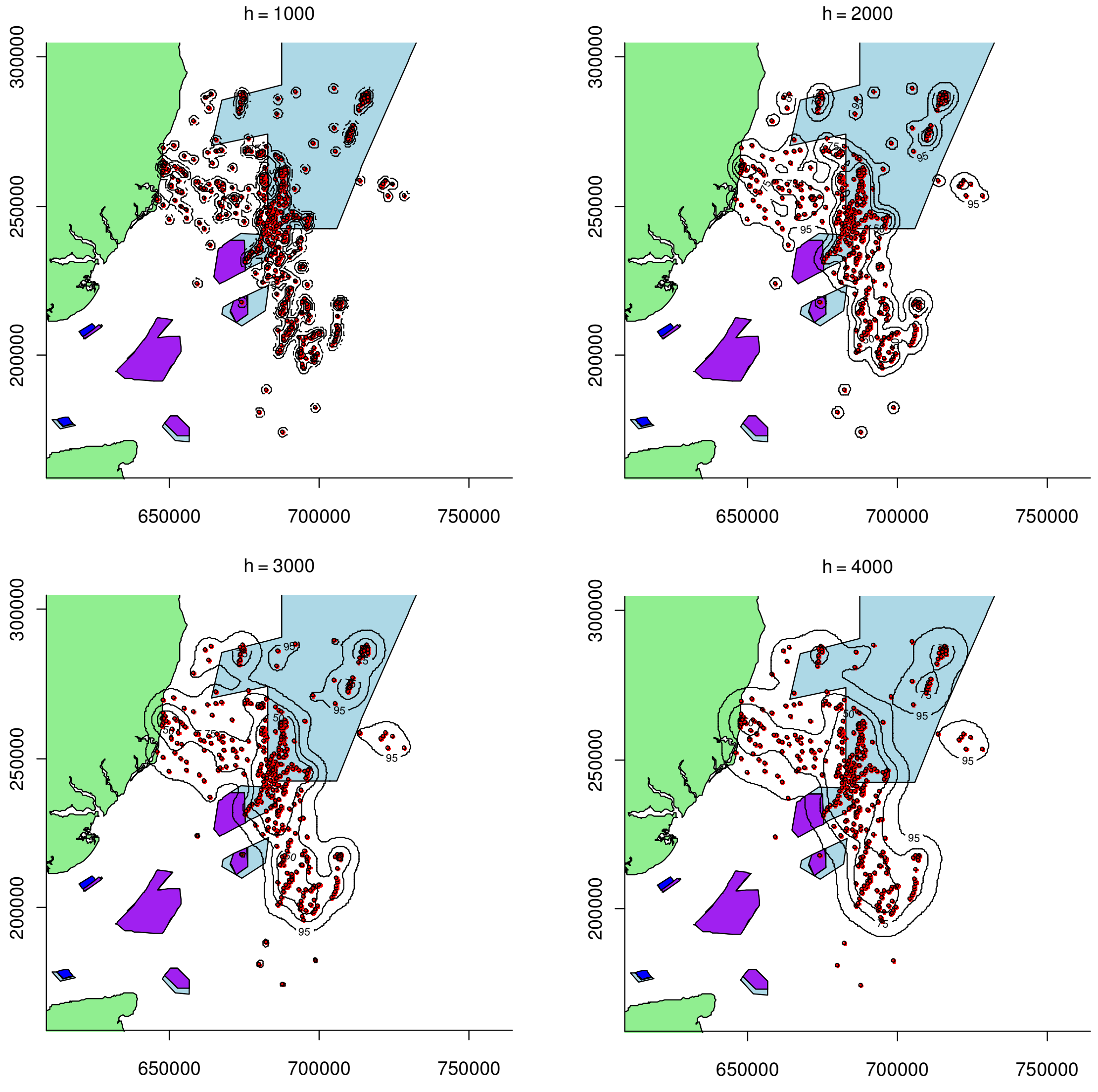
When this is compared to an output in the R-package example given in dataset ‘puechabon’, a much clearer kernel is produced, thus in the R example output LSCV is clearly suitable to the data, where values of ‘h’ of around 70-80 are chosen.

```
data(puechabon)
loc <- puechabon$locs[, c("X", "Y")]
id <- puechabon$locs[, "Name"]
ud <- kernelUD(loc, id)
udvol <- getvolumeUD(ud)
ver <- getverticeshr(ud, 95)
elev <- getkasc(puechabon$kasc, "Elevation")
udbis <- kernelUD(loc, id, h = "LSCV")
plotLSCV(udbis)
```



For our analyses, we found no problems when using the jitter() function compared to others (http://old.nabble.com/Again-KernelUD-and-LSCV-td4630731.html). Thus, we were able to induce only a very small amount of noise to produce a convergence with LSCV – when noise was increased, similar kernels were produced, but too much noise in the data could mask the biological signals one is interested in.

Therefore, it is also recommended by Clément Calenge to investigate the data manually and apply an appropriate smoothing parameter. Hence, we tried increasing the smoothing parameter manually, albeit acknowledging this would not be the minimum h given through LSCV.



Clearly increasing the value of h produces more sensible kernels. However, this approach is subjective and is not clear-cut. Furthermore, non-convergence in the estimation is very frequent with LSCV and consequently, the *ad hoc* "href" option is set up by default in the function kernelUD(). In other analysis software such as RANGES, the *ad hoc* method is defaulted to when LSCV offers no convergence. This *ad hoc* smoothing method, for the estimation of the smoothing parameter is for a bivariate normal kernel defined as:

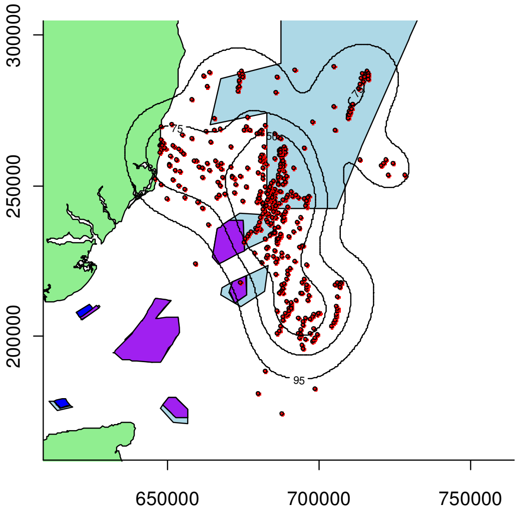
$$h = Sigma*n^{(-1/6)}$$

where

$$Sigma = 0.5*(sd(x)+sd(y))$$

(Calenge 2006)

Using this approach for the example data (bird 334) above, produces an 'h' smoothing parameter of 7054. The resulting kernel is shown below.

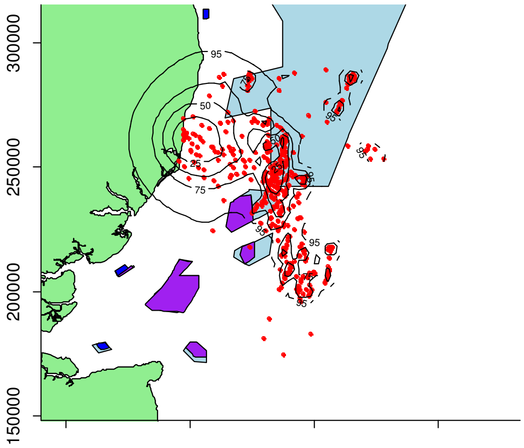


This bivariate-normal smoother appears to give quite a large 50% kernel, similar to the h = 4000 in the above test plots. In all the analyses we conducted, using the *ad hoc* method is likely to over-estimate this 50% kernel, resulting in a kernel that may not be wholly representative – i.e. 50% of the points appear not to lie in the 50% kernel. However, this same issue was encountered in all the techniques tested.

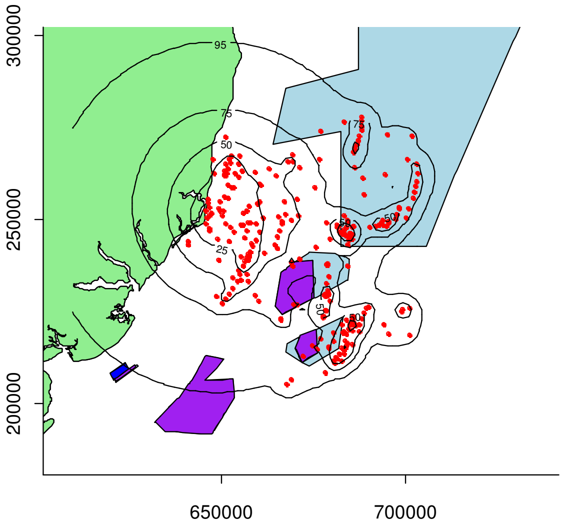
It is also well-known that the *ad hoc* method can produce biased results for distributions that are not unimodal (Worton 1989). Some of the birds in this study also showed apparent multi-modal distributions. Therefore, we also estimated another method for assessing the utilisation distribution, the Brownian Bridge (Horne *et al*. 2007).

The Brownian Bridge Movement Model (BBMM) is based on a random walk approach between successive pairs of points and is arguably is the least biased method, and therefore the most appropriate for these types of data, as concluded by Ens *et al*. (2008). This is because it assumes locations are non-independent, incorporates time between the locations into the model, and is not unduly affected by clusters. The BBMM uses two smoothing parameters: (1) related to the locational error, and (2) another based on the animal's mobility. Here, we calculated the first parameter using the approximate suitable mean locational error, typically near 5 m, however we used a value of 15 m as more conservative (Ens *et al*. 2008), with little difference on the final results. The second parameter was calculated from the function 'liker' that can be used to find the maximum likelihood estimation of this parameter (Horne *et al*. 2007). Results of the BBMM are given below for all offshore locations for the four birds presented in this report.

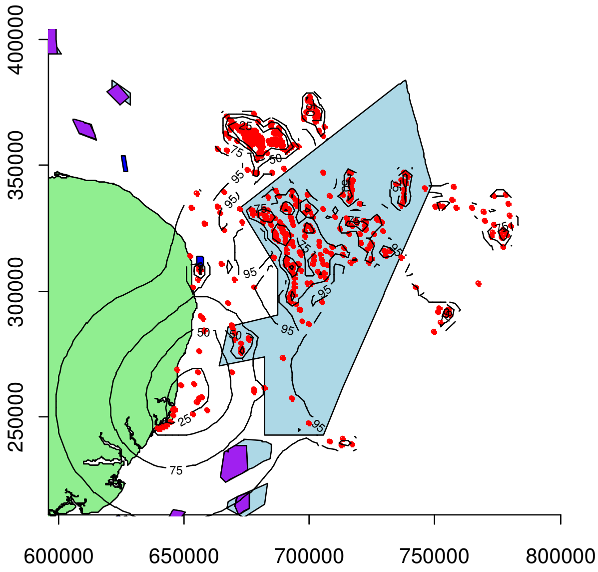
334



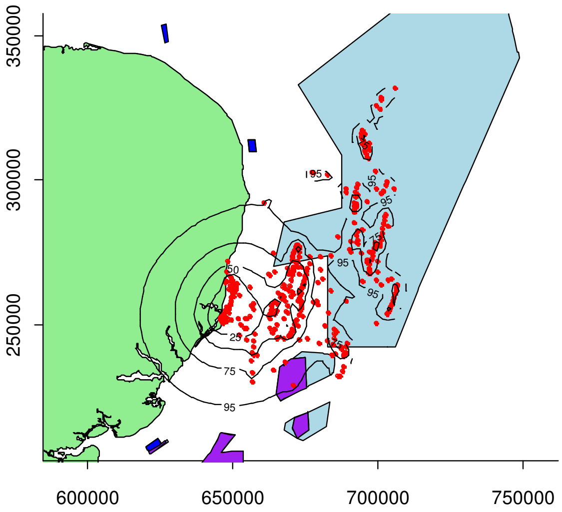
336



407



408

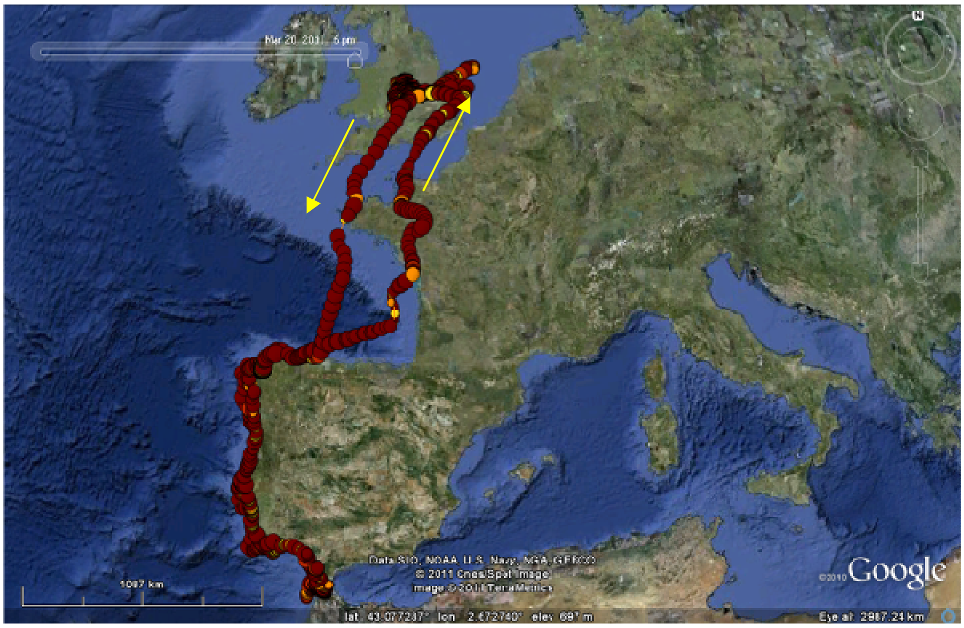


The BBMM seemed to work well, in particular for birds 334 and 408. However, for birds 336 and 407, the 95% utilisation distribution encompassed a wide area near the colony, and also incorporated wind farms that were never visited by the birds. As such, there was risk of over-predicting the utilisation distribution for these birds.

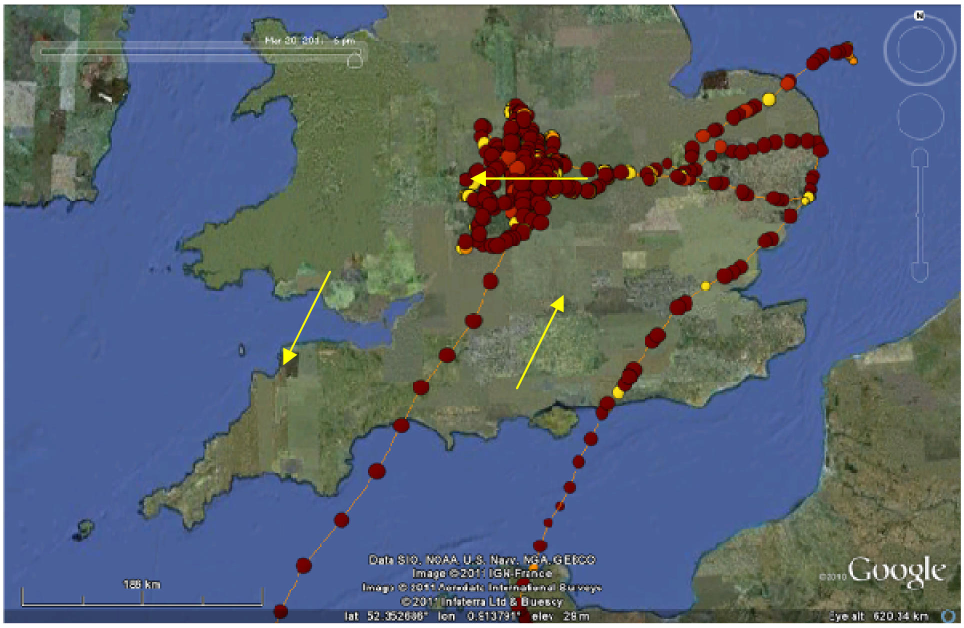
We therefore acknowledge that no technique here was perfect. Although the *ad hoc* method is likely biased here, we feel for the purposes of overlap that it was most appropriate. For the 95% kernel the *ad hoc* method was the most conservative for birds 336 and 407 (i.e. avoided making large over-predictions of percentage overlap with wind farms not encountered), but in contrast one could also argue that the BBMM was most conservative for 334 and 408. However, we favour the *ad hoc* approach here mainly because the over-predictions appeared greater than the under-predictions. Further tests will be carried out to identify improved kernel utilisation distributions for these datasets.

Appendix 2 Summary of non-breeding movements of Lesser Black-backed Gull 407.

Overall route (yellow arrows show travel direction post-breeding).



UK movements prior to migration (on November 27 2010).



Over-winter locations.