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Measuring the Interaction Between Marine Features of Special Protection Areas with Offshore Wind Farm Development Sites Through Telemetry: Final Report

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EXECUTIVE SUMMARY

1. The UK government has a commitment to obtain 20% of the UK's energy 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 included 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 impact 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 – Lesser Black-backed Gull *Larus fuscus* and the Great Skua *Stercorarius skua*. 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 are already operational or which are under construction) and proposed wind farm development sites;
   ii. To understand the extent to which these feature species use the areas of operational, consented and proposed wind farms;
   iii. To provide an assessment of the flight altitudes of these feature species that could usefully inform collision risk modelling.

4. Fieldwork for Lesser Black-backed Gulls was conducted at a mixed gull colony at Orford Ness, Suffolk, UK. Fieldwork for Great Skuas was conducted at the Foula SPA, Shetland, UK, and also at the Hoy SPA, Orkney, UK.

4. In summer 2011, GPS tags were fitted to 14 Lesser Black-backed Gulls at Orford Ness, part of the Alde-Ore Estuary SPA. This was in addition to 11 birds tagged at this site in 2010. Following the tagging of four Great Skuas on the Foula SPA in Shetland in 2010, a further 10 birds were tagged in 2011. Ten Great Skuas were also tagged on the Hoy SPA in the Orkney archipelago. All individuals tagged were members of breeding pairs, and were caught on the nest.

5. To assess the effects of devices and harnesses, separate control birds and their nests were also monitored. Comparison was made between: (1) territory attendance; (2) breeding success; and (3) over-winter survival. No significant differences were found with respect to any of these parameters for Lesser Black-backed Gulls and thus it was concluded that the devices and harnesses used were suitable for the species across the temporal scales they were utilised. In contrast, for Great Skua, there was strong evidence that the devices and harnesses used in 2011 led to reduced over-winter survival. The particular devices and harnesses used were thus suitable for Lesser Black-backed Gull across the year, but were not suitable for Great Skua outwith the breeding season. The results of this evaluation are summarised in Thaxter *et al.* (in prep.), in order to help direct future bio-logging research and conservation for both species. Due to the apparent impacts of the devices and harnesses used on over-winter survival in Great Skuas, the results reported here are restricted to observations from the breeding season.

6. Initial investigation summarised the connectivity shown by Lesser Black-backed Gulls with the areas of operational, consented and proposed offshore wind farms. The proportion of birds that used areas of operational, consented and proposed offshore wind farm areas was highest in 2010 (70% of 10 birds), similar in 2011 (78% of 18 birds) and lowest in 2012 (57% of 14 birds), with all birds using the large Round 3 East Anglia zone, for which wind farm project proposals have been submitted. Connectivity with operational wind farms was more limited, with up to 50% of birds (in 2010) recorded in the area of the Greater Gabbard offshore wind farm, and one bird (in 2010 and 2012) recorded in the area of the Scroby Sands wind farm. Despite the apparent high numbers of birds interacting with operational, consented and proposed wind farms, the total time spent and spatial extent of overlap of areas used with operational, consented and proposed offshore wind farms was more limited. The percentage of time spent in the areas of operational, consented and proposed offshore wind farms peaked at 4% in 2010 and the percentage of total area usage at 14% in the same year.

7. For Lesser Black-backed Gulls, the use of offshore areas and thus of the areas of operational, consented and proposed offshore wind farms during the breeding season (covering the pre-breeding, breeding and post-breeding periods) showed (1) individual, (2) seasonal, (3) sex-specific and (4) annual variations. Individual birds tracked across multiple years differed in their seasonal patterns of wind farm usage, with some birds foraging in the areas of operational, consented and proposed wind farm in some years but not in others. Use of offshore areas and the areas of operational, consented and proposed offshore wind farms showed a peak between late June and early July, corresponding to the chick-rearing period. Males used offshore areas and the areas of operational, consented and proposed wind farms significantly more than females later in the season. Birds used areas of operational, consented and proposed offshore wind farms more during 2010 than other years, a pattern that could not be explained solely by annual differences in productivity. The use of the areas of operational, consented and proposed offshore wind farm at this colony is highly ephemeral for this species and variable between years. In such cases, tracking birds over longer time periods may be needed, without which assessments of the potential impacts of offshore renewable developments may incorrectly estimate the magnitude of risks posed to protected seabird populations.

8. This study also revealed individual, sex-specific differences and cross-breeding season variation in the time budgets and area utilisation of Great Skuas and thus the extent of interaction with proposed offshore wind farm development zones. In keeping with known-sex differences for this species, males had longer foraging trips than females and spent longer away from the nest; however, patterns of behaviour across the season were similar between sexes. Accounting for these sources of variation, there was some fluctuation in overall seasonal patterns, particularly the duration of individual foraging trips and time spent away from the nest, which showed curvilinear patterns for birds from Foula and an increasing pattern for birds from Hoy across Julian date and chick age. There were no consistent patterns in changes of spatial habitat use across the season in the size of total area usage or percentage overlap of total area usage with proposed offshore wind farm development zones; for birds from Foula, there was no difference in core and total foraging area distributions between chick-rearing and incubation. The diet of Great Skuas at Foula was dominated by betho- and bathy-pelagic forage fish species (68% pellets collected), particularly Argentine (*Argentina* spp) and Poor Cod (*Trisopterus minutus*), but also included seabird, mammalian (e.g. rabbit), beetle, and goose barnacle (*Lepas* spp) remains. The trends across the season in time spent in the areas of proposed offshore wind farms were colony-specific (increasing for birds from Foula, decreasing for birds from Hoy) in keeping with the different situation of proposed offshore wind farm development zones in proximity to the colonies. This highlights the

value of focusing on multiple colonies for assessing seabird-wind farm interactions. It is hoped that these results will be of particular value in helping to inform future impact assessments seeking to understand the extent of effects on Great Skuas at these SPAs.

9. Altitude data from the GPS tags were used to investigate the flight heights of Lesser Black-backed Gull and Great Skua during the breeding season, providing information on flight height distributions that could inform collision risk models and thus the potential impact of offshore wind farms on this species. Flight altitudes were modelled within a Bayesian framework to assess the factors that might cause variation in flight heights. Lesser Black-backed Gulls flew at higher altitudes over land than over water, and at lower altitudes in near-shore waters than waters more than 200 m offshore. Birds also flew at higher altitudes during the day than during the night. A relatively small proportion of birds' time was spent in flight regardless of light level, but this was particularly true during darkness. The flight altitudes of Great Skuas tended to be lower than those of Lesser Black-backed Gulls, although no significant relationships were found between flight altitudes and time of day or whether birds were flying over the land or the sea. Although the altitudes that they flew at reduced the risk of collision with offshore wind turbines relative to Lesser Black-backed Gulls, breeding Great Skuas spent more time in flight, and more time at sea.

10. Information was available on the migratory routes and wintering areas of 18 Lesser Black-backed Gulls over 2010/11, 2011/12 and 2012/13. For those individuals for which information was complete, over the three years, four birds remained in the UK and 13 migrated to wintering areas to the south, to wintering areas in Iberia or North Africa, with one bird (in 2010/11) reaching as far south as Mauritania. Migration routes in and out of England were concentrated in a band across the English Channel, becoming more dispersed across the Bay of Biscay. The exposure of birds to the potential effects associated with offshore wind farms was thus highest in these areas (mainly UK, France, Spain, and Portugal). The proportionally larger size of developments in the English Channel meant that statistics of usage were high for wind farm areas in this region. However, estimated usage of offshore wind farm sites was greatest in Spain and Portugal, with a maximum of eight birds using the area of a single site. To our knowledge, this study represents the first direct assessment of the exposure to offshore wind farms of a breeding feature species of a Special Protection Area outside the breeding period.

1. INTRODUCTION

1.1 Background

The UK government has a commitment to obtain 20% of the UK's energy 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 sites within the North Sea may also overlap the foraging areas of seabirds that are features of protected sites. Offshore wind farms may potentially have an impact on 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) 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 Lesser Black-backed Gull *Larus fuscus* and the Great Skua *Stercorarius skua*. 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 are already operational or which are under construction) and proposed wind farm development sites;
ii. To understand the extent to which these feature species use the areas of operational, consented and proposed wind farms;
iii. To provide an assessment of the flight altitudes of these feature species that could usefully inform collision risk modelling.

Here, we present the findings from across the three years of study, providing an overview of work summarised in three previous annual reports (Thaxter *et al*. 2011; 2012a; 2013). The report is divided into five main chapters that provide detailed assessment of the variation in the movements and connectivity with offshore wind farms shown by Lesser Black-backed Gulls and Great Skuas during the breeding season, the flight heights of Lesser Black-backed Gulls and Great Skuas and the interactions with offshore wind farms shown by Lesser Black-backed Gulls during the migration and wintering periods.

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*. 2012b). However, considerable variation in foraging area usage may occur between colonies and both within and between breeding seasons. 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*. 2004a, 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 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 (Band 2000; Cook *et al.* 2012; Furness *et al*. 2013; Johnston *et al*. 2014). Flight altitudes of different species are typically assessed during boat surveys that are undertaken to inform the baseline of the EIA. These produce estimates of flight heights, typically in bands, and are only carried out during the day and in good weather conditions (Camphuysen *et al*. 2004; Johnston *et al*. 2014). Few precise assessments of flight altitudes exist. Radar studies have begun to provide useful information (e.g. Desholm & Kahlert 2005; Desholm *et al*. 2006; Shamoun-Baranes & van Loon 2006; Plonczkier & Simms 2012), although identifying the species concerned is not generally possible with this technique, and radar measurements can also be hampered by poor weather (Hüppop *et al*. 2006; Schmaljohann *et al.* 2008). Digital imagery in aerial surveys of offshore wind farms is becoming increasingly common (Buckland *et al.* 2012), but, like radar, it is also difficult to identify individuals to species level (Mellor & Maher 2008; Hexter 2009). However, new developments in GPS technology have given rise to systems that collect data over very short sampling intervals, resulting in improved precision and accuracy[1] in altitude measurements. Individual seabirds can now be fitted with small devices that measure their position in three dimensions. As these tracking devices can be long-lived, they also allow assessment of a bird's flight behaviour in a variety of conditions, including those that are known to affect flight altitude, such as season, weather and time of day (Drewitt & Langston 2006; Dokter *et al*. 2013; Kemp *et al*. 2013).

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 to 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 to 3 m, therefore giving information in unprecedented detail, which would be extremely useful for collision risk assessment.

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[1] 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.

2. METHODS

2.1 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 (Garthe & Hüppop 2004), but have received less attention. Other species include Northern Gannet, 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).

2.1.1 Lesser Black-backed Gull

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[2]). At-sea data have been used to investigate the species' distributions and habitat associations, for instance in the German North Sea (Schwemmer & Garthe 2008), and placement within multi-species feeding associations (Camphuysen & Webb 1999). Research has also focused particularly on general breeding biology, diet, and kleptoparasitism (Camphuysen 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.

2.1.2 Great Skua

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,

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

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*. 2004a; 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.

2.2 Field Sites

2.2.1 Lesser Black-backed Gull

Fieldwork was conducted at a mixed colony of Lesser Black-backed Gulls and herring gulls *Larus argentatus* at Orford Ness, Suffolk, UK (52°4’N, 1°33’E), part of the Alde-Ore Estuary SPA. This colony at Orford Ness was first established in the 1960s and, by 1998, the SPA population had increased to 21,700 apparently occupied nests (AONs). However, the Orford Ness colony has recently reduced in size, to 5,500 AONs in 1998-2002 (Mitchell *et al.* 2004) and to around 550-640 pairs in 2010 (Marsh 2013).

In the UK, different ‘rounds’ of offshore wind farm developments have taken place (DECC 2009[3]). The initial ‘Round 1’ developments were much smaller (From less than 100 km^2) than those currently being proposed under the latest ‘Round 3’ developments (largest up to 8660 km^2) (DECC 2009). The Orford Ness colony is located near to a number of these different wind farms, which are also within the foraging range of Lesser Black-backed Gulls (Thaxter *et al.* 2011; 2012a; 2013). These include the existing ‘Round 1’ sites (such as Scroby Sands), Round 2 sites, some of which are operational or were under construction during the period of study (Greater Gabbard[4]), additional consented extensions to these sites (such as Galloper), and the larger ‘Round 3’ East Anglia zone for which consent application proposals for development have now been submitted[4]. See Figure 2.1 for a map of the location of these wind farms.

2.2.2 Great Skua

Fieldwork for Great Skuas was conducted at the 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. The species has been the subject of a number of studies at this site (e.g. Hamer *et al*. 1991; Hamer & Furness 1993; Votier *et al*. 2007; 2008).

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[3] http://www.thecrownestate.co.uk/energy-infrastructure/offshore-wind-energy/ (accessed 30/10/2013)

[4] Source: www.4coffshore.com/offshorewind/ (last accessed 26/10/2013). The Greater Gabbard wind farm is *ca*. 30 km to the southeast of the colony (Fig. 1), and was in construction during the tracking study. At the start (on 5 June 2010), the first individual turbines had already been installed (19 May 2010). By August 2011, the Met mast foundations had been installed, three turbines were producing power, and array cable installation had started. By the 7 October 2011 117/140 turbines had been installed, which rose to 122 on 11 November 2011, 133 on 31 January 2012. By 21 March 2012, all 140 turbines had been installed. Very few birds and tracks crossed this wind farm site, even during 2010 when few turbines were present. Therefore, the impact of this site on the overall movement of birds is difficult to place in context but is likely to have negligible impact on the overall spatial patterns recorded over the course of the study.

The species was also studied at the Hoy SPA, UK (58°52’N, 3°24’W), this work led by the University of the Highlands and Islands (UHI).

Birds from both sites have the potential to forage in the breeding season within Scottish Territorial Waters (STW) short and medium term option zones, as described in Marine Scotland (2011), as well as proposed Round 3 zones (Figure 2.1).

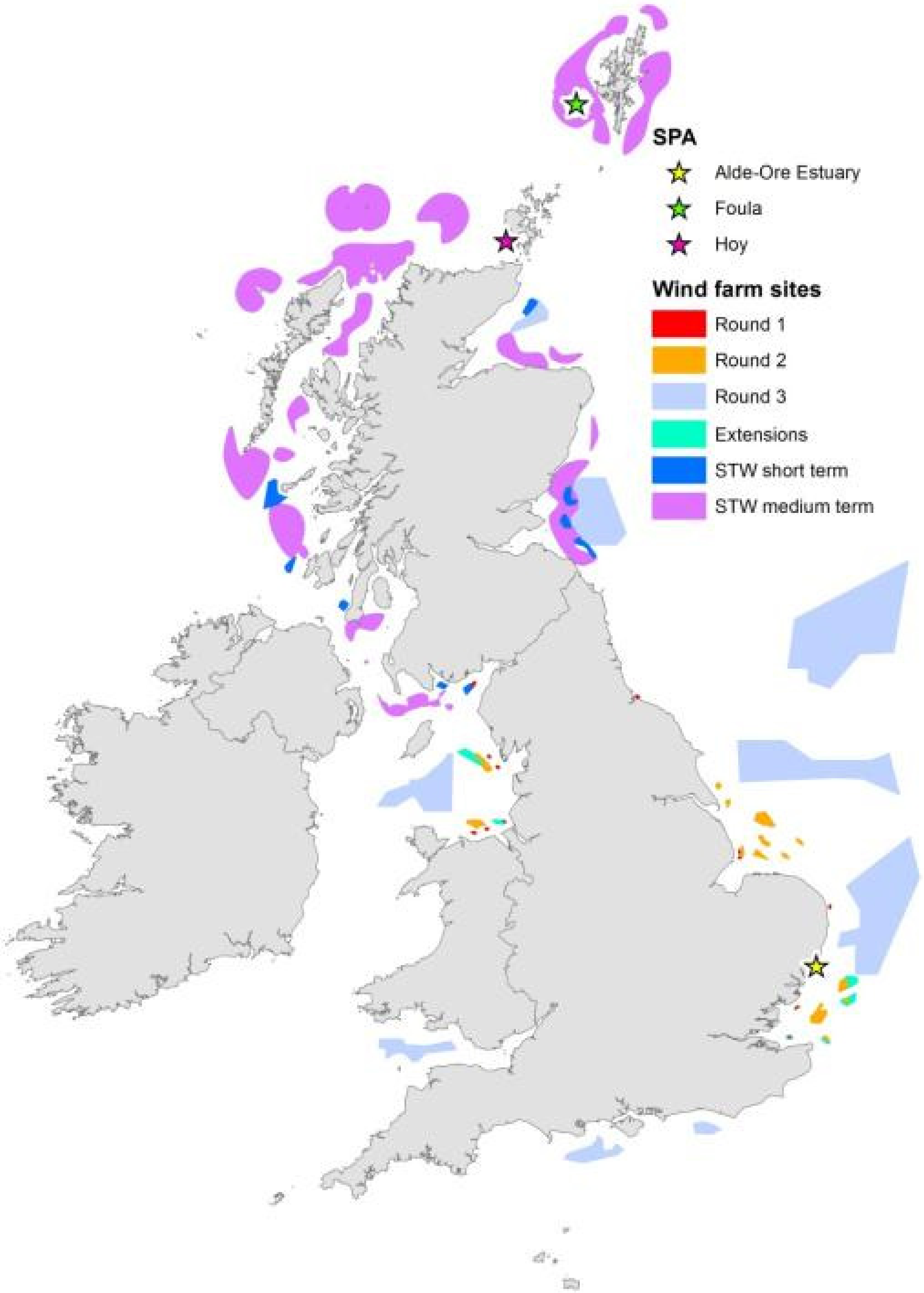

Figure 2.1 Location of existing and consented offshore wind farm sites and proposed development zones in the UK in relation to the study sites.

2.3 Capture and Attachment Methods

The use of tracking devices (hereafter 'devices') – bio-logging – is commonplace in wildlife research for studying the movement, behaviour, and physiology of animals (Murray & Fuller 2000). However, in any such study, it is important to be able to determine whether the attachment of devices has any deleterious effects, both for the welfare of the individuals marked and to ensure that it is known that the behaviour of the individuals has not been affected and thus that robust scientific conclusions can be drawn from the study. Such monitoring should also help to highlight where there are issues for future studies and to enable improvements to be made to the design and attachment of devices.

In this study, adult Lesser Black-backed Gulls were captured at the nest using a walk-in wire mesh cage trap during the late incubation stage, and Great Skuas were captured using either a remote-controlled nest-snare trap, walk-in trap or woosh net also during incubation.

In 2010, GPS devices (weighing 21g; Bouten *et al.* 2013) were attached to 11 Lesser Black-backed Gulls using either: a leg-loop harness (n = 3 birds, Rappole & Tipton 1991), Teflon body harness with a breast strap (n = 4 birds), or Teflon wing-harness (n = 4 birds) (Thaxter *et al.* in prep.). GPS devices were also fitted to four Great Skuas in 2010 using a leg-loop harness. Following initial evaluation of the use of these different attachment methods (Thaxter *et al.* in prep. for a full description of the harness methods used), GPS devices were attached to a further 14 Lesser Black-backed Gulls and 20 Great Skuas (10 each at Foula and Hoy) in 2011 using a wing harness. All devices (plus harnesses) were <3% body weight (max. 2.9% and 1.8% for Lesser Black-backed Gulls and Great Skuas, respectively).

A full appraisal of the potential impacts of the attachment of the tags to the birds is provided in Thaxter *et al.* (in prep.).To assess the effects of harnesses and devices, separate control birds and their nests were also monitored. Control birds were captured at the nest using the techniques described above, and fitted with colour-rings only. Comparison was made between: (1) territory attendance; (2) breeding success; and (3) over-winter survival.

No significant differences were found with respect to any of these parameters for Lesser Black-backed Gulls and thus it was concluded that the devices and harnesses used were suitable for the species across the temporal scales they were utilised. In contrast, for Great Skua, there was strong evidence that the devices and harnesses used in 2011 led to reduced over-winter survival. The devices and harnesses used were thus suitable for Lesser Black-backed Gull across the year, but were not suitable for Great Skua outwith the breeding season. The results of this evaluation have been written up in Thaxter *et al.* (in prep.), in order to help direct future bio-logging research and conservation for both species. Due to the apparent impacts of the devices and harnesses used on over-winter survival in Great Skuas, the results reported here are restricted to observations from the breeding season.

Nests of tagged gulls were monitored during the breeding season in which they were caught through approximately weekly visits to the site. However, once chicks had hatched, they were highly mobile within the colony and hence it was not possibly to reliably follow their survival. Furthermore, in subsequent years, due to the high nesting density of gulls in the colony, it was not possible to reliably determine which nests belonged to returning tagged individuals. Due to these difficulties, it was not possible to always determine the start and end of breeding attempts of tagged individuals or the stage of the breeding attempts. Analyses thus considered information from the nests of both tagged and control birds to provide general information on mean laying and hatching dates and breeding success for the colony as a whole.

2.4 The GPS System

To assess the movements of birds and their time budgets and flight heights, we used GPS tags developed by the University of Amsterdam (Bouten *et al.* 2013). Each tag included a GPS sensor, a microcontroller with a 4Mb flash-memory, a pressure sensor, an accelerometer, a solar panel, a battery, a battery charger, and a radio transceiver, with a total weight (plus harness) of 21 g (< 3% body mass, mean weight of adults captured: 851±85g, range: 710-955g). Two-way wireless VHF data communication allowed data to be downloaded remotely to a field-based laptop, and new sampling protocols to be uploaded. An on-board local clock gave the date and time for each GPS fix. A virtual perimeter of approximately 200 m^2 around the Orford Ness gull colony and the two skua colonies was used to determine when birds were 'within' the colony attending nest sites, and away from the colony on foraging trips.

Fixes were taken continuously at intervals, ranging from every 3 seconds to 30 minutes during breeding. The fix interval was initially varied to optimize the capture of movements and behaviour while minimizing the likelihood of gaps in the data due to low battery voltage and lack of memory, which can result from high-resolution measurements over an extended time period. Following this initial phase, tags were set to record at either 5 or 10 minute intervals, depending on battery quality, during foraging trips, with 30 minute intervals used when birds were at the nest site (to conserve battery power). In all years, GPS rates were set to either 15 or 30 minutes before birds departed on migration.

2.5 Data

For Lesser Black-backed Gulls, data in this study cover the period from June 2010 to August 2013. Tags gradually wore out, so that fewer measurements were taken per bird in each successive year, and some tags stopped working completely before August 2013 (Table 2.1). Data for Great Skuas were collected during the breeding seasons of 2010 and 2011 only.

Breeding periods and seasonal definitions

For Lesser Black-backed Gull, data on bird movements and time budgets were collected between early March and early-October when birds were linked to the Orford Ness breeding colony, covering: (i) pre-breeding (ca. March-May); (ii) breeding (ca. May-July); and (iii) post-breeding (ca. July-September) periods. The approximately weekly checks of the Orford Ness colony did not allow precise hatching and laying dates to be determined for individuals (while nests of individuals tagged in previous years, could not always be precisely located). Therefore, using monitoring information of nests of both tagged birds and un-tagged controls, we estimate approximate first egg and first egg-hatching dates to indicate approximate incubation and chick-rearing phases. These estimations were made using a combination of known incubation durations of 24-27 days and chick-rearing periods 30-40 days (Robinson 2005), and the dates of the first and last checks before and after egg laying or hatching.

For Great Skua, as for Lesser Black-backed Gull, the temporal extents of the breeding seasons of birds at each colony as a whole were determined through estimation of the first egg laying dates and last chick fledging dates across the colony. These estimations were made using a combination of known incubation durations of 24-27 days and chick-rearing periods of 30-40 days (Robinson 2005) and hatching dates. The breeding season was thus defined as lasting from 11 May to 16 August at Hoy (in 2011) and from 10 May to 15 August at Foula (in both 2010 and 2011). More precise information for individual nests was also used to assess changes in the behaviour of tagged birds before and after eggs hatched.

Sex-specific information

For Lesser Black-backed Gull, birds were by sexed using head and bill length measurements that were recorded along with body mass on capture (Coulson *et al.* 1983; Camphuysen 2011). A total of 13 males and nine females were sexed and included in further analyses.

For Great Skua, sexes of birds were determined using DNA (Hoy only), previous known information of sexes (both colonies), and biometrics of body size, head-bill measurements and wing length (both colonies). A total of six males (three each at Foula and Hoy) and eight females (five at Hoy, three at Foula) were sexed and included in further analyses. Three of these birds were considered as 'likely' to be the sex given based on mate size (one female, and two males) and were deemed suitable for inclusion in analyses. Due to small sample sizes for each colony, these data had to be pooled across colonies for an overall comparison and data are therefore indicative of likely effects present.

Table 2.1 Deployment periods for tags on (a) Lesser Black-backed Gulls and (b, c, d) Great Skuas.

(a) Lesser Black-backed Gull

Tag	Date tagged	Data collection end date	Reason data collection ended	Harness type
334	15/06/2010	29/07/2011	Tag malfunction	Wing
335	05/06/2010	07/07/2010	Tag malfunction	Leg-loop
336	15/06/2010	19/08/2012*	Tag malfunction	Wing
345	05/06/2010	10/07/2010	Tag malfunction	Leg-loop
347	05/06/2010	N/A	Tag fell off	Leg-loop
384	15/06/2010	21/06/2010	Tag malfunction	Body
388	15/06/2010	17/05/2011*	Death of bird	Body
391	15/06/2010	28/07/2011	Bird did not return in 2012	Body
395	15/06/2010	06/07/2013*	Unknown	Body
407	15/06/2010	15/08/2012*	Unknown	Wing
408	15/06/2010	14/07/2010	Bird did not return in 2011	Wing
457	21/05/2011	19/06/2011	Tag malfunction	Wing
459	21/05/2011	01/06/2013*	Death of bird	Wing
460	21/05/2011	24/05/2013	Unknown	Wing
478	21/05/2011	21/05/2013*	Unknown	Wing
479	21/05/2011	28/04/2013	Unknown	Wing
480	21/05/2011	07/06/2012	Unknown	Wing
481	21/05/2011	11/07/2011	Unknown	Wing
482	21/05/2011	15/06/2012	Tag malfunction	Wing
483	21/05/2011	26/05/2013	Unknown	Wing
484	21/05/2011	08/06/2013	Unknown	Wing
485	21/05/2011	05/06/2013*	Unknown	Wing
486	21/05/2011	02/06/2013*	Unknown	Wing
492	21/05/2011	14/06/2013*	Unknown	Wing
493	21/05/2011	17/06/2013*	Death of bird	Wing

*Gaps in data collection due to low battery life and tag wear and tear.

(b) Great Skua – Foula 2010

Tag	Date tagged	Data collection end date	Harness type
340	21/06/2010 17:07	24/06/2010	Leg-loop
342	22/06/2010 13:35	23/06/2010	Leg-loop
348	23/06/2010 15:35	08/07/2010	Leg-loop
349	22/06/2010 11:10	28/07/2010	Leg-loop

(c) Great Skua – Foula 2011

Tag	Date tagged	Data collection end date	Harness type
415	03/06/2011 17:41	13/07/2011	Wing
418	05/06/2011 19:06	17/08/2011	Wing
419	07/06/2011 07:45	25/08/2011	Wing
450	05/06/2011 10:56	29/08/2011	Wing
451	04/06/2011 20:24	15/08/2011	Wing
454	06/06/2011 17:12	11/09/2011	Wing
465	04/06/2011 19:20	18/09/2011	Wing
470	04/06/2011 11:40	17/08/2011	Wing
476	06/06/2011 20:55	27/08/2011	Wing
487*	09/06/2011 10:20	23/08/2011	Wing
488*	04/06/2011 09:32	06/06/2011	Wing

(d) Great Skua – Hoy 2011

Tag	Date tagged	Data collection end date	Harness type
392	14/06/2011 10:20	03/07/2011	Wing
400	12/06/2011 18:15	19/07/2011	Wing
409	12/06/2011 12:50	24/07/2011	Wing
420	12/06/2011 09:43	07/07/2011	Wing
448	11/06/2011 18:38	24/08/2011	Wing
467	12/06/2011 17:05	20/08/2011	Wing
471	11/06/2011 17:01	24/08/2011	Wing
472	12/06/2011 11:30	14/06/2011	Wing
473	11/06/2011 14:02	21/08/2011	Wing
475	12/06/2011 16:20	30/06/2011	Wing

3. INDIVIDUAL, SEX-SPECIFIC, SEASONAL AND ANNUAL VARIATION IN LESSER BLACK-BACKED GULL-WIND FARM INTERACTIONS DURING THE BREEDING SEASON

3.1 Introduction

The marine environment is under increasing pressure from human activities, including fisheries, shipping and boat traffic, oil and gas, and renewable energy developments (Syvitski *et al.* 2005; Halpern *et al.* 2008). Offshore wind farms form an ever increasing component of this marine infrastructure and are a key part of the UK Government's plan to obtain 20% of energy from renewable sources by 2020. It is therefore important to properly quantify the impacts that proposed offshore wind farms, alongside those already operational or consented, may have on marine wildlife and habitats.

Seabirds are key components of marine ecosystems, and as mobile species, have potential to be affected by offshore wind farms through direct collision mortality, being displaced from foraging areas, having flight paths diverted (barrier effect), or through changes to their foraging habitats and prey (Garthe & Hüppop 2004; Desholm and Kahlert 2005; Masden *et al.* 2009; Furness *et al.* 2013). In the UK, full consideration is given to each of these potential effects through the Environmental Impact Assessment (EIA) process for proposed developments, while the potential impacts on populations of birds at protected sites, for example sites classified as Special Protection Areas (SPAs) under the EU Birds and Habitats Directive, are given particular consideration in the EU through Habitats Regulations Assessment (HRA). Specific data on the links (here defined as 'connectivity') between a particular SPA and the development of interest are often lacking, however, meaning that precautionary information, such as representative foraging ranges (Thaxter *et al.* 2012b) may be required to evaluate potential impacts. Consequently, there is a pressing need to demonstrate connectivity directly.

The increased availability and affordability of technologies in recent years, including radar, thermal imagery, acoustic monitoring, high definition imagery and telemetry have offered an increasing number of ways to assess potential impacts of offshore renewable energy developments on wildlife (Carstensen *et al.* 2006; Desholm *et al.* 2006; Maclean *et al.* 2009; Scheidat *et al.* 2011; Furness *et al.* 2012). For seabirds, telemetry is a particularly useful tool, and the increasing miniaturisation of bird-borne devices (hereafter 'tags') has led to many studies of species' foraging movements (Hamer *et al.* 2007; Thaxter *et al.* 2011; 2012a; 2013) and permits a more detailed investigation of potential interactions with offshore wind farms (see Gyimesi *et al.* 2011; Langston & Teuten 2012; Camphuysen 2011; Soanes *et al.* 2013). Knowledge of seabirds' interactions with these sites is currently best served through GPS technology, which gives detailed information on seabird movements.

In order to evaluate the potential interaction of birds from colonies with offshore wind farms, however, it is important that the data collected can be considered to be representative of their movements over a given period. Species-specific requirements and economic restrictions have previously dictated when and how many birds to tag and the types of devices used. Affordable short-life tags are increasingly employed, but their use may be restricted to periods when seabirds are readily tagged (i.e. during the breeding season), meaning that their outputs are not representative of a species' annual cycle. Further, it is well known that changes food availability may alter the behaviour of birds between years and through the breeding season (Bearhop *et al.* 2001; Hamer *et al.* 2000; Pettex *et al.* 2010). Individual dietary specialisation is also widespread in generalist species such as gulls (Bolnick *et al.* 2003; Nemiroff & Despland 2007; Martins *et al.* 2008; Araújo *et al.* 2011), resulting in individual differences in seabird foraging behaviour (Mcleery & Sibly 1986; Watanuki 1992; Votier *et al.* 2004a; Woo *et al.* 2008). Sex-differences in foraging behaviour may also influence habitat use

(Lewis *et al.* 2002; Thaxter *et al.* 2009; Camphuysen 2011; Pettex *et al.* 2012). Quantifying these additional sources of variability is necessary to build up a coherent picture of seabird-wind farm interactions, without which impact assessment may incorrectly characterise the extent of risk posed by a development on a particular population.

This study focuses on the Lesser Black-backed Gull (the UK sub-species of which is *L. fuscus graellsii*), a breeding feature at 10 SPAs in the UK (Stroud *et al.* 2001). At-sea data have previously been used to investigate the distribution and habitat associations of Lesser Black-backed Gulls (Kubetzki & Garthe 2003), and offshore surveys have been extensively used to quantify the numbers and distributions of birds using the areas of proposed developments to inform impact assessments (Fox *et al.* 2006). However, such data cannot reveal the breeding origins of the individuals recorded. Only relatively recently have Lesser Black-backed Gulls been tracked from breeding colonies (Shamoun-Baranes *et al.* 2011; Klaassen *et al.* 2012). Lesser Black-backed Gulls may forage up to 180 km offshore during the breeding season (Thaxter *et al.* 2012b). Hence, there is potential for birds from several UK colonies to forage in areas of operational, consented and proposed offshore wind farms. Lesser Black-backed Gulls are considered to be at particular risk from collision (Garthe & Hüppop 2004; Furness *et al.* 2013) being classed as the third most sensitive species to this effect out of 38 considered by Furness *et al.* (2013), but are considered to be at lower risk from disturbance and displacement during wind farm construction/decommissioning and operation (31st most sensitive of 38 species, Furness *et al.* 2013).

Tracking systems are now available to monitor the movements of individuals over long-periods of time at fine-scale resolution (Vardanis *et al.* 2011; Shamoun-Baranes *et al.* 2011; Bouten *et al.* 2013). Using such a GPS-based system, we investigated the movements of individual Lesser Black-backed Gulls during the pre-breeding, breeding, and post-breeding periods (between March and September) from an SPA in southern England in relation to operational, consented and proposed offshore wind farms. Using data collected over three separate years, we tested whether time budgets and area utilisation, especially with respect to occurrences in the areas of operational, consented and proposed wind farms, varied due to: (1) individual (2) seasonal (3) sex-specific, and (4) annual differences in behaviour.

3.2 Methods

3.2.1 Post-processing of data

Seasonal definitions

Information on estimated incubation and chick-rearing periods (see section 2.5 for more details) was used to inform the assessment of changes of behaviours through the potential pre-breeding, breeding (incubation and chick-rearing), and post-breeding phases. Note that in both 2010 and 2012 the colony suffered a complete breeding failure (see results), hence chick-rearing periods whilst defined on graphs, do not necessarily indicate the precise breeding status of the colony or individual birds.

Sex-specific data

Where possible, the sex of each tagged bird was determined to allow assessment of movements of males and females (see section 2.3 for details).

Parameters assessed

For the purposes of analyses, data on the following parameters were summarised for 5-day periods through the pre-breeding, breeding, and post-breeding periods.

i. Trip statistics

We defined foraging trips by the departure and subsequent return of individuals to their nest sites. For all trips, we calculated (a) an offshore foraging range (the maximum point reached offshore from the colony); (b) the total travel distance per trip (by summing distances between GPS points along the route); and (c) trip duration (time elapsed between departure and return). We also separated daytime and night-time trips by virtue of their start times and returns to the colony in relation to the periods of sunrise and sunset, to assess the diurnal variation in these trip statistics.

ii. Time budgets

For all trips, we calculated the (total, diurnal and nocturnal) time spent (a) at the nest, (b) in offshore areas and (c) in the areas of operational, consented and proposed offshore wind farms. Together with time at the nest, this enabled a complete time budget to be constructed for each individual in each year for each consecutive 5-day period, for both total time, diurnal periods, and nocturnal periods (the latter defined by the periods between sunset and sunrise).

iii. Area usage

Area usage analyses focussed on observations during trips only, and thus the areas that might have been used for foraging and other activities away from the colony. Area utilisation was assessed using kernel density estimation (KDE, Worton 1989). The 50%, 75% and 95% KDEs of the utilisation distribution, were taken to represent the core, middle, and total areas, respectively – although in line with other studies (e.g. Soanes *et al.* 2013), here we present only the core and total area usage for simplicity. Least Squares Cross Validation (LSCV) was used to estimate the smoothing parameter (e.g. Hamer *et al.* 2007; Thaxter *et al.* 2010). Data were filtered to a 30 minute rate for spatial analysis, and for each 5-day period through the season, for each individual each year, we calculated (a) the total area, (b) area offshore, and (c) the area within operational, consented and proposed wind farms used. Separate investigation based on observations when travel speeds were <4km.h^{-1}, representing likely resting and foraging locations (Shamoun-Baranes *et al.* 2011), provided similar results to those based on all observations (R^2 = 85%). We provide some descriptive information for overlap of core forging areas using 50% KDEs. However, for more detailed analyses of area usage away from the colony, we focus on total area usage using the 95% KDE to represent equivalency to total time away from the nest from temporal analyses. All time budget and kernel analyses were conducted using R 2.15.0 (R Development Core Team 2013).

3.3 Analyses

We used General Additive Mixed-effects Modelling (GAMM) and General Additive Modelling (GAMs) (Wood 2006) frameworks to investigate the potential variation in trip statistics, time budgets, and area utilisation due to: (1) individual (2) seasonal (3) sex-specific, and (4) annual variation. These factors and covariates were investigated for each of the parameters outlined above. Separate modelling was conducted using all observations and using diurnal and nocturnal observations only.

To initially test individual variation between years and seasons, GAMs were specified to include two separate fixed terms of: *Year*BirdID* and *s(Jdate,BirdID).* To test for seasonal, sex-specific, and annual variation, GAMMs were used with a random effect for ''bird identity' (BirdID) included to account for repeated measures on individual birds, with slopes for individual birds allowed to vary across Julian date. GAMMs contained a smooth term for Julian date (Jdate, degrees of freedom, k = 6), and fixed effects of 'sex' and 'year'. To assess further interactions of these effects, we tested for variation in seasonal variation between years and between sexes by specifying a smoothed interaction with year and sex in the model. An autoregressive (AR1) term was specified to account for temporal autocorrelation.

Models used data summarised for 5-day periods and were often compositional. I.e. models for time budgets considered the proportion of the total time for which data were obtained within each period spent (a) at the nest, (b) in offshore areas and (c) in the areas of operational, consented and proposed offshore wind farms. Models for area usage considered (a) the total area, and the proportion of thus (b) offshore and (c) in the areas of operational, consented and proposed offshore wind farms. Where models considered proportions, we modelled the response with an offset term of the total area or time available in the 5-day period. We also included terms for the number of birds followed per 5-day period (specified as a weight in the model) to allow for unequal sample sizes across 5-day periods. For spatial analyses the amount of data available in the pre- and post-breeding periods varied according to the number of birds remaining in the area of the breeding colony with active tags. Therefore, the number of GPS fixes was included as a fixed effect to allow for unequal numbers data points available for 5-day periods in computing individual kernels. All models were fitted with either Poisson or negative binomial distributions (as indicated in Appendices 3.1 and 3.2), and used F-tests and dAIC to assess the significance of main effects and interactions using stepwise removal of non-significant terms. Values, where specified, are given as the means ±1 SD unless otherwise stated. All analyses were performed using R Version 2.15.0 (R Development Core Team 2013).

3.4 Results

3.4.1 Breeding productivity summary

Using information on the dates of first recorded eggs and of first chicks, the frequency of nest checks and known incubation and chick-rearing periods we estimated that the incubation period in the colony during 2010, 2011 and 2012 lasted between 7 May and 17 June (Julian date, 127-168), 5 May and 12 June (125-163), and 7 May and 17 June (105-144), respectively. We estimated that the chick-rearing period for these years lasted between 3 June and 27 July (154-208), 1 June and 22 July (152-203), and 11 May and 2 July (132-184).

During 2011, the number of eggs hatched per nest averaged between 1.3 and 2.2, and the number of chicks raised up to 9 July per nest averaged between 0.7 and 2.0 (based on the min and max values for all nests) (Thaxter *et al.* in prep.). During 2010 and 2012 very few chicks fledged. The number of eggs hatched per nest averaged between 0.5 and 1.5 in 2010, and 0.2 and 2.6 in 2012, thereafter nests failed either due to direct predation of eggs, chicks or adults, or colony disturbance (Thaxter *et al.* in prep.).

3.4.2 Summary of connectivity with operational, consented or proposed offshore wind farms

Seven of 10, 14 of 18 (bird 336 excluded due to a paucity of data) and eight of 14 birds in 2010, 2011, and 2012, respectively, used the areas of operational, consented or proposed offshore wind farms. All of these used the large Round 3 East Anglia development zone. Five, six and four birds, in 2010, 2011 and 2012 respectively, also used the Greater Gabbard wind farm (now fully constructed and operational); however, this wind farm was in construction over the period of this study[5] (see also methods). A further five, nine and four birds, in 2010, 2011 and 2012 respectively, overlapped with the consented Galloper extension to the Gabbard site that does not yet have any turbines (as of 26/10/2013[2]). One bird (407) overlapped with an operational Round 1 site at Scroby Sands during both 2010 and 2012.

The time spent offshore across all birds was an average of 15%, 6% and 7% in 2010, 2011, and 2012, respectively. Although the East Anglia zone was used most of all wind farm areas, the time spent even in this large zone across birds only amounted to 4% (maximum per bird, 15%), 1% (8%), and <1% (1%) of total time budgets of birds in 2010, 2011 and 2012 respectively (Table 3.1) and much less time was spent in the smaller existing, consented, and proposed wind farms in each year.

The overlaps of the total and core areas (95% KDE and 50% KDEs) used by birds and the areas of offshore wind farms were on average 54% and 25%, 36% and 17%, and 28% and 21% in 2010, 2011, and 2012, respectively. The overlap of 95% KDEs, representing total movements of birds away from the colony, had greatest overlap with the East Anglia zone, but the all-bird 95% KDE (‘Total’ in Table 3.2) across all wind farms in 2010, 2011 and 2012 still only amounted to 14% (max per bird, 42%), 7% (31%) and 2% (10%) in each year (Table 3.2).

3.4.3 Individual variation

Trip statistics, time budgets, and space use

Individual variation in time budgets, area usage and trip statistics is shown in Tables 3.1, 3.2 and 3.3, respectively. Birds varied as to whether they foraged inshore, offshore, or showed a mixture of both (Table 3.3, Figure 3.2). Therefore, individuals differed significantly in summary statistics of trip duration, foraging range, and distance travelled per trip (Table 3.4, Appendices 3.1 and 3.2). These variations in use of habitat inshore and offshore were reflected in significant differences in the extent of offshore area usage in both time budgets and kernel 95% KDE overlaps and, in turn, this resulted in a significant difference in the potential interaction between individuals and offshore wind farms (Tables 3.1, 3.2, and 3.4, Appendices 3.1 and 3.2). While there were often similarities in when during the season peaks in offshore and wind farm usage were greatest (see seasonal section below and Figure 3.3), there were nonetheless differences in how individuals behaved between during the course of a season and between years, with some birds showing more extensive offshore overlap in some years but not others (Figures 3.2 and 3.3, Table 3.6, Appendix 3.1). Therefore, the extent of offshore usage and hence wind farm interactions by individual birds should not be presumed to be the same between different years.

3.4.4 Sex-specific variation

Trip statistics

Females made significantly longer trips overall than males (Tables 3.4 and 3.5; Appendices 3.1 and 3.2); however, there was no difference in the distance reached from the colony or travel distance per trip (Table 3.4, Appendices 3.1 and 3.2). There was a significant sex*Julian Date interaction for all trip

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[5] www.4coffshore.com/offshorewind/ (last accessed 26/10/2013)

statistics (Table 3.4), relating to the timing of peaks and troughs in behavioural patterns (Figure 3.6). For example, the trips of both males and females decreased from pre-breeding to the start of incubation thereafter increasing; however, males showed an earlier increase than females (Figure 3.6a), the timing for males being just prior to incubation. Correspondingly, males also had an earlier trough in the relationship for offshore foraging range and total travel distance per trip than females (Figure 3.6a), just before incubation in both cases compared to females, early during incubation. The timing of secondary peaks in foraging range and distance travelled were similar between the sexes (Figure 3.6a).

Time budgets

There were no overall differences in total time spent away from the nest, time offshore, or time spent in the areas of offshore wind farms (Tables 3.4 and 3.5, Appendices 3.1 and 3.2). Consistent with the patterns seen above for trip duration, the total time spent away from the nest showed a clear difference between the sexes across the season (significant difference for sex*Julian Date, Table 3.4, Appendices 3.1 and 3.2), with a later reduction in time spent away from the nest in females compared to males (Figure 3.6b). These troughs were also slightly later than those recorded at the individual trip level. There was no significant difference between sexes in the time spent offshore across Julian Date (Table 3.4). Although time spent within wind farms was only a small fraction of the total time budget, males spent significantly more time than females in the areas of offshore wind farms at a slightly earlier time of the year (Table 3.4, Appendices 3.1 and 3.2, Figure 3.6b; 3% compared to <1%).

Area usage

There was no overall difference between the sexes in total area usage (size of the 95% KDE), the total overlap of the 95% KDE with offshore areas, and offshore wind farm overlaps. However, when examining the night-time data only, the area usage of males showed a significantly larger overlap with offshore wind farms (3.0±9.2% and 1.4±6.4%, Tables 3.4 and 3.5). Total area usage (95% KDE size) varied significantly across Julian Date according to sex (Table 3.4, Appendices 3.1 and 3.2, Figure 3.6c), as indicated by a later breeding season peak for females compared to males (Figure 3.6c). There was no difference between sexes in the overlap of the 95% KDE with offshore areas or offshore wind farms (Table 3.4, Appendices 3.1 and 3.2); however, the peak in wind farm overlap for males was nearly 10% compared to only 4% in females at a similar time during breeding.

3.4.5 Seasonal variation

All best fit models included a highly significant smoothed term of Julian date, indicating substantial season variation in all parameters (Table 3.4, see also Figure 3.3, Appendices 3.1 and 3.2), and some were also improved through inclusion of an interaction between year*Julian date (Table 3.4, Appendices 3.1 and 3.2).

Trip statistics

Foraging trips showed a decreasing trend in trip duration throughout pre-breeding periods (Figure 3.5a), until the start of incubation (Figure 3.5a), accompanied by reductions in total offshore foraging range and distance travelled per trip. Trip durations and distance travelled per trip then gradually increased across the season towards post-breeding. However, offshore foraging range peaked during late breeding (27 June, Julian date 178, 34.4±3.0%) and thereafter decreased – this latter pattern reflected in the general decrease in offshore usage at this time in the season (see below). However, patterns were not consistent between years, with a significant year*Julian date interaction for all trip statistics (Table 3.4, Figure 3.5a). In particular, during 2011, trip duration increased much more slowly with date than in other years. This pattern most likely reflected the greater success of nests further into chick-rearing, with parents still operating under a central place foraging constraint later in the season.

Time budgets

Consistent with the patterns for trip duration above, for all years, the time spent away from the nest decreased towards incubation, and thereafter increased towards post-breeding. However, in contrast with trip duration, there was no significant difference between years in this pattern. While there was a greater frequency of trips during chick-rearing during 2011, this was counteracted by the annual patterns seen in trip duration. The time spent offshore decreased from pre-breeding through to the start of incubation (Figure 3.5b) – during pre-breeding, many birds spent overnight periods on the sea-surface just offshore floating with the tide (see also Figure 3.7b). The time spent offshore across years showed a secondary peak on 20 June (Julian date 171) at 7.3±4.7% (Figure 3.5b), although the peak was earlier in 2011 (Figure 3.5b, 10 June, Julian date 161, 6.7±1.5%), resulting in a significant difference between years in this pattern (Table 3.4, Appendices 3.1 and 3.2). The magnitude of this second offshore peak during breeding was much higher in 2010 compared to other years (24.2±6.1% on 25 June in 2010, Julian date 176 , compared to < 10% in other years) (see overall means section below). The greater extent of offshore usage later during the breeding season resulted in a clear distinctive peak in time spent in wind farm areas, that was twice as high in 2010 (4.5±1.8% on 30 June, Julian date 181) compared to other years (2011, 1.1±0.4% at Julian date 171; 0.3±0.2% at Julian date 176, Figure 3.5b). However, there was no significant difference between years in this pattern (Table 3.4, Appendices 3.1 and 3.2). The greater amount of time spent offshore during pre-breeding was on average closer to the colony as shown through individual trips (see also Figure 3.5a), hence not resulting in wind farm interactions at this time of year.

Area usage

The total size of the 95% KDE showed a clear decrease during pre-breeding coinciding with the start of incubation (2011 and 2012 – Figure 3.5c), and thereafter peaked again later during breeding. This pattern matched the increase in total time spent away from the nest, and similarly showed no significant annual differences (Figure 3.5c, Table 3.4). A range contraction was recorded post-breeding with ranges then increasing again just prior to migration. As with time spent offshore, the overlap of 95% KDEs with offshore areas was larger during pre-breeding than in incubation, thereafter peaking later during breeding. Progressively less area overlaps were then recorded offshore towards the end of the breeding season. Significant annual variation was recorded in this pattern (Table 3.4, Appendices 3.1 and 3.2, Figure 3.5c), with earlier peaks seen in 2010 than other years. The overlap of the 95% KDE with offshore wind farms showed a single clear peak on 20 June (at Julian date 171, 4.3±1.4%, Figure 3.5c), and was similar in timing across years (no significant Julian Date*year effect, Table 3.4, Appendices 3.1 and 3.2). The magnitude of this second peak was over twice as high in 2010 compared to other years (2010: 8.6±3.2%, 2011: 3.3±1.1%, 2012: 1.3±0.5%).

3.4.6 Annual variation

After accounting for all other sources of variation, there was a significant difference recorded between years in all parameters assessed (Table 3.4, Table 3.6), with the exception of one model for night-time distance covered per foraging trip (Table 3.4).

Trip statistics

Across the three years of study, foraging trips were significantly longer in duration in 2010 than both 2011 and 2012 (Tables 3.4 and 3.6, Appendices 3.1 and 3.2), and covered a greater overall total distance, reaching further offshore (Tables 3.4 and 3.6, Appendices 3.1 and 3.2).

Time budgets

During 2010, more total time was spent away from the nest but a great deal more time was spent in offshore areas than other years, resulting in a greater use of offshore wind farms in 2010 (Tables 3.4 and 3.6, Appendices 3.1 and 3.2).

Area usage

The size of 95% KDEs and the percentage overlap of these ranges with offshore areas and the areas of offshore wind farms were also significantly greater in 2010 than other years (Tables 3.1 and 3.2, Appendix 3.2).

3.5 Discussion

For the first time, we have revealed detailed interactions of a protected feature species, Lesser Black-backed Gull, of a UK SPA, with offshore wind farm areas both through the pre-breeding, breeding and post-breeding periods and between years. The maximum foraging range of Lesser Black-backed Gulls found here (159 km, Table 3.3) matched that previously reported (Thaxter *et al.* 2012b). There was no apparent effect of tags and harnesses on the behaviour of Lesser Black-backed Gulls throughout the year (Thaxter *et al.* in prep). Therefore, these data are taken as representative of normal behaviour for this species.

3.5.1 Connectivity with offshore wind farms

Initial investigation into the interaction of Lesser Black-backed Gulls with offshore wind farms revealed likely individual, and annual variation, warranting the further detailed analyses presented. Indeed, some birds never interacted with any wind farms (Tables 3.2 and 3.3). Of all birds tracked, the proportion of birds that used areas of operational, consented and proposed offshore wind farm areas was highest in 2010 (70% of 10 birds), similar in 2011 (78% of 18 birds) and lowest in 2012 (57% of 14 birds), with all birds using the large Round 3 East Anglia zone, for which wind farm project proposals have been submitted. Connectivity with operational wind farms was more limited, with up to 50% of birds (in 2010) recorded in the area of the Greater Gabbard offshore wind farm, and one bird (in 2010 and 2012) recorded in the area of the Scroby Sands wind farm. Up to 50% of birds (in 2010 and 2011) used the Galloper extension to the Greater Gabbard site that is consented, but that contains no turbines at present (Tables 3.2 and 3.3). Other operational wind farms are located in the area, potentially in foraging range (such as London Array I/II, Figure 3.1), but were not used by birds from this colony during pre-breeding, breeding, and post-breeding periods. Despite the apparent high numbers of birds interacting with wind farms, the total time spent and spatial extent of overlap of areas used with offshore wind farms was more limited (Tables 3.2 and 3.3). The percentage of time spent in the areas of offshore wind farms peaked at 4% in 2010 and the percentage of total area usage at 14% in the same year. These figures are thought more representative of the extent of the interaction than simply the numbers of birds. Whilst this investigation gives initial perspectives on the extent of horizontal use of space by Lesser Black-backed Gulls at sea, these data alone do not pin-point the 3-dimensional use of these sites, in particular operational sites. Therefore, this information should be combined with further investigation of flight heights provided in Chapter 5.

3.5.2 Individual variation in behaviour and use of the areas of offshore wind farm areas

Individual Lesser Black-backed Gulls showed significant differences in their behaviour, with some foraging over a wider area and more offshore than others. Furthermore, individuals differed significantly in their wind farm usage across the season and between years (Table 3.4, Appendices 3.1 and 3.2), therefore individual interactions across multiple years should not be presumed the same (see also bird 395 in Figure 3.2). However, for many individuals throughout the season, patterns were similar, but the magnitude of the peaks were different between years; this also suggested patterns were not simply an artefact of different groups of individuals tracked each year. Among other seabird species, behavioural plasticity in individual behaviour (Pettex *et al.* 2010) may guard against rapid environmental change in ecosystems that are prone to long-term degradation (Nusey *et al.* 2007). For those species reliant on discards, individual variability in behavioural responses to changes in vessel activity has been recorded for Northern Gannets (Votier *et al.* 2010). This extent of inter- and intra-individual variation also merits further attention.

Although we had no indication of diet in this study, individual patterns may be linked to dietary specialisation, which for generalist predators, is widespread (Bolnick *et al.* 2003; Poore & Hill 2006; Martins *et al.* 2008; Araújo *et al.* 2011). Specialisation may be driven through sex- or age-specific differences in size, efficiency, or dominance (Stillman *et al.* 2002; Lewis *et al.* 2002), but has also been recorded in absence of these factors (Schindler *et al.* 1997; Stillman *et al.* 2002; Ropert-Coudert *et al.* 2003). Among seabirds, dietary specialisation (e.g. Mcleery & Sibly 1986; Watanuki 1992) may be reflected in foraging behaviour (Votier *et al.* 2004a; Woo *et al.* 2008), and individuals may perform repeated foraging trips to the same destinations (e.g. Irons 1998; Hamer *et al.* 2000; Bearhop *et al.* 2006; Soanes *et al.* 2012). Therefore, the repeated use of offshore habitat by some, but not all, Lesser Black-backed Gulls greatly increases their chances of wind farm interactions, possibly through a dependency on marine prey.

3.5.3 Seasonal and sex-specific variation in behaviour and use of the areas of offshore wind farm areas

The likelihood of birds using offshore wind farm areas was not constant across the season. The early peak in temporal and spatial use of offshore areas was due to more birds spending time just offshore roosting, particularly overnight (See Figure 3.7), as also recorded by Shamoun-Baranes *et al.* (2011). However, a second peak occurred later during the chick-rearing period, resulting in a corresponding increase in the use of the areas of offshore wind farms between late June and early July, and accompanied by a greater total area usage and time away from the nest. In all years, birds increasingly used inland areas during the post-breeding period, prior to migration.

Variation in temporal and spatial use of offshore areas thus reflects the stage of the breeding season and, in particular, the onset of chick-rearing. When productivity of the colony was greatest in 2011, gulls made increasingly offshore foraging trips at a time when chicks were first recorded. Changes in the use of habitat or dietary changes across the season (Schwemmer & Garthe 2008) between incubation and chick-rearing have also been recorded in other species (e.g. Ito *et al.* 2010). Through at-sea surveys, Schwemmer and Garthe (2008) recorded Black-headed Gulls *Chroicocephalus ridibundus* switching to marine feeding sites over the season, attributing this to a decrease in prey availability/quality in terrestrial habitats.

Such patterns may also be driven by sex-differences that are frequent among seabirds (e.g. Greig *et al.* 1985; Gray & Hamer 2001; Lewis *et al.* 2002; 2005, Thaxter *et al.* 2009). At a separate colony of Lesser Black-backed Gulls, at Texel, Netherlands, males were found to forage more offshore than females who used a greater mosaic of different habitats (Camphuysen 2011). In our study, females made longer trips than males (although this encompassed total trips outside of breeding), males also had a significantly greater extent of offshore usage later in the season during chick-rearing than females, which also translated into a greater use of offshore wind farm areas at this time. Note, that in some cases, these movements are likely to have involved birds that lost chicks during the chick-rearing period. Thus, the results cannot be solely attributed to male-female differences in nest attendance or provisioning behaviour. Lesser Black-backed Gulls are known to take a range of prey items from terrestrial sources such as plant material, invertebrates, mammals, and refuse, as well as marine and freshwater prey (Kubetzki & Garthe 2003; Camphuysen 1995; Camphuysen *et al.* 1995). The greater offshore habitat use by males may be linked to contribution of more fish prey and females a greater range of terrestrial items (Camphuysen 2011), though this needs further substantiation.

Early-season sex-differences were also seen in the timing of peaks and troughs in the seasonal patterns observed in trip statistics and time budgets. For example, trip duration of male birds reduced from pre-breeding to incubation quicker than females – as also shown through time budgets and total time away from the nest. These differences may be a result of females returning to the colony slightly later than males after acquiring the nutrients needed to develop and then lay their eggs, whilst the male defends the nest site. Such patterns have been suggested for other species elsewhere (Wanless & Harris 1986; Thaxter *et al.* 2009).

Seasonal patterns in habitat use were not constant between years. In particular, the time spent away from the nest (and total size of 95% KDEs), as well as the spatio-temporal overlap with offshore areas showed consistent season*year variation. For instance, more pronounced peaks in offshore area usage were recorded in 2010, than in either 2011 or, especially, 2012. Although productivity differences between sympatric species are not always linked to differences in foraging behaviour and food availability (Kim & Monaghan 2006), demographics have been shown to influence diet and habitat use (Washburn *et al.* 2013). It is possible that habitat use changes in the current study are linked to the timing of breeding, or the extent of failed breeder movements. For example, eggs hatched approximately two to three weeks earlier in 2012, and this could explain the earlier increase in length of foraging trips in 2012 than other years.

3.5.4 Diurnal variation

Some interesting differences between daytime and night-time activity of birds was also recorded. Birds used larger areas during the day than at night (Figure 3.7c, see also Figure 3.4), as would be expected to minimise predation risk and increase foraging efficiency. This finding is consistent with the fact that birds spent less time flying at night – see Chapter 7. Some roost areas were also identified at nearby estuaries north and south of the colony further along the coast (see examples presented in Appendix 3.3), behaviour that has parallels with the diurnal and nocturnal behaviour seen in some wintering waders (e.g. Burton & Armitage 2005). Time spent away from the nest was also lowest during early breeding, as also would be predicted from nest attendance duties of individual parents (Figure 3.7b). As mentioned above, the difference pre-breeding between day and night overlap with offshore areas was most striking (Figure 3.7b and 3.7c, see also Appendix 3.3). The assessment of night periods in this study was taken as the time between sunset and sunrise the following day. Behaviour of birds during twilight periods may still partially reflect daytime behaviour, and therefore patterns may be even more pronounced than presented here.

3.5.5 Annual variation in behaviour and use of the areas of offshore wind farm areas

After accounting for all other sources of variation, the overall temporal and spatial use of offshore areas, and in turn the areas of offshore wind farm areas, was significantly greater in 2010 than in 2011 and 2012. These differences were reflected in nearly all measures investigated (Table 3.4). Such patterns could have been driven through differences in productivity of birds affecting behaviour. If food supplies are short, Lesser Black-backed Gull productivity may be affected by lower feeding rate, chick starvation and predation rate (Bukacinski *et al.* 1998). Lesser Black-backed Gulls are mainly piscivorous during breeding, but exploit other prey when fish are not available (Bustnes *et al.* 2010). Annual variation in foraging behaviour is widely reported for other seabirds such as Northern Gannets *Morus bassanus* (e.g. Hamer *et al.* 2007; Pettex *et al.* 2012), linked to variation in temporal and spatial distribution of prey (Hamer *et al.* 2007). However, only moderate annual variability in at-sea distributions has been reported elsewhere (Schwemmer & Garthe 2008). Conceivably, alterations to foraging habitat may have played a part in annual patterns in this study. However, the low productivity of the colony in both 2010 and 2012 does not alone explain the considerable difference in offshore usage seen between these two years. For scavenging species, foraging behaviour can also change through alterations to fisheries activity (Bearhop *et al.* 2001; Torres *et al.* 2011), or dietary switching to man-made resources (Ramírez *et al.* 2012). Given that Lesser Black-backed Gulls are dependent on discards and fisheries waste (Bustnes *et al.* 2010), frequently associated with vessels out at sea, but are reliant on man-made refuse (Camphuysen 1995; Camphuysen *et al.* 1995), these factors require further investigation.

3.5.6 The importance of longer term tracking

The increasing use of tracking devices to investigate movements and area usage has helped tighten the focus on the importance of sampling protocols to sufficiently assess area utilisation (Seaman *et al.* 1999; Borger *et al.* 2006; Soanes *et al.* 2013). Many fine-scaled assessments of home range have been conducted during the breeding season using short-lived devices which have been deployed on individuals for relatively limited time periods (e.g. Hamer *et al.* 2007; Thaxter *et al.* 2010), governed mainly by when catching of birds is feasible, or limited by economic or time constraints. Such data are also used as a key basis in identifying potential marine protected areas (e.g. Wilson *et al.* 2009; Le Corre *et al.* 2012; O'Brien *et al.* 2012), and are increasingly being used to assess the extent of interaction with offshore renewable energy devices (Camphuysen 2011; Gyimesi *et al.* 2011; Langston & Teuten 2012; Soanes *et al.* 2013). Therefore, the issue of how long to track birds is a central consideration for tracking studies. For offshore renewable energy developments, understanding of the temporal and spatial use of wind farm project areas is vital, as the conclusions are then used further in assessment of potential impacts of feature species of protected sites. Use of offshore areas and offshore wind farms by Lesser Black-backed Gulls in this study was highly ephemeral across the pre-breeding, breeding and post-breeding periods, and shorter term investigation may have given a very different perspective. The annual variation in the temporal and spatial use of offshore areas and thus the areas of offshore wind farms also highlights the need for repeated study of colonies across multiple seasons to fully quantify the risk posed by offshore renewable energy developments to protected populations.

Table 3.1 Summary of individual Lesser Black-backed Gull time budget analyses, including total time away from the nest (on trip), percentage of time spent in offshore areas, and within offshore wind farms, for (a) 2010, (b) 2011, and (c) 2012, and pooled data across birds for (d) sex-specific and diurnal variation.[1]

(a) 2010

Bird	Total time (hrs)	On trip (%)	Offshore (%)	Proportion in wind farm (%)				
				Greater Gabbard	East Anglia	Galloper Extension	Scroby Sands	All wind farms
334	3145	99	17	<1	4	<1		5
335	728	86	1					
336	1403	40	15	<1	2	<1		3
345	779	77	5	<1	1	<1		2
384	128	51	0					
388	517	65	0					
391	306	93	8		<1			<1
395	654	94	19	2	3	1		6
407	720	80	43		15		<1	15
408	624	82	38	2	13	2		16
Total	5859	71	25	<1	7	1	<1	8

(b) 2011

Bird	Total time (hrs)	On trip (%)	Offshore (%)	Proportion in wind farm (%)				
				Greater Gabbard	East Anglia	Galloper Extension	Scroby Sands	All wind farms
334	2503	100	12	<1	2	1		3
391	2749	41	0					
395	2583	50	1					
407	3132	68	13		1	<1		1
457	462	27	1		<1			<1
459	1515	58	7		1	<1		1
460	4036	25	4		<1			<1
478	1767	53	11		1	<1		1
479	3274	39	4	<1	1	<1		1
480	2030	62	1		<1			<1
481	1180	45	2		<1			<1
482	2824	29	9	<1	2	<1		2
483	2073	46	2					
484	1689	58	0					
485	1740	43	1	<1	<1	<1		0
486	3041	43	12	<1	2	1		3
492	935	52	6		<1			<1
493	1804	62	29	<1	8	<1		9
Total	36834	46	7	<1	1	<1		1

(c) 2012

Bird	Total time (hrs)	On trip (%)	Offshore (%)	Proportion in wind farm (%)				
				Greater Gabbard	East Anglia	Galloper Extension	Scroby Sands	All wind farms
395	2143	68	0					
407	3647	58	9	<1	1	<1	<1	1
459	1383	57	6		<1	<1		<1
460	5075	30	5	<1	<1	<1		<1
478	2102	53	17					
479	4676	29	1					
480	1408	80	5					
482	2291	90	13	<1				<1
483	2630	43	5					
484	2267	83	10					
485	2314	79	3		<1			<1
486	4378	25	5	<1	<1	<1		<1
492	3018	45	7		<1			<1
493	3125	62	14		1			1
Total	40458	51	7	<1	<1	<1	<1	<1

(d) Male / female; day / night

	Total time (hrs)	On trip (%)	Offshore (%)	Proportion in wind farm (%)				
				Greater Gabbard	East Anglia	Galloper Extension	Scroby Sands	All wind farms
Male	46758	43	9	<1	1	<1		2
Female	32158	62	8	<1	1	<1	<1	1
Day	52298	49	6	<1	1	<1	<1	1
Night	30853	53	13	<1	1	<1	<1	1

[1] Note, more data have been added for previous years since the publication of Thaxter *et al.* (2012) and (2013), hence figures presented here may not match those originally presented.

Table 3.2 Summary of individual Lesser Black-backed Gull kernel overlap analyses, including total bird kernel sizes, percentage overlap of kernels with offshore areas, and percentage overlap with the areas of operational, consented and proposed offshore wind farms, for (a) 2010, (b) 2011, and (c) 2012, and (d) sex-specific and diurnal kernels across birds, using GPS data filtered to a 30 minute sampling rate.[1]

(a) 2010

Bird	**No. fixes**	**Area (km^2)**		**Offshore KDE overlap (%)**		**Wind farm KDE overlap of 95% KDE (%)**				
		95% KDE	**50% KDE**	**95%**	**50%**					
						East Anglia	**Galloper Extension**	**Greater Gabbard**	**Scroby Sands**	**All**
334	6087	3491	94	72	33	21	2	<1		23
335	1226	665	139	23	7					0
336	2634	1974	63	72	31	12	5	1		18
345	1162	2574	118	37	7	9	3	<1		12
384	129	528	56	19	5					0
388	664	345	65	36	22					0
391	565	700	70	60	20	<1	<1			0
395	1244	2615	69	61	29	13	4	2		19
407*	1092	8855	704	68	56	28			<1	28
408	952	2973	250	89	38	40	2	<1		42
Total	15755	10370	206	65	29	25	2	1	<0.1	27

* The core 50% KDE of only bird (407) overlapped with offshore wind farms, 2% with East Anglia.

(b) 2011

Bird	**No. fixes**	**Area (km^2)**		**Offshore KDE overlap (%)**		**Wind farm KDE overlap of 95% KDE (%)**				
		95% KDE	**50% KDE**	**95%**	**50%**					
						East Anglia	**Galloper Extension**	**Greater Gabbard**	**Scroby Sands**	**All**
334	4856	3457	70	42	47	10	3	1		13
391	2155	371	65	28	12					0
395	2564	331	51	26	14					0
407	4201	2267	148	40	23	13				13
457	257	338	37	43	6	5				5
459	1836	3435	247	33	20	6	<1			6
460	6119	435	72	34	21					0
478	1956	2204	169	55	19	8	<1			8
479	4760	1455	102	35	9	10				10
480	2636	2463	156	8	19					0
481	1177	659	83	30	10					0
482	3441	2035	182	72	10	17	2	<1		19
483	1916	1763	201	13	17					0
484	1995	1093	73	9	12					0
485	2091	2148	267	13	10	<1				0
486	4777	3540	274	56	3	9	2	1		13
492	1004	613	79	33	18	3				3
493	2319	5161	392	76	40	29	2	1		31
Total	50060	7016	213	41	20	10	1	<1		12

(c) 2012

Bird	No. fixes	Area (km^2)		Offshore KDE overlap (%)		Wind farm KDE overlap of 95% KDE (%)				
		95% KDE	50% KDE	95%	50%	East Anglia	Galloper Extension	Greater Gabbard	Scroby Sands	All
395	2360	1031	60	10	21					0
407	4933	3394	127	34	20	7	1		<1	8
459	1347	691	71	40	28		<1			<1
460	4925	471	123	39	16	3	1	1		5
478	1856	915	121	30	42					0
479	7086	874	75	15	0					0
480	2059	731	62	25	18					0
482	3768	670	83	45	30					0
483	2172	1235	99	14	36					0
484	3609	495	57	39	19					0
485	3482	2673	258	13	19					0
486	4286	929	101	21	2	2				2
492	3251	1034	102	20	22					0
493	3620	2973	218	40	26	10				10
Total	48754	6068	134	17	22	5	1		<1	6

(d) Male / females; day / night

Bird	No. fixes	Area (km^2)		Offshore KDE overlap (%)		Wind farm KDE overlap of 95% KDE (%)				
		95% KDE	50% KDE	95%	50%	East Anglia	Galloper Extension	Greater Gabbard	Scroby Sands	All
M	68037	9046	147	35	26	9	0	<0.1	0	9
F	42635	7498	200	41	22	10	2	0	0	12
Day	69706	9397	188	41	12	11	2	1	0	14
Night	44863	6789	147	48	32	11	1	0	<0.1	13

[1] Note, more data have been added for previous years since the publication of Thaxter *et al.* (2012) and (2013), hence figures presented here may not match those originally presented.

Table 3.3 Trip statistics for individual Lesser Black-backed Gulls tracked across the course of this study for 2010, 2011 and 2012. Two birds marked with an asterisk were excluded from total mean calculations due to their shift in nest site to areas away from Orford Ness either during or between breeding seasons.[1]

Year	Bird	Trip duration (hrs)		Offshore foraging range (km)		Total distance (km)		Number of trips		
		Mean	Max	Mean	Max	Mean	Max	Inshore	Offshore	Total
2010	334*	39.4±50.5	133.2	63.9±18.1	88.6	208.5±269.8	678.4	8	6	14
	335	11.4±25.7	149.4	24.6±10.9	32.8	37.2±76.1	450.4	53	2	55
	336	12.1±17.4	76.7	28.8±19.9	66.3	67.7±76.3	302.8	20	23	43
	345	9.7±24.4	166.7	28.4±23.6	60.0	51.8±125.1	733.1	53	6	59
	384	6.6±8.3	23.3	0.4±0	0.4	18.6±30.8	102.2	10	0	10
	388	7.7±9.9	46.5	13.2±0.7	13.8	18.5±23.8	98.0	40	1	41
	391	2.7±2.6	11.6	23.6±8.5	39.3	19.4±25.6	113.0	64	9	73
	395	7.5±14	73.9	29.8±2.8	32.2	19.6±27.5	86.8	25	8	33
	407	15.4±29.6	117.3	60.1±59.4	158.7	122.6±259.4	893.7	22	13	35
	408	8±16.9	102.3	24.3±25.7	99.7	46.1±89.7	513.5	38	20	58
	All	8.8±19.1	166.7	30.6±31.8	158.7	44.5±108.1	893.7	333	88	421
2011	334*	117±156.5	729.6	35.3±23.1	74.4	494.6±545.7	2225.6	9	13	22
	336*	21.3±0	21.3	0±0		37.1±0	37.1	1	0	1
	391	2.8±2.6	12.3	15.6±13.6	36.2	13.8±13.9	96.8	399	5	404
	395	4.6±5.7	47.5	24.9±9.5	36.3	13.3±17.7	109.2	276	7	283
	407	8.6±12	145.0	17±18	93.0	34.4±55.4	565.5	177	70	247
	457	2.3±1.4	6.8	26.6±36.2	52.2	12.8±18.8	118.6	51	3	54
	459	4.8±5.3	35.6	21±18.4	90.9	54.7±71.3	454.9	156	29	185
	460	5.4±6.2	51.7	20±9.4	39.7	21.9±25.8	133.4	162	24	186
	478	6.2±7.6	71.0	21.9±19.4	72.6	38.7±62.3	360.6	122	28	150
	479	4.9±15.5	216.4	33±23.2	80.2	33.2±76.7	998.7	236	28	264
	480	5.8±7.8	49.2	15.8±17.4	58.8	39.5±50.6	304.1	215	4	219
	481	2.6±2.2	13.5	16.2±15.8	49.8	22.2±23.6	128.0	194	10	204
	482	3.6±3.8	20.7	34.3±23.2	80.0	36.5±53.1	366.1	177	55	232

Year	Bird	Trip duration (hrs)		Offshore foraging range (km)		Total distance (km)		Number of trips		
		Mean	Max	Mean	Max	Mean	Max	Inshore	Offshore	Total
	483	3.5±5.2	69.8	6.6±6.6	22.0	44.2±62.4	484.8	258	14	272
	484	4.2±5.2	43.8	1.8±2.4	5.4	25.7±34.8	223.2	233	1	234
	485	5.6±11.7	116.6	20.1±12.5	46.7	39.9±56	445.9	125	8	133
	486	6.7±6	32.3	43.6±16.5	90.2	73.8±62.4	328.2	142	53	195
	492	5.4±5.3	28.9	10.8±12	51.4	22.4±26.4	130.0	70	14	84
	493	4.5±4.4	26.3	36.3±24.8	124.0	54.9±70.8	416.2	164	87	251
	All	4.7±7.5	216.4	26.0±21.8	124.0	34.0±53.2	998.7	3167	453	3620
2012	336*	85.3±116.4	167.6	0.4±0	0.4	73.2±96.4	141.4	2	0	2
	395	5.5±17.1	253.9	7.2±5	10.7	10.9±51	771.5	232	2	234
	407	8.5±13.9	154.3	16±26	158.5	29.3±67.1	677.8	204	45	249
	459	5±5.6	35.7	16±25.3	100.7	15.2±27.7	272.3	143	14	157
	460	4.7±12.9	206.2	10.5±11.4	47.8	16.6±26.6	377.8	272	49	321
	478	3.9±8.4	130.7	11.1±4.3	18.7	16±28	429.8	243	40	283
	479	4±4.6	46.8	11.8±10.8	35.8	22.4±23	149.6	330	12	342
	480	9.4±9.3	52.8	12±2.9	16.1	20.2±36.1	280.9	111	8	119
	482	10.5±14.9	174.8	12.4±7.4	30.5	25.8±32.2	220.0	153	40	193
	483	4.2±5.7	72.3	8.2±5.6	23.9	28.1±46.2	417.7	246	23	269
	484	9.9±9.6	56.5	9.3±7.4	39.1	18.3±22.1	134.2	159	30	189
	485	11±27.5	231.3	23.9±57.9	49.2	43.6±116.7	663.2	110	21	131
	486	3.7±3.5	21.5	20.3±20	67.0	20.3±25.9	222.7	247	34	281
	492	5.7±9.1	74.4	7.9±8.6	47.9	20.5±43.9	405.0	212	27	239
	493	5±14.5	193.9	18.3±17.2	71.0	25±59	788.8	316	60	376
	All	5.9±12.1	253.9	13.7±20.3	158.5	21.8±46.5	788.8	2980	405	3385

[1] Note, more data have been added for previous years since the publication of Thaxter *et al.* (2012) and (2013), hence figures presented here may not match those originally presented.

Table 3.4 Summary of significant parametric and smoothed terms fitted for spatial and temporal analyses of Lesser Black-backed Gull data – for full analysis results see Appendices 3.1 and 3.2.

Period	Section	Measure	Sex	Year	s(Jdate)	s(Jdate, Year)	s(Jdate, Sex)	s(Jdate, BirdID)	Year* BirdID
Total	Trip statistics	Trip duration	*	*	*	*	*	*	*
		Foraging range offshore		*	*	*	*	*	*
		Distance covered per trip		*	*	*	*	*	*
	Time	Time away from nest		*	*		*	*	*
		Time offshore		*	*	*		*	*
		Time in wind farm		*	*		*	*	*
	Space	Total area usage		*	*		*	*	*
		Offshore usage		*	*	*		*	*
		Wind farm overlap		*	*			*	*
Day	Trip statistics	Trip duration	*	*	*	*	*	*	*
		Foraging range offshore		*	*		*	*	*
		Distance covered per trip		*	*			*	*
	Time	Time away from nest		*	*		*	*	*
		Time offshore		*	*	*	*	*	*
		Time in wind farm		*	*		*	*	*
	Space	Total area usage		*	*		*	*	*
		Offshore usage		*	*	*		*	*
		Wind farm overlap		*	*		*	*	*
Night	Trip statistics	Trip duration	*	*	*	*	*	*	*
		Foraging range offshore		*	*		*	*	*
		Distance covered per trip			*	*	*	*	*
	Time	Time away from nest		*	*	*		*	*
		Time offshore		*	*			*	*
		Time in wind farm		*	*			*	*
	Space	Total area usage		*	*	*	*	*	*
		Offshore usage		*	*	*		*	*
		Wind farm overlap	*	*	*			*	*

Table 3.5 Means and maximums across all consecutive 5-day periods per year for measures of trip statistics, time budgets and area usage for male and female Lesser Black-backed Gulls. All spatial overlaps are for the 95% KDE.

Period	Measure	Parameter	Males		Females	
			Mean±SD	Max	Mean±SD	Max
Total	Trip statistics	Trip duration (hrs)	7.1±12.2	231.3	4.8±10.2	253.9
		Foraging range offshore (km)	22.3±27.7	158.7	26.0±20.8	124
		Total distance travelled (km)	31.7±62.4	943.1	28.7±53.2	998.7
	Time budgets	%Time away from nest (total)	71.0±23.0	100	67.9±27.6	100
		% Time offshore (total)	8.1±14.0	98.4	8.4±14.5	94.4
		% Time in wind farm (total)	0.8±3.9	41.5	1.5±5.3	52
	Area usage	Size of 95% KDE (km^2) (total)	841±792	6077	760±696	4055
		% Overlap offshore (total)	33.6±18.2	92.2	34.2±22.7	93
		% Wind farm overlap (total)	1.8±6.6	49	3.1±8.4	61.9
Day	Trip statistics	Trip duration (hrs)	3.3±2.7	13.8	2.5±2.0	15.8
		Foraging range offshore (km)	24.1±19.2	90.9	31.2±18.6	90.2
		Total distance travelled (km)	21.9±32.9	301.3	21.9±34.1	354.4
	Time budgets	%Time away from nest (total)	43.8±16.4	74.3	39.8±18.4	89.5
		% Time offshore (total)	2.3±6.5	59.9	4.0±9.3	63.4
		% Time in wind farm (total)	0.5±2.2	20.3	1.0±3.5	28.8
	Area usage	Size of 95% KDE (km^2) (total)	785±786	5441	744±634	3876
		% Overlap offshore (total)	28.4±17.6	89.2	29.3±23.1	93.3
		% Wind farm overlap (total)	1.8±6.6	45.8	3.1±8.2	59.3
Night	Trip statistics	Trip duration (hrs)	10.9±16.2	231.3	8.5±15.8	253.9
		Foraging range offshore (km)	21.8±29.8	311.3	23.5±21.3	124
		Total distance travelled (km)	42.3±80.6	943.1	40.1±73.8	998.7
	Time budgets	%Time away from nest (total)	26.8±13.7	76.5	28.1±16.4	100
		% Time offshore (total)	5.7±11.0	100	4.3±8.8	87.4
		% Time in wind farm (total)	0.3±2.1	24.2	0.5±2.1	29
	Area usage	Size of 95% KDE (km^2) (total)	583±480	4402	472±450	3194
		% Overlap offshore (total)	41.0±18.3	96.6	40.9±22.9	92.2
		% Wind farm overlap (total)	1.4±6.4	55.6	3.0±9.2	66.4

Table 3.6 Means and maximums across all consecutive 5-day periods per year for measures of trips statistics, time budgets, and area usage for Lesser Black-backed Gulls in 2010 (10 birds, 347 trips), 2011 (19 birds, 3590 trips) and 2012 (15 birds, 3372 trips). All spatial overlaps are for the 95% KDE.

Period	Measure	Parameter	2010		2011		2012		Total mean	
			Mean±SD	Max	Mean±SD	Max	Mean±SD	Max	Mean±SD	Max
Total	Trip statistics	Trip duration (hrs)	8.4±19.3	166.7	4.7±7.5	216.4	5.9±12.1	253.9	5.4±7.1	253.9
		Foraging range offshore (km)	38.2±36.9	158.7	31.2±21.2	124	15.3±21.3	158.5	24.3±23.8	158.7
		Total distance travelled (km)	41.9±110.9	893.71	34.0±53.3	998.7	21.8±46.5	943.1	28.8±54.9	998.7
	Time budgets	%Time away from nest (total)	77.9±24.8	100	61.4±25.6	100	72.4±25.4	100	67.9±26.1	100
		% Time offshore (total)	15.8±22.4[1]	94.4	6.5±11.7[2]	68.3	7.3±12.9[3]	100	7.9±14.1[4]	100
		% Time in wind farm (total)	4.9±11.3[1]	52	1.3±3.8[2]	24.9	0.2±1.2[3]	10.3	1.2±4.8[4]	52
	Area usage	Size of 95% KDE (km^2) (total)	1037±1111	6077	900±801	4477	592±419	2869	776±723	6077
		% Overlap offshore (total)	45.2±24.2	92	33.8±22.1	93	31.5±17.1	76.1	34.0±20.6	93
		% Wind farm overlap (total)	7.2±13.8	61.9	3.2±7.9	44.2	0.7±3.4	32.6	2.5±7.6	61.9
Day	Trip statistics	Trip duration (hrs)	2.7±2.4	12.7	2.7±2.3	14.6	2.8±2.2	15.8	2.7±2.2	15.8
		Foraging range offshore (km)	23.1±16.6	73.4	31.2±18.9	90.9	20.8±16.7	69.7	28.0±18.8	90.9
		Total distance travelled (km)	17.5±27.5	159.9	26.4±38.7	354.4	15.0±21.9	211.4	21.0±32.4	354.4
	Time budgets	%Time away from nest (total)	51.8±18.8	89.5	38.5±15.5	76.6	41.1±19.1	74.3	40.7±17.8	89.5
		% Time offshore (total)	10.2±15.8	63.4	3.6±7.8	50.8	1.3±3.7	37.1	3.3±8.2	63.4
		% Time in wind farm (total)	3.1±6.7	28.8	0.9±2.7	19.8	0.1±0.8	7.9	0.8±3.0	28.8
	Area usage	Size of 95% KDE (km^2) (total)	1025±1088	5441	835±712	4762	583±445	2689	745±685	5441
		% Overlap offshore (total)	42.8±25.1	92.9	30.3±22.4	93.3	24.8±15.6	76.8	29.3±20.7	93.3
		% Wind farm overlap (total)	6.7±13.0	59.3	3.1±7.9	43	0.8±3.6	29.3	2.5±7.5	59.3
Night	Trip statistics	Trip duration (hrs)	14.2±26.1	166.7	8.0±11.1	216.4	9.9±17.2	253.9	9.3±15.5	253.9
		Foraging range offshore (km)	51.0±44.3	158.7	31.2±22.6	124	14.3±21.9	311.3	22.7±25.6	311.3
		Total distance travelled (km)	67.0±151.7	893.7	46.3±68.9	998.7	30.3±64.3	943.1	39.6±74.6	998.7
	Time budgets	%Time away from nest (total)	26.1±13.1	87.1	22.9±14.4	76.5	31.3±15.7	100	27.2±15.5	100
		% Time offshore (total)	5.6±7.9	31	2.9±6.1	41.5	6.0±12.0	100	4.6±9.5	100
		% Time in wind farm (total)	1.8±5.3	29	0.4±1.4	9.5	<0.1±0.6	7.1	0.4±2.1	29
	Area usage	Size of 95% KDE (km^2) (total)	633±564	2750	571±559	4402	416±256	1808	508±457	4402
		% Overlap offshore (total)	50.5±21.8	96.6	39.1±22.0	93.5	39.6±18.6	80.2	40.6±20.8	96.6
		% Wind farm overlap (total)	7.2±15.3	66.4	2.8±8.1	47.3	0.5±3.4	31.4	2.3±8.1	66.4

Time offshore and time in wind farm areas as proportion of time away from nest = 1, 2010: 18.1±11.5% and 5.6±2.2%, 2, 2011: 11.5±20.1% and 2.2±6.4%, 3, 2012: 10.3±17.3% and 0.3±1.5%, and 4, total mean: 11.7±19.7% and 1.7±6.3%.

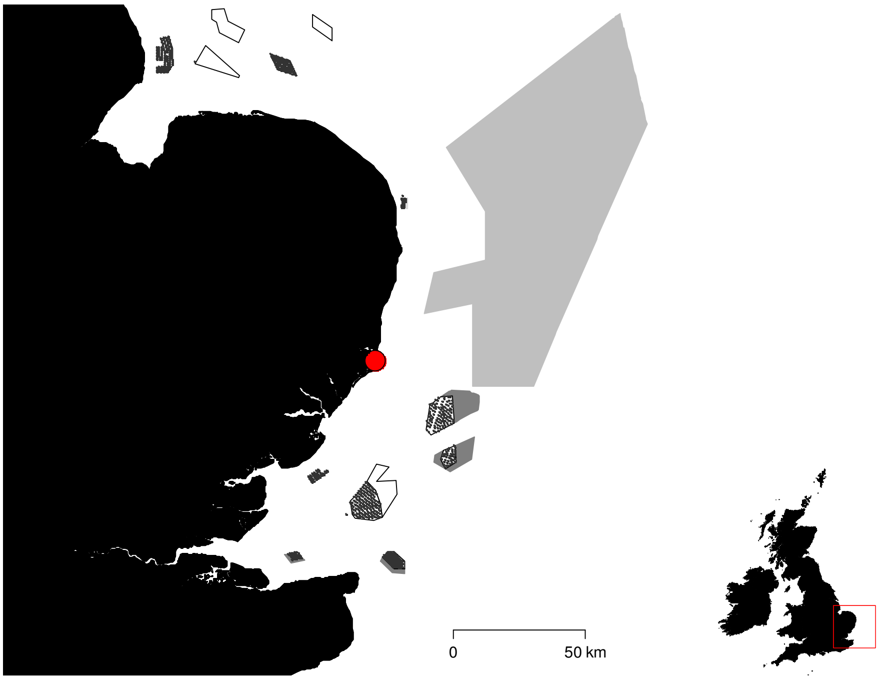


Figure 3.1 Location of Orford Ness, part of the Alde-Ore Estuary SPA, in SE England. Also shown are operational Round 1 (light grey) and Round 2 (white) wind farms, proposed extensions (dark grey) to these sites, and Round 3 (mid-grey) wind farm development zones, with turbines in operational wind farms in the area shown as black dots. The location of the Lesser Black-backed Gull breeding colony is also highlighted (red circle).

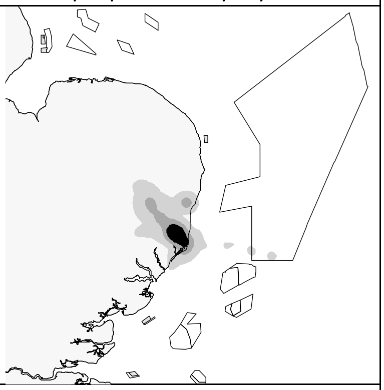
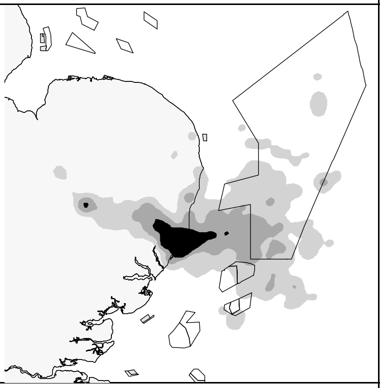
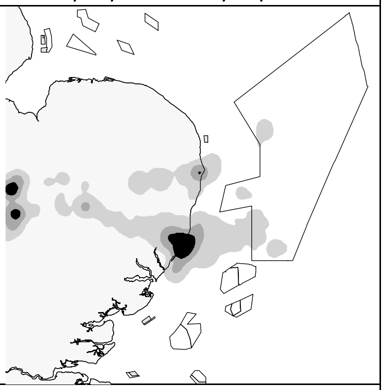
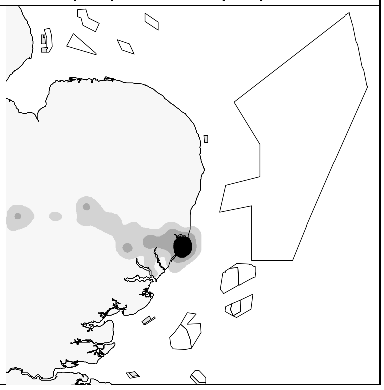
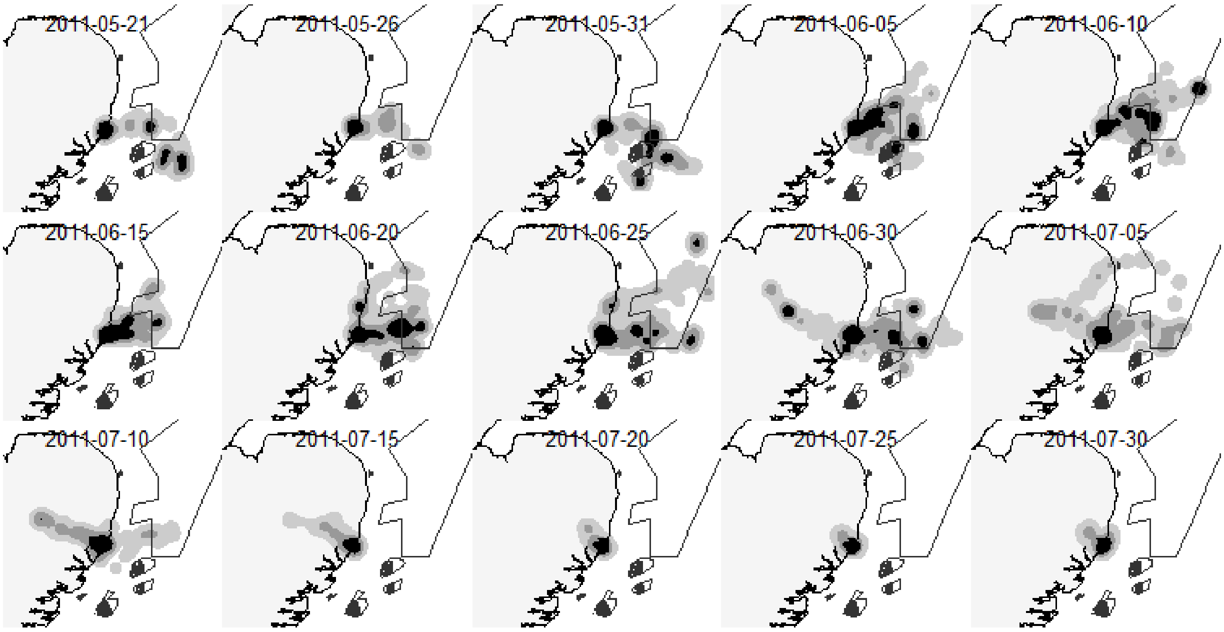
Bird	2010	2011	2012
395	15/06/2010 - 21/07/2010	29/03/2011 - 15/07/2011	23/03/2012 - 05/07/2012
			
486		22/05/2011 - 26/09/2011	24/03/2012 - 23/09/2012
			
493		21/05/2011 - 04/08/2011	20/02/2012 - 06/07/2012
			
483		22/05/2011 - 17/08/2011	19/03/2012 - 07/07/2012
			

Figure 3.2 Example of individual variation in area use for four Lesser Black-backed Gulls across different years. Shown are the 95% (light grey) representing total area usage, 75% KDEs (medium grey) and 50% KDE, representing core area usage. Also shown are polygons representing all wind farms in the nearby area (see Figure 3.1 for wind farm details), and the start and end times of data feeding into the kernels.

Bird 493



Bird 459

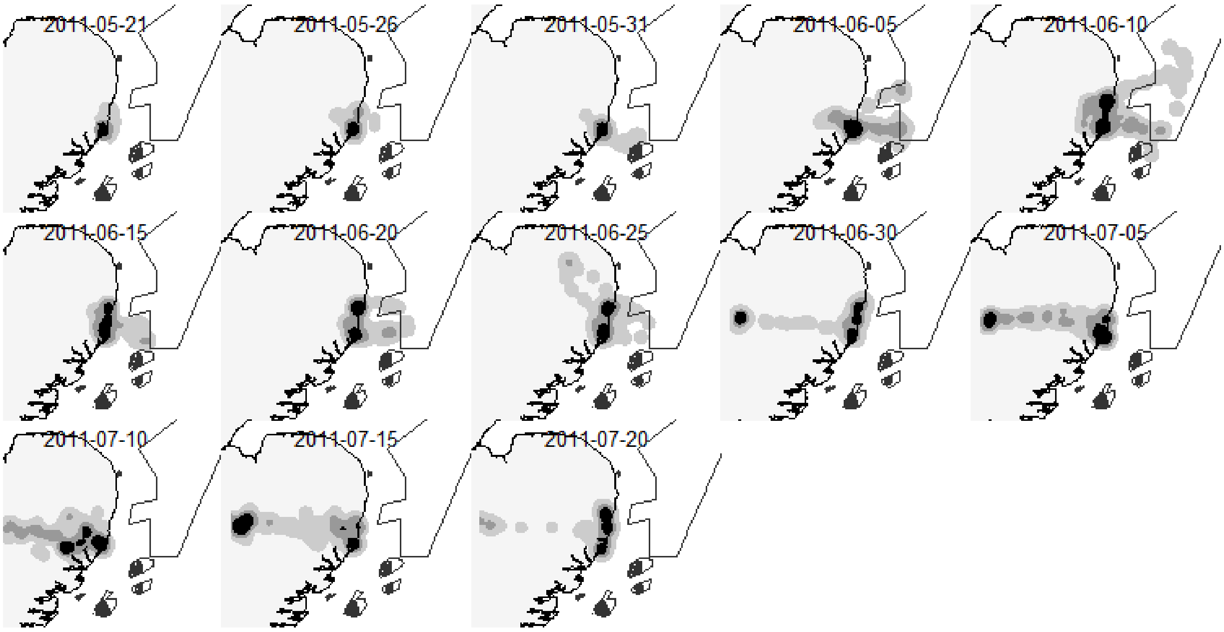


Figure 3.3 Example kernels for two Lesser Black-backed Gulls tracked from the Orford Ness colony in 2011 showing seasonal variation – each map is a 5-day period and the time stamp denotes the beginning of the 5-day section. Shown are the 95% (light grey) representing total area usage, 75% KDEs (medium grey) and 50% KDE, representing core area usage. Also shown are polygons representing all wind farms in the nearby area (see Figure 3.1 for wind farm details).

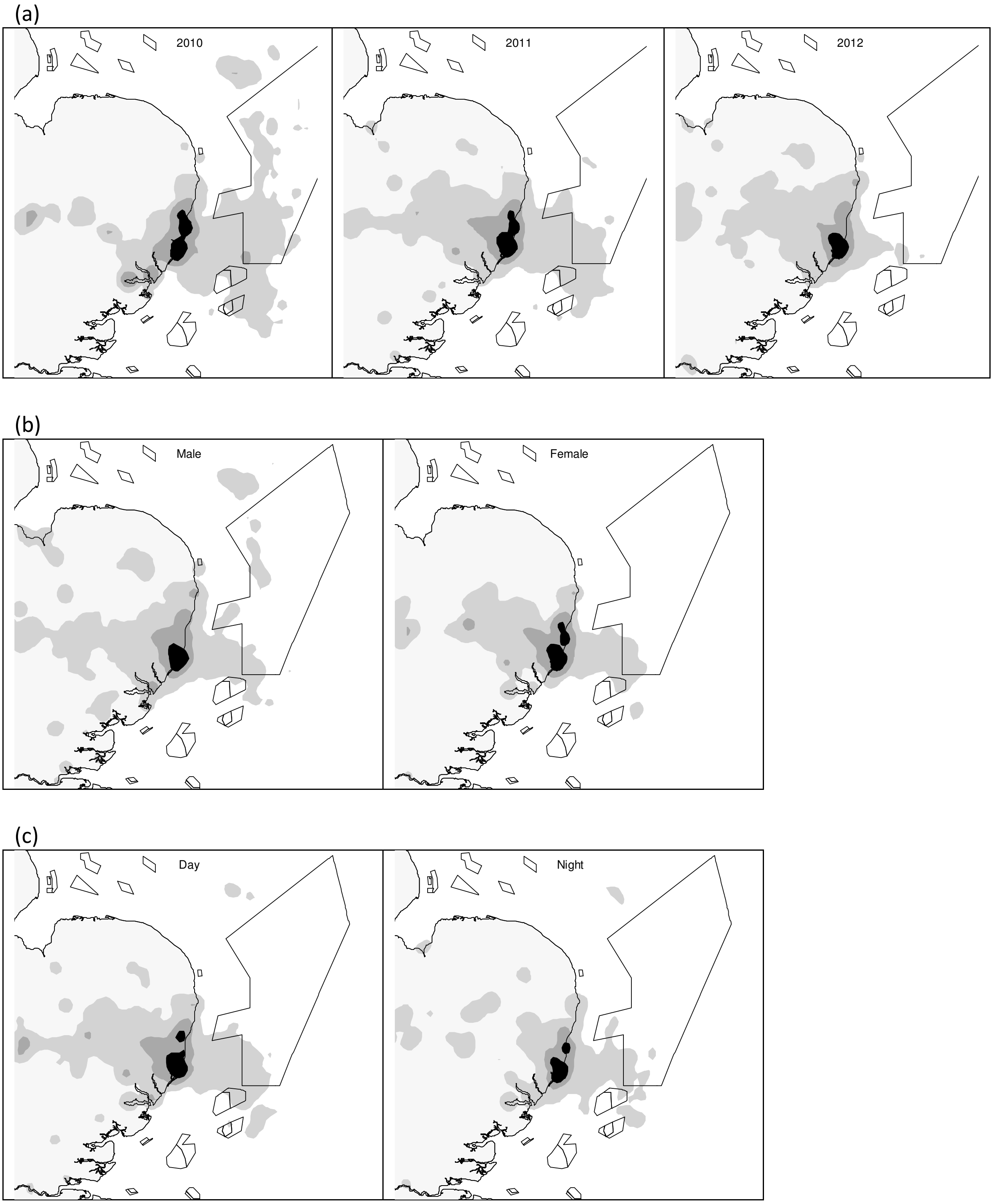
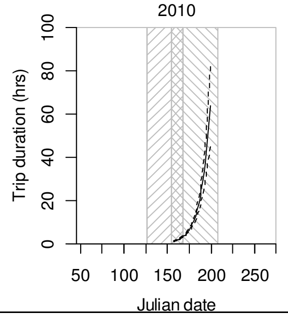
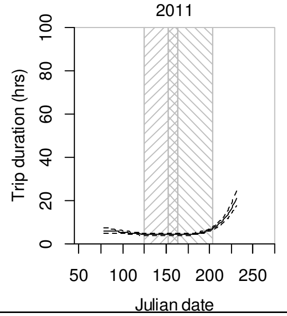
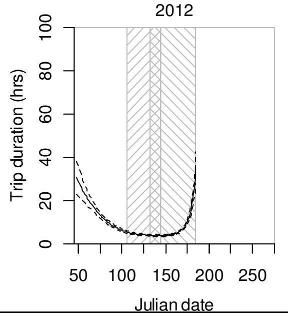
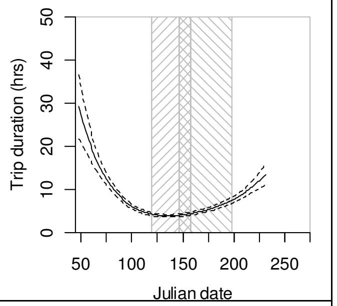
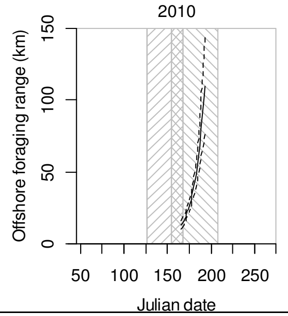
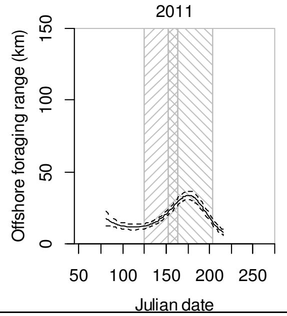
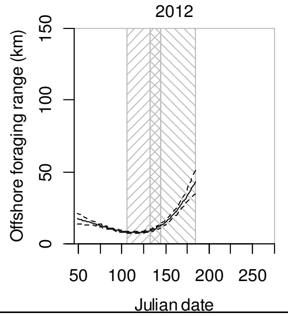
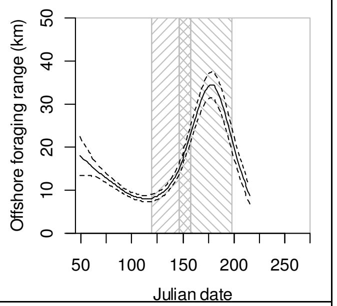
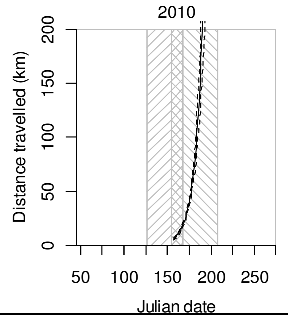
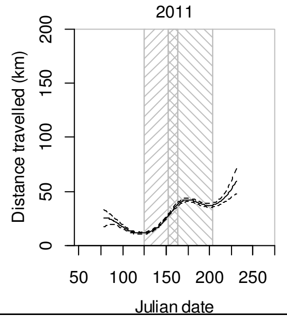
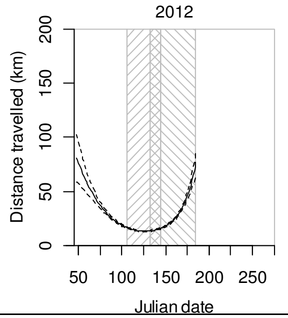
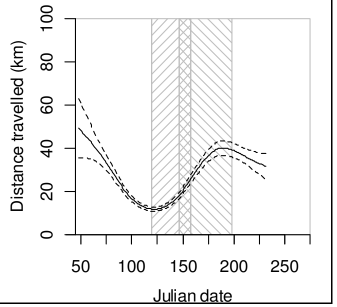
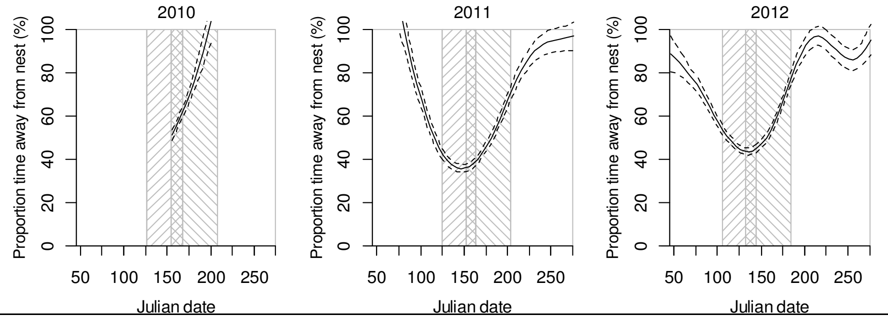
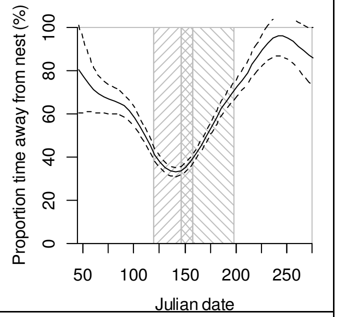
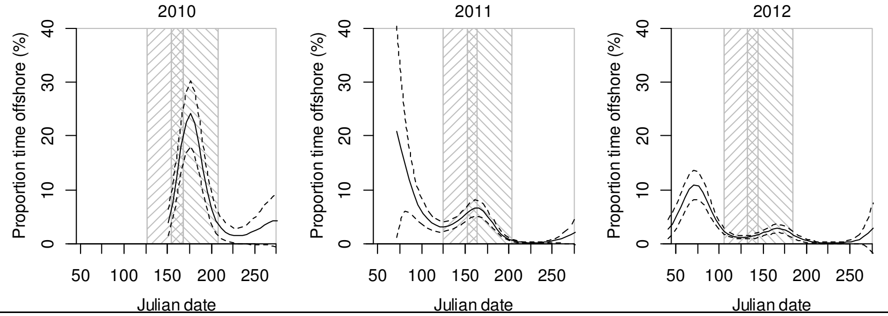
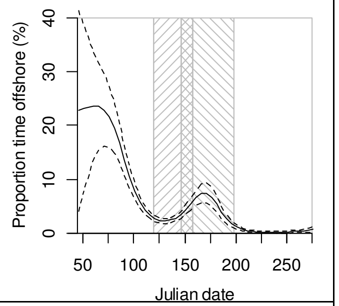
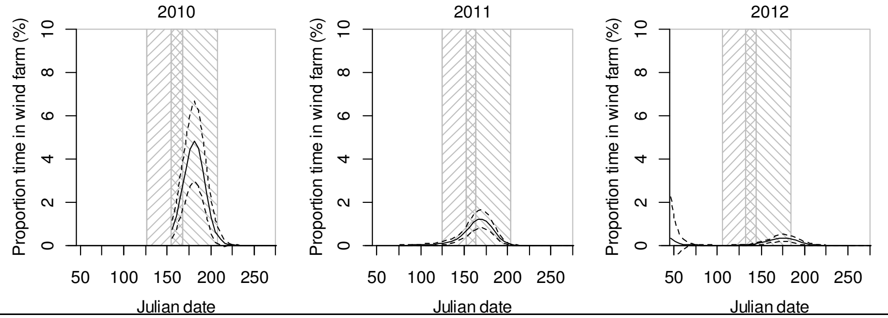
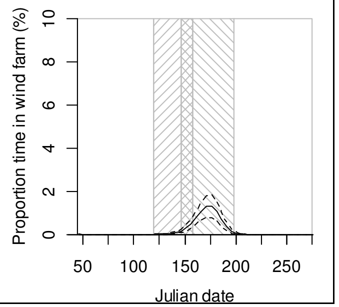


Figure 3.4 Spatial area usage by Lesser Black-backed Gulls during (a) respective years of 2010, 2011, 2012, (b) by male and female Lesser Black-backed Gulls, and (c) by all birds between day and night. Shown are the 95% (light grey) representing total area usage, 75% KDEs (medium grey) and 50% KDE, representing core area usage. Also shown are polygons representing all wind farms in the nearby area (see Figure 3.1 for wind farm details).

(a) Summary statistics

	2010	2011	2012	Overall
Trip duration				
Foraging range offshore				
Total distance travelled per trip				

(b) Time budgets

Time away from nest		
Time spent offshore		
Time spent in wind farm		

(c) Area usage

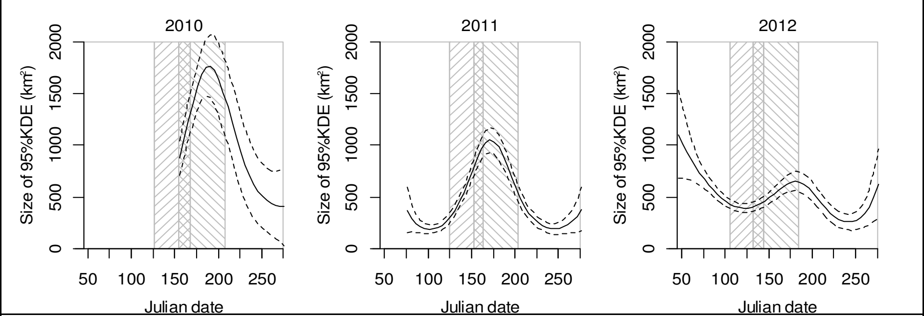
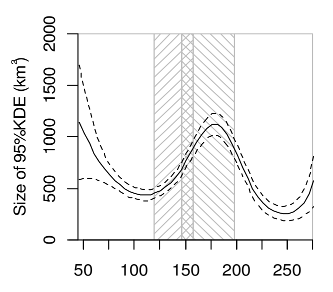
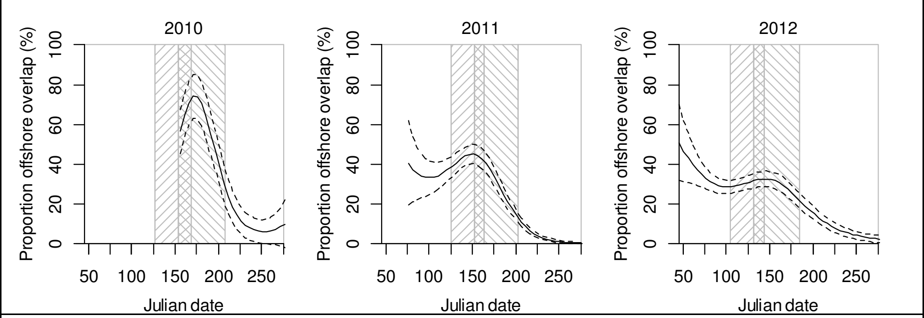
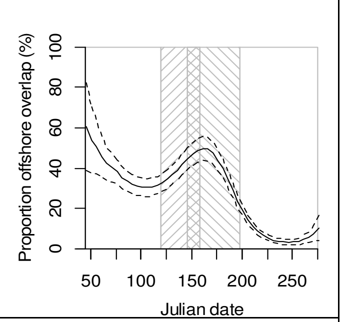
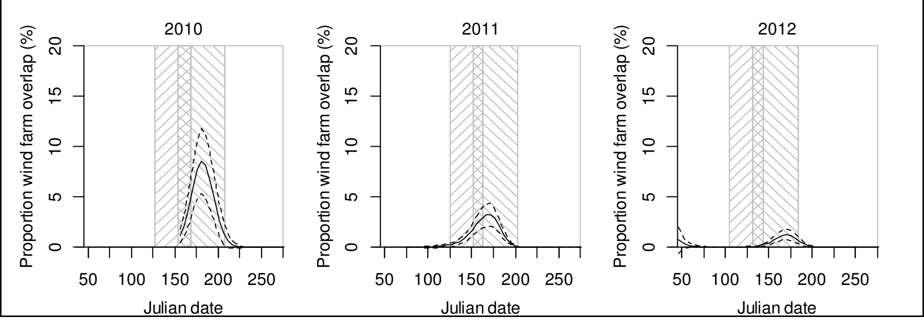
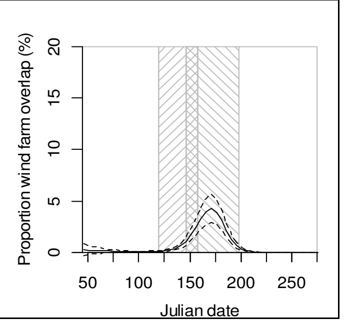
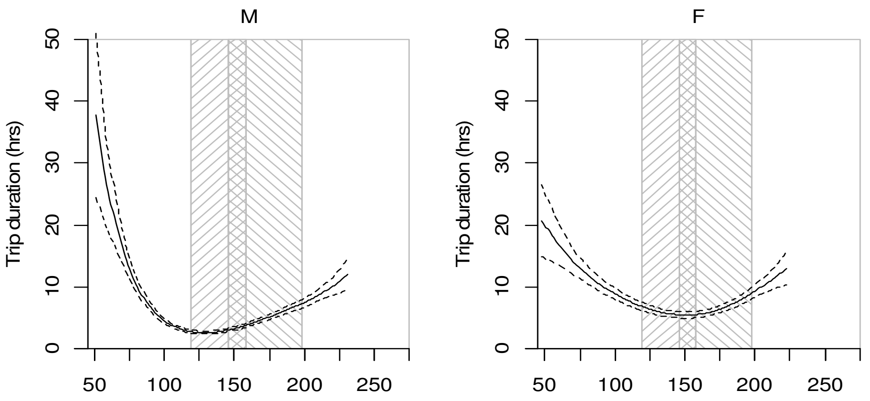
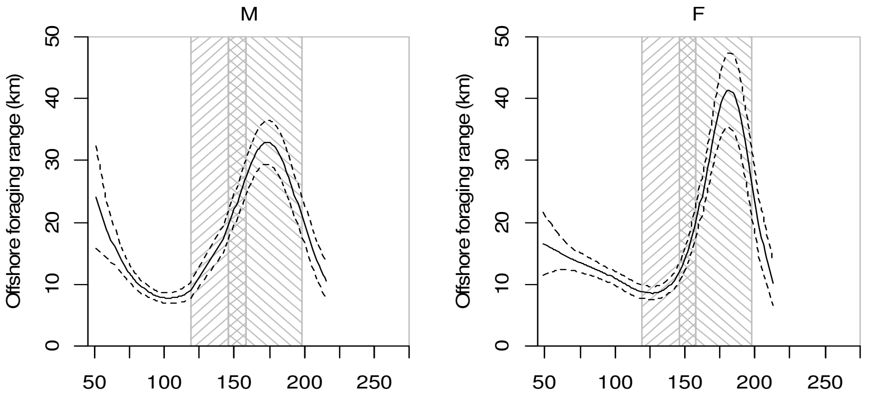
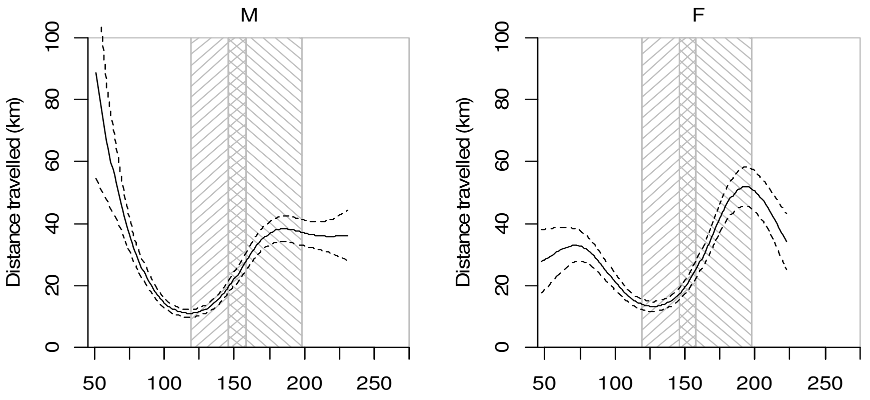
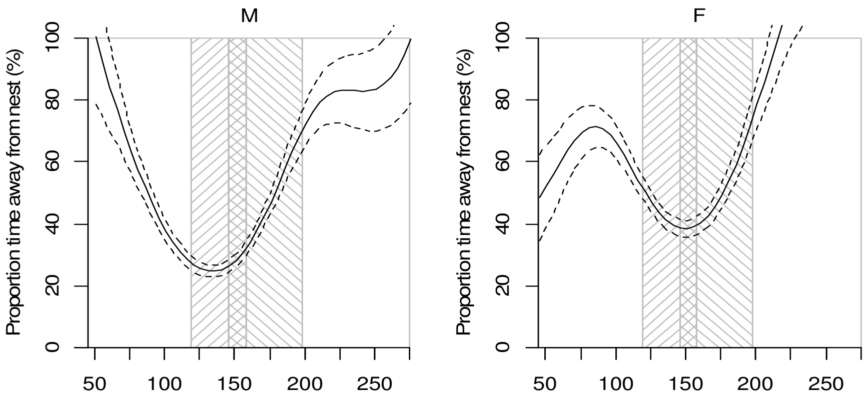
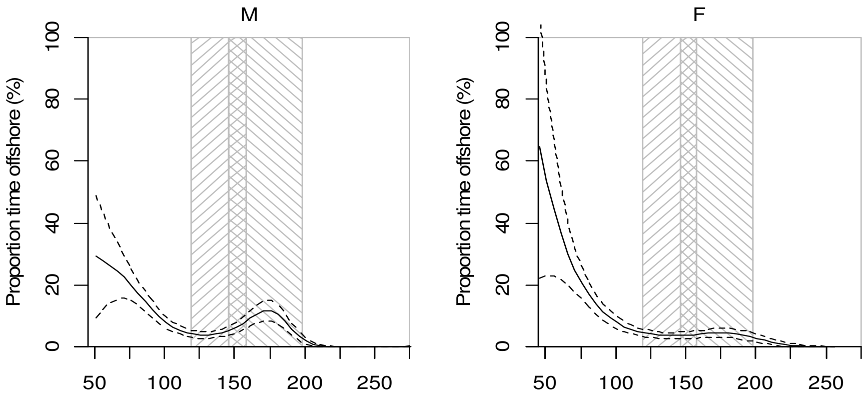
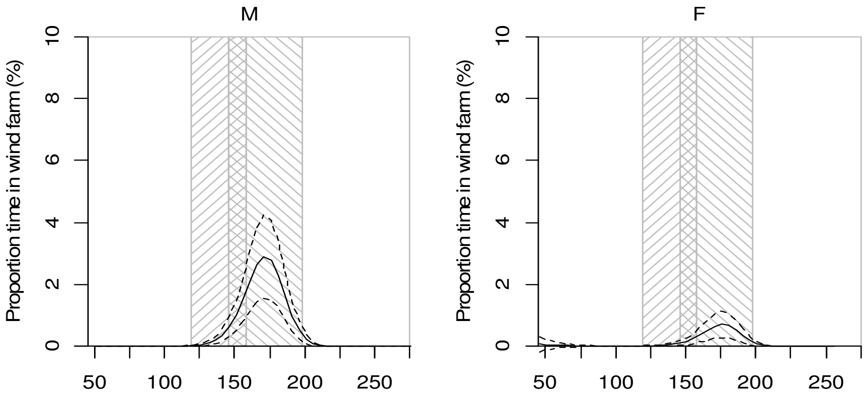
		Overall
Total area	 	
Offshore area	 	
Wind farm area overlap	 	

Figure 3.5 Seasonal and seasonal*annual differences in relationships for Lesser Black-backed Gulls derived from GAMMs and GAMs for: (a) summary statistics (trip duration, foraging range and distance travelled per trip) (b) time budgets (time spent away from the nest, time spent offshore and time spent in wind farm areas) and (c) area usage (total area usage (95% KDE size), overlap with offshore areas (of 95% KDE) and overlap with offshore wind farms); significance of effects are given in Table 3.4; trips here exclude post-breeding ‘trips’ that had no return back at the colony in the same year.

(a) Summary statistics

Trip duration	
Foraging range	
Total distance travelled per trip	

(b) Time budgets

Measure	
Time away from nest	
Time spent offshore	
Time spent in wind farm	

(c) Area usage

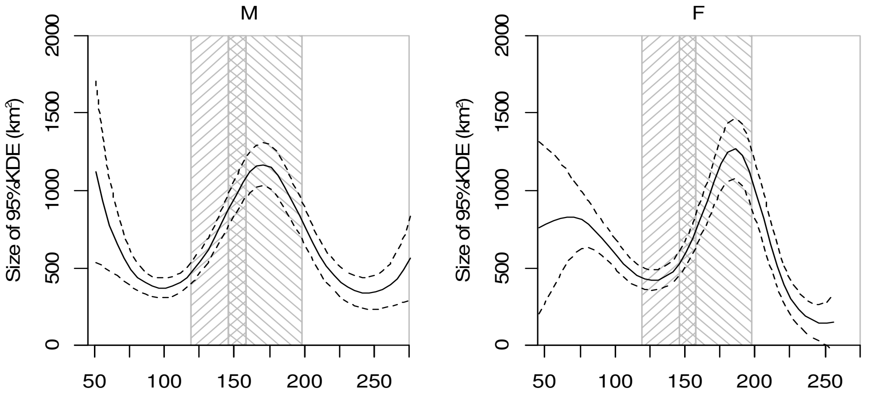
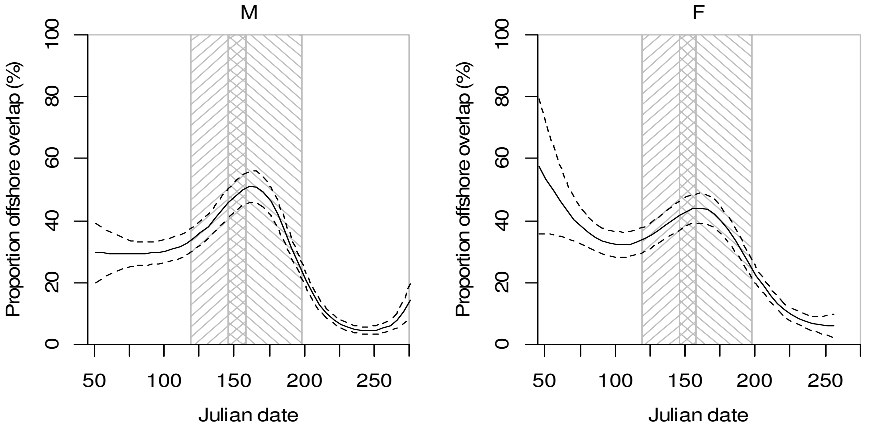
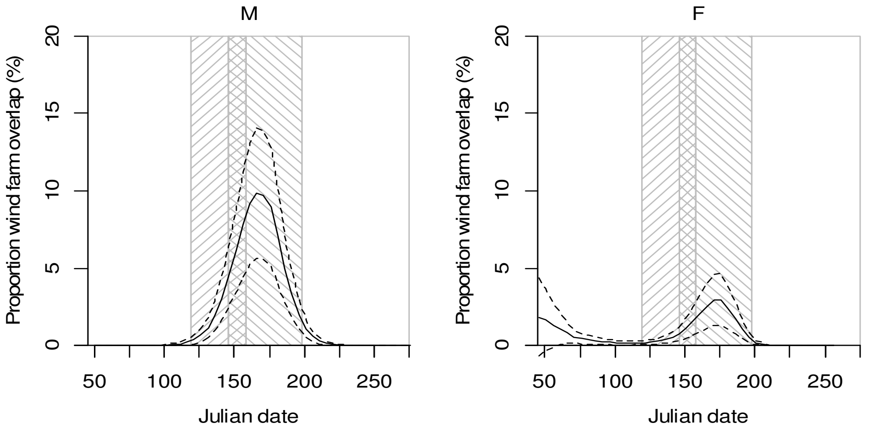
<table>
<tr><th>Measure</th><th></th></tr>
<tr><td>Total area</td><td>
</td></tr>
<tr><td>Offshore area</td><td>
</td></tr>
<tr><td>Wind farm area overlap</td><td>
</td></tr>
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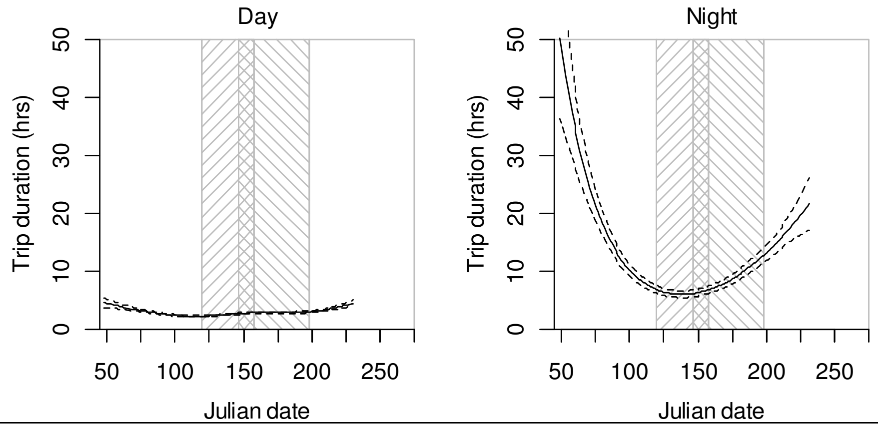
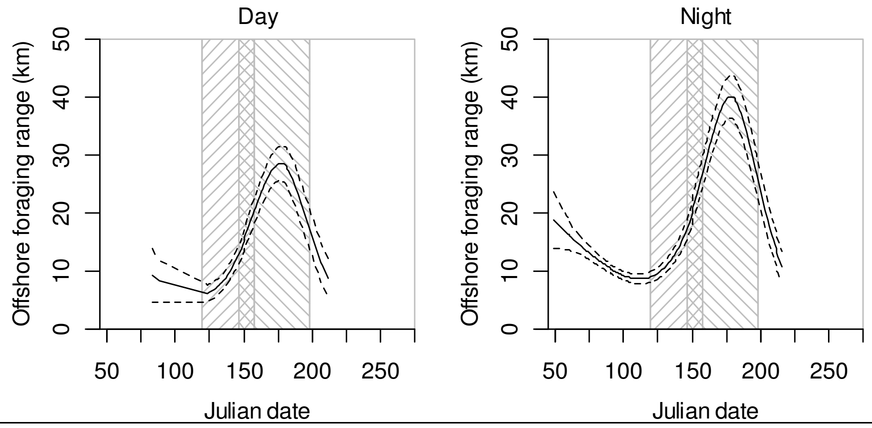
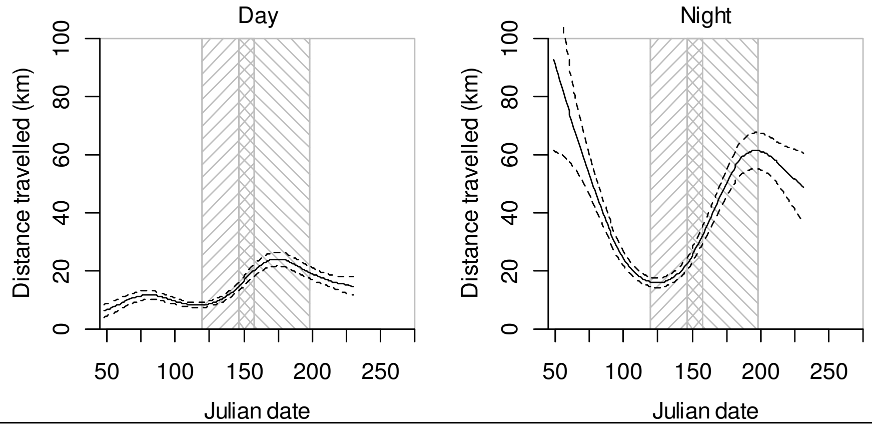
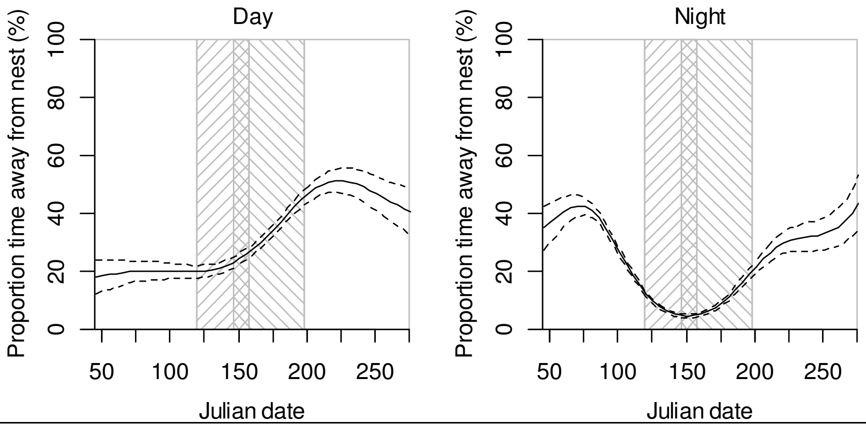
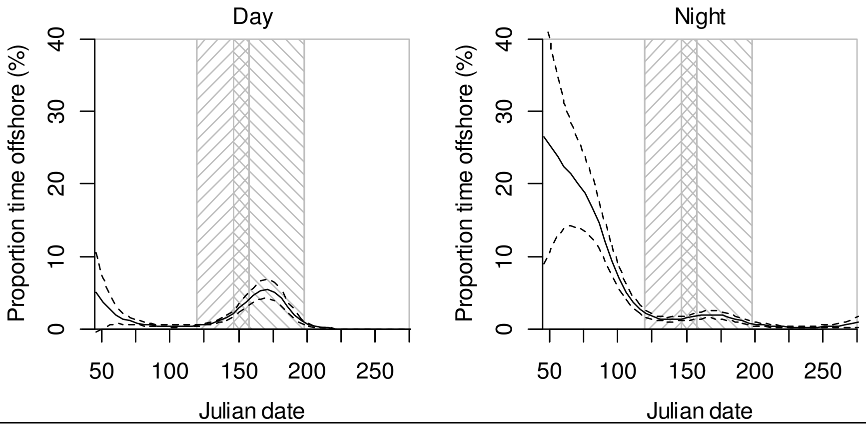
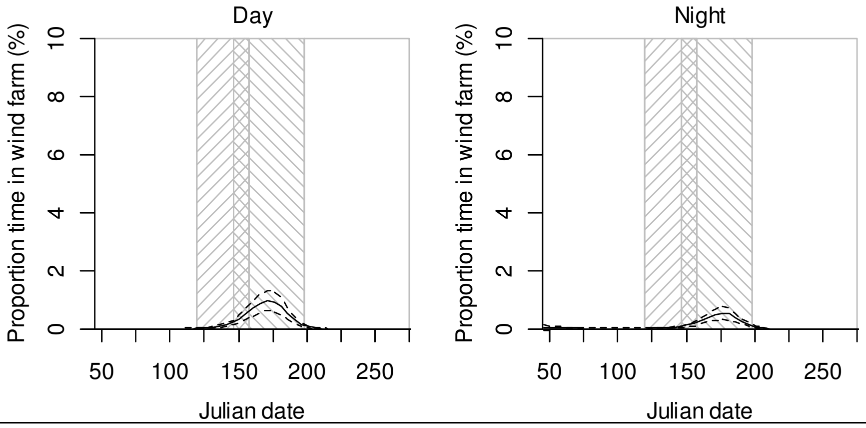
Figure 3.6 Sex-specific*annual differences in relationships for Lesser Black-backed Gulls derived from GAMMs and GAMs for: (a) summary statistics (trip duration, foraging range and distance travelled per trip) (b) time budgets (time spent away from the nest, time spent offshore and time spent in wind farm areas) and (c) area usage (total area usage (95% KDE size), overlap with offshore areas (of 95% KDE) and overlap with offshore wind farms; significance of effects are given in Table 3.4.

(a) Summary statistics

Measure	
Trip duration	
Foraging range offshore	
Total distance travelled per trip	

(b) Time budgets

Measure	
Time away from nest	
Time spent offshore	
Time spent in wind farm	

(c) Area usage

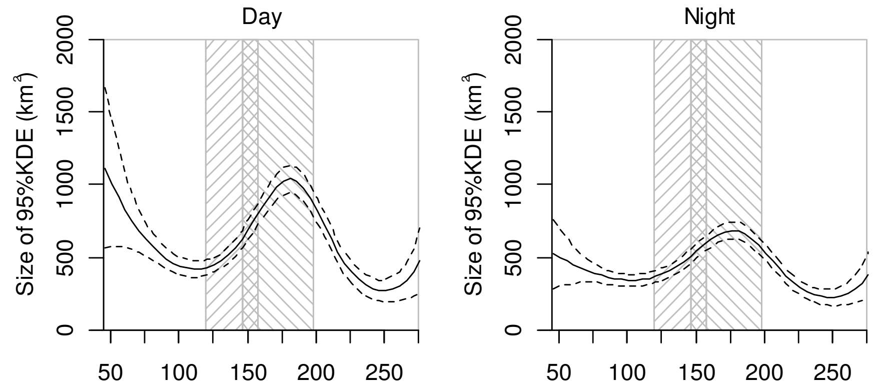
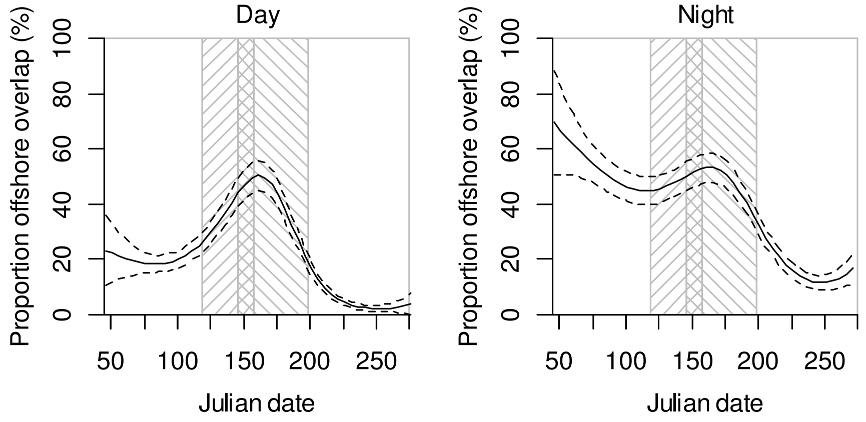
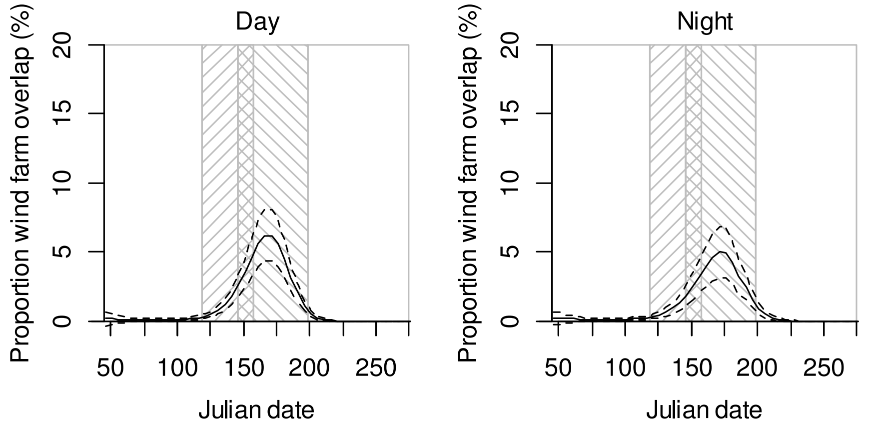
Measure	
Total area	
Offshore area	
Wind farm area overlap	

Figure 3.7 Diurnal*annual differences in relationships for Lesser Black-backed Gulls derived from GAMMs and GAMs for: (a) summary statistics (trip duration, foraging range and distance travelled per trip), (b) time budgets (time spent away from the nest, time spent offshore and time spent in wind farm areas) and (c) area usage (total area usage (95% KDE size), overlap with offshore areas (of 95% KDE) and overlap with offshore wind farms); significance of effects are given in Table 3.4.

4. INDIVIDUAL, SEX-SPECIFIC, SEASONAL AND ANNUAL VARIATION IN GREAT SKUA-WIND FARM INTERACTIONS DURING THE BREEDING SEASON

4.1 Introduction

The marine environment is under increasing pressure from human activities, including fisheries, shipping and boat traffic, oil and gas, and renewable energy developments (Syvitski *et al*. 2005; Halpern *et al*. 2008). Offshore wind farms form an ever increasing component of this marine infrastructure and are a key part of the UK Government's plan to obtain 20% of energy from renewable sources by 2020. It is therefore important to properly quantify the impacts that proposed offshore wind farms, alongside those already operational or consented, may have on marine wildlife and habitats.

Following the approach taken for Lesser Black-backed Gulls (see Chapter 3 for further background), this chapter investigates variation in wind-farm interactions for the Great Skua, a breeding feature at several SPAs in the UK (Stroud *et al*. 2001). At-sea data have previously been used to investigate the at-sea distributions of Great Skuas (e.g. Tasker *et al*. 1985; Seys *et al*. 2001) and offshore surveys have been extensively used to quantify the numbers and distributions of birds using the areas of proposed developments to inform impact assessments (e.g. Fox *et al*. 2006). However, such data cannot reveal the breeding origins of the individuals recorded. Hence, there is potential for birds from several UK colonies to forage in areas of operational, consented and proposed offshore wind farms. Great skuas are considered to be at particular risk from collision (Garthe & Hüppop 2004; Furness *et al*. 2013) being classed as ninth most sensitive species to this effect out of 38 considered by Furness *et al*. (2013).

Tracking systems are now available to monitor the movements of individuals over long-periods of time at fine-scale resolution (Vardanis *et al*. 2011; Shamoun-Baranes *et al*. 2011; Bouten *et al*. 2013). Using such a GPS-based system, we investigated the movements of individual Great Skuas during the breeding season (between June and August, as defined in section 2.5) from two SPAs in Scotland – the Foula SPA in Shetland and Hoy SPA in Orkney – in relation to proposed offshore wind farm development zones (see Fig. 2.1 for a map of development zones located in the area). We tested whether time budgets and area utilisation varied due to (1) individual and (2) sex-specific differences, and (3) across the breeding season (in relation to Julian date and chick age).

4.2 Methods

4.2.1 Post-processing of data

Seasonal definitions

Data on bird movements and time budgets were collected across the breeding season (incubation and chick-rearing) for birds from Foula and Hoy. Data used in the analyses presented here were limited to the periods that tagged birds were associated with the colony, further restricted to the breeding seasons determined for the colony as a whole (see section 2.5 for more details).

The numbers of tagged birds for which data were available declined over the breeding season and data were only available by the end of the defined breeding seasons of the colonies as a whole for two birds (two males from Hoy, 471 and 467, that eventually fledged chicks). The variability of available data is accounted for in all analyses (see below). Information for birds from Foula was restricted to periods of certain breeding (up to 15 July, when the last monitoring visit was completed), whereas monitoring of nests at Hoy continued throughout chick-rearing allowing certainty over a wider extent of the season.

Sex-specific data

The sex of each bird tagged was determined where possible to assess the difference in movements between males and females (see section 2.3 for details).

Parameters assessed

i. Trip statistics

We defined foraging trips by the departure and subsequent return of individuals to their nest sites. For all trips, we calculated (a) the foraging range (the maximum point reached offshore from the colony); (b) the total travel distance per trip (by summing distances between GPS points along the route); and (c) trip duration (time elapsed between departure and return). We also separated day and night trips by evaluating departure and return times to the colony in relation to the periods of local sunrise and sunset, to assess the diurnal variation in these trip statistics.

ii. Time budgets

For all trips, we calculated the (total, diurnal and nocturnal) time spent away from the territory and in the areas of proposed offshore wind farm development zones. Together with time at the nest, this enabled a complete time budget to be constructed for each individual in each year for each consecutive day period, both for the 24 h period and for the day and night.

iii. Area usage

Area utilisation was assessed using kernel density estimation (KDE, Worton 1989). The 50%, 75% and 95% KDEs of the utilisation distribution were taken to represent the core, middle, and total areas, respectively, although in line with other studies (e.g. Soanes *et al*. 2013), here we present only the core and total area usage for simplicity. Least Squares Cross Validation (LSCV) was used to estimate the smoothing parameter (e.g. Hamer *et al*. 2007; Thaxter *et al*. 2010). Data were filtered to a 30 minute rate for spatial analysis, and for each 5-day period through the season, for each individual each year, we calculated (a) the total area, (b) area offshore, and (c) the area within proposed offshore wind farm development zones. Separate investigation based on observations when travel speeds were <4km.h^{-1}, representing likely resting and foraging locations (Shamoun-Baranes *et al*. 2011), provided similar results to those based on all observations (R-sq = 89%). We provide some descriptive information for overlap of core foraging areas using 50% KDEs. However, for more detailed analyses of area usage away from the colony, we focus on total area usage using the 95% KDE to represent equivalency to total time away from the nest from temporal analyses. All time budget and kernel analyses were conducted using R 2.15.0 (R Development Core Team 2012).

iv. Diet

For additional perspective on the diet of adult Great Skuas at Foula in 2011, we also present information collected from pellets from breeding territories of birds. Pellets were collected throughout incubation and chick-rearing in a systematic fashion covering all study nests in the colony. A total of 57 nests were studied for diet, which included the nests of all 10 birds carrying GPS devices, and the nests of the 10 colour-ringed control birds. Pellets were examined for general prey items and classified into major prey items of: fish, seabird, mammalian (e.g. rabbit), beetle, goose barnacle (*Lepas spp*), egg shell and pollution (some pellets contained multiple prey items). For 'fish' pellets, remains were examined for presence of otoliths, which were collected for subsequent identification of fish species. Data were also categorised by the incubation and chick-rearing periods of the monitored nests, to examine potential differences in diet across the season and for comparison with foraging movement information.

4.2.2 Analyses

We used General Additive Mixed-effects Modelling (GAMM) and General Additive Modelling (GAMs) frameworks to investigate the potential variation in trip statistics, time budgets, and area utilisation due to (1) individual, (2) seasonal and (3) sex-specific variation. Seasonal variation was assessed both across Julian date and in relation to the hatching dates of the eggs of tagged individuals. This latter covariate (chick age) was included to test for trends in relation to changing demands on the adults. However, chick age and Julian date were highly correlated and so were examined in separate multivariate models including the equivalent additional effects. A separate factor of 'colony' was included in the analysis to account for potential differences between birds from Foula and Hoy. Only a small amount of data was available for four birds from Foula in 2010, hence information was pooled for 2010 and 2011. These factors and covariates were investigated for each of the parameters outlined above. Separate modelling was conducted using all observations and using diurnal and nocturnal observations only.

To initially test individual variation across the breeding season, GAMs were specified to include two separate models with fixed terms of: *s(Jdate,birdID)* and *s(chick age, birdID).* For simplicity of analyses, model convergence and avoidance of over parameterisation, we restricted all models to two-way interactions. To test for seasonal and sex-specific variation, GAMMs were used with a random effect for 'bird identity' (*birdID*) included to account for repeated measures on individual birds. GAMMs contained a smooth term for Julian date (Jdate, degrees of freedom, k = 6), and fixed effects of 'sex' and 'colony'. To assess further interactions of these effects, we tested for variation in seasonal variation between sexes by specifying a smoothed interaction in the model. An autoregressive (AR1) term was specified to account for temporal autocorrelation.

To maximise the data available, models for Great Skuas were specified for daily periods for time analyses and as 5-day periods for spatial analyses, the latter restricted by number of points per section needed to compute area distribution. Models were often compositional. I.e. models for time budgets considered the proportion of the total time for which data were obtained within each period spent (a) at the nest, (b) in offshore areas and (c) in the areas of proposed offshore wind farm development zones. Models for area usage considered (a) the total area, and the proportion of thus (b) offshore and (c) in the areas of proposed offshore wind farm development zones. Therefore, in these cases we modelled the response with an offset term of the total area or time available in the periods. We also included terms for the number of birds followed per period (specified as a weight in the model) to allow for unequal sample sizes across periods. The number of GPS fixes was included as a fixed effect to allow for unequal numbers data points available for periods in computing individual kernels. All models were fitted with either Poisson or negative binomial distributions, and used F-tests and dAIC to assess the significance of main effects and interactions using stepwise removal of non-significant terms. Values, where specified, are given as the means ±1 SD unless otherwise stated. All analyses were performed using R Version 2.15.0 (R Development Core Team 2012).

4.4 Results

4.4.1 Breeding productivity summary

Breeding productivity of Great Skuas was similar between Foula and Hoy in 2011. At Foula in 2011, observations of nests of tagged birds (n = 10), colour-ringed controls (n = 10) and additional pairs from two further study plots (n = 37 and 53, total of 110 pairs), showed a mean of 1.8±0.3 eggs laid per nest. The mean number of eggs hatched at Foula in 2011 was 1.5±0.6 and the mean number of chicks per nest up to the 15 July was between a minimum of 0.8±0.8 and maximum of 1.1±0.8. For 53 nests in an additional study plot monitored up to 12 August 2011, only between 0.1 and 0.4 chicks fledged per nest.

At Hoy in 2011, the mean number of eggs laid per nest for tagged birds (n = 10) and colour ringed controls (n = 10) was 1.9±0.3. The mean number of chicks per nest was between a minimum of 1.1±0.7 and a maximum of 1.8±0.6 and the number fledged up to the 14 August 2011 was 0.2±0.5 for the 20 tagged and control birds and 0.5 for a separate group of 53 nests monitored during the same year at Hoy.

4.4.2 Summary of connectivity with proposed offshore wind farm development zones

All Great Skuas that made offshore trips from Foula in 2010 (three out of four birds; the tag on bird 342 ceased communication shortly after deployment) overlapped with the N4-N6 Scottish Territorial Waters zone near to Foula. Similarly, the offshore trips of all 10 birds in 2011 overlapped with this same zone. Of the nine birds for which there were breeding season data from Hoy, the offshore trips of two birds did not overlap with any proposed offshore wind farm development zones, while those of six showed connectivity with the N1 STW zone, and one other bird made a long foraging excursion overlapping with Moray, NE2 and NE1 zones (Tables 4.1 and 4.2; see also Fig. 4.1).

The time spent away from the territory in proposed offshore wind farm development zones during the breeding season amounted to 7% for birds from Foula and 2% for birds from Hoy, time for which for birds from both colonies, was mostly during the day (5% and 2% for Foula and Hoy respectively; Table 4.1). The time spent by individual birds from Foula in the N4-N6 zone ranged from 3% to 13% across both 2010 and 2011 (Table 4.1). For birds from Hoy, use of the N1 zone by birds varied between <1 to 6% (Table 4.1).

The overlap of the 95% KDE with proposed offshore wind farm development zones was 22% and 8% for all birds from Foula and Hoy respectively (Table 4.2). For birds from Foula, the overlap with Scottish Territorial Waters zone N4-N6 ranged between 11 and 35% across the 10 birds, and for the N1 zone that was used the most by birds from Hoy, individual bird overlaps ranged from 3% to 30%. The percentage overlap of the 95% KDE with off proposed offshore wind farm development zones was greatest during the day than at night at both colonies (Table 4.2), and the size of this total area usage kernel during the day was 60% and 130% greater than at night for birds from Foula and Hoy, respectively (Table 4.2).

4.4.3 Individual variation

Trip statistics, time budgets, and space use

Individual variation in time budgets, area usage and trip statistics is summarised in Tables 4.1-4.3, with the results of analyses of these metrics presented in Table 4.4 and Appendices 1 and 2. Individuals differed significantly in summary statistics of trip duration, foraging range, and distance travelled per trip (Tables 4.3 and 4.4, Appendices 4.1 and 4.2). These variations translated into significant differences in the extent of offshore area usage in both time budgets and kernel 95% KDE overlaps, and in turn resulted in a significant difference in the potential interaction between individuals with proposed offshore wind farm development zones (Tables 4.3 and 4.4, Appendices 4.1 and 4.2).

4.4.4 Sex-specific variation

Trip statistics

Males made significantly longer trips overall than females (Tables 4.4 and 4.5; Appendices 4.1 and 4.2), however, there was no difference in the distance reached from the colony or travel distance per trip (Table 4.4, Appendices 4.1 and 4.2). There was a significant sex*chick age interaction for all trip statistics (Table 4.4), relating to the timing of peaks and troughs in behavioural patterns (Fig. 4.2a), however such patterns were not consistent across daytime and night time periods and for Julian date there was no significance shown. Such patterns were also influenced by the greater amount of data available for males later in the season from Hoy.

Time budgets

The total time spent away from the nest by males was significantly greater than for females, in total and for the day and night (Tables 4.4 and 4.5, Appendices 4.1 and 4.2). Of the 173 trips made by females, 75% were solely during daylight hours, and this proportion was no different to males (72% of 497 trips). Therefore the number of trips and the length of individual periods away from the nest explained why the percentage of time spent away from the nest was greater for males. No other seasonal*sex interactions were recorded (Table 4.4) indicating similar general behaviour between males and females across Julian date and chick age (Fig. 4.2b shows trends plotted over Julian Date and chick age). There was also no difference between sexes in the temporal extent of interaction with the areas of proposed offshore wind farm development zones.

Area usage

There was no overall difference between the sexes in the extent of area usage (size of the 95% KDE) for all periods of the day combined, nor in the total overlap of the 95% KDE with proposed offshore wind farm development zones (Tables 4.4 and 4.5 and Appendices 4.1 and 4.2; Fig. 4.1). However, during the night, females exhibited a larger proportional overlap with proposed offshore wind farm development zones than males (Table 4.5, see also Appendix 4.3). Interactions of sex*Julian Date and sex*chick age were not significant (Table 4.4, Fig. 4.2c). Night-time area usage by both sexes was also generally much smaller than day-time area usage (Tables 4.5, Fig. 4.1).

4.4.5 Seasonal differences

Spatial movements during incubation and chick-rearing

Comparison of spatial movements during incubation and chick-rearing was assessed for 10 birds from Foula in 2011. After accounting for number of days tracked, the total area usage (95% KDE) was no different between incubation and chick-rearing stages ($F_{1,13}$ = 3.607, P = 0.073) and the same was also true for the core (50% KDE) area ($F_{1,13}$ = 4.205, P = 0.055). The extent of the overlap with the N4-N6 STW zone was no different between stages of the season for either the core ($F_{1,13}$ = 1.157, P = 0.296) or total area usage ($F_{1,13}$ = 2.074, P = 0.167).

Diet

In total, 151 pellets were collected between 10 June and 14 July 2011 from 45 of 57 nests monitored at Foula (for some nests checked, no pellets were found). The diet of breeding birds at Foula in 2011 was dominated by fish (68.2%, Table 4.7), and a slightly higher proportion of pellets included fish in the chick-rearing period compared to during incubation (74.1% compared to 69.3%). A total of 13.2% of pellets also included mammalian prey, which was almost three times more prevalent in the diet of incubating birds than during chick-rearing. Seabirds made up 14.6% of pellets, which were twice as abundant in the chick-rearing diet than in incubation. However, sample sizes of both mammalian and seabird pellets were relatively small (e.g. seabird: eight pellets in incubation, 11 pellets in chick-rearing, Table 4.7). Goose barnacles (*Lepas* spp) were also recorded in diets of both incubating and chick-rearing birds in similar amounts, and smaller proportions of pellets contained beetles and egg shell remains, with two in chick-rearing also containing pollution – one had a considerable length of fishing line, and another contained small, thin circular pieces of plastic.

Of those pellets that contained fish, a small number also contained otoliths allowing identification of fish species. Most of these (80%) were collected during incubation. Only five pellet samples were collected during chick-rearing of which three contained species of Argentine (*Argentina* spp) (four otoliths) and two contained Haddock (*Melanogrammus aeglefinus*) (four otoliths). Of the remaining 20 samples in incubation, 32% contained remains of *Argentina* spp and 32% contained Poor Cod (*Trisopterus minutus*). Other recorded prey items were Black Seabream (*Spondyliosoma cantharus*), Blue Whiting (*Micromesistius poutassou*), Norway Pout (*Trisopterus esmarkii*) and Whiting (*Merlangius merlangus*) (Table 4.7). In total 93 otoliths were recovered from the 20 samples from incubating birds (Table 4.7). The different digestion rates of fish prey species make conversion of these items into real proportions in adult diets problematic, unlike the pellet frequency occurrence information above. However, from these data, the most frequent prey item by otolith proportion was Poor Cod (26 otoliths, 50.5%), whereas Argentine was represented in much lower proportion at 19.4%, and all other species were recorded in lower than 10% of all otoliths.

A total of 34 pellets were recovered from nine birds with GPS devices (mean, 3.8±1.7 pellets per bird, range 1-7) across the season, and of these, 30 pellets (88%) contained fish remains. For a small number (four) of foraging trips from Great Skuas at Foula, we also linked the prey from pellets to individual foraging trips. These four trips all preceded the discovery of very fresh fish pellets (unfortunately without otoliths) at the territory, and confirmed the foraging trips to locations north and west of the colony leading up to a deep oceanic trench were being extensively used for feeding (Fig. 4.3).

Continuous changes in movements over the season

Best fit models often included a significant smoothed term of Julian date or chick age, indicating seasonal variation in some but not all parameters (Table 4.4, Appendices 4.1 and 4.2).

Trip Statistics

Notably, variation across Julian date and chick age was apparent for trip duration but not for foraging range or distance travelled per trip (Table 4.4, Fig. 4.4a). Furthermore, for birds from Foula, foraging trips showed a slight decrease in duration over Julian date and a curved reducing and subsequently increasing pattern across chick-age (Fig. 4.4a). In contrast, for birds from Hoy, a greater span of data across Julian Date revealed an increasing pattern of trip duration (reflecting the two additional birds from Hoy tracked until mid-August) (Table 4.4; Fig. 4.4a).

Time budgets

The time spent away from the nest on foraging trips at sea increased significantly over the course of the season (over Julian date) for birds from both Foula and Hoy (Table 4.4, Appendices 4.1 and 4.2). There were no differences between colonies in this regard (Tables 4.4 and 4.4); however, over chick age, as with trip duration, birds from Foula showed the same curving decrease and increase in time spent away from the nest compared to a generally increasing pattern for birds from Hoy (Fig. 4.4b).

The time spent in areas of proposed offshore wind farm development zones, although showing no trend with date overall across colonies, did show differing patterns for birds from Foula and Hoy due to the different proximity of areas available for birds to interact with (Table 4.4, Appendices 4.1 and 4.2). The time spent by birds from Foula in the closely-situated N4-N6 STW zone increased across Julian Date. In contrast, for birds from Hoy there was a slight decrease in time spent in areas of proposed offshore wind farm development zones, mostly within the N1 zone with both Julian Date (edf = 1, F = 7.82, P = 0.006) and chick age (edf = 1, F = 8.45, P = 0.004, Appendix 1). The time spent in proposed offshore wind farm development zones across the season was relatively small at both colonies (e.g. increasing from 5% to 9% across Julian Date for birds from Foula, and staying at less than 3% through the breeding season for birds from Hoy).

Area usage

The total size of the 95% KDE showed no overall significant changes across the breeding season after accounting for overall colony differences (Tables 4.4 and 4.6). However, for birds from Foula, the total area size increased from ca. 4000 to 6000 km^2 (Fig. 4.4c) before falling again during later chick-rearing. For birds from Hoy, a simple decreasing pattern was seen across both Julian Data and chick age, again albeit not significant (Fig. 4.4c).

As for time budgets, a difference was found between colonies in the relationships between the extent of overlap with proposed offshore wind farm development zones and both date within the breeding season and chick age. No clear relationships were apparent for birds from Foula (P > 0.05 – Appendix 4.1), but for birds from Hoy, the extent of overlap decreased both in relation to Julian Date (edf = 4.202, F = 4.394, P = 0.005) and chick age (edf = 4.817, F = 7.871, P = 0.001, Appendix 4.1).

4.5 Discussion

This study has revealed detailed interactions between Great Skuas from two SPAs and proposed offshore wind farm development zones during the breeding season. The foraging behaviour and territory attendance of Great Skuas were similar to information presented elsewhere in the literature, and productivity of Great Skuas during the breeding season was no different between birds fitted with devices using harnesses and unequipped colour-ringed control birds (Thaxter *et al*. in prep). Therefore, there were no apparent effects of tagging during the breeding season, and data presented are assessed to be representative of normal behaviour for this species at this time.

4.5.1 Diets, individual variation in behaviour and use of the areas of proposed offshore wind farm development zones

Some general information on diet were collected in this study for particular territories. As with studies at Handa (e.g. Votier *et al*. 2004a) and Foula in previous years (Furness 1987), Great Skuas at Foula in 2011 showed evidence of specialised individual diets, dominated mainly by fish – 68% of all pellets contained fish remains. For birds carrying GPS devices, 88% pellets found in territories contained fish remains. Although our sample sizes were small, this could indicate potential specialisation of all individuals equipped with GPS devices. For generalist predators, individual dietary specialisation may be widespread (Bolnick *et al.* 2003; Poore & Hill 2006; Martins *et al.* 2008; Araújo *et al.* 2011) and among seabirds (e.g. Mcleery & Sibly 1986; Watanuki 1992) may be reflected in foraging behaviour (Votier *et al.* 2004a; Woo *et al.* 2008). For Great Skuas, foraging areas of individuals specialising on seabird prey spent less time foraging and ranged over smaller areas than those feeding on fish prey (Votier *et al*. 2004a). Despite this potential specialisation, there was still substantial variation in individual foraging ranges, area usage and temporal parameters throughout the breeding season, and all birds had the potential to forage in proposed offshore wind farm development zones.

There was a prevalence of bentho-pelagic (e.g. Norway Pout, Poor Cod, Whiting, Black Seabream) and bathy-pelagic (e.g. Blue Whiting, and some *Argentina* spp) prey species (see Froese & Pauly 2011), as well the demersal Haddock in the diet of Great Skuas at Foula in 2011. Great Skuas feed extensively on discards, sandeels and seabirds (Hamer *et al*. 1991; Phillips *et al*. 1999), and species such as Whiting and Haddock are frequent in discard biomass (Hudson & Furness 1989, Garthe *et al*. 1996; Furness 2003). Votier *et al*. (2004b) also recorded Whiting and Haddock prevalent in the diet of breeding Great Skuas at Foula over six years. The diet recorded at Foula in this study in 2011, therefore, strongly suggests that birds were likely targeting discards at sea or obtaining prey items through piracy. Most of these species are found between 10-400m (e.g. Black Seabream, 5-300m, usually 300-400m; Haddock, 10-450m usually 10-200m; Norway pout, 50-300m, usually 100-200m; Poor Cod, 1-440m, usually 15-200m; Whiting 10-200m, usually 30-100m), but Blue Whiting (150-3000m) and some *Argentina* species can occur over much deeper depths (Froese & Pauly 2011).

Some interesting further descriptive patterns were also noticeable across the study population. Only two pellets collected from the main study plot of territories of colour-ringed control pairs and tagged birds (n = 20 territories) contained mammalian remains (e.g. rabbit) (2/54 pellets), whereas 67% (n = 42 pellets) contained fish. However, other individual territories monitored within this plot contained much higher proportions of mammalian prey – for one nest (B10), six out of eight pellets (75%) contained mammalian remains, and another very close nearby had 38% (three out of eight pellets). This could indicate a degree of mammalian specialisation, however, more information is ideally needed to substantiate this.

4.5.2 Connectivity with and use of proposed offshore wind farm development zones

All 10 birds from Foula overlapped in area usage, time spent and direct connectivity with the nearby N4-N6 STW zone. Such a result was not surprising given the close proximity of this area to the SPA. Birds foraged predominately to the north and west of the colony, focusing much foraging effort between the colony and the oceanic trench marking the edge of the continental shelf. Further investigation of diet and prey observed in pellets confirmed that birds were likely using such areas to gather food. For the 10 birds from Hoy, nine provided data to assess connectivity with proposed offshore wind farm development zones. Most (67%) showed connectivity with the N1 STW zone, and one bird made a long foraging trip overlapping Moray, NE2, and NE1 zones. In total, the area overlap with proposed offshore wind farm development zones amounted to 22% and 8% for birds from Foula and Hoy respectively, and the time in these zones was 7% and 2% of the total time budgets of birds from Foula and Hoy respectively.

4.5.3 Seasonal and sex-specific variation in behaviour and use of proposed offshore wind farm development zones

Sex-specific variation

Male Great Skuas spent significantly more time away from the nest than females and made foraging trips of longer duration. These results are in keeping with many previous studies whereby female skuas take more nest defensive duties than males (Furness 1987; Hamer & Furness 1993), linked to reversed sexual size dimorphism (RSD, Furness 1987). Such parental roles linked to foraging behaviour are seen among a wide suite of species exhibiting dimorphism and for Great Skuas the evolution of RSD has been suggested as being driven by parental roles (Furness 1987). However, such popular views have not always received empirical support (e.g. Catry *et al*. 1999), precipitating a need for continued research. Note, however, that our sample sizes for sex-specific variation are limited and pooled across colonies, therefore conclusions should be treated with caution and as indicative only.

In our study, there was some evidence of variations between sexes in some temporal parameters over the course of the breeding season, but sample sizes were quite low and there was little overall significant variation for most parameters. Interestingly, both sexes spent increasingly more away from the territory across Julian date, showing similarities with Great Skua pairs monitored at the nest during the 1970s (Furness 1987). However, as also noted by Furness (1987), the extent of this division of labour varies between colonies and species.

Despite these known overall differences between males and females in temporal aspects, there is very little known about the potential differences between sexes in foraging behaviour at sea. We found no significant differences in distance reached or distance travelled per foraging trip, nor any difference between sexes in area coverage. Consequently there was no overall difference in overlaps with proposed offshore wind farm development zones between the sexes. It was not possible in this study to sufficiently assess sex-specific differences in diets, although during breeding, feeding niches between the sexes of skua species are thought to be similar (Furness 1987), but ideally more detailed study is needed to assess foraging efficiency to further refine our understanding of sex-specific foraging behaviour in this species.

Seasonal variation

Pooling information across all birds, there was no overall difference between areas used between incubation and chick-rearing. This was also reflected in a similarity in overall diet between phases, albeit with some more subtle differences such as the increased prevalence of mammalian prey in incubation diets. This latter difference may have suggested a greater amount of time spent at the territory earlier in the season increased predation on mammalian prey during incubation.

Some seasonal variation was also apparent across temporal parameters. For birds from Hoy, trips increased in duration across the season, whereas for birds from Foula, negative and curvilinear patterns were seen for Julian date and chick age, respectively. For both colonies, however, the time spent away from the territory by adults increased across both Julian date and chick age. The productivity of birds from both Foula and Hoy was similar in 2011 but only a very small proportion of chicks fledged, with many nests failing at the chick stage – at Foula, in particular, many nests failed during mid-July. It is therefore conceivable that adults were working progressively harder to find food as the season progressed. Such patterns have been observed elsewhere in other species in times of poor food availability (e.g. Ashbrook *et al*. 2008).

Given the different locations of proposed offshore wind farm development zones relative to the colonies (see Fig. 2.1), it is not surprising that different patterns were also recorded in seasonal use of these zones that largely reflected seasonal variation in overall foraging patterns.

4.5.4 Diurnal variation

As with Lesser Black-backed Gulls, Great Skuas also showed differences in their total area usage during day and night periods – overall total area usage was 60% and 130% larger during the day than night for birds from Foula and Hoy, respectively. Consequently, the potential for use of proposed offshore wind farm development zones was greater during the day than at night.

Many species of seabirds are thought to hunt mostly by visual cues during day, night, or both periods (Shealer 2002 In Biology of Marine Birds) with some species showing flexibility in nocturnal behaviour linked to moon-lit or star lit foraging opportunities (e.g. Regular *et al*. 2011). Great Skuas are known to forage both during the day and at night (Votier *et al*. 2006) – Votier *et al*. (2006) observed Great Skuas at St. Kilda frequently foraging at night predating Leach's Storm Petrels (*Oceanodroma leucorhoa*). Seabirds were also recorded in the diet of Great Skuas studied at Foula in 2011, many of which were thought to be auks. Such seabird prey was recorded in much lower proportions in the diet of adults through pellets than that of fish prey. However, pellets and direct recoding of prey (e.g. carcasses) can yield differing results for diet, particularly for seabird prey (Votier *et al*. 2001), and furthermore it is unknown at what time of day such seabird prey were captured.

4.5.5 Conclusions

This study has revealed individual, sex-specific differences and cross-breeding season variation in the time budgets and area utilisation of Great Skuas and thus the extent of interaction with proposed offshore wind farm development zones. Telemetry methods and studies such as this will continue to be crucial in our understanding of the extent of interaction between protected features species of SPAs and offshore development areas, from which we can also learn a great deal more about the foraging ecology of species. Although the data in this study were relatively limited, they highlight the importance of understanding variation in time budgets and area utilisation between individuals and through time and should provide the means to understand how many individuals should be tracked and for how long (e.g. Soanes *et al*. 2013) to enable adequate assessment of seabird-wind farm interactions.

Table 4.1 Summary of individual Great Skua time budget analyses for the breeding season, including total time at the nest and on trips, percentage of time spent on trips, and within offshore wind farms, for (a) Foula and Hoy, and pooled data across birds for (b) sex-specific and diurnal variation.[1]

(a)

Bird	Total time (hrs)	On trip (%)	Proportion in wind farm (%)					
			Moray	NE2	NE1	N1	N4-N6	All wind farms
Foula (2010)								
340	47	44					3	3
342[2]	-	-	-	-	-	-	-	-
348	114	27					6	6
349	143	55					13	13
Total	304	43					9	9
Foula (2011)								
415	29	50					3	3
418	257	14					3	3
419	652	46					8	8
450	830	34					6	6
451	972	18					5	5
454	943	35					7	7
465	982	37					7	7
470	984	42					6	6
476	915	35					11	11
487	867	41					8	8
Total	7429	35					7	7
Hoy (2011)								
400	429	19				6		6
409	429	30	<1	<1	1			1
420	245	28				<1		<1
448	262	13				<1		<1
467	1539	48				2		2
471	1558	42						
472	39	22						
473	218	23				4		4
475	318	15				2		2
Total	5038	36	<1	<1	<1	2		2

(b)

	Total time (hrs)	On trip (%)	Proportion in wind farm (%)					
			Moray	NE2	NE1	N1	N4-N6	All wind farms
Both colonies combined								
Male	13182	27.4				1	6	6
Female[3]	4914	41.9	<1	<1	<1	1	2	3
Foula								
Night	19404	7.6					1	1
Day		27.5					6	6
Hoy								
Night	12594	6.1			<1	<1		<1
Day		29.8	<1	<1	<1	2		2

[1] Note, more data have been added for previous years since the publication of Thaxter *et al.* (2012a) and (2013), hence figures presented here may not match those originally presented.

[2] Insufficient data were available for bird 342 to construct meaningful time budgets.

[3] For analysis of sex-specific variation, males and females were pooled across colonies, however sample sizes are low and thus results are treated as indicative only.

Table 4.2 Summary of individual Great Skua kernel overlap analyses for the breeding season, including total bird kernel sizes, and percentage overlap with proposed offshore wind farm development zones, for (a) Foula and Hoy, and (b) sex-specific and diurnal kernels across birds, using GPS data filtered to a 600s sampling rate.[1]

(a)

Bird	**No. fixes**	**Area (km^2)**		**Wind farm KDE overlap of 95% and 50% KDE (%) (“95% KDE”,”50% KDE”)**					
		95% KDE	**50% KDE**	**N4-N6**	**N1**	**NE1**	**NE2**	**Moray**	**All**
Foula (2010)									
340	31	1450	349	12, 0					12, 0
348	45	4436	820	16, 33					16, 33
349	137	2731	590	35, 21					35, 21
Foula (2011)									
415	26	1019	159	11, 0					11, 0
418	126	1510	305	35, 16					35, 16
419	1652	5093	973	22, 34					22, 34
450	1384	10941	1799	11, 30					11, 30
451	723	4064	597	34, 44					34, 44
454	1714	10323	1826	14, 31					14, 31
465	1507	7291	1560	12, 19					12, 19
470	1907	9194	2007	12, 23					12, 23
476	1556	6209	994	18, 52					18, 52
487	1301	6670	1425	14, 27					14, 27
Total	12109	18453	3227	9, 31					9, 31
Hoy (2011)									
400	221	3069	766		29, 51				29, 51
409	355	3368	663			10, 20	<1, 0	<1, 0	10, 20
420	278	3007	527		4, 2				4, 2
448	59	2564	706		3, 1				3, 1
467	2134	5969	909		13, 0				13, 0
471	1835	910	119						0, 0
472[2]	-	-	-						0, 0
473	199	3419	780		30, 16				30, 16
475	120	2667	665		23, 22				23, 22
Total	5201	8621	1145		13, 0	2,0	<1, 0		15, 0

(b)

Bird	No. fixes	Area (km^2)		Wind farm KDE overlap of 95% and 50% KDE (%) (“95% KDE”,”50% KDE”)					
		95% KDE	50% KDE	N4-N6	N1	NE1	NE2	Moray	All
Both colonies combined									
Male	7528	23732	3606	6, 12	5, 0	2, 0			13, 12
Female	2244	15760	2574	9, 33	6, 0				15, 33
Foula									
Night[3]	2608	14251	2789	9, 26					9, 26
Day	9501	20878	3645	8, 30					8, 30
Hoy									
Night[3]	490	5349	1158		4, 0	5, 2			9, 2
Day	4711	9742	1392		13, 0	3, 0	<1, 0		16, 0

[1] Note, more data have been added for previous years since the publication of Thaxter *et al.* (2012a) and (2013), hence figures presented here may not match those originally presented.

[2] Insufficient data were available for bird 472 to allow reliable assessment of spatial movements.

[3] Note, for Foula, night-time fixes were obtained for all but bird 415, with two having less than five fixes, two having less than 50, with the remainder having more than 100 fixes each up to a maximum of 613 (bird 470). For Hoy, night-time fixes were obtained for only five of the eight birds (two had more than 195 fixes, one had 75 fixes, and two had less than 10 fixes).

Table 4.3 Trip statistics for individual Great Skuas tracked during the breeding season from Foula (2010 and 2011) and Hoy (2011).

Year	Colony	Bird	N trips	Trip duration (hrs)		Foraging range (km)		Total distance (km)	
				Mean	Max	Mean	Max	Mean	Max
2010	Foula	340	1	15.9	15.9	117.0	117.0	259.4	259.4
		348	15	4.8±3.2	12.7	49.9±35.5	126.4	106.2±76.9	274.3
		349	25	12.3±9.5	30.5	92.4±69.8	218.7	211.4±166.5	579.1
		All	41	11.0±5.7	30.5	86.4±34.0	218.7	192.3±78.4	579.1
2011	Foula	415	1	14.0	14.0	71.5	71.5	168.4	168.4
		418	6	6.4±4.0	13.3	65.4±27.1	96.8	145±65.5	223.7
		419	21	15.1±13.2	51.5	84.4±60.4	264.7	235±176.5	786.8
		450	30	10.7±18.2	102.8	67.6±47.5	177.8	165.6±120.1	463.3
		451	48	3.3±2.1	9.2	29.4±20.7	95.2	71.7±50.8	238.8
		454	38	7.6±6.5	36.0	74.2±45.4	159.6	181.2±119.5	477.3
		465	44	7.8±5.1	23.8	73.2±43.8	180.3	164.4±101.3	412.0
		470	38	10.2±6.5	28.6	96.5±41.9	192.3	226±110.5	488.4
		476	72	4.3±3.3	17.4	48.5±33.5	162.6	110.2±82.3	397.4
		487	47	6.8±5.7	30.9	68.1±46.1	169.3	152.4±109.9	468.5
		All	345	8.6±3.9	30.9	67.9±18.4	192.3	162.0±48.4	488.4
	Hoy	400	17	4.6±3.0	13.4	96.1±41.3	147.8	212.9±102.3	391.4
		409	25	5.1±8.5	42.6	38±46.6	181.7	102.7±160.9	763.7
		420	19	3.6±2.8	10.1	33.9±34.1	115.1	83.1±85.6	289.6
		448	11	3.4±3.2	10.1	43.7±42.7	101.9	110.2±114.6	309.8
		467	120	5.7±7.6	64.3	51.9±46.1	170.8	132.6±130.2	716.1
		471	139	4.4±3.9	18.4	25.4±17.9	77.0	81.6±69.2	354.8
		472	3	1.4±0.3	1.6	2.6±2.2	5.1	5.9±4	10.3
		473	11	4.4±2.4	8.0	75.9±48.4	135.5	163.6±103.7	289.3
		475	22	2.1±1.8	6.8	33.2±36.6	119.5	75.1±85.3	291.9
		All	367	3.9±1.4	8.0	44.5±27.6	135.5	107.5±58.7	291.9

Table 4.4 Summary of significant parametric and smoothed terms fitted for spatial and temporal analyses of Great Skua data – for full analysis results see Appendices 4.2 and 4.3. ‘*’ = P < 0.05, ‘.’ = P < 0.10.

Period	Section	Measure	Sex	s(Jdate)	s(chick age)	s(Jdate, colony)	s(chick age, colony)	s(Jdate, sex)	s(chick age,sex)	s(Jdate, birdID)	s(chick age, birdID)
Total	Trip statistics	Trip duration	*	*	*	*			*	*	*
		Foraging range offshore							*	*	*
		Distance covered per trip							*	*	*
	Time	Time away from nest	*	*	*					*	*
		Time in wind farm				*	*			*	*
	Space	Total area usage								*	*
		Wind farm overlap	.			*				*	*
Day	Trip statistics	Trip duration			.	*	*			*	*
		Foraging range offshore							*	*	*
		Distance covered per trip								*	*
	Time	Time away from nest	*	*	*					*	*
		Time in wind farm				*	*			*	*
	Space	Total area usage								*	*
		Wind farm overlap	.								
Night	Trip statistics	Trip duration	*	*	*				*	*	*
		Foraging range offshore								*	*
		Distance covered per trip								*	*
	Time	Time away from nest	*	*	*					*	*
		Time in wind farm				*				*	*
	Space	Total area usage								*	*
		Wind farm overlap	*							*	*

Table 4.5 Means and maximums across all consecutive day periods per year for measures of trips statistics, time budgets, and area usage for male and female Great Skuas; all spatial overlaps are for the 95% KDE.

Period	Measure	Parameter	Males		Females	
			Mean±SD	Max	Mean±SD	Max
Total	Trip statistics	Trip duration (hrs)	7.6±4.4	64.3	3.9±1.5	17.4
		Foraging range offshore (km)	54.6±24.3	264.7	45.3±23.5	162.6
		Total distance travelled (km)	143.2±60.0	786.8	102.4±50.6	397.4
	Time budgets	%Time away from nest (total)	39.1±7.4	100	25.3±8.8	82.4
		% Time in wind farm (total)	3.9±3.1	8.0	3.2±3.9	7.5
	Area usage	Size of 95% KDE (km^2) (total)	4185±2909	11938	4283±2193	8977
		% Wind farm overlap (total)	8.0±9.9	36.3	21.9±12.5	49.2
Day	Trip statistics	Trip duration (hrs)	4.2±1.8	15.6	3.8±1.8	13.3
		Foraging range offshore (km)	40.2±14.6	163.9	43.9±27.5	135.5
		Total distance travelled (km)	97.9±36.6	512.6	100.6±59.3	309.8
	Time budgets	%Time away from nest (total)	31.1±7.1	78.6	23.1±8.2	66.9
		% Time in wind farm (total)	3.1±2.6	28.7	2.9±3.1	29.2
	Area usage	Size of 95% KDE (km^2) (total)	4462±3137	12259	3967±1655	6875
		% Wind farm overlap (total)	8.4±9.7	37.7	22.2±13.2	52.2
Night	Trip statistics	Trip duration (hrs)	10.7±6.3	64.3	5.7±4.9	17.4
		Foraging range offshore (km)	68.8±31.0	264.7	49.6±30.5	162.6
		Total distance travelled (km)	186.7±85.2	786.8	110.9±68.9	397.4
	Time budgets	%Time away from nest (total)	8.0±1.9	51.3	2.2±3.0	21.5
		% Time in wind farm (total)[1]	0.8±0.9	2.8	0.3±0.9	2.9
	Area usage	Size of 95% KDE (km^2) (total)	2213±1413	5675	3190±1410	5442
		% Wind farm overlap (total) [1]	8.3±10.8	36.8	28.3±13.6	46.2

[1] Only one female Great Skua from Foula (476), and none from Hoy were recorded in the areas of proposed wind farm zones during the night.

Table 4.6 Means and maximums across all consecutive day periods for measures of trip statistics, time budgets and area usage for Great Skuas tagged at Foula and Hoy; all spatial overlaps are for the 95% KDE.

Period	**Measure**	**Parameter**	**Foula**		**Hoy**	
			Mean±SD	**Max**	**Mean±SD**	**Max**
Total	Trip statistics	Trip duration (hrs)	8.6±3.9	102.8	3.9±1.4	64.3
		Foraging range offshore (km)	67.9±18.4	264.7	44.5±27.6	181.7
		Total distance travelled (km)	161.3±50.5	786.8	107.5±58.7	291.9
	Time budgets	%Time away from nest (total)	35.2±10.9	100	27.5±11.6	100
		% Time in wind farm (total)	6.8±4.3	71.8	2.0±2.0	28.7
	Area usage	Size of 95% KDE (km^2) (total)	5532±2598	13316	3337±2219	10823
		% Wind farm overlap (total)	21.8±11.7	56.6	8.2±10.8	34.7
Day	Trip statistics	Trip duration (hrs)	5.4±2.2	13.7	3.3±1.2	15.6
		Foraging range offshore (km)	50.9±16.3	177.8	42.1±29.7	163.9
		Total distance travelled (km)	118.5±41.1	434.6	98.6±64.0	512.6
	Time budgets	%Time away from nest (total)	28.5±23.9	80.3	23.9±8.9	78.6
		% Time in wind farm (total)	5.3±3.1	44.1	1.9±2.0	28.7
	Area usage	Size of 95% KDE (km^2) (total)	5488±2575	14044	3538±2606	10748
		% Wind farm overlap (total)	21.9±11.6	54.8	8.2±10.7	36.1
Night	Trip statistics	Trip duration (hrs)	11.8±8.0	102.8	5.8±4.2	64.3
		Foraging range offshore (km)	84.5±29.3	264.7	54.4±36.6	181.7
		Total distance travelled (km)	200.6±78.6	786.8	141.4±84.6	763.7
	Time budgets	%Time away from nest (total)	6.7±4.7	50	3.6±4.0	51.3
		% Time in wind farm (total)[1]	1.5±1.5	10.4	<0.1±<0.1	0.4
	Area usage	Size of 95% KDE (km^2) (total)	3415±1735	8360	1517±767	3298
		% Wind farm overlap (total) [1]	18.9±12.6	46.2	4.2±10.2	35.4

Table 4.7 Contents of pellets collected from territories of incubating and chick-rearing Great Skuas at Foula during 2011 (n = 151 pellets from 45 nests of 57 nests monitored); data are presented as (a) the proportion of prey items in pellets collected and (b) (i) the proportion of 'fish' pellets containing otoliths identified to particular fish species and (ii) the proportion of the total number of otoliths collected identified to particular fish species.

(a)

Stage	Fish	Beetle	Seabird	Goose barnacle	Rabbit	Pollution	Egg Shell	Unknown	No. Pellets
Incubation	47								47
	1	1							1
	1		1						1
				4					4
	3			3					3
						1			1
					11				11
			6						6
		1	1						1
Sub-total %	69.3	2.7	10.7	9.3	14.7	1.3	0.0	0.0	75
Chick	1			1			1		1
	34								34
	1	1							1
	1		1				1		1
	1			1					1
	1		1						1
				2					2
						1			1
					3				3
			8						8
	1		1						1
Sub-total %	74.1	1.9	20.4	7.4	5.6	1.9	3.7	0.0	54
Unknown / Fail	10								9
	1	1							1
				1					1
					6				5
			3						3
								1	1
Sub-total %	50.0	4.5	13.6	4.5	27.3	0.0	0.0	4.5	22
Total %	68.2	2.6	14.6	7.9	13.2	1.3	1.3	0.7	151

(b)

(i)

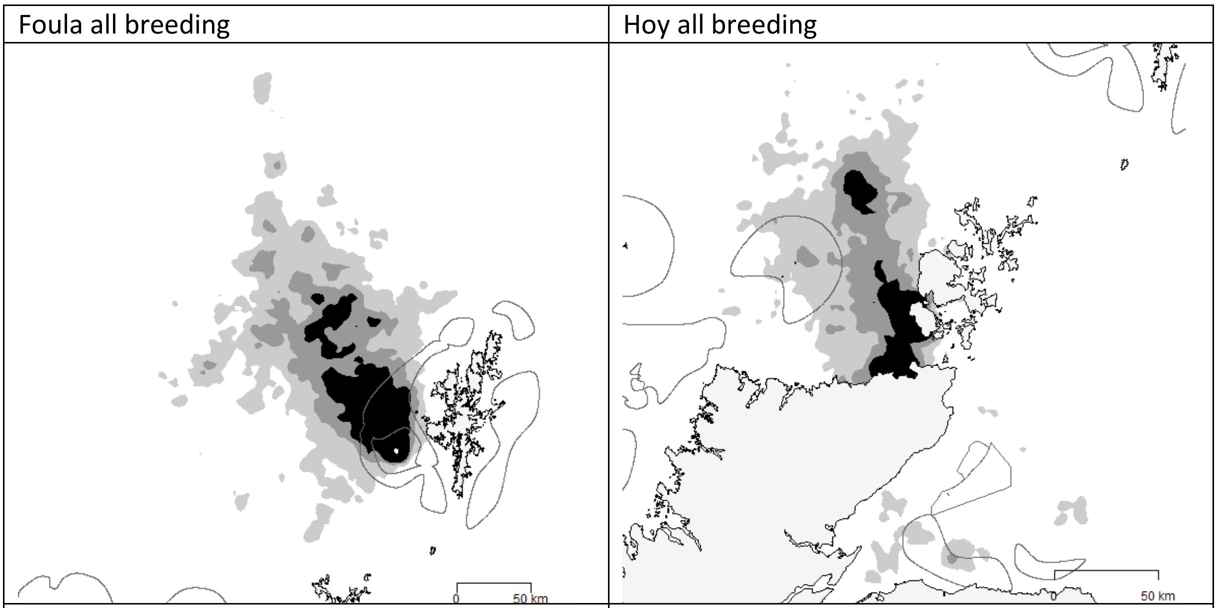
Species	**Multiple prey pellets (pellet number)**					**Single prey pellets**	**% prey**
	1	**2**	**3**	**4**	**5**		
Argentine		1	1	1		5	32.0
Black Seabream			1			1	8.0
Blue Whiting			1			1	8.0
Haddock						5	20.0
Norway Pout		1			1	1	12.0
Poor Cod	1	1		1	1	4	32.0
Unknown						1	4.0
Whiting	1					2	12.0
Total pellets	1	1	1	1	1	20	

(ii)

Species	**Multiple prey pellets (pellet number)**					**Single prey pellets**	**% prey**
	1	**2**	**3**	**4**	**5**		
Argentine		2	1	8		7	19.4
Black Seabream			1			1	2.2
Blue Whiting			2			2	4.3
Haddock						9	9.7
Norway Pout		3			2	2	7.5
Poor Cod	6	7		3	5	26	50.5
Unknown						1	1.1
Whiting	1					4	5.4
Total otoliths	7	12	4	11	7	93	

Foula all breeding

Hoy all breeding



Foula Incubation

Foula chick-rearing

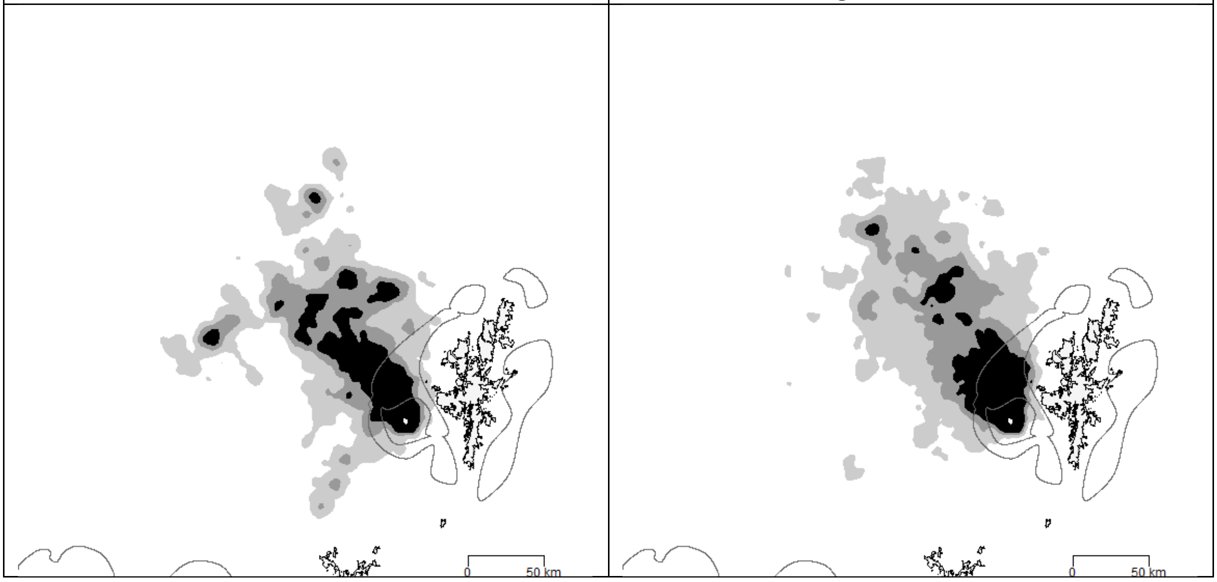
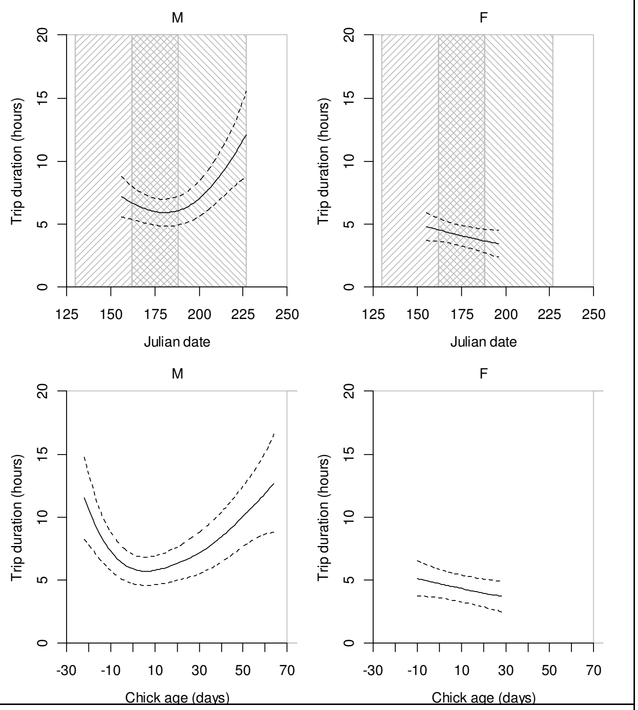
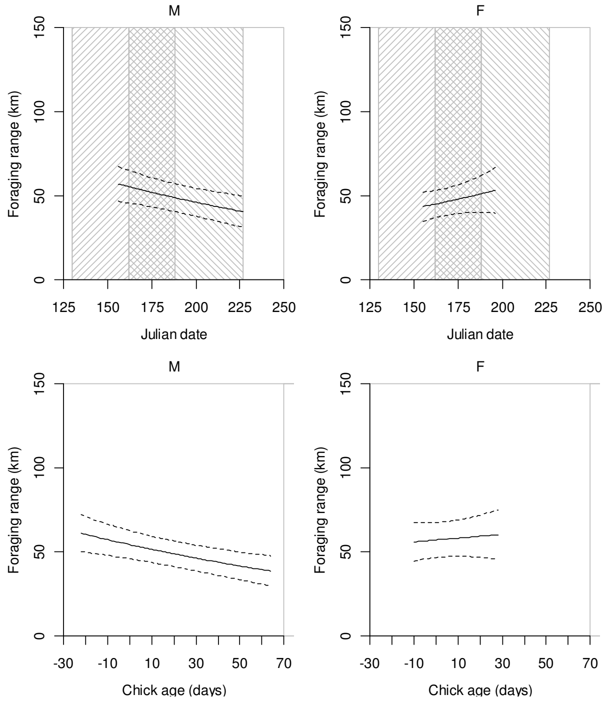
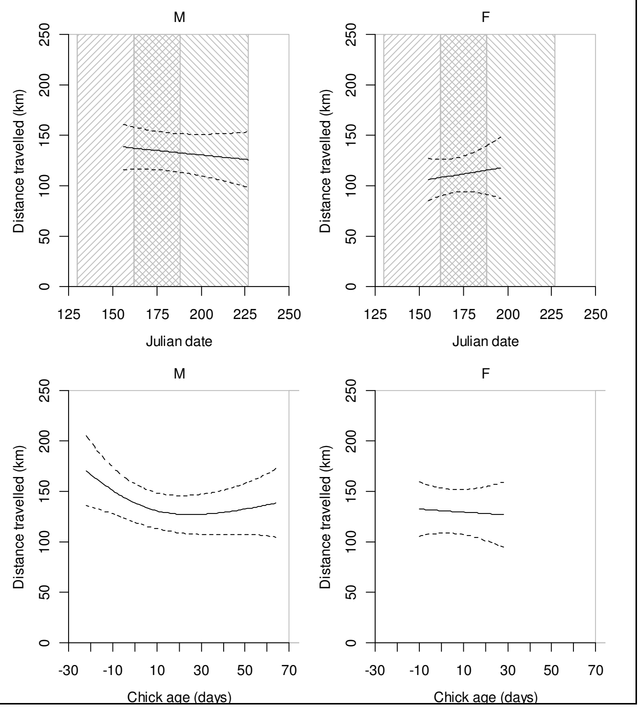


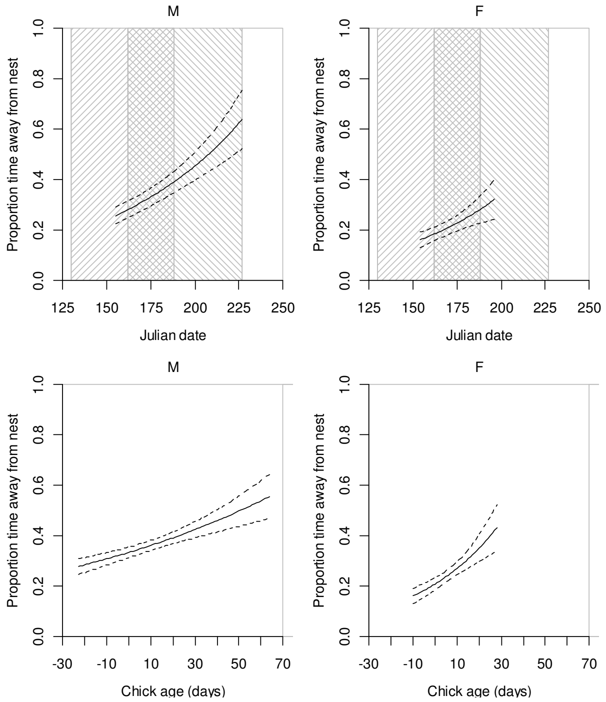
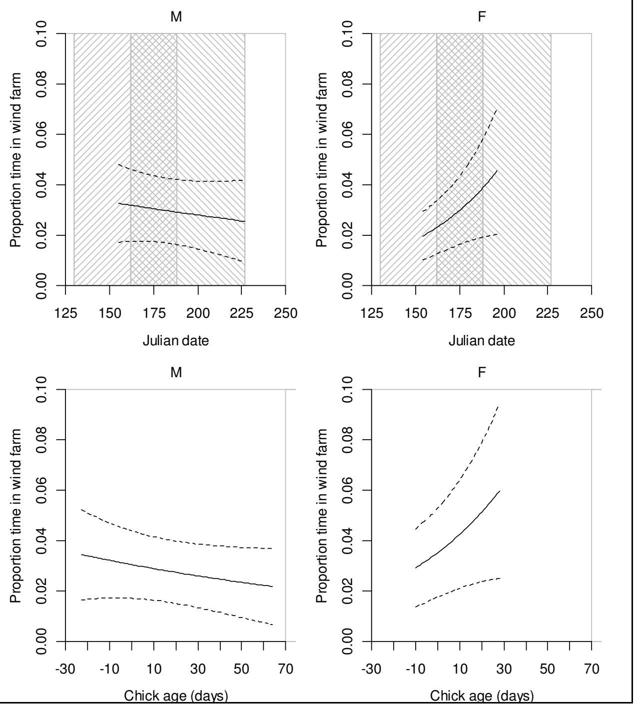
Figure 4.1 Spatial area usage by Great Skuas from Foula and Hoy during the breeding season, and for Great Skuas from Foula for the incubation and chick-rearing periods. Shown are the 95% (light grey) representing total area usage, 75% KDEs (medium grey) and 50% KDE, representing core area usage; wind farm zones are outlined for Scottish medium term zones, short-term Zones (Beatrice in the Moray Firth), and the Round 3 Moray Firth Zone; 95% KDE = light grey; 75% KDE = dark grey; 50% KDE = black.

(a) Summary statistics

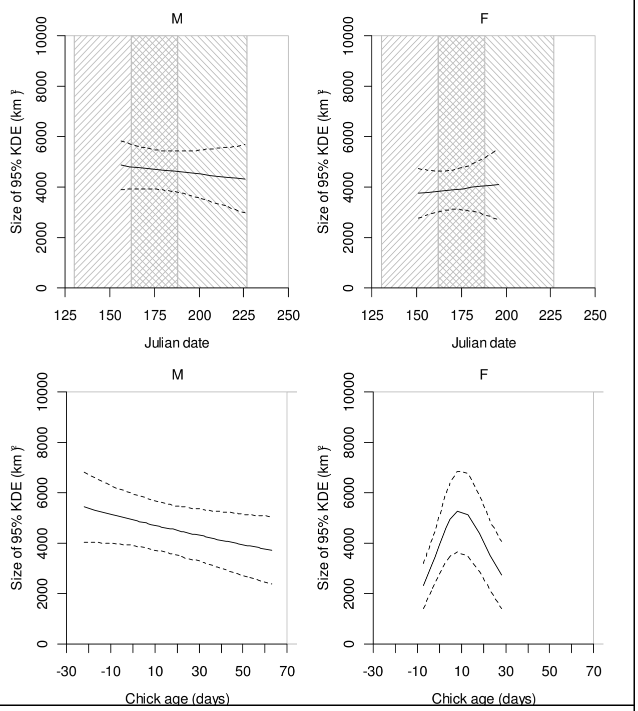
Trip duration	
Foraging range	

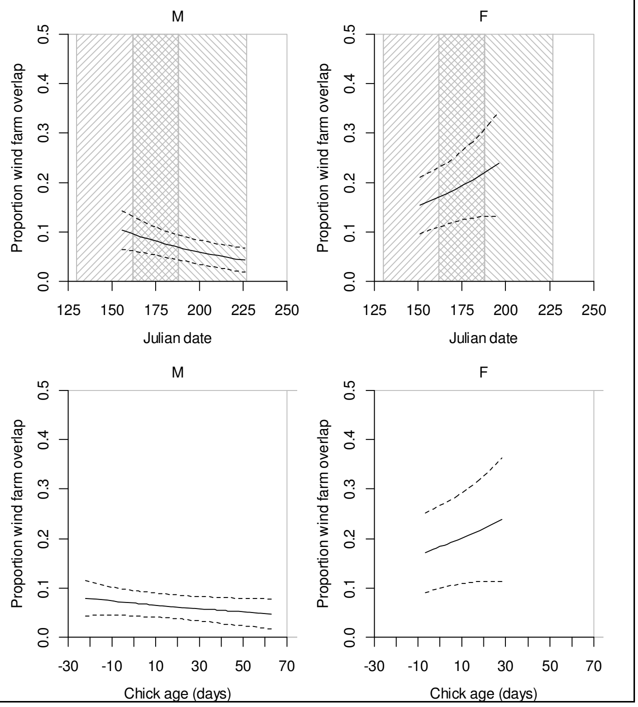
Total distance travelled per trip	

(b) Time budgets

Measure	
Time away from territory	
Time spent in wind farm	

(c) Area usage

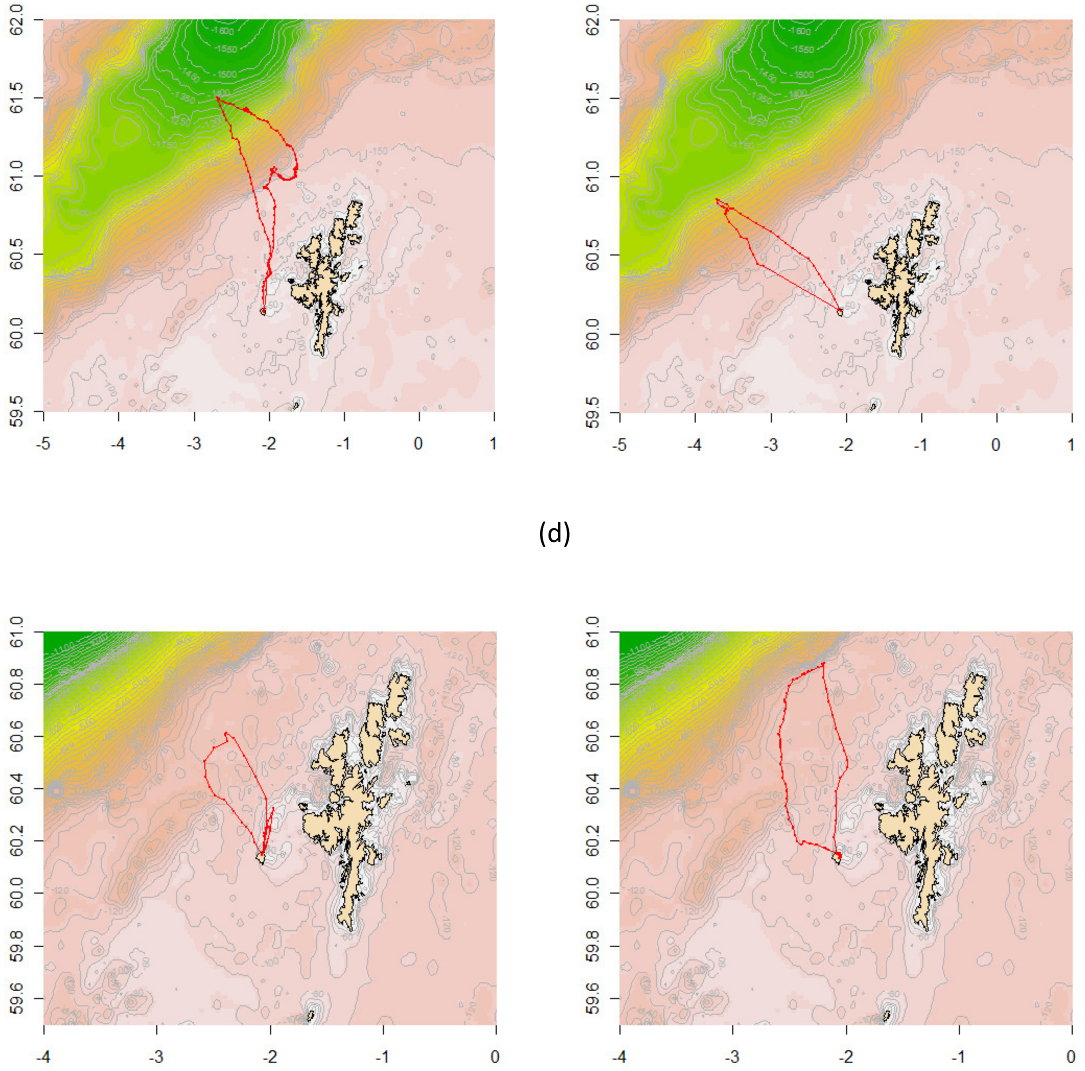
<table>
<tr><th>Measure</th><th></th></tr>
<tr><td>Total area</td><td>


</td></tr>
<tr><td>Wind farm area overlap</td><td>


</td></tr>
</table>

Figure 4.2 Sex-specific*season differences in relationships for Great Skua (using data from Foula and Hoy combined) derived from GAMMs for: (a) Summary statistics – trip duration, foraging range, and distance travelled per trip, (b) Time budgets, time spent away from the nest, and time spent in wind farm zones, and (c) Spatial use, total area usage (95% KDE size), and overlap (of 95% KDE) with offshore wind farms; significance of effects are given in Table 4.4.

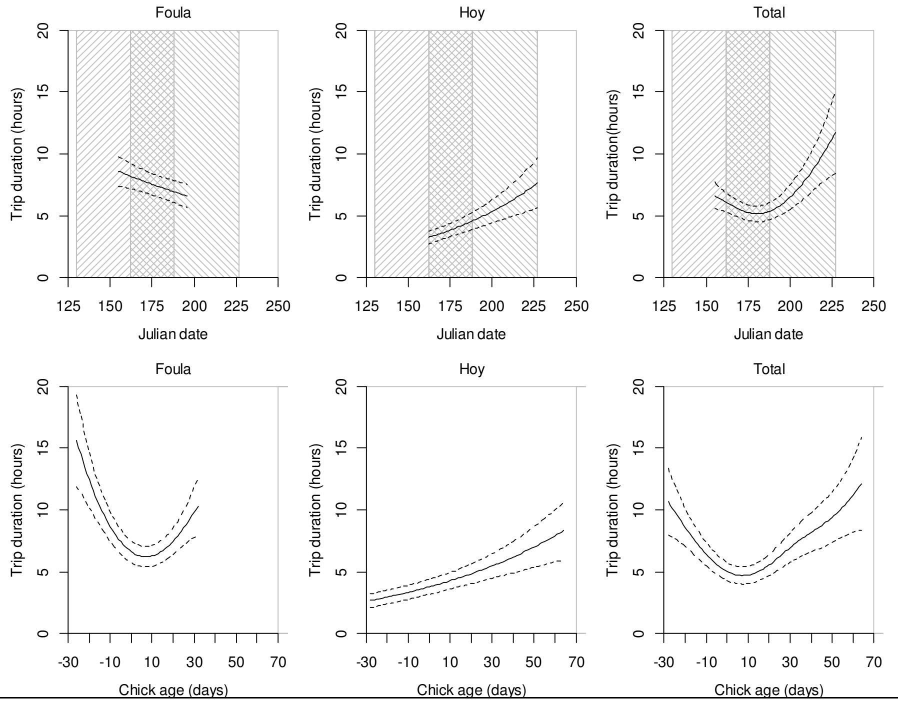
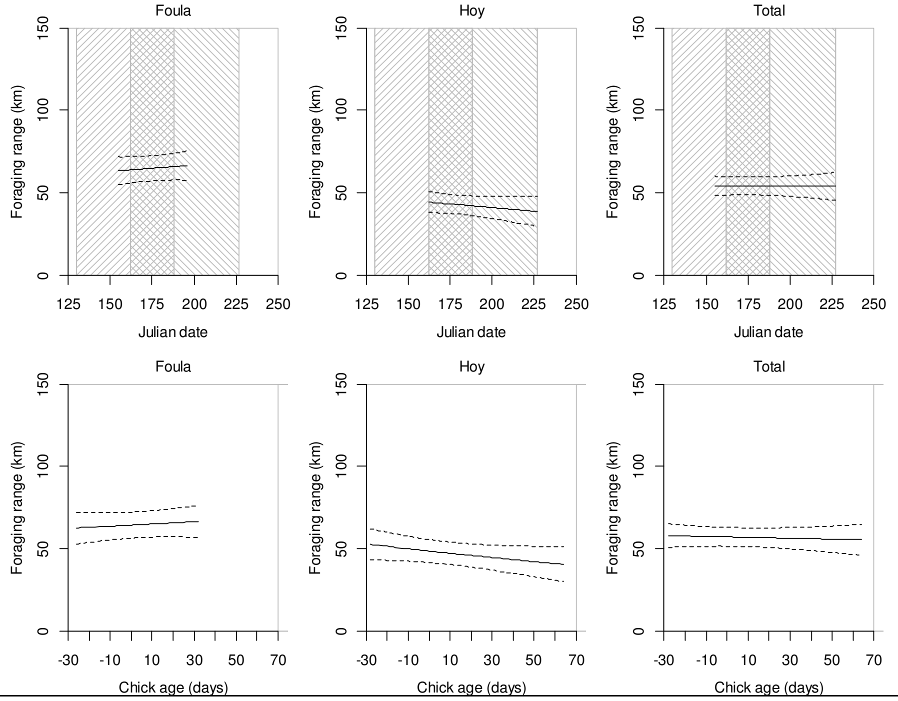
(a) (b)

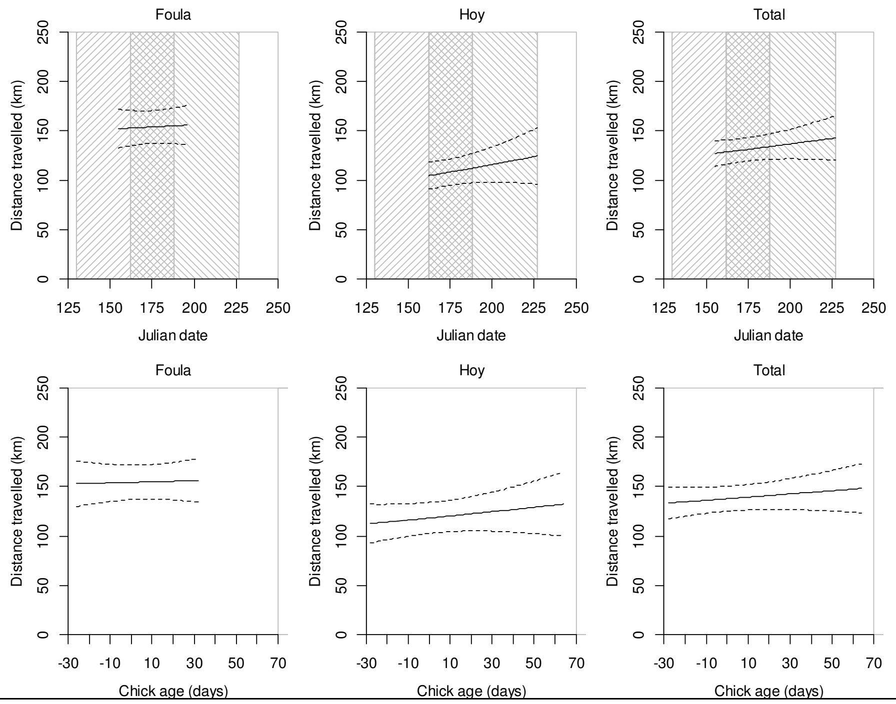


(c) (d)

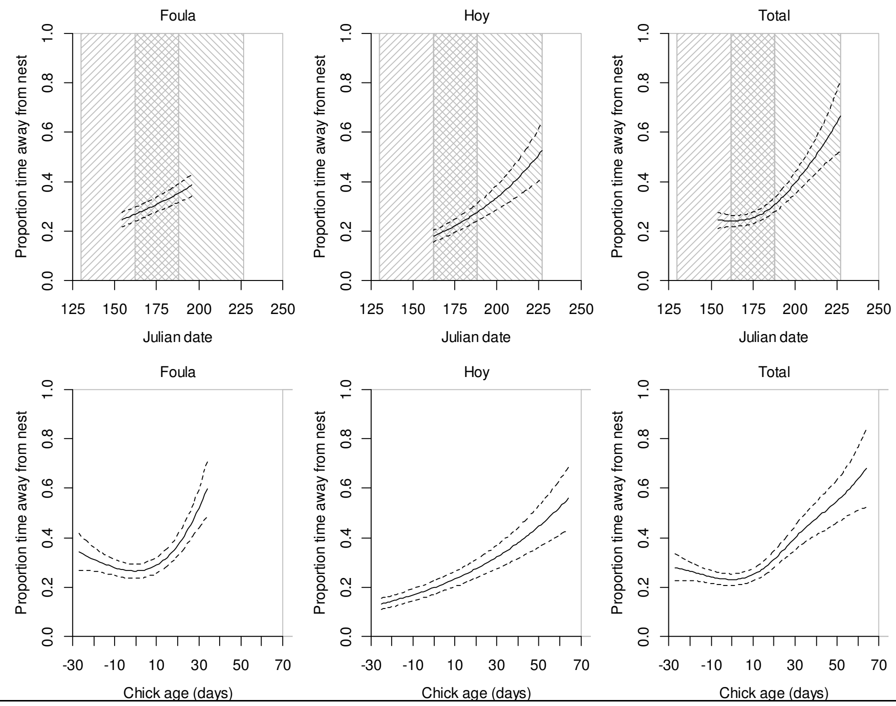
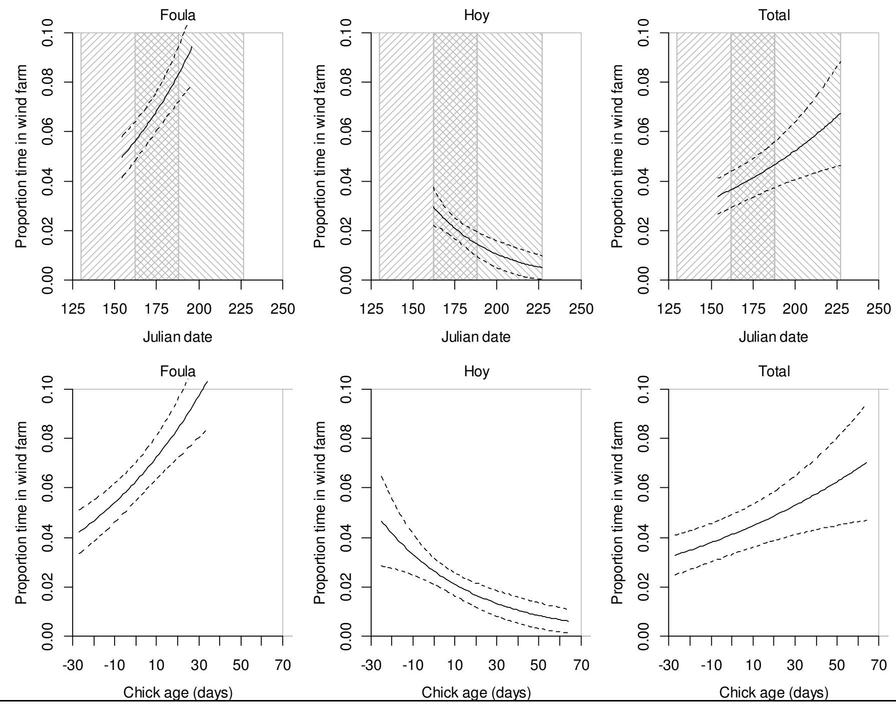
Figure 4.3 Linking pellet information collected from Great Skua breeding territories and foraging behaviour on feeding trips derived from GPS data, assessed here from very fresh fish pellets collected the next morning following a known feeding trip: (a) Bird 454 trip 30/06/2011 09:17:10 – 01/07/2011 00:16:50 during chick rearing; (b) Bird 465 trip 24/06/2011 20:06 – 25/06/2011 06:42 during incubation – one chick hatched the next day; (c) Bird 451 – two trips one immediately after the other with the bird returning and leaving again immediately – between 10/07/2011 00:39:36 – 10/07/2011 07:41:19 during chick-rearing; (d) Bird 419 trip 11/06/2011 09:49 – 11/06/2011 18:23 during incubation.

(a) Summary statistics

Trip duration	
Foraging range offshore	

Total distance travelled per trip	

(b) Time budgets

Time away from nest	
Time spent in wind farm	

(c) Area usage

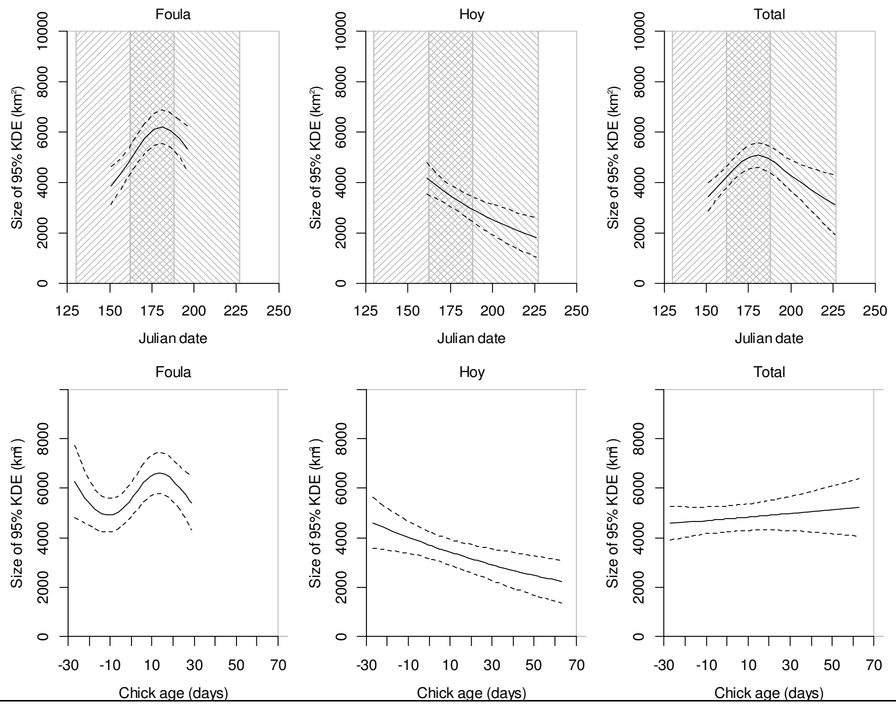
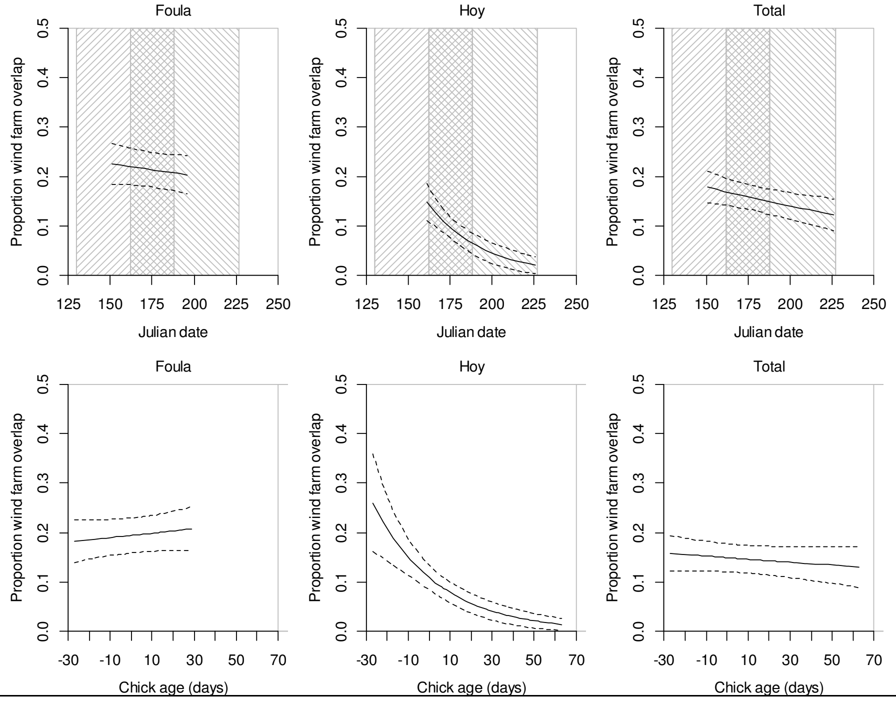
Measure	
Total area	
Wind farm area overlap	

Figure 4.4 Seasonal differences in relationships from GAMMs for Great Skua (using data from Foula and Hoy combined) derived from GAMMs for: (a) Summary statistics – trip duration, foraging range, and distance travelled per trip, (b) Time budgets, time spent away from the nest, and time spent in wind farm zones, and (c) Spatial use, total area usage (95% KDE size), and overlap (of 95% KDE) with offshore wind farms; significance of effects are given in Table 4.4.

5. MODELLING FLIGHT HEIGHTS OF LESSER BLACK-BACKED GULLS

5.1 Introduction

Anthropogenic climate change is arguably one of the greatest threats facing ecosystems on which humans rely (UK National Ecosystem Assessment 2011). Governments around the world are therefore investing in low-carbon renewable energy sources in an attempt to offset and slow global environmental change, and legislating accordingly. The obligation to obtain 20% of energy consumed from renewable sources by 2020 is enshrined in European Union law (Directive 2009/28/EC), and offshore wind is one means by which European governments are working towards this target. As an island nation on the eastern edge of the Atlantic Ocean, the UK is well placed to make use of this energy source (Boyle 2007). Since 2001, a number of offshore wind farms have come into operation in UK territorial waters, and many more much larger projects are planned and have been granted permission (Breton & Moe 2009).

Concerns have been raised about the environmental impact of such developments, not least because it is hard for comprehensive research to keep pace with the scale and speed of project initiation and completion (Fox *et al*. 2006; Inger *et al*. 2009). Seabirds are among the species for which adverse effects of offshore wind farms have been suggested and reported (Garthe & Hüppop 2004; Furness *et al*. 2013), with collision risk a primary concern (Everaert & Stienen 2007).

One of the main factors determining whether an individual bird is likely to collide with a turbine is the height at which it flies (Garthe & Hüppop 2004; Furness *et al.* 2013; Johnston *et al.* 2014), although this is also influenced by other aspects of their behaviour and ecology, such as their ability to detect turbines and take avoidance action (Garthe & Hüppop 2004; Johnston *et al.* 2014). Until recently, information on seabird flight altitudes has been scant and largely based on measures from boat-based surveys (Johnston *et al.* 2014), which only take place during the day and result in estimates of bird flight heights within the observer's visible range. Boat-based surveys are restricted by weather conditions (Camphuysen *et al*. 2004). Information on seabird flight altitudes has also been available from radar studies, although identifying the species concerned is not generally possible with this technique, and radar measurements may also be hampered by poor weather. The recent development of digital aerial surveys also offers a potential means to assess flight altitudes. GPS tracking, whereby individual seabirds are fitted with small devices that measure their position in three dimensions, offers an alternative to these methods, with potentially fewer limitations. As these tracking devices can be long-lived, they also allow assessment of a bird's flight behaviour in a variety of conditions, including those that are known to affect flight altitude, such as season, weather and time of day (Dokter *et al*. 2013; Kemp *et al*. 2013).

In this study, we use GPS tracking technology to investigate flight heights of the Lesser Black-backed Gull, a long-lived seabird of conservation concern in the UK (Eaton *et al*. 2009). The breeding colony locations (Mitchell *et al*. 2004) and foraging range (Thaxter *et al*. 2012b) of this species mean that there is a high probability of interactions with offshore wind farms (Thaxter *et al*. 2011; 2012a; 2013) and the species has been identified as being at risk from wind farms in a number of assessments. We aim to assess the altitudes at which Lesser Black-backed Gulls fly, providing information on flight height distributions that could inform collision risk models and thus the potential impact of offshore wind farms on this species. Specifically, we assess the factors that might cause variation in flight heights.

5.2 Methods

5.2.1 Analysis

Flight altitudes were modelled within a Bayesian framework (Wade 2000; Ellison 2004), using OpenBUGS 3.2.2 (Lunn *et al*. 2009) and data processing was carried out in R (R Development Core Team 2013) and ArcGIS (ESRI). Semi-variograms revealed that temporal autocorrelation was low for observations 60 minutes apart. We therefore sub-sampled the data to select a maximum of one observation in each 60 minute period, to produce a dataset with limited temporal autocorrelation. Data points were only considered during the time of the year that birds were associated with the breeding colony at Orford Ness (which lasted up to some months after the end of the breeding season for certain individuals), so that birds' altitudes were assessed for the entire time they were in the vicinity of the breeding colony (Table 5.1). All data points were classified as 'terrestrial', 'coastal' (within an arbitrary 200 m of the coastline) or 'marine' (more than 200 m from the coastline). We calculated the true altitude of birds at any given point, accounting for tidal state and land height for marine and terrestrial observations respectively. Tidal data were obtained from the British Oceanographic Data Centre website (https://www.bodc.ac.uk/data/online_delivery/ntslf/), using the tide gauge at Harwich, approximately 30 km from the Orford Ness gull colony. Information on land altitude was obtained from the Shuttle Radar Topography Mission (SRTM) 90 m digital elevation data (http://srtm.csi.cgiar.org/), aggregated at the 1 km square level.

Table 5.1 Date ranges within which tagged Lesser Black-backed Gulls were present at Orford Ness each year, the observations taken within which were included in the Bayesian model of flight altitudes (only showing birds for which tag malfunction within the breeding season did not occur).

Tag number	Year	Arrived at colony	Left colony
334	2010	NA	24/10/2010
	2011	12/04/2011	29/07/2011*
336	2010	NA	14/08/2010
	2011	27/03/2011	09/08/2011
388	2010	NA	31/07/2010
391	2010	NA	07/09/2010
	2011	03/04/2011	28/07/2011*
395	2010	NA	22/07/2010
	2011	20/03/2011	16/07/2011
	2012	23/03/2012	05/07/2012
	2013	30/03/2013[1]	06/07/2013*
407	2010	NA	17/07/2010
	2011	20/03/2011	30/07/2011
	2012	13/03/2012	15/08/2012*
408		NA	14/07/2010*
459	2011	NA	24/07/2011
	2012	21/03/2012	23/06/2012
	2013	27/03/2013	01/06/2013*
460	2011	NA	05/11/2011
	2012	15/03/2012	17/10/2012[2]
	2013	25/03/2013	24/05/2013*
478	2011	NA	05/08/2011
	2012	18/02/2012	NA[3]

Tag number	Year	Arrived at colony	Left colony
	2013	27/03/2013[3]	21/05/2013*
479	2011 2012 2013	NA 26/03/2012 26/03/2013	05/10/2011 09/10/2012 28/04/2013*
480	2011	NA	14/08/2011
481	2011 2012	NA 07/04/2012	11/07/2011* 07/06/2012*
482	2011 2012	NA 16/02/2012	16/09/2011 15/06/2012*
483	2011 2012 2013	NA 19/03/2012 10/03/2013	17/08/2011 07/07/2012 26/05/2013*
484	2011 2012 2013	NA 16/03/2012 27/03/2013	01/08/2011 18/06/2012 08/06/2013*
485	2011 2012 2013	NA 27/03/2012[4] 04/04/2013	02/08/2011 18/07/2012 05/06/2013*
486	2011 2012 2013	NA 24/03/2012 04/03/2013[5]	17/09/2011 04/09/2012 02/06/2013*
492	2011 2012 2013	NA 16/03/2012 14/03/2013	02/07/2011 20/07/2012 14/06/2013*
493	2011 2012 2013	NA 19/02/2012 05/03/2013	05/08/2011 27/06/2012 17/06/2013*

*Corresponds to 'Data collection end date' in Table 2.1.

[1] Data gap between 26/03/2013 (when bird was in London, on return migration) and 30/03/2013, when bird was back at Orford Ness.

[2] Data gap between 17/10/2012, when bird was at Orford Ness, and 27/10/2012, when bird was on Portuguese coast.

[3] Data gap between 26/05/2012, when bird was at Orford Ness, and 27/03/2013, when bird was at Orford Ness.

[4] Data gap between 22/10/2011, when bird was in central England, and 27/03/2012, when bird was back at Orford Ness.

[5] Data gap between 07/10/2012, when bird was in East Anglia, and 04/03/2013, when bird was back at Orford Ness.

A Bayesian state-space modelling approach was chosen (e.g. Newman *et al.* 2009; Harrison *et al.* 2011; King 2012). Bird behaviour was divided into discrete states based on speed and location, and these states were assumed to be known. After Shamoun-Baranes *et al*. (2011), speeds of less than 1 kmh^{-1} were classified as sitting, those between 1 and 4 kmh^{-1}as walking or swimming, and greater than 4 kmh^{-1} as flying. The speed categories greater than 1 kmh^{-1} were further subdivided; walking on land was separated from swimming at sea or near the coast, and flying was modelled as a separate state for overland, at the coast and out at sea. Six states in total were therefore considered (Table 5.2).

Table 5.2 Behavioural states used in Bayesian state-space model.

Behavioural state	Speed	Location
1	<1 kmh^{-1}	Land, coast & sea
2	1 – 4 kmh^{-1}	Land
3	1 – 4 kmh^{-1}	Coast & sea
4	>4 kmh^{-1}	Land
5	>4 kmh^{-1}	Within 200 m of coast
6	>4 kmh^{-1}	More than 200 m from coast

5.2.2 Process model

The distribution of altitudes at which birds fly was assumed to be a log-normal distribution for each state. This enables a variety of distribution shapes, and was supported by previous analysis of flight distributions (Johnston *et al*. 2014). The mean and standard deviation of the log-normal distributions for each state were estimated as part of the model. A random effect on the mean of the log-normal distribution was included for each bird, allowing individuals to have variable height preferences. Information on diurnal activity was included as a covariate, with each data point categorized as 'day', 'night' or 'twilight' (within half an hour either side of sunrise or sunset). This factor variable was modelled with an additive effect on the mean of the log-normal distributions.

5.2.3 Observation model

As the GPS tags record altitude with error (Eens *et al*. 2008), we included an observation model describing the error rate. The error in altitudinal measurements was assumed to be a normal distribution around the true altitude, and the standard deviation of the normal distribution was linearly related to the dilution of precision (a measure of GPS reliability) of each observation. An alternative model additionally considered a term accounting for the potential bias between observed altitude and true altitude, i.e. inaccuracy in the observed altitude provided by GPS; however this model failed to converge. This may suggest that the bias between observed altitude and true altitude is small; alternatively the bias, or inaccuracy, maybe correlated with the error, or precision, of GPS estimates and hence maybe reflected in confidence limits.

5.2.4 Model fitting

We used MCMC to fit the model (Gilks *et al*. 1996). Priors were vague and initial values were randomly generated from the prior distributions (Table 5.3). Three chains were run and convergence was assessed by examination of mixing in the chains, BGR statistics and estimates of MC error. The first 40,000 iterations in each chain were discarded as burn-in and the chain was run for a further 200,000 iterations.

Table 5.3 Parameters estimated in the model and associated prior distributions

Model part	Parameter	Prior
Process model	Mean of lognormal altitude distribution (1 for each state)	N(0, 100)
	Standard deviation of lognormal altitude distribution (1 for each state)	Unif(0, 200)
	Standard deviation of individual random effect	Unif(0, 200)
Observation model	Intercept of standard deviation of observation error	Unif(0, 200)
	Coefficient of dilution of precision for the standard deviation of observation error	Unif(0, 200)

5.3 Results

Lesser Black-backed Gull altitude was found to vary significantly with behavioural state (Table 5.4). As expected, birds travelling at less than 1 kmh^{-1} were observed at very low altitudes, with the vast majority within 30 cm of ground or sea level, which is likely for individuals standing, sitting on the nest, or floating on the water (Figure 5.1a). A similar trend was seen for birds moving at moderate speeds (1 to 4 kmh^{-1}) over water, which is congruent with swimming or floating with a current (Figure 5.1c). Individuals moving at this speed over land were still largely less than 30 cm from the ground, indicating walking, although there were higher proportions at slightly higher altitudes (up to about 4 m), which could represent small vertical movements around the nest, or at feeding sites, as well as time spent on elevated perches (Figure 5.1b).

Altitudes were higher for birds moving at greater than 4 kmh^{-1}, which is consistent with flight (Figure 5.2). Birds flying within 200 m of the coast had a lower flight altitude distribution (50% of observations within 6.66 m of water level) than those flying over land or sea, which might have indicated birds flying low as they gained or lost altitude on departure or arrival from their coastal colony or roosting site (Figure 5.2.b). 50% of observations over land were with 22.10 m of ground level, and 50% of observations more than 200 m from the coast were within 12.79 m of sea level. Altitude over land was therefore higher than that over sea (Figures 5.2.a and 5.2.c).

Tagged birds spent different proportions of time in their various behavioural states at different times of the day (Table 5.5). At every light level, birds spent the vast majority of their time relatively immobile, either sitting or swimming. At night birds spent more time in this state than during the day or at dusk and dawn, although this difference was not quite significant ($\chi^2_2 = 5.06$, $P = 0.08$). Birds spent a significantly higher proportion of their time flying overland during the day than at night ($\chi^2_1 = 6.24$, $P = 0.01$), and significantly more time flying near the coast during daytime than at twilight or night time ($\chi^2_2 = 7.26$, $P = 0.03$). Birds spent a relatively low proportion of their time flying more than 200 m from the coast regardless of light level.

The difference between the log mean flight altitudes over land and the two water categories was significant, while that between water near the coast and open sea was almost significant (Table 5.4, Figure 5.3).

The altitude of birds travelling at more than 4 kmh^{-1} also varied with light levels (Figure 5.4). During the day, birds flying over land spent a greater proportion of their time at higher altitudes than they did at dawn or dusk, or at night (Figure 5.4.a). While 50% of observations were within 22.10 m of the ground in daylight, the corresponding heights for twilight and darkness were 11.97 m and 14.02 m respectively. Birds flying within 200 m of the coast were most likely to be at low altitudes at dusk or dawn, when 50% of observations were within 2.52 m of water level, than at other times of day (50% of observations fell within 5.43 m of water level at night, and 6.66 m by day), perhaps indicating that these were the times they were flying low due to departure or arrival at nesting or roosting sites (Figure 5.4.b). Birds flying more than 200 m from the coast were more likely to be at low altitudes during darkness, when 50% of observations were within 5.57 m of sea level, than they were during either daylight (50% at or below 12.79 m) or twilight (50% at or below 10.41 m).

5.3.1 Observation error

Error on altitude measurements was assessed using dilution of precision, and was found to increase as dilution of precision increased (Figure 5.5).

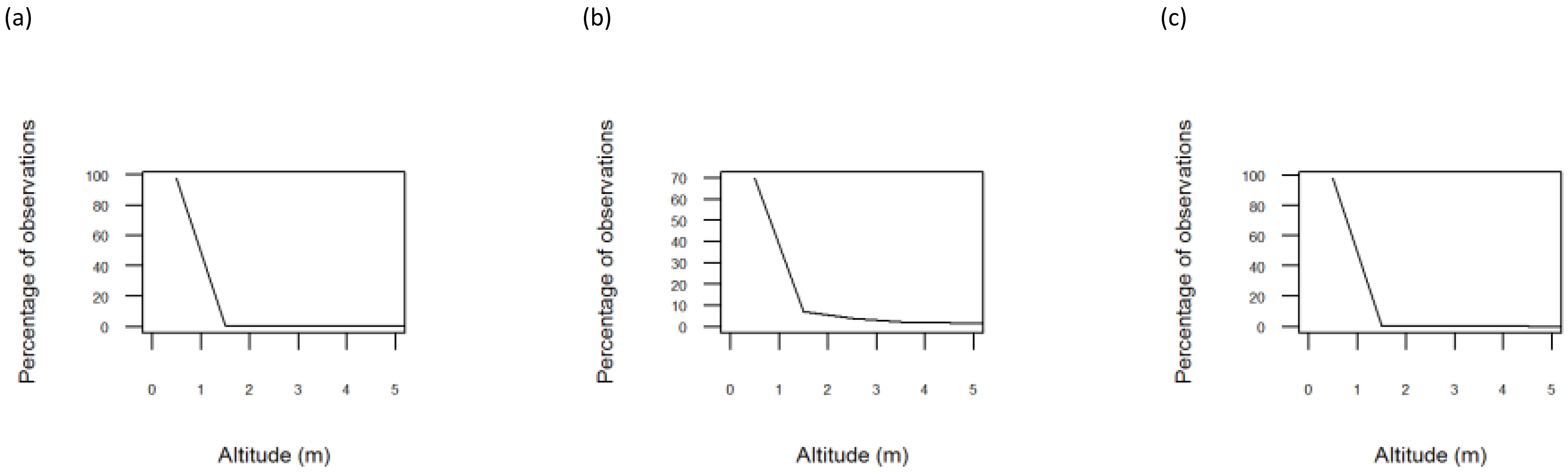


Figure 5.1. Altitudes of tagged Lesser Black-backed Gulls during the day moving at (a) less than 1 kmh^{-1} over land or water; (b) 1 to 4 kmh^{-1} over land; (c) 1 to 4 kmh^{-1} over water.

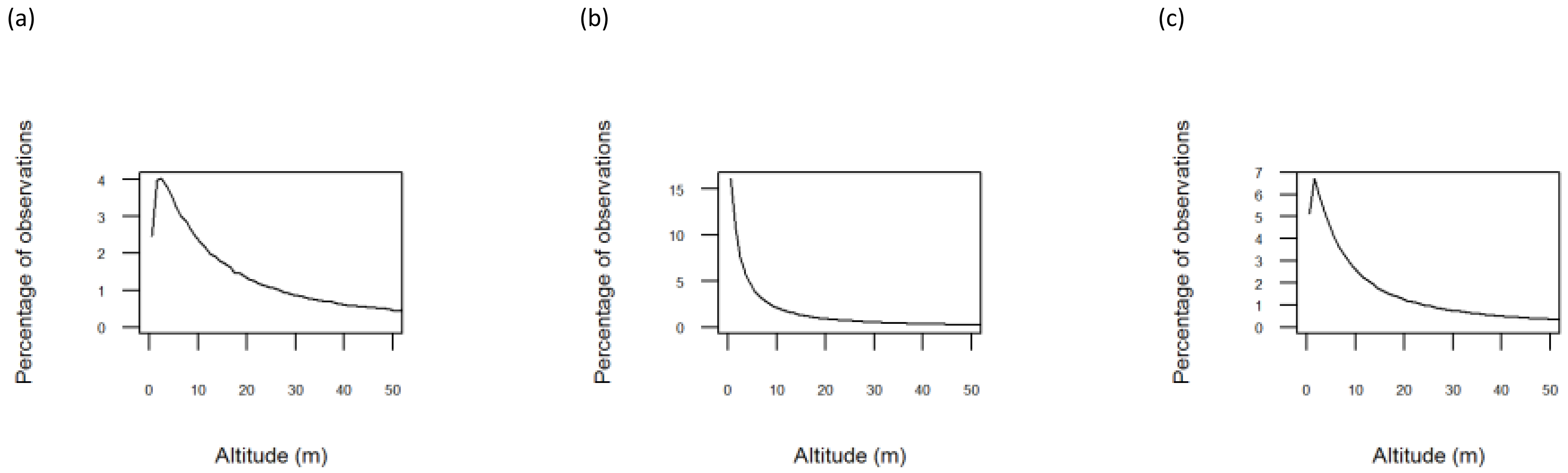


Figure 5.2. Altitudes of tagged Lesser Black-backed Gulls moving at more than 4 kmh^{-1} during the day (a) over land; (b) within 200 m of the coast; (c) more than 200 m from the coast.

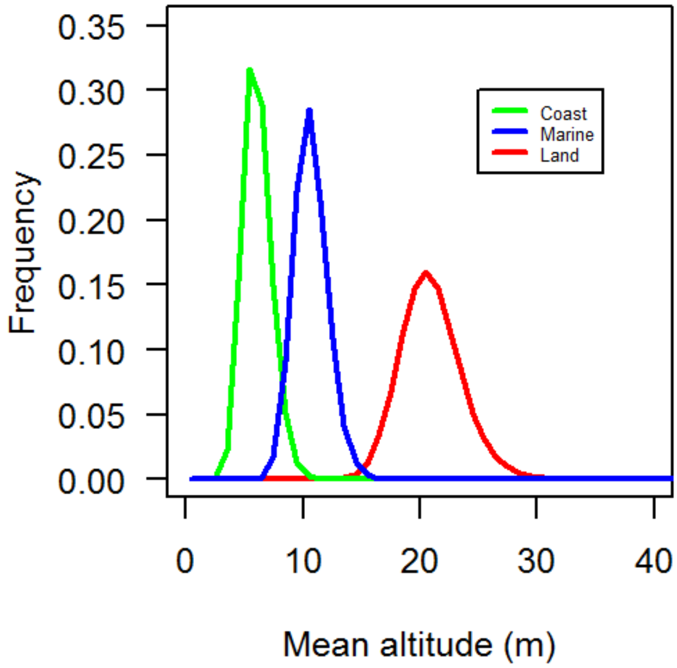


Figure 5.3 Mean altitude distributions of tagged Lesser Black-backed Gulls moving at more than 4 kmh^{-1} during the day.

Table 5.4 Credible intervals for state-space model of Lesser Black-backed Gull altitude.

Parameter	Lower 2.5% credible interval	Median	Upper 97.5% credible interval
State 1 mean log altitude (daylight)	-10.16	-8.88	-7.89
State 2 mean log altitude (daylight)	-2.32	-1.64	-1.04
State 3 mean log altitude (daylight)	-25.26	-15.75	-9.42
State 4 mean log altitude (daylight)	2.86	3.10	3.32
State 5 mean log altitude (daylight)	1.47	1.89	2.27
State 6 mean log altitude (daylight)	2.30	2.55	2.79
State 4 mean log altitude (twilight)	2.18	2.48	2.79
State 5 mean log altitude (twilight)	-0.27	0.94	1.92
State 6 mean log altitude (twilight)	1.98	2.34	2.70
State 4 mean log altitude (darkness)	2.38	2.64	2.90
State 5 mean log altitude (darkness)	1.11	1.70	2.23
State 6 mean log altitude (darkness)	1.41	1.72	2.02
State 1 SD of log altitude	15.51	18.68	23.08
State 2 SD of log altitude	8.40	10.59	13.49
State 3 SD of log altitude	23.85	54.86	125.60
State 4 SD of log altitude	2.29	2.41	2.53
State 5 SD of log altitude	2.71	3.52	4.67
State 6 SD of log altitude	2.14	2.39	2.66
Intercept of standard deviation of observation error	56.97	59.33	61.70
Coefficient of dilution of precision for the standard deviation of observation error	19.28	20.04	20.80
Standard deviation of individual random effect	0.15	0.28	0.57

Table 5.5 Percentage of time tagged Lesser Black-backed Gulls spent engaged in different behavioural states according to light level.

	Behavioural state					
	<1 kmh^{-1}	**1-4 kmh^{-1}**		**>4 kmh^{-1}**		
Time of day	**Land, coast & sea**	**Land**	**Coast & sea**	**Land**	**Coast**	**Sea**
Daylight	81.5%	2.5%	0.7%	12.1%	5.3%	2.7%
Twilight	83.5%	1.9%	1.6%	7.7%	0.8%	4.4%
Darkness	92.0%	1.1%	3.1%	2.1%	0.3%	1.4%

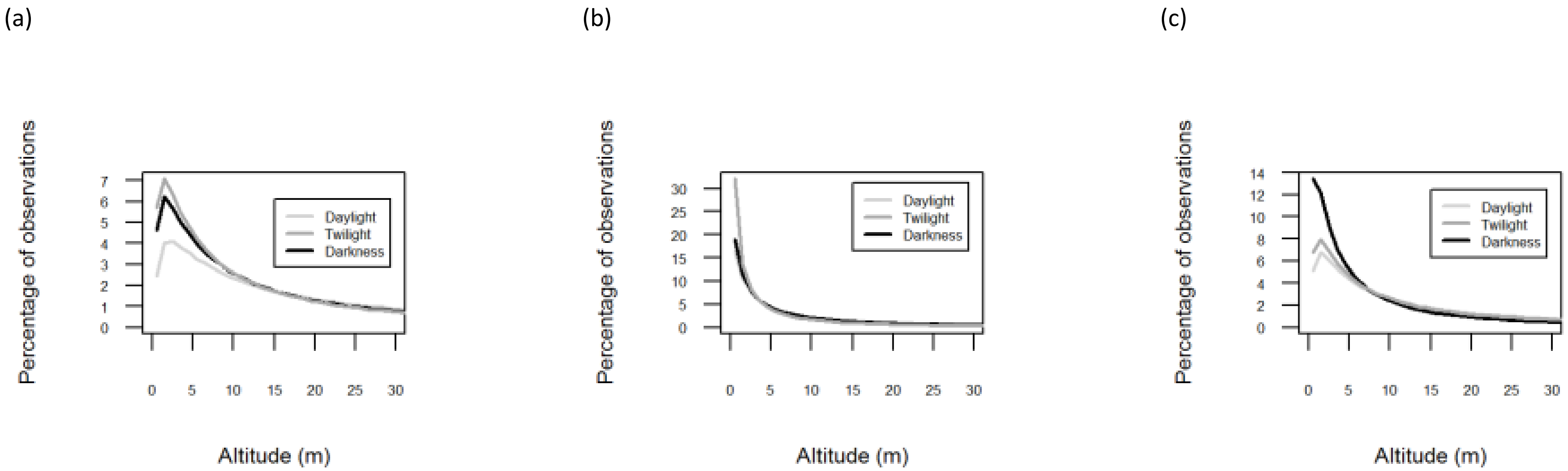


Figure 5.4 Altitudes of tagged Lesser Black-backed Gulls moving at more than 4 kmh^{-1} (a) over land; (b) within 200 m of the coast; (c) more than 200 m from the coast at different light levels.

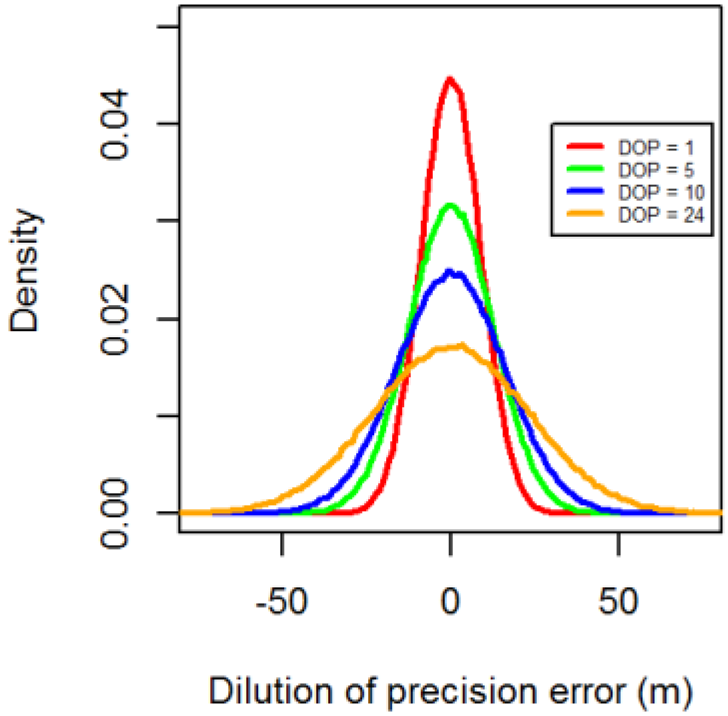


Figure 5.5 Dilution of precision error, which was found to increase as dilution of precision itself increased.

5.4 Discussion

Lesser Black-backed Gulls affiliated with their breeding colony were shown to fly higher overland than over water, and higher at day than during the night. Flight altitude was lower than recorded in other studies based on observations from boats (e.g. Garthe & Hüppop 2004). A recent study by Johnston *et al*. (2014), which modelled observations primarily from boat-based surveys, estimated that 28.2% of Lesser Black-backed Gulls flew at a height that put them at risk of colliding with offshore wind turbine rotor blades. The findings from our study using GPS suggest the proportion of birds at risk of collision could be lower, since their recorded flight altitudes were lower. The reason for these differences could stem from the drawbacks of boat-based surveys, including inaccurate flight height estimates, limitations on survey conditions, and birds' flight heights differing from normal because of the presence of a boat. The birds assessed in boat-based surveys might not necessarily be breeding individuals either, and hence might behave differently. The data used in the present study were superior to those collected from boat-based surveys, since they are more accurate and precise, give positions of Lesser Black-backed Gulls over the entire breeding season, and were collected in a range of conditions across several years.

As Lesser Black-backed Gulls were found to fly higher over land than over water, and spent a greater proportion of their flight time over land than over water, they could potentially be at greater risk of collision with onshore renewable developments than offshore. Lesser Black-backed Gulls have proved to be well-adapted to human environments, including cities with tall buildings where members of this species will breed, roost or forage (Raven & Coulson 1997). However, other gull species have been found to collide with onshore wind turbines (Krijgsveld *et al*. 2009), and the constraints on a Lesser Black-backed Gull's visual system that would determine how well able they are to detect wind turbines and other human objects are not well understood (Martin 2011).

Previous research has indicated that birds might be more at risk of collision with man-made structures when they are flying at night than during the day (e.g. Dolbeer 2006; Furness *et al*. 2013). The results of this study show Lesser Black-backed Gulls fly lower, especially over water, during hours at darkness than during the day, reducing the likelihood of birds coming into contact with turbine blades. However, it is possible that this reduction in collision risk is offset by poorer visibility at night, which could make turbine blades, or even masts, harder to detect and therefore avoid. Relatively little time was spent flying at all at night, though, further decreasing the risk of interactions with offshore developments during darkness and suggesting that collisions with turbines at night might be less probable than during the day.

5.4.1 Future work

To our knowledge, this study represents the best data available on Lesser Black-backed Gull flight height to inform collision risk modelling. However, various factors known to affect bird flight (including that of gulls), such as weather conditions (Shamoun-Baranes & van Loon 2006; Finn *et al*. 2012; Kemp *et al*. 2013), were not considered in the analysis. An improved model could include, for example, precipitation, wind speed and direction. Also, this analysis only used data collection while birds were still primarily roosting at, or close to, their breeding colony. Altitudes might be quite different at other times of the year, and in particular on migration, when variable atmospheric conditions and the need for sustained flight might require different flight strategies (Shamoun-Baranes *et al*. 2010; Mateos-Rodríguez & Liechti 2011). A recent study using GPS recorded Lesser Black-backed Gulls flying at greater heights than in this study on migration (Klaassen *et al.* 2012). Furthermore, this study only considered 25 individuals from a single colony, all of which were breeding adults. It is possible that gulls breeding elsewhere, or birds of different ages, might exhibit variation in their flight altitudes.

6. MODELLING FLIGHT HEIGHTS OF GREAT SKUAS

6.1 Introduction

As discussed in section 5.1, a number of offshore wind farms have come into operation in UK territorial waters since 2001, with many more much larger projects are planned (Breton & Moe 2009). The potential effects of offshore wind farms on birds include direct collision mortality, displacement from foraging areas, barrier effects to commuting or migrating birds, or changes to their foraging habitats and prey, collision with turbines being a particular concern for a number of species (Everaert & Stienen 2007). As collision risk is partly influenced by flight height (Garthe & Hüppop 2004; Furness *et al*. 2013; Johnston *et al.* 2014), accurate and precise information on this is key to assessing the effects of offshore wind turbines on seabirds.

In this study, we use GPS tracking technology to investigate flight heights of the Great Skua, a long-lived seabird of conservation concern in the UK (Eaton *et al*. 2009). The breeding colony locations (Mitchell *et al*. 2004) and foraging range (Thaxter *et al*. 2012b) of this species mean that there is a high probability of interactions with offshore renewable energy developments, including wind farms (Thaxter *et al*. 2011; 2012a; 2013) and the species has been identified as being at risk from wind farms in a number of assessments. We aim to assess the altitudes at which Great Skuas fly, providing information on flight height distributions that could inform collision risk models and thus the potential impact of offshore wind farms on this species. Specifically, we assess the factors that might cause variation in flight heights.

6.2 Methods

6.2.1 Analysis

Flight altitudes were modelled within a Bayesian framework (Wade 2000; Ellison 2004), using OpenBUGS 3.2.2 (Lunn *et al*. 2009) and data processing was carried out in R (R Development Core Team 2013) and ArcGIS (ESRI).

Semi-variograms revealed that temporal autocorrelation was low for observations 60 minutes apart. We therefore sub-sampled the data to select a maximum of one observation in each 60 minute period, to produce a dataset with limited temporal autocorrelation. Data points were only considered during the time of the year that birds were known to be breeding from nest monitoring on Foula and Hoy (see section 2.5), so that birds' altitudes were assessed for the entire time they were breeding (Table 6.1). All data points were classified as 'terrestrial' or 'marine' depending on whether the bird was over land or sea at the time of recording[6]. We calculated the true altitude of birds at any given point, accounting for tidal state and land height for marine and terrestrial observations respectively. Tidal data were obtained from the British Oceanographic Data Centre website (https://www.bodc.ac.uk/data/online_delivery/ntslf/), using the tide gauge at Lerwick (for birds breeding on Foula) and Wick (for birds breeding on Hoy), approximately 50 km and 45 km from the Foula and Hoy breeding colonies respectively. Information on land altitude was obtained from the Shuttle Radar Topography Mission (SRTM) 90 m digital elevation data (http://srtm.csi.cgiar.org/), aggregated at the 1 km square level.

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[6] Unlike for Lesser Black-backed Gulls, a 'coastal' category was not included due to paucity of data within this category.

Table 6.1 Date ranges within which data were considered in the Bayesian model of flight altitudes for tagged Great Skuas.

Tag number	Breeding colony	Year	Breeding season data period
340	Foula	2010	21/06/2010 – 24/06/2010*
342	Foula	2010	22/06/2010 – 23/06/2010*
348	Foula	2010	23/06/2010 – 28/06/2010*
349	Foula	2010	22/06/2010 – 28/06/2010*
392	Hoy	2011	14/06/2011 – 24/06/2011$
400	Hoy	2011	12/06/2011 – 05/07/2011$
409	Hoy	2011	12/06/2011 – 05/07/2011$
415	Foula	2011	03/06/2011 – 04/06/2011$
418	Foula	2011	05/06/2011 – 16/06/2011$
419	Foula	2011	07/06/2011 – 04/07/2011$
420	Hoy	2011	12/06/2011 – 24/06/2011$
448	Hoy	2011	11/06/2011 – 24/06/2011$
450	Foula	2011	05/06/2011 – 13/07/2011$
451	Foula	2011	04/06/2011 – 15/07/2011*
454	Foula	2011	06/06/2011 – 15/07/2011*
465	Foula	2011	04/06/2011 – 15/07/2011*
467	Hoy	2011	12/06/2011 – 15/08/2011
470	Foula	2011	04/06/2011 – 15/07/2011*
471	Hoy	2011	11/06/2011 – 15/08/2011
472	Hoy	2011	12/06/2011 – 14/06/2011$
473	Hoy	2011	11/06/2011 – 24/06/2011$
475	Hoy	2011	12/06/2011 – 30/06/2011$
476	Foula	2011	06/06/2011 – 15/07/2011*
487	Foula	2011	04/06/2011 – 14/07/2011$

*Field work ended so outcome of breeding unknown.

$ Breeding attempt failed.

A Bayesian state-space modelling approach was chosen (e.g. Newman *et al.* 2009; Harrison *et al.* 2011; King 2012). Bird behaviour was divided into discrete states based on speed and location, and these states were assumed to be known. The model used for Lesser Black-backed Gulls was adapted (section 5.2.1), but in a simplified manner, as fewer data were available for the Great Skuas. Only four states were therefore used. Speeds of less than 4 kmh^{-1} were classified as sitting, walking or swimming, and greater than 4 kmh^{-1} as flying. These speed categories were further subdivided into separate terrestrial and marine data points (Table 6.2).

Table 6.2 Behavioural states used in Bayesian state-space model.

Behavioural state	Speed	Location
1	<4 kmh^{-1}	Land
2	<4 kmh^{-1}	Sea
3	>4 kmh^{-1}	Land
4	>4 kmh^{-1}	Sea

6.2.2 Process model

The distribution of altitudes at which birds fly was assumed to be a log-normal distribution for each state. This enables a variety of distribution shapes, and was supported by previous analysis of flight distributions (Johnston *et al.* 2014). The mean and standard deviation of the log-normal distributions for each state were estimated as part of the model. A random effect on the mean of the log-normal distribution was included for each bird, allowing individuals to have variable height preferences. Information on diurnal activity was included as a covariate, with each data point categorized as 'day', 'night' or 'twilight' (within half an hour either side of sunrise or sunset). This factor variable was modelled with an additive effect on the mean of the log-normal distributions.

6.2.3 Observation model

As the GPS tags record altitude with error (Eens *et al*. 2008), we included an observation model describing the error rate. The error in altitudinal measurements was assumed to be a gamma distribution around the true altitude, and the standard deviation of the gamma distribution was linearly related to the dilution of precision (a measure of GPS reliability) of each observation. As for Lesser Black-backed Gull, an alternative model additionally considered a term accounting for the potential bias between observed altitude and true altitude, i.e. inaccuracy in the observed altitude provided by GPS; however this model failed to converge. This may suggest that the bias between observed altitude and true altitude is small; alternatively the bias, or inaccuracy, maybe correlated with the error, or precision, of GPS estimates and hence maybe reflected in confidence limits.

6.2.4 Model fitting

We used MCMC to fit the model (Gilks *et al*. 1996). Priors were vague and initial values were randomly generated from the prior distributions (Table 6.3). Three chains were run and convergence was assessed by examination of mixing in the chains, BGR statistics and estimates of MC error. The first 40,000 iterations in each chain were discarded as burn-in and the chain was run for a further 200,000 iterations.

Table 6.3 Parameters estimated in the model and associated prior distributions

Model part	Parameter	Prior
Process model	Mean of lognormal altitude distribution (1 for each state)	N(0, 100)
	Standard deviation of lognormal altitude distribution (1 for each state)	Unif(0, 200)
	Standard deviation of individual random effect	Unif(0, 200)
Observation model	Intercept of standard deviation of observation error	Gamma(0.01, 0.01)
	Coefficient of dilution of precision for the standard deviation of observation error	Gamma(0.01, 0.01)

6.3 Results

Great Skua altitude was found to vary with behavioural state (Table 6.4). As expected, birds travelling at less than 4 kmh^{-1} were observed at very low altitudes, with the vast majority within 30 cm of ground or sea level, which is likely for individuals standing, sitting on the nest, floating on the water, swimming, walking (Figure 6.1a for birds during the day).

Altitudes were higher for birds moving at greater than 4 kmh^{-1}, which is consistent with flight (Figure 6.2 for birds during the day). During daylight hours, 50% of observations over land were within 2.15 m of ground level, and 50% of observations over sea were within 0.21 m of sea level. Altitude over land was therefore higher than that over sea (Figures 6.2.a and 6.2.b). However, the difference between the log mean flight altitudes of Great Skuas over land and sea was not quite significant (Table 6.4, Figure 6.3 for birds during the day).

Tagged birds spent different proportions of time in their various behavioural states at different times of the day (Table 6.5). At every light level, birds spent the majority of their time (61.1%) relatively immobile or moving at slow speeds (sitting, walking or swimming). Birds on land spent a significantly greater proportion of their time in this state during darkness and twilight than during the day ($\chi^2_2 = 567.65$, $P < 0.001$). A similar relationship was found for birds at sea ($\chi^2_2 = 101.65$, $P < 0.001$). Birds only spent 2.1% of their time flying overland, a significantly higher proportion of which took place during the day than at twilight ($\chi^2_1 = 11.09$, $P < 0.001$) or at night ($\chi^2_1 = 63.53$, $P < 0.001$). An average of 36.8% of Great Skuas' time was spent flying at sea, with significantly more activity during the day than at dusk and dawn ($\chi^2_1 = 117.04$, $P < 0.001$) or night time ($\chi^2_1 = 905.20$, $P < 0.001$).

The altitude of birds travelling at more than 4 kmh^{-1} was not affected to a large extent by light levels (Figure 6.4). During the day, birds over land flew at higher altitudes than they did at dawn or dusk, or at night (Figure 6.4a). While 50% of observations were within 2.15 m of the ground in daylight, the corresponding heights for twilight and darkness were 0.64 m and 1.06 m respectively. Birds flying at sea were more likely to be at low altitudes regardless of light level. During the day, 50% of observations were within 0.21 m of sea level, while at twilight the corresponding figure was 0.42 m, and in darkness it was 0.63 m.

6.3.1 Observation error

Error on altitude measurements was assessed using dilution of precision, and was found to increase as dilution of precision increased (Figure 6.5).

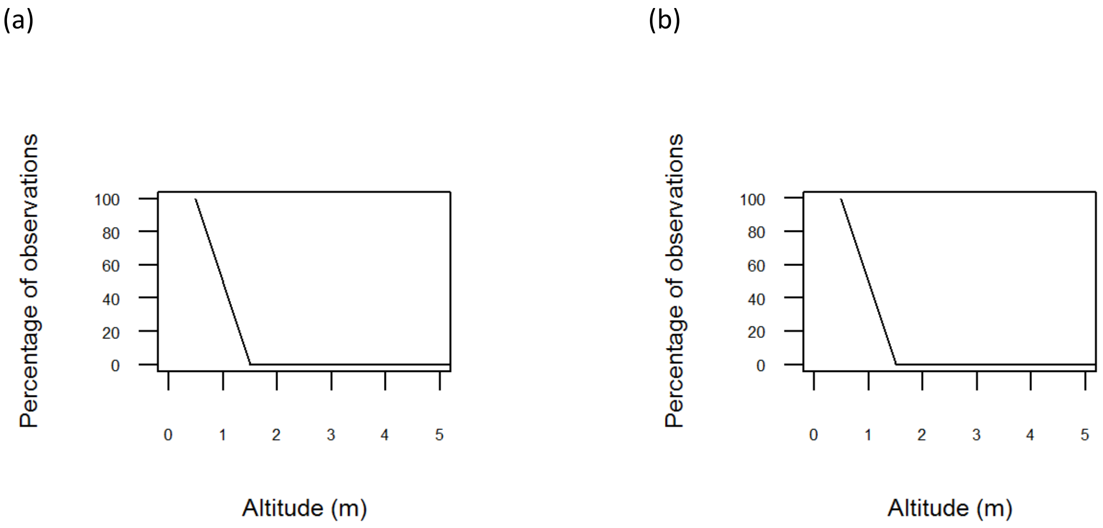

Figure 6.1. Altitudes of tagged Great Skuas during the day moving at (a) less than 4 kmh^{-1} over land; (b) less than 4 kmh^{-1} over sea.

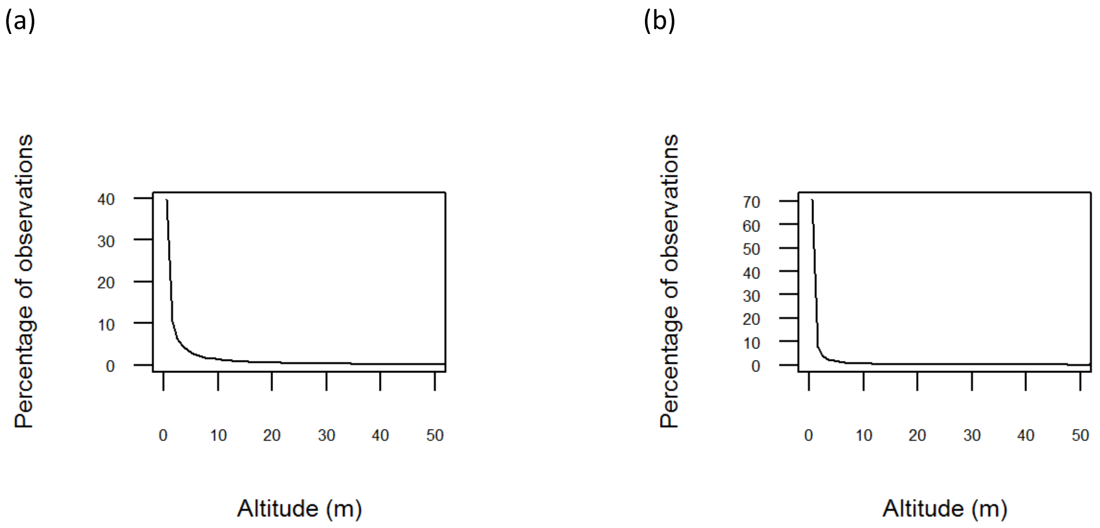

Figure 6.2. Altitudes of tagged Great Skuas moving at more than 4 kmh^{-1} during the day (a) over land; (b) over sea.

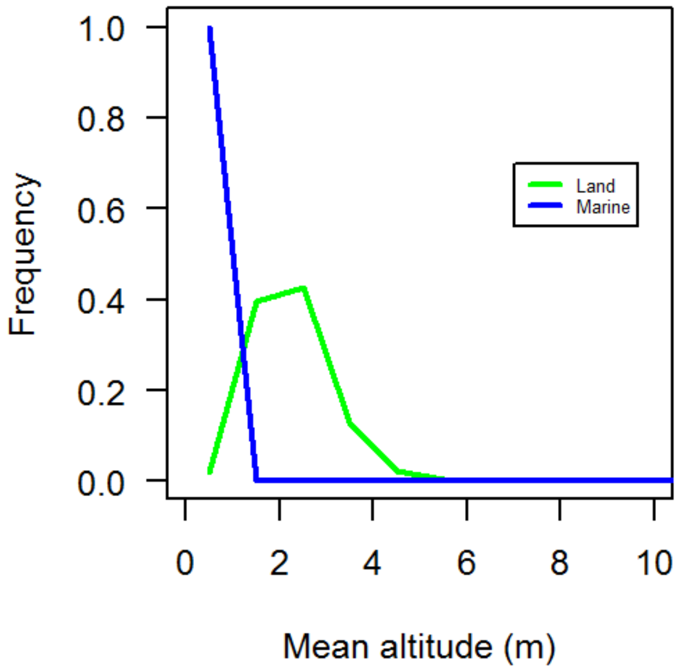

Figure 6.3 Mean altitude distributions of tagged Great Skuas moving at more than 4 kmh^{-1} during the day.

Table 6.4 Credible intervals for state-space model of Great Skua altitude.

Parameter	**Lower 2.5% credible interval**	**Median**	**Upper 97.5% credible interval**
State 1 mean log altitude (daylight)	-27.18	-19.55	-14.94
State 2 mean log altitude (daylight)	-29.44	-20.50	-14.43
State 3 mean log altitude (daylight)	0.05	0.76	1.41
State 4 mean log altitude (daylight)	-2.25	-1.56	-0.96
State 3 mean log altitude (twilight)	-13.47	-0.44	1.77
State 4 mean log altitude (twilight)	-1.69	-0.86	-0.11
State 3 mean log altitude (darkness)	-1.34	0.06	1.25
State 4 mean log altitude (darkness)	-1.17	-0.46	0.18
State 1 SD of log altitude	21.44	35.24	65.75
State 2 SD of log altitude	30.00	53.69	101.50
State 3 SD of log altitude	5.50	6.78	8.45
State 4 SD of log altitude	7.54	8.36	9.29
Intercept of standard deviation of observation error	721.90	754.50	787.00
Coefficient of dilution of precision for the standard deviation of observation error	63.24	72.47	81.91
Standard deviation of individual random effect	-1.69	1.31	3.12

Table 6.5 Percentage of time tagged Great Skuas spent engaged in different behavioural states according to light level.

	Behavioural state			
	<4 kmh-1		>4 kmh-1	
Light level	Land	Sea	Land	Sea
Daylight	33.9%	24.4%	2.3%	39.4%
Twilight	45.1%	26.6%	1.1%	27.2%
Darkness	47.4%	29.5%	0.9%	22.1%

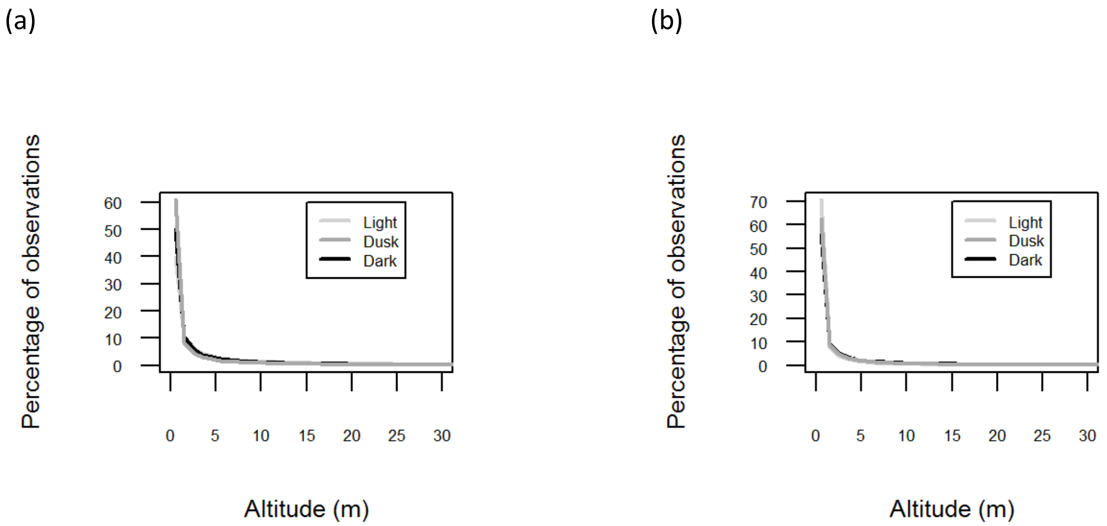

Figure 6.4 Altitudes of tagged Great Skuas moving at more than 4 kmh^{-1} (a) over land; (b) over sea.

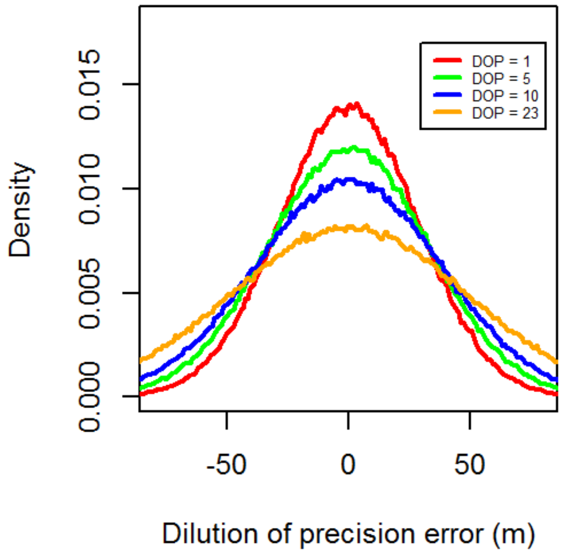

Figure 6.5 Dilution of precision error, which was found to increase as dilution of precision itself increased.

6.4 Discussion

The flight altitudes of Great Skuas tended to be lower than those of Lesser Black-backed Gulls, although no significant relationships were found between flight altitudes and time of day or whether birds were flying over the land or the sea. Flight altitude was low (typically within 5 m of the land/sea surface) and was lower than the altitude recorded in other studies based on observations from boats (e.g. Garthe & Hüppop 2004). However, a recent study by Johnston *et al*. (2014), which modelled observations primarily from boat-based surveys, estimated that 94.1% of Great Skuas would fly below 20 m above sea level. The findings from our study using GPS data agree with this.

Previous research has indicated that birds might be more at risk of collision with man-made structures when they are flying at night than during the day (e.g. Dolbeer 2006; Furness *et al*. 2013). The results of this study show the flight altitude of Great Skuas is apparently not affected greatly by light levels, and since it was found to be consistently low, the collision risk should be small regardless of light level. However, it is possible that collision risk is higher at night because of poorer visibility, which could make turbine masts, harder to detect and therefore avoid even if birds are flying below blade height. Since Great Skuas spent approximately 8% of their time flying at night, collision with masts or other objects low in the water could be a danger if this species' night vision and/or ability to detect objects in front of them is poor.

6.4.1 Future work

To our knowledge, this study represents the best data available on Great Skua flight height to inform collision risk modelling. However, various factors known to affect bird flight, such as weather conditions (Shamoun-Baranes & van Loon 2006; Finn *et al*. 2012; Kemp *et al*. 2013), were not considered in the analysis. An improved model could include, for example, precipitation, wind speed and direction. Also, this analysis only used data collection while birds were breeding. Altitudes might be quite different at other times of the year, and in particular on migration, when variable atmospheric conditions and the need for sustained flight might require different flight strategies (Shamoun-Baranes *et al*. 2010; Mateos-Rodríguez & Liechti 2011). Furthermore, this study only considered 24 individuals from two colonies in the same part of the world (Scotland), all of which were breeding adults. It is possible that Great Skuas breeding elsewhere, or birds of different ages, might exhibit variation in their flight altitudes.

6.4.2 Comparison with gulls

The results from this chapter make an interesting comparison with those from Chapter 5, in which the flight altitudes of Lesser Black-backed Gulls were considered. Great Skuas spent a larger proportion of their time flying than did Lesser Black-backed Gulls, and were also more maritime, although this could be partly an artefact of the island colonies on which they were nesting, compared to the mainland Lesser Black-backed Gull colony of Orford Ness. Great Skuas flew at lower altitudes than Lesser Black-backed Gulls, and were apparently less sensitive to light levels, as their flight heights varied less than those of Lesser Black-backed Gulls in different light conditions. Overall, the results suggest that breeding Great Skuas are at relatively lower risk of collision with offshore wind turbines than Lesser Black-backed Gulls, as they flew at lower altitudes (broadly agreeing with Johnston *et al*. 2014), although this might be partly offset by the greater amount of time Great Skuas spend at sea, especially at night.

7. LESSER BLACK-BACKED GULL INTERACTIONS WITH OFFSHORE WIND FARMS DURING THE MIGRATION AND WINTERING PERIODS

7.1 Introduction

The need to minimise man-made climate change and the increasing energy demands of an ever expanding population means that national governments are diversifying their portfolios of energy acquisition. Consequently, the marine environment is facing numerous pressures from an increasing number of man-made offshore developments, including offshore wind farms and wave and tidal devices (Syvitski *et al.* 2005). In the UK, three main 'rounds' of wind farm developments have taken place, the latest of which is on a much larger scale than previously developments (DECC 2009[7]). Further developments are also taking place in other European countries[8]. As such, there is currently a mix of existing, consented, and proposed developments in the offshore waters of many European countries and consequently a pressing need to understand the potential conflicts between human resource use and marine wildlife conservation on a wide geographical scale.

The UK holds internationally important numbers of breeding seabird, which have the potential to be affected by offshore developments in several ways. Placing structures, such as wind turbines or underwater structures offshore may directly reduce the available habitat for foraging and feeding, pose a direct collision risk to species, indirectly affect habitat and prey, or present a direct barrier to movement (Garthe & Hüppop 2004; Desholm and Kahlert 2005; Masden *et al.* 2009; Furness *et al.* 2013). These impacts relate not only to when seabirds are raising chicks during the breeding season, but also during non-breeding periods as birds disperse over a wider area. Many species of seabird in the UK are long-distance migrants, over-wintering in destinations such as southern Europe and North Africa (Wernham *et al.* 2002). Barrier effects and collision risks are particularly relevant to migration and non-breeding movements (Drewitt & Langston 2006; Masden *et al.* 2009), yet a lack of precise information for many seabird species outside of breeding seasons has made direct assessment of these factors problematic. Furthermore, the direct 'connectivity' between offshore developments and particular breeding colonies have seldom been quantified outwith the breeding season, making it harder to assess the potential risk posed to protected populations (e.g. Special Protection Areas, SPAs, Stroud *et al.* 2001). To reduce the reliance on precautionary information within Environmental Impact Assessments, hotspots where exposure risk is greater, for instance along migratory flyways, need to be quantified. Such information can also be used to cumulatively consider the impact of multiple developments, including those outside the UK, on protected populations.

The recent advent of high resolution GPS tracking telemetry has allowed the movements of species of seabird to be investigated offshore in unprecedented detail, allowing a direct assessment of renewable energy developments on protected populations of seabirds (see Gyimesi *et al.* 2011; Langston & Teuten 2012; Camphuysen 2011; Soanes *et al.* 2013). Here we use long-term GPS telemetry to investigate the movements away from a protected breeding site in southeast England during migration and wintering periods, of a feature species, the Lesser Black-backed Gull (the UK sub-species of which is *L. fuscus graellsii*). This species is classed as the third most sensitive species to collision risk out of 38 considered by Furness *et al.* (2013). The likely migration routes and destinations for this species are known from colour-ringing studies (Jorge *et al.* 2011). Furthermore, recently developed GIS tools have generalised the likely areas through which Lesser Black-backed Gulls might migrate (Wright *et al.* 2012). However, general patterns cannot pinpoint the specific

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[7] www.thecrownestate.co.uk/energy-infrastructure/offshore-wind-energy/ (last accessed 30/10/2013)
[8] www.4coffshore.com/offshorewind/ (last accessed 26/10/2013)

migration zones that particular populations may use and specific interactions that may take place. Previous tracking work has shown the use of long-term tracking data for studying the migration of this species (e.g. Klaassen *et al.* 2012). However, to date the use of such data to understand migration zones for particular breeding populations and hence assessment of wind farm interactions during non-breeding and migration, has not yet been undertaken.

Here, we use information collected through GPS tags attached to breeding Lesser Black-backed Gulls to assess the spatio-temporal intensity of area usage and wind farm interactions during non-breeding (migration and wintering) periods and pose the following key questions:

(1) Where is the potential exposure to offshore wind farms greatest during non-breeding (migration and wintering) periods?

(2) When is the potential exposure to offshore wind farms greatest during non-breeding (migration and wintering) periods?

(3) What overlap is there with offshore wind farms within the flight paths of Lesser Black-backed Gulls from this protected site?

For the latter, we assessed the overlap with offshore wind farms that are in the following stages of development: in concept/early planning, identified as development zones, have consent applications submitted or authorised, under construction, or fully commissioned and operational.

7.2 Methods

7.2.1 Data manipulation

Migration and wintering period statistics

A total of three non-breeding periods provided information in this study (Tables 7.1 and 7.2). Due to solar charging issues with some tags, sections of migration routes were sometimes not recorded (Tables 7.1 and 7.2). The total travel distance per migration route was assessed by summing distances travelled between GPS points along the route. We calculated the maximum distance reached from the breeding colony to the over-wintering destination. We also defined periods of migration, including autumn and spring migration passage, separate to the over-wintering period. Following Klaassen *et al.* (2012), migration was defined as beginning on the last day on which the bird was present at the colony, and excluded post-migratory trips from migration phases, that were included in the assessment of post-breeding in Chapter 3. The end of the autumn migration was defined as the arrival at the destination site, with spring migration and subsequent re-arrival at the breeding site defined in a similar way (Klaassen *et al.* 2012).

Spatial exposure to the potential effects associated with offshore wind farms

Maps of intensity of area usage were used to assess the spatial exposure of the population to the potential effects associated with offshore wind farms. Using a fishnet grid of 20 x 20 km, we initially counted and plotted the number of birds and routes that passed through particular squares of the grid. We then assessed the intensity of offshore usage for each individual by summing the total distance travelled and total time spent per 20 x 20 km grid square in each year, and then averaging for individuals across years. The average time and distance travelled per square was then calculated across all birds for each square to provide an assessment of intensity. Averages were taken rather than sums to avoid potential biases due to gaps in individual migration and wintering periods. A single bird in 2010 went as far south as Mauritania (Figures 7.1 and 7.2). Given this was the only individual to do so, intensity maps are presented for a grid only to the north of Africa for a more detailed characterisation of the general pattern for individuals from the Alde-Ore SPA.

Temporal exposure to the potential effects associated with offshore wind farms

In addition to studying where intensity of area usage was greatest, we considered when during the year exposure to the potential effects associated with offshore wind farms was greatest, and how long were birds exposed in key areas along migration routes. Using information from the spatial analysis, we assessed the temporal intensity of area usage directed at two key areas along the route: (a) the English Channel, and (b) the Bay of Biscay. Migration routes were initially plotted for all birds as latitude against Julian date identifying these regions. The areas of these regions were then defined using the same grid used for spatial analysis, and the time that birds spent crossing these regions per individual 'transit', the time of year this occurred, and the mean travel speed were calculated. Temporal exposure was then represented through frequency bar plots of time of year across Julian date. All spatial and temporal investigations conducted using R 2.15.0 (R Development Core Team 2013).

Overlaps with offshore wind farms

To assess the migratory flyways of Lesser Black-backed Gulls the migration routes of all birds were plotted, and connectivity of UK wind farms was assessed directly using GIS shapefiles. Information on the locations of operational and proposed wind farm sites that were in the flight paths of Lesser Black-backed Gulls, including countries in Europe and Africa, were digitised from available sources (e.g. www.4coffshore.com/offshorewind/; last accessed 26/10/2013). Further understanding of connectivity with wave and tidal locations was provided in Soanes *et al.* (2012). The overlap of individual migration routes with the areas of individual offshore wind farm sites was then assessed. We focused on wind farms that were at the following stages of development: (1) concept/early planning, (2) consent application submitted, (3) consent authorised, (4) in construction, and (5) fully commissioned, i.e. excluding those dormant, cancelled, and sites that had failed in consent.

To provide a measure of spatial and temporal extent of usage, the total distance travelled (km) across and the total time spent (hrs) were then summarised for individual wind farm areas (Tables 7.4 and 7.5, Appendices 7.1 and 7.2). Using R 2.15.0 (R Development Core Team 2013). We initially calculated the area overlaps between our analysis squares (20 x 20 km) and the digitised offshore wind farm polygons to obtain a proportional coverage per square per wind farm. These proportions were then used to calculate the distance travelled and time spent by each individual within wind farm areas within each square. Consequently, we calculated the total distance travelled and time spent per bird in each wind farm area by summing the values for individual 20 km squares. Mean values of distance travelled and time spent within wind farm areas were calculated for each individual if multiple years of data were available – this approach avoided undue bias from particular individuals with more data available. Finally, we quantified the overall mean across birds for time spent and distance travelled in wind farm areas, including zeros for those birds whose tracks did not overlap with particular squares. As there were gaps in the records for some individuals, we acknowledge that this approach means that the values presented will provide an underestimate of usage in some areas. We also acknowledge that with this approach, individual tracks of birds may cross a square and not necessarily the wind farm area itself. However, the grid-based approach is more useful for migration and wintering periods to appropriately characterise the usage of the close area of the wind farm as well as the wind farm itself, thus offering a potentially more pragmatic and useful metric rather than the simple crossing of wind farm polygons, the latter of which may underestimate the potential for wind farm interaction.

7.3 Results

7.3.1 Migration and non-breeding behaviour

Information on migration and wintering locations were available for 18 Lesser Black-backed Gulls. For 2010/11, 2011/12 and 2012/13, information was available for six, 15 and 11 birds respectively, and of these, six, 14, and six birds had sufficiently functioning tags (Table 7.1) to provide a full picture of over-winter information. For example, for 2012/13, although information on the timing of departure from the colony was available for five birds, gaps during the winter period of over 100 days prevented a full picture being obtained (Tables 7.1 and 7.2). Some birds (four in 2011/12 and at least one in 2012/13 remained in the UK overwinter, Table 7.1). However, no birds stayed in the UK during 2010. Additional information from three other birds, observed abroad with malfunctioning tags or that did not subsequently return to Orford Ness, brought the final number of birds migrating to seven, 11 and six respectively in each over-winter period. Data were available on two consecutive years for 10 birds, though gaps in their records for six birds prevented a complete comparison of summary statistics. Data were available for three years for a further single individual (395) (see Appendix 7.3). Wintering destinations were consistent within individuals between years. For those individuals for which information was complete, over the three years, four birds remained in the UK and 13 migrated to wintering areas to the south.

Birds reached mean maximum distances of 2,935±1,380 km, 1,344±841 km, and 1,247±928 km from the colony during winters of 2010/11, 2011/12, and 2012/13, respectively (Table 7.2). Destinations of birds leaving the UK were Mediterranean areas of Spain, Portugal and Morocco, while one bird in 2010 reached as far south as Mauritania (Tables 7.1 and 7.2, Figure 7.1). Distances reached, and total distances travelled were greatest in 2010/11 (Table 7.2), largely due to those six birds that provided data in 2010/11 all leaving the UK. The total time away from the colony, and overall speed, of tracked birds was similar between years (Table 7.1).

7.3.2 Spatial exposure

Spatial analysis of intensity of use per grid square provided a clear picture of the migration zone that birds from this colony used. A clear concentration of migration routes was recorded across the English Channel, that fed through the Channel Islands, and crossed the northern French province of Bretagne (Figures 7.3 and 7.4). Up to 11 birds used this route, with a maximum intensity of up to 8 birds per square recorded (Figure 7.3), and peak values for the mean total distance travelled and mean time per square of 5 km and 0.6 hours (Figure 7.4). The migration routes then crossed the Bay of Biscay at lesser intensity. Some individuals traversed the Bay of Biscay, while others followed the coast of northern France. A maximum migration intensity (11-18 birds in Figure 7.3) was seen around the coast of northern Spain and Portugal. Higher values for the mean total distance travelled and mean time per square around the coast of southern Spain and Morocco (Figures 7.4 and 7.5) reflected individual over-wintering sites.

7.3.3 Temporal exposure

The migration of birds from UK latitudes through to overwintering southerly latitudes was relatively rapid (Figure 7.5). Birds crossed the English Channel on outward migration across a wide period beginning in late July to September (two birds departing the UK almost immediately after leaving the breeding colony), and lasting up to early December (birds that remained in the UK for a period before migration). The peak outward migration was during the first week of November (Figure 7.6). Return migration journeys were much more focused temporally with birds reaching the Bay of Biscay as early as mid-February, and a peak of activity through this area during mid-March, and with birds reaching the English Channel shortly after (Figure 7.6). Birds reached UK shores as late as mid-April (Figure 7.6, see also return to colony in Table 7.2). The mean exposure time for birds in these regions was 26 hours and 63 hours in the English Channel and Bay of Biscay on outward migrations (Table 7.3). However, exposure time was longer during return migrations, at 46 hours and 76 hours for both regions respectively, due to slower mean travel speeds (Table 7.3).

7.3.4 Connectivity

Direct connectivity

The migration routes of four, six and five birds (11/18 across all years) directly overlapped with UK offshore wind farm sites during the 2010/11, 2011/12, and 2012/13 migration and winter periods, respectively. These included existing and proposed extensions of London Array I/II (one bird each in 2010/11 and 2011/12 respectively), Gunfleet Sands (one bird in 2010/11) and Kentish Flats (one bird in 2012/13). Birds also frequently occurred in the areas of three Round 3 offshore wind farm development zones – East Anglia (one bird in 2011/12) and Navitus Bay (five routes of three birds, one of which crossed three times) and Rampion (two birds, three routes) in the English Channel.

Quantification using the spatial intensity grid

Every individual flew close to wind farm sites at some point during their migration (Figures 7.1 and 7.2, Tables 7.4 and 7.5, Appendices 7.1 and 7.2). Using summary information for 20x20 km grid squares, we summarised the amount of travel distance and time spent by each bird in each wind farm area (Tables 7.4 and 7.5, Appendices 7.1 and 7.2). A total of one wind farm in Belgium, seven in Spain, 17 in France, 18 in Great Britain, and three in Portugal overlapped with the intensity grid (Tables 7.4 and 7.5). All of those in Belgium and Spain were in concept/early planning stages, two in France had consent authorised and one in Portugal was commissioned. British sites contained the highest mixture of sites at various stages of development.

A maximum of seven birds were estimated to use the areas of the Saint-Bieuc and d'Aïse wind farm sites in the English Channel during migration, while six and five birds were estimated to use the areas of the Navitus Bay and Rampion sites. High values for the mean total distance travelled were also recorded for Navitus Bay (Table 7.4).

The English Channel is also focus of wave and tidal developments such as the Alderney tidal power site (Soanes *et al.* 2012), which was also crossed by one individual Lesser Black-backed Gull and approached by two others (Figures 7.1 and 7.2). Sites to the south of the Orford Ness colony were also overlapped by birds setting out and returning from migration, six birds estimated to use the area of the Gunfleet Sands I/II sites, for example (Tables 7.4 and 7.5).

However, estimated usage of offshore wind farm sites was greatest in Spain and Portugal (Figures 7.3 and 7.4). Eight birds were estimated to use the area of SeAsturLab Phase 2 in Spain and 13 to use the area of WindFloat - Phase 1 in Portugal (Tables 7.4 and 7.5, Appendices 7.1 and 7.2). Despite these number of birds, the small size of these Spanish and Portuguese sites resulted in proportionally smaller values for the mean total distance travelled and mean time per site (Tables 7.4 and 7.5).

7.4 Discussion

7.4.1 Summary of migration and wintering routes

The use of fine-scaled, long-term GPS tracking has, for the first time, provided a direct assessment of the exposure to offshore wind farms of a breeding feature species of a Special Protection Area outside the breeding period. Tracking of a total of 18 Lesser Black-backed Gulls across three consecutive migration periods revealed mixed migration strategies, with at least four (Table 7.1) remaining in the UK and 13 migrating to areas further south, to wintering areas in Iberia or North Africa, with one bird (in 2010/11) reaching as far south as Mauritania. The migration band of birds leaving the UK was of greatest spatial intensity across the outer Thames Estuary, the central English Channel and Channel Islands and northern France. Thereafter, birds were more dispersed across the Bay of Biscay before becoming more concentrated around the coasts of northern Spain and Portugal (Figures 7.3-7.5). The exposure of birds to the potential effects associated with offshore wind farms was thus highest in these areas. The proportionally larger size of developments in the English Channel meant that statistics of usage were high for wind farm areas in this region. However, estimated usage of offshore wind farm sites was greatest in Spain and Portugal, with a maximum of eight birds using the area of a single site.

For those that left the UK, crossing the English Channel and Bay of Biscay, the timing of migration was found to be variable on outward routes (late-July to early December, peaking in November) on account of individual birds either leaving the UK straight after breeding, or remaining for longer elsewhere in the UK. However, return routes were more focused temporally (mid-February to mid-April, peaking in mid-March).

7.4.2 Migration behaviour

The migration behaviour for Lesser Black-backed Gulls in this study showed some similarities with birds tracked from the Netherlands (Klaassen *et al.* 2012), and also matched previous ringing studies (Jorge *et al.* 2011; Wright *et al.* 2012). For example, the direct mean distance to over-wintering sites across all years in our study (1607 km) was close to that reported by Klaassen *et al.* 2012 (1672 km). Furthermore, migration routes of gulls, as also seen in Klaassen *et al.* (2012), sometimes, but not always, hugged the coast presumably as the provision of ridge-soaring opportunities reduced energetic costs (Klaassen *et al.* 2012). However, in contrast to those birds from the Netherlands (Klaassen *et al.* 2012), all Lesser Black-backed Gulls from Orford Ness had no choice but to cross open water at some point on their journey due to simple geography of the breeding colony and the UK.

7.4.3 Application to Environmental Impact Assessment

Offshore wind farms may potentially impact birds through a number of effects, including displacement from areas of habitat, indirect effects on habitat and prey, collision and presenting a direct barrier to movement. The latter two effects are most relevant during migration periods, although birds may also potentially be sensitive to direct or indirect habitat effects during the winter. The Lesser Black-backed Gull is considered most sensitive to collision (Garthe & Hüppop 2004; Furness *et al.* 2013), ranked as third most sensitive (out of 38 species considered) to this effect by Furness *et al.* (2013). The species' migration routes might also potentially become diverted due to the presence of wind farms, which could detrimentally affect energy expenditure (Masden *et al.* 2009). The energetic consequences of flight paths being diverted around individual wind farms for the breeding success or survival of seabirds are thought likely to be minimal in many species (Masden *et al.* 2009). However, the potential for cumulative effects from multiple wind farms is somewhat harder to assess. Within EIAs the cumulative assessment is seldom able to consider specific developments outside of breeding that could have an impact on a protected population. The information presented here is likely to be of considerable use to the industry by being able to pinpoint particular proposed, consented and existing developments that lie within key migration routes for particular populations, while helping to provide a methodology for quantifying usage of particular areas.

7.4.4 Conclusions and further work

For the first time, we have provided a direct assessment of the exposure to offshore wind farms of a breeding feature species of a Special Protection Area outside the breeding period. This study focused on one particular protected site for one feature species. However, it would be extremely valuable to investigate other the populations of Lesser Black-backed Gulls from other SPAs in the UK in a similar manner or the exposure of other migratory species to offshore wind farms outwith the breeding season (Stroud *et al.* 2001). These populations may have different migration and non-breeding movements and hence may be exposed to different wind farm sites. The method here used the total time and distance travelled per grid square to provide an assessment of the spatio-temporal exposure of birds to particular offshore wind farm sites. This approach is fully transferable to many species. For example, another species, great black-backed gull *Larus marinus*, to our knowledge has not been tracked from breeding colonies, and represents a case in point where the approach used here would be highly relevant and would avoid current reliance only ringing information and at-sea boat surveys (see Seys *et al.* 2001).

Further research into migration strategies of Lesser Black-backed Gulls is also of high importance. Satellite-tracked Lesser Black-backed Gulls from sites in the Netherlands also showed a consistent pattern of visiting the UK during spring and autumn passage periods, with some birds then migrating south along similar routes to those from the Alde-Ore SPA (Klaassen *et al.* 2012). Further study into the similarities of migratory and wintering strategies of other population of Lesser Black-backed Gull, as well as the repeatability of migration routes (see Appendix 7.3), will also inform the extent of repeated wind farm interaction of birds from particular protected sites.

Migration bottlenecks are considered one of four key types of marine protected area (European Commission 2007). Long-term tracking of individuals provides a key tool to help identify key areas used by protected species during migration periods, and thus in aiding their conservation.

Table 7.1 Migration summary for all Lesser Black-backed Gulls followed during the course of this study. The number of birds with fully working tags denotes those for which we were able to be certain of over-wintering destinations – birds with gaps in their data (i.e. not fully working) were still used for square-by-square assessments in Figs 7.3 and 7.4.

Winter	Number of birds with fully working tags	Number of birds leaving UK	Number of birds staying in UK	Other	Total number migrating	Destination countries
2010/11	6	6	0	Tagged bird seen in Morocco but didn't return to colony	7	Spain, Portugal, Morocco, Mauritania
2011/12	14[a]	10	4[a]	Bird with broken tag seen in Morocco (ringing data)	11	Spain, Portugal, Morocco
2012/13	7[b]	6	1[b]	Bird with broken tag seen in Spain (ringing data)	7	Spain, Portugal, Morocco
Total	17[c]	13	4		16	

[a] One bird, 485, had large data gaps preventing full assessment (Table 7.2);

[b] Four birds (478, 485, 486, 492) had large data gaps (Table 7.2) – these birds may have remained in the UK but a full appraisal was not possible;

[c] Out of a total of 18 birds, data gaps for one bird, 485, in both non-breeding period 2011/12 and 2012/13, prevented certain assessment of wintering destination (Table 7.2).

Table 7.2 Migration and over-wintering information for individual Lesser Black-backed Gulls for 2010/11, 2011/12 and 2012/13 . Data on travel distance and time away from the colony are also provided excluding information from gaps in coverage (where there were gaps in GPS fixes of >3 hours). Wintering destination key: southern Iberia/North Africa (1), UK (0), unknown ‘-’.

Over-winter period	Bird	Left colony	Returned to colony	Maximum distance from colony (km)	Travel distance incl. gaps (km)	Travel distance excl. gaps (km)	Time away from colony (days)	Time not recorded (days)	Time excl. gaps (days)	Speed (km/day)	Wintering destination
2010/11	334	24/10/2010	12/04/2011	2233	14441	14326	170	16	154	93	1
	336	14/08/2010	27/03/2011	1947	18299	18126	225	31	194	93	1
	391	07/09/2010	03/04/2011	5122	18376	18150	208	2	206	88	1
	395	22/07/2010	20/03/2011	2114	13396	13237	241	16	225	59	1
	407	17/07/2010	20/03/2011	1970	14583	14573	246	7	239	61	1
	388[1]	31/07/2010	17/05/2011[a]	4226	23478	22462	290	17	273	82	1
	Mean	19/08/2010	06/04/2011	2935±1380	17096±3765	16812±3447	230±40	15±10	215±41	79±16	
2011/12	336	09/08/2011	27/04/2012	1947	10938	9126	262	139	123	74	1
	395	16/07/2011	23/03/2012	1881	13719	13701	251	18	233	59	1
	407	30/07/2011	13/03/2012	1965	13422	12418	227	14	213	58	1
	459	24/07/2011	21/03/2012	1893	19993	19327	241	2	239	81	1
	460	05/11/2011	15/03/2012	2211	11918	11918	131	0	131	91	1
	478	05/08/2011	18/02/2012	180	8795	8628	197	27	170	51	0
	479	05/10/2011	26/03/2012	2028	14295	14295	173	0	173	83	1
	480	14/08/2011	08/04/2012	1720	20260	20088	238	3	235	85	1
	482	16/09/2011	16/02/2012	300	5314	5132	153	49	104	49	0
	483	17/08/2011	19/03/2012	1723	9741	9741	215	0	215	45	1
	484	01/08/2011	16/03/2012	1909	13838	12931	228	3	225	57	1
	485[2]	02/08/2011	27/03/2012	212	3812	3812	238	156	82	46	-
	486	17/09/2011	24/03/2012	1842	12641	11205	189	58	131	86	1

Over-winter period	Bird	Left colony	Returned to colony	Maximum distance from colony (km)	Travel distance incl. gaps (km)	Travel distance excl. gaps (km)	Time away from colony (days)	Time not recorded (days)	Time excl. gaps (days)	Speed (km/day)	Wintering destination
	492	02/07/2011	16/03/2012	211	7589	7589	258	0	258	29	0
	493	05/08/2011	19/02/2012	132	8226	7953	198	42	156	51	0
	Mean	17/08/2011	17/03/2012	1344±840	11633±4676	11191±4582	213±39	34±50	179±56	63±19	
2012/13	395[3]	05/07/2012	30/03/2013	2026	12173	11551	268	79	189	61	1
	459	23/06/2012	27/03/2013	1878	18803	16516	277	84	193	86	1
	460[4]	17/10/2012	25/03/2013	2211	11107	9554	159	33	126	76	1
	478[5]	09/10/2012	27/03/2013	-	-	-	169	169	-	-	-
	479	09/10/2012	26/03/2013	2028	12142	11114	168	38	130	85	1
	483	07/07/2012	10/03/2013	1725	10167	9986	246	57	189	53	1
	484	18/06/2012	27/03/2013	1887	16355	15073	282	30	252	60	1
	485	18/07/2012	04/04/2013	195	1897	1591	260	231	29	55	-
	486[6]	04/09/2012	04/03/2013	208	1544	1544	181	147	34	45	-
	492	20/07/2012	14/03/2013	206	3907	3790	237	122	115	33	-
	493	27/06/2012	05/03/2013	109	6739	6625	251	130	121	55	0
	Mean	05/08/2012	20/03/2013	1247±928	9483±5876	8734±5251	227±48	102±64	138±71	61±17	

[1] Bird captured by a fishermen in Mauritania;

[2] Data lost between 22/10/2011, when bird was in central England, and 27/03/2012, when bird was back at Orford Ness;

[3] Data lost between 26/03/2013 (when bird was in London, on return migration) and 30/03/2013, when bird was back at Orford Ness;

[4] Data lost between 17/10/2012, when bird was at Orford Ness, and 27/10/2012, when bird was on Portuguese coast;

[5] Data gap between 26/05/2012, when bird was at Orford Ness, and 27/03/2013, when bird was at Orford Ness;

[6] Data lost between 07/10/2012, when bird was in East Anglia, and 04/03/2013, when bird was back at Orford Ness.

Table 7.3 Temporal presence of individual Lesser Black-backed Gulls in two key regions for potential offshore wind farm developments (a) the English Channel and (b) the Bay of Biscay. 'Ins speed' is the instantaneous speed (see Klaassen *et al.* 2012). Note, blank cells indicate where gaps were present in the data, preventing full assessment for the two regions.

(a)

Year	Bird	Outward				Return			
		Start	**End**	**Duration (hrs)**	**Ins Speed (km/h)**	**Start**	**End**	**Duration (hrs)**	**Ins Speed (km/h)**
2010/11	334	31/10	31/10	6.6	52±23.1	09/04	11/04	40.0	12.7±16.3
	336	14/08	14/08	8.2	49.2±7.5	24/03	26/03	38.7	12.1±16.8
	388								
	391	07/11	09/11	39.5	14.8±20.3	01/04	01/04	4.2	52.2±28.8
	395	25/07	26/07	13.7	25.7±20	27/03	28/03	17.4	20.6±17.4
	407	27/11	27/11	0.9	62.3	19/03	20/03	26.5	14.8±16.9
2011/12	336	29/08	29/08	6.1	49.2±6.2				
	395	25/07	26/07	29.6	14.3±18.3	18/03	22/03	81.5	7.3±15.7
	407					05/03	07/03	35.4	12.1±16.9
	459					17/03	19/03	34.4	10.7±17.3
	460	06/11	06/11	5.1	70.4±28.6	11/03	13/03	41.5	12.2±14.6
	479	22/11	22/11	7.6	34.8±24.7	22/03	24/03	45.9	11.3±14.4
	480	28/10	29/10	20.6	21.2±21.3	02/04	06/04	82.6	10.8±15.3
	483	28/10	05/11	193.8	19.9±30.1	17/03	18/03	23.4	20.2±21.2
	484					10/03	12/03	36.3	10.7±13.5
	486					22/03	24/03	36.0	16.8±21.2
2012/13	395	09/08	09/08	7.0	39.6±23	22/03	22/03	3.6	56.9±39.6
	459								
	460					12/03	15/03	60.3	12±17.2
	479	03/11	04/11	5.6	5±12.5	13/03	21/03	182.6	6.3±12.1
	483	27/10	27/10	2.6	87.9±34.4				
	484	18/11	20/11	40.2	8.7±16.9	03/03	05/03	36.6	11.4±15
	Mean			**25.8±48.2**	**22.8±25.5**			**45.9±40.1**	**11.6±16.9**

(b)

Year	Bird	Outward				Return			
		Start	End	Duration (hrs)	Ins Speed (km/h)	Start	End	Duration (hrs)	Ins Speed (km/h)
2010/11	334	31/10	01/11	14.7	48.4±21.7	07/04	09/04	51.4	15.4±18.2
	336	14/08	17/08	54.9	20.2±23.1	21/03	24/03	68.1	15.2±18.4
	388	21/11	21/11	0.4	66.1				
	391	09/11	20/11	254.3	10±16.9	26/03	30/03	95.6	19±23.6
	395	26/07	28/07	51.0	20±21.6	26/03	27/03	17.8	35.9±30.8
	407	27/11	29/11	34.2	24.2±29.4	17/03	18/03	29.3	31.7±25.8
2011/12	336	29/08	01/09	58.2	12.3±19.1				
	395	26/07	28/07	42.0	23.8±26.9	17/03	17/03	10.2	45.8±33.9
	407	18/12	22/12	97.6	10.9±18.6	03/03	05/03	45.2	21±25.8
	459	23/11	23/11	8.1	43±22.4	16/03	17/03	14.7	29.8±30.3
	460	06/11	09/11	60.9	20.3±24.6	03/03	08/03	113.1	13.5±22.7
	479	23/11	24/11	33.5	20.9±25.1	16/03	22/03	149.6	10.7±18.5
	480	04/11	05/11	21.9	46.9±19	28/03	02/04	111.0	10.3±12.5
	483	05/11	06/11	6.6	78.7±14.1	15/03	17/03	42.9	18.5±23.8
	484	06/12	16/12	238.4	9.9±12.8	02/03	07/03	107.1	11.1±20.7
	486					11/03	22/03	255.7	6.4±11.9
2012/13	395	09/08	12/08	71.5	11.6±17.2	20/03	21/03	11.5	22.6±28
	459					16/03	18/03	32.8	23.3±23.7
	460					10/03	11/03	17.4	52.1±54.9
	479					10/03	13/03	58.1	14±26.3
	483	27/10	28/10	17.6	37.6±34.4	03/03	03/03	0.6	50
	484					19/02	03/03	277.2	10.2±15.6
	Mean			**62.7±73.8**	**17.3±22.7**			**75.5±77.4**	**14.8±21.8**

Table 7.4 Overlap of the tracks of individual Lesser Black-backed Gulls with offshore wind farm sites during the migration and wintering periods, expressed as mean distance travelled (km) within the site and as a percentage of individual distance budgets (see Appendix 7.1, for values across all birds).

Country	Wind farm	Status	No birds	Mean distance (km) / bird	Mean % / bird	Total distance (km)
Belgium	THV Mermaid	1	1	0.0028±0.0121	0.0001±0.0003	0.05
Spain	HiPRWind	1	4	0.0237±0.0463	0.0002±0.0003	0.43
	Proyecto EMERGE	1	1	0.0056±0.0238	0.0000±0.0002	0.10
	Proyecto Idermar Phase 1	1	1	0.0006±0.0027	0.0000±0.0000	0.01
	Proyecto Idermar Phase 2	1	1	0.0006±0.0027	0.0000±0.0000	0.01
	Proyecto Idermar Phase 3	1	1	0.0006±0.0027	0.0000±0.0000	0.01
	SeAsturLab Phase 2	1	8	0.0668±0.1326	0.0005±0.0011	1.20
	SeAsturLab Phase 3	1	5	0.0208±0.0484	0.0001±0.0003	0.37
France	Cherbourg	1	5	0.0250±0.0429	0.0002±0.0003	0.45
	Cote d'Albatre II	1	1	0.0030±0.0129	0.0000±0.0001	0.05
	Courseulles-Sur-Mer	1	3	0.8252±2.0664	0.0061±0.0155	14.85
	d'Aïse	1	7	1.2257±1.8273	0.0087±0.0129	22.06
	Des Minquiers	1	4	0.0241±0.0591	0.0002±0.0005	0.43
	Fécamp	1	3	0.1808±0.5182	0.0014±0.0039	3.25
	Haute Normandie	1	2	0.0134±0.0391	0.0001±0.0003	0.24
	Le Tréport	1	2	0.0655±0.2219	0.0005±0.0017	1.18
	Les Grunes	1	4	0.1687±0.4112	0.0012±0.0031	3.04
	Neoen	1	3	0.0157±0.0384	0.0001±0.0003	0.28
	Noirmoutier	1	3	0.3818±1.3143	0.0027±0.0089	6.87
	Portes en Ré	1	4	0.0256±0.0559	0.0002±0.0004	0.46
	Saint-Brieuc	1	7	1.8531±2.8466	0.0133±0.0206	33.36
	Saint-Nazaire	1	3	0.2352±0.7550	0.0015±0.0050	4.23
	Vendée	1	3	0.1033±0.3070	0.0008±0.0025	1.86
	WIN 2	3	2	0.0781±0.2274	0.0006±0.0017	1.41
	WINFLO Wind turbine	3	2	0.0033±0.0100	0.0000±0.0001	0.06
Great Britain	East Anglia One	2	1	0.0417±0.1770	0.0009±0.0037	0.75
	East Anglia rest	2	1	2.1964±9.3186	0.0462±0.1958	39.54
	ETI Floating Offshore Wind	1	1	0.0033±0.0138	0.0000±0.0001	0.06
	Galloper Wind Farm	3	4	1.2575±3.5955	0.0122±0.0335	22.63
	Greater Gabbard	5	3	0.7240±2.1517	0.0064±0.0199	13.03
	Gunfleet Sands 3	5	4	0.0161±0.0372	0.0001±0.0003	0.29
	Gunfleet Sands I + II	5	6	0.1001±0.2088	0.0008±0.0015	1.80
	Inner Dowsing	5	1	0.0875±0.3711	0.0018±0.0078	1.57
	Kentish Flats	5	2	0.0515±0.1502	0.0004±0.0013	0.93
	Kentish Flats Extension	3	2	0.0429±0.1254	0.0004±0.0011	0.77
	Lincs	5	1	0.3752±1.5917	0.0078±0.0333	6.75
	London Array Phase 1	5	4	0.6249±1.6006	0.0046±0.0116	11.25
	London Array Phase 2	3	4	0.1693±0.3623	0.0014±0.0031	3.05
	Lynn	5	1	0.0875±0.3713	0.0018±0.0078	1.58
	Navitus Bay Wind Park 1	1	6	1.7356±3.2279	0.0141±0.0293	31.24
	Rampion	2	5	0.8819±3.0701	0.0053±0.0177	15.87
	Scroby Sands	5	2	0.2275±0.9289	0.0047±0.0195	4.09
	Thanet	5	1	0.0169±0.0716	0.0001±0.0005	0.30
Portugal	WindFloat - Phase 1	5	13	0.1318±0.0906	0.0011±0.0009	2.37
	WindFloat - Phase 2	1	3	0.0114±0.0349	0.0001±0.0003	0.20
	WindFloat - Phase 3	1	3	0.0114±0.0349	0.0001±0.0003	0.20
	Total all birds (km)					254.58
	% total distance					2.68

Status: 1 – Concept/Early Planning; 2 – Consent Application Submitted; 3 – Consent Authorised; 4 – In construction; 5 – Fully Commissioned.

Table 7.5 Overlap of the tracks of individual Lesser Black-backed Gulls with offshore wind farm sites during the migration and wintering periods, expressed as mean time (hrs) within the site and as a percentage of individual time budgets (see Appendix 7.2, for values across all birds).

Country	Wind farm	Status	No birds	Mean time (hrs) / bird	Mean % / bird	Total time (hrs)
Belgium	THV Mermaid	1	1	0.0008±0.0032	0.0000±0.0001	0.01
Spain	HiPRWind	1	4	0.0009±0.0023	0.0000±0.0001	0.02
	Proyecto EMERGE	1	1	0.0001±0.0006	0.0000±0.0000	0.00
	Proyecto Idermar Phase 1	1	1	0.0000±0.0001	0.0000±0.0000	0.00
	Proyecto Idermar Phase 2	1	1	0.0000±0.0001	0.0000±0.0000	0.00
	Proyecto Idermar Phase 3	1	1	0.0000±0.0001	0.0000±0.0000	0.00
	SeAsturLab Phase 2	1	8	0.0152±0.0355	0.0003±0.0007	0.27
	SeAsturLab Phase 3	1	5	0.0018±0.0046	0.0000±0.0001	0.03
France	Cherbourg	1	5	0.0006±0.0011	0.0000±0.0000	0.01
	Cote d'Albatre II	1	1	0.0002±0.0007	0.0000±0.0000	0.00
	Courseulles-Sur-Mer	1	3	0.1457±0.4099	0.0039±0.0109	2.62
	d'Aïse	1	7	0.0502±0.0802	0.0013±0.0023	0.90
	Des Minquiers	1	4	0.0051±0.0122	0.0001±0.0004	0.09
	Fécamp	1	3	0.0055±0.0160	0.0002±0.0005	0.10
	Haute Normandie	1	2	0.0010±0.0033	0.0000±0.0001	0.02
	Le Tréport	1	2	0.0031±0.0091	0.0001±0.0003	0.06
	Les Grunes	1	4	0.0153±0.0377	0.0004±0.0009	0.28
	Neoen	1	3	0.0014±0.0035	0.0000±0.0001	0.03
	Noirmoutier	1	3	0.1210±0.5008	0.0028±0.0114	2.18
	Portes en Ré	1	4	0.0074±0.0238	0.0002±0.0006	0.13
	Saint-Brieuc	1	7	0.0673±0.1254	0.0016±0.0028	1.21
	Saint-Nazaire	1	3	0.0159±0.0582	0.0004±0.0013	0.29
	Vendée	1	3	0.0096±0.0276	0.0003±0.0007	0.17
	WIN 2	3	2	0.0056±0.0193	0.0002±0.0007	0.10
	WINFLO Wind turbine	3	2	0.0001±0.0004	0.0000±0.0000	0.00
Great Britain	East Anglia One	2	1	0.0309±0.1313	0.0014±0.0058	0.56
	East Anglia rest	2	1	0.3942±1.6724	0.0174±0.0736	7.10
	ETI Floating Offshore Wind	1	1	0.0005±0.0019	0.0000±0.0001	0.01
	Galloper Wind Farm	3	4	0.1166±0.3225	0.0045±0.0129	2.10
	Greater Gabbard	5	3	0.0632±0.1652	0.0023±0.0065	1.14
	Gunfleet Sands 3	5	4	0.0006±0.0016	0.0000±0.0001	0.01
	Gunfleet Sands I + II	5	6	0.0045±0.0092	0.0001±0.0003	0.08
	Inner Dowsing	5	1	0.0150±0.0638	0.0006±0.0026	0.27
	Kentish Flats	5	2	0.0128±0.0379	0.0005±0.0015	0.23
	Kentish Flats Extension	3	2	0.0107±0.0317	0.0004±0.0013	0.19
	Lincs	5	1	0.0744±0.3157	0.0031±0.0130	1.34
	London Array Phase 1	5	4	0.0549±0.1844	0.0014±0.0043	0.99
	London Array Phase 2	3	4	0.0210±0.0655	0.0008±0.0026	0.38
	Lynn	5	1	0.0151±0.0639	0.0006±0.0026	0.27
	Navitus Bay Wind Park 1	1	6	0.0556±0.0975	0.0014±0.0026	1.00
	Rampion	2	5	0.0981±0.2826	0.0023±0.0064	1.77
	Scroby Sands	5	2	0.0827±0.3494	0.0036±0.0154	1.49
	Thanet	5	1	0.0006±0.0027	0.0000±0.0001	0.01
Portugal	WindFloat - Phase 1	5	13	0.0102±0.0203	0.0003±0.0005	0.18
	WindFloat - Phase 2	1	3	0.0005±0.0014	0.0000±0.0001	0.01
	WindFloat - Phase 3	1	3	0.0005±0.0014	0.0000±0.0001	0.01
	Total all birds (hrs)					27.65
	% total time					0.95

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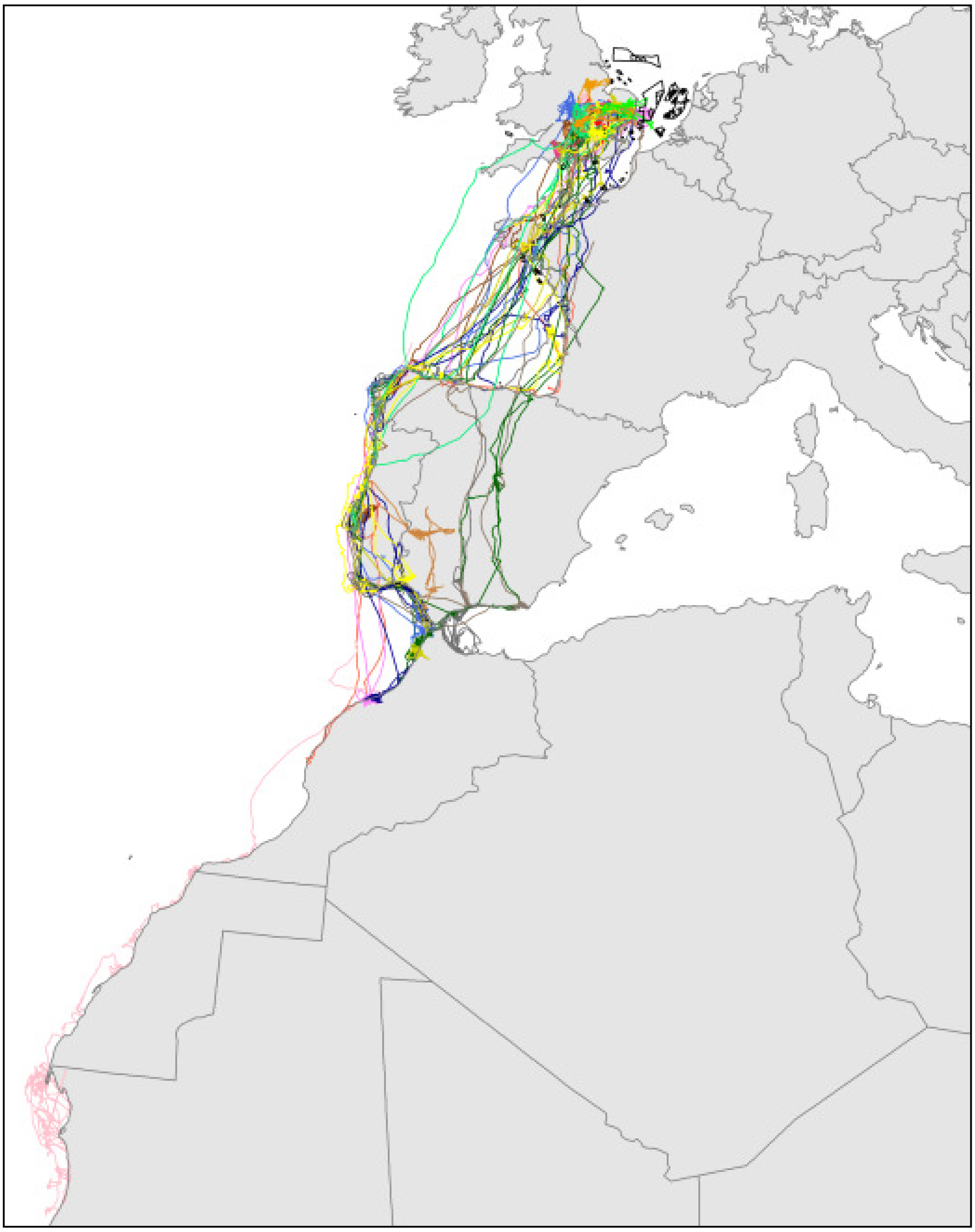

Figure 7.1 Migration routes and wintering areas of 18 Lesser Black-backed Gulls tagged at Orford Ness over 2010/11, 2011/12 and 2012/13. Each colour represents a different bird with repeated migration routes by individual birds expressed as the same colour.

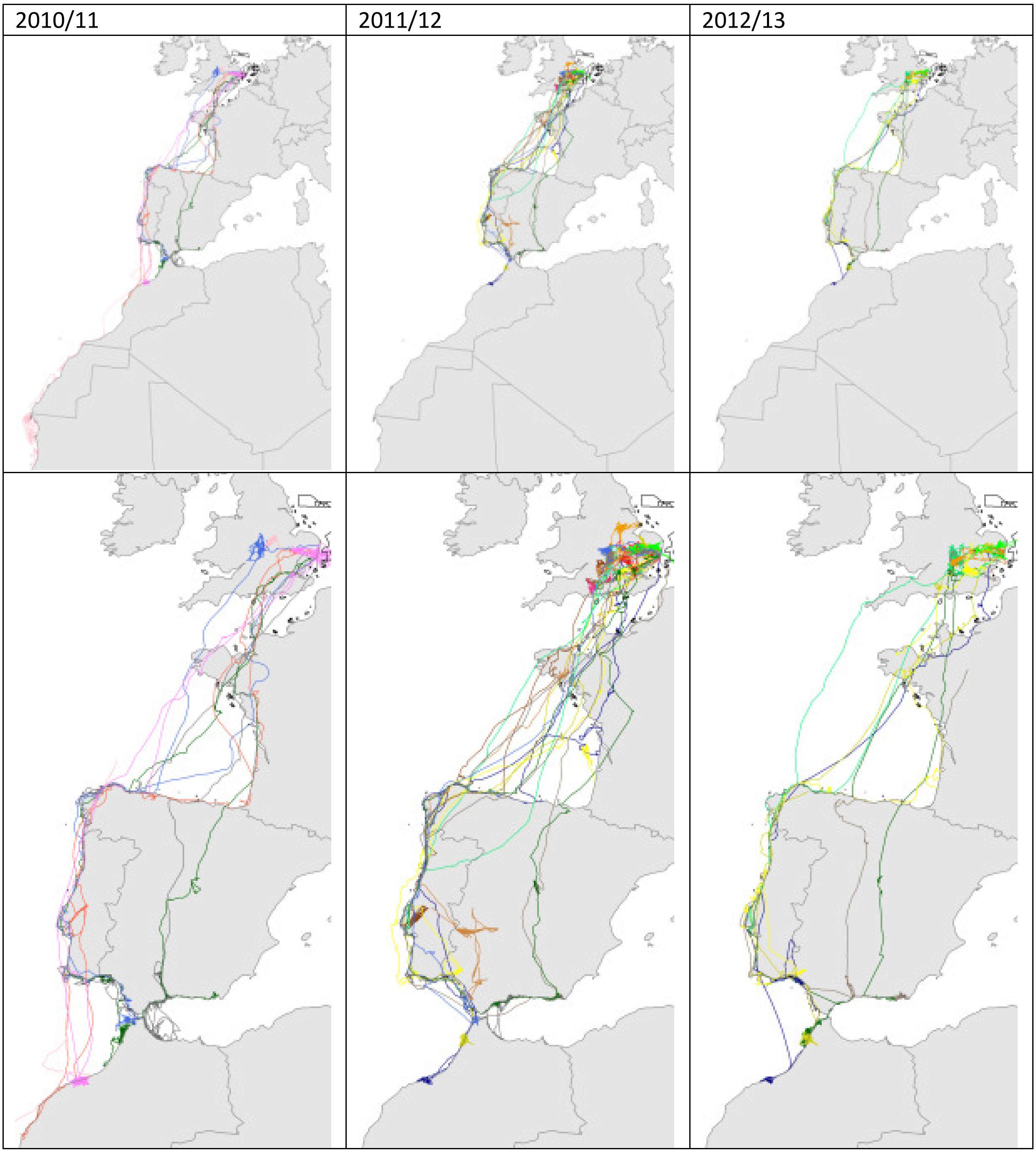

Figure 7.2 Migration routes and wintering areas of 18 Lesser Black-backed Gulls tagged at Orford Ness over each of 2010/11, 2011/12 and 2012/13. Each colour represents a different bird with repeated migration routes of individual birds expressed as the same colour; shown also are two plot extents, the top maps include the destination of a single bird (388) that reached as far south as Mauritania; bottom maps are focussed to show the detail of other tracks.

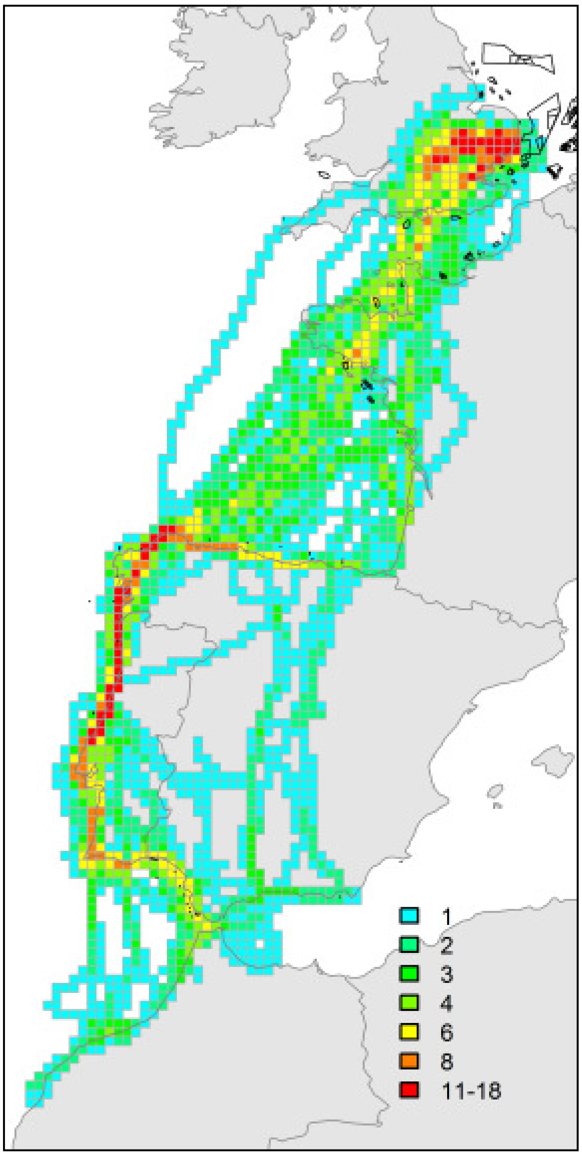

Figure 7.3 Intensity of area usage by Lesser Black-backed Gulls during migration and wintering periods expressed as number of birds per square.

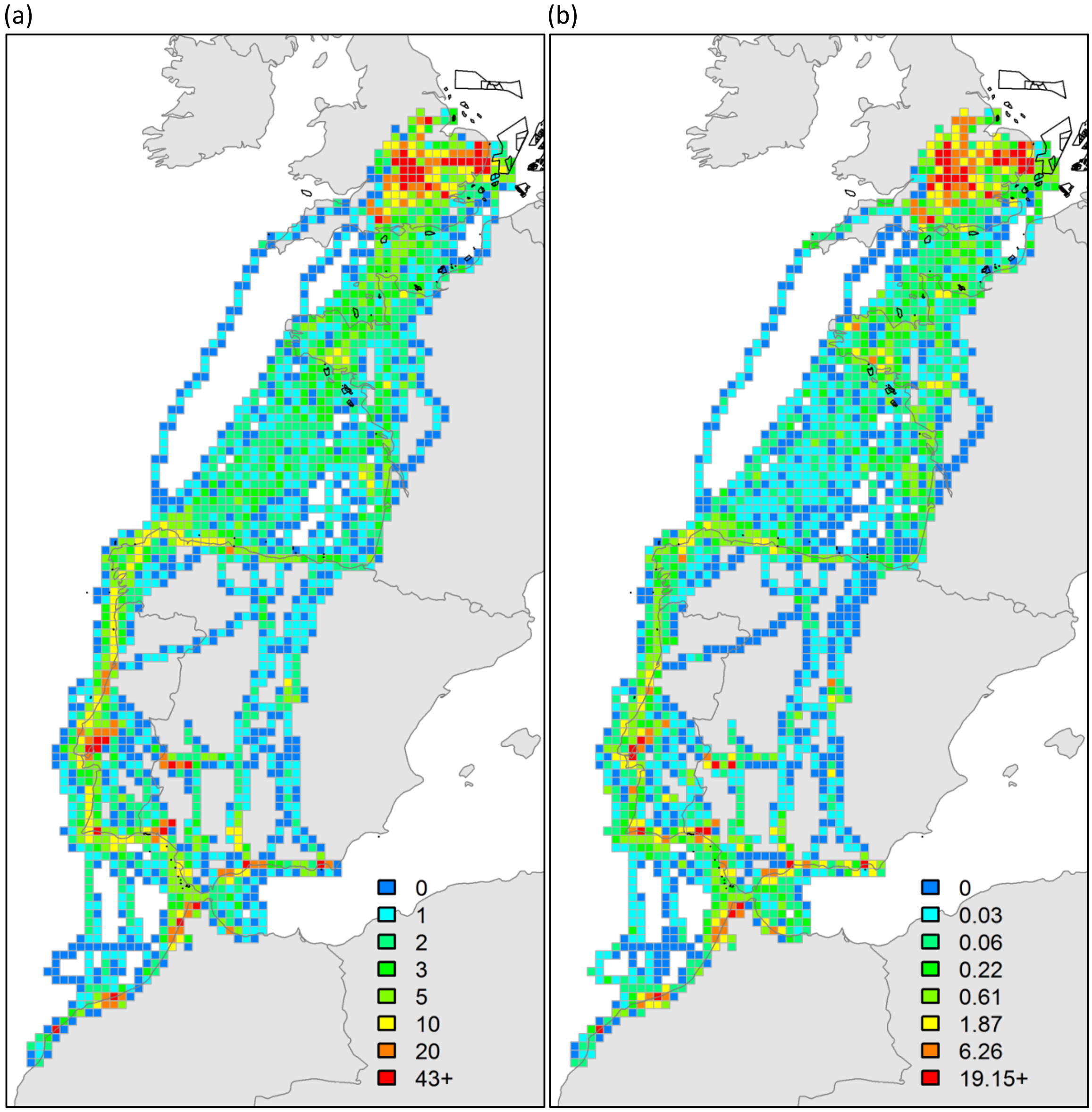

Figure 7.4 Intensity of area usage during migration and wintering periods for all Lesser Black-backed Gulls in all years expressed as (a) mean total distance travelled (km) per square and (b) mean time spent (hrs) per square.

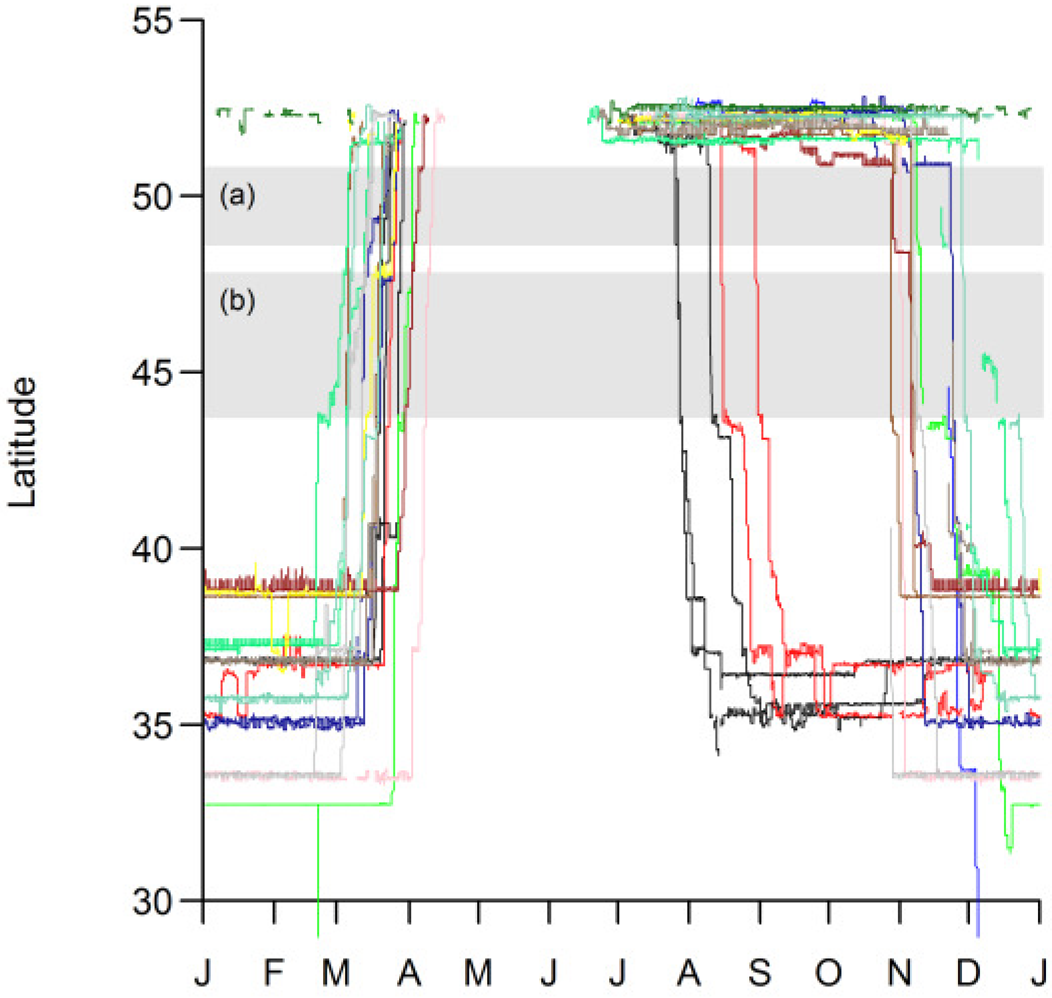

Figure 7.5 The timing of migration of individual Lesser Black-backed Gulls as shown by latitude plotted across the year. Each bird is plotted as a different colour showing movements away from UK latitudes at 52ºN to overwintering sites further south. Shaded areas represent two key regions for potential offshore wind farm developments (a) the English Channel and (b) the Bay of Biscay.

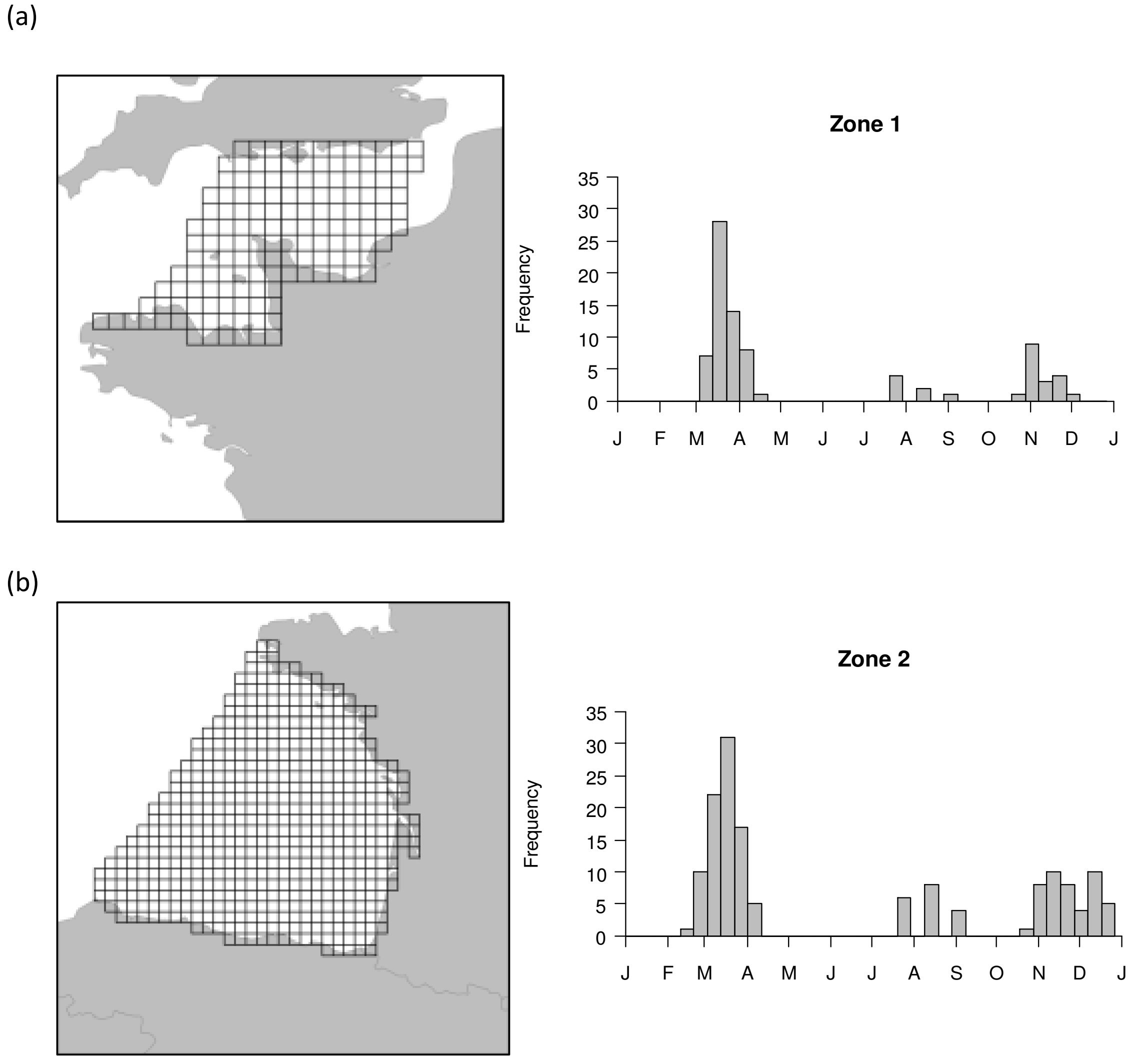

Figure 7.6 Timing of migration routes through (a) the English Channel and (b) the Bay of Biscay as shown by the overlap of GPS fixes with the areas indicated. Frequencies represent the numbers of days that individual 'transits' overlapped the indicated regions.

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References

Araújo, M.S., Bolnick, D.I. & Layman, C.A. 2011. The ecological causes of individual specialisation. *Ecology Letters,* **14,** 948-958.

Ashbrook, K., Wanless, S., Harris, M.P., & Hamer, K.C. 2008. Hitting the buffers: conspecific aggression undermines benefits of colonial breeding under adverse conditions. *Biology Letters*, **4**, 630-633.

Band, W. 2000. *Windfarms and birds: calculating a theoretical collision risk assuming no avoidance action*. Scottish Natural Heritage Report.

Banks, A.N., Burton, N.H.K., Austin, G.E., Carter, N., Chamberlain, D.E., Holt, C., Rehfisch, M.M., Wakefield, E. & Gill, P. 2005. *The potential effects on birds of the Greater Gabbard offshore wind farm report for February 2004 to March 2005*. BTO Research Report No. 419, Thetford, UK.

Bearhop, S., Thompson, D.R., Phillips, R.A., Waldron, S., Hamer, K.C., Gray, C.M., Votier, S.C., Ross, B.P. & Furness, R.W. 2001. Annual variation in Great Skua diets: The importance of commercial fisheries and predation on seabirds revealed by combining dietary analyses. *Condor*, **103**, 802-809.

Bearhop, S., Phillips, R.A., McGill, R., Cherel, Y., Dawson, D.A. & Croxall, J.P. 2006. Stable isotopes indicate sex-specific and long-term individual foraging specialisation in diving seabirds. *Marine Ecology Progress Series,* **311,** 157-164.

Bolnick, D.I., Svanbäck, R., Fordyce, J.M., Yang, L.H., Davis, J.M., Hulsey, C.D. & Forister, M.L. 2003. The ecology of individuals: incidence and implications of individual specialization. *American Naturalist,* **161,** 1-28.

Borger, L., Franconi, N., De Michele, G., Gantz, A., Meschi, F., Manica, A., Lovari, A. & Coulson, T. 2006. Effects of sampling regime on the mean and variance of home range size estimates. *Journal of Animal Ecology,* **75,** 1393-1405.

Bouten, W., Baaij, E.W., Shamoun-Baranes, J. & Camphuysen, C.J. 2013. A flexible GPS tracking system for studying bird behaviour at multiple scales. *Journal of Ornithology*, **54**, 571-580.

Boyle, G. 2007. Offshore wind: the potential to contribute a quarter of UK electricity by 2024. *Wind Engineering*, **31**, 65-74.

Breton, S.P. & Moe, G. 2009. Status, plans and technologies for offshore wind turbines in Europe and North America. *Renewable Energy*, **34**, 646-54.

Buckland, S.T., Burt, M.L., Rexstad, E.A., Mellor, M., Williams, A.E. & Woodward, R. 2012. Aerial surveys of seabirds: the advent of digital methods. *Journal of Applied Ecology*, **49**, 960-967.

Bukacinski, D., Bukacinski, M. & Spaans, A.L. 1998. Experimental evidence for the relationship between food supply, parental effort and chick survival in the Lesser Black-backed Gull *Larus fuscus*. *Ibis,* **140,** 422-430.

Burton, N.H.K. & Armitage, M.J.S. 2005. Differences in the diurnal and nocturnal use of intertidal feeding grounds by Redshank *Tringa totanus*. *Bird Study,* **52**, 120-128.

Bustnes, J.O., Barrett, R.T. & Helberg, M. 2010. Northern Lesser Black-backed Gulls: what do they eat? *Waterbirds,* **33,** 534-540.

Calladine, J. 1997. A comparison of Herring Gull *Larus argentatus* and Lesser Black-backed Gull *Larus fuscus* nest sites: their characteristics and relationships with breeding success. *Bird Study*, **44**, 318-326.

Camphuysen C.J. 1995. Herring Gull *Larus argentatus* and Lesser Black-backed Gulls *Larus fuscus* feeding at fishing vessels in the breeding season: competitive scavenging versus efficient flying. *Ardea*, **83,** 365-380.

Camphuysen, C.J., Calvo, B., Durinck, J., Ensor, K., Follestad, A., Furness, R.W., Garthe, S., Leaper, G., Skov, H., Tasker, M.L. & Winter, C.J.N. 1995. *Consumption of discards by seabirds in the North Sea*. Final report to the European Comm., study contr. BIOECO/93/10, NIOZ-Report 1995-5, Netherlands Institute for Sea Research, Texel.

Camphyusen, C.J. 2011. *Lesser Black-backed Gulls nesting at Texel Foraging distribution, diet, survival, recruitment and breeding biology of birds carrying advanced GPS loggers*. Royal Netherlands Institute for Sea Research, Texel, NIOZ-Report 2011-05.

Camphuysen, C.J., Fox, A.D., Leopold, M.F. & Petersen, I.K. 2004. *Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore windfarms in the U.K.* Report commissioned by COWRIE. Koninklijk Nederlands Instituut voor Onderzoek der Zee.

Camphuysen, C.J., Scott, B. & Wanless, S. 2006. Distribution and foraging interactions of seabirds and marine mammals in the North Sea: multi-species foraging assemblages and habitat-specific feeding strategies. In: Boyd, I., Wanless, S. & Camphuysen, C.J. (eds) *Top predators in marine ecosystems: Their role in monitoring and management*, pp. 82-97. Conservation Biology 12. Cambridge University Press, Cambridge, UK.

Camphuysen C.J. & Webb A. 1999. Multi-species feeding associations in North Sea seabirds: jointly exploiting a patchy environment. *Ardea,* **87**, 177-198.

Carstensen, J., Henriksen, O.D. & Teilmann, J. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series 2006,* **321,** 295-308.

Catry, P., Phillips, R.A. & Furness, R.W. 1999. Evolution of reversed sexual size dimorphism in skuas and jaegers. *Auk*, **116**, 158-168.

Cook, A.S.C.P., Johnston, A., Wright, L.W. & Burton, N.H.K. 2012. *A review of flight heights and avoidance rates of birds in relation to offshore wind farms*. Strategic Ornithology Support Services Project SOSS-02. BTO Research Report 618.

Cramp, S. & Simmons, K. (eds). 1977. *Handbook of the Birds of Europe, the Middle East and North Africa: The Birds of the Western Palearctic Vol. 1*, Oxford University Press, Oxford.

Daunt, F., Wanless, S., Peters, G., Benvenuti, S., Sharples, J., Grémillet, D. & Scott, B. 2006. Impacts of oceanography on the foraging dynamics of seabirds in the North Sea. In: Boyd, I., Wanless, S. & Camphuysen, C.J. (eds) *Top predators in marine ecosystems: Their role in monitoring and management*, pp. 177-190. Conservation Biology 12. Cambridge University Press, Cambridge, UK.

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

Desholm, M. & Kahlert, J. 2005. Avian collision risk at an offshore wind farm. *Biology Letters*, **1**, 296-298.

Desholm, M., Fox, A.D., Beasley, P.D.L. & Kahlert, J. 2006. Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. *Ibis,* **148**, 76-89.

Dokter, A.M., Shamoun-Baranes, S., Kemp, M.U., Tijm, S. & Holleman, I. 2013. High altitude bird migration at temperate latitudes: a synoptic perspective on wind assistance. *PLoS ONE,* **8**, e52300.

Dolbeer, R.A. 2006. Height distribution of birds recorded by collisions with civil aircraft. *Journal of Wildlife Management,* **70**, 1345-1350

Drewitt, A.L. & Langston, R.H.W. 2006. Assessing the impacts of wind farms on birds. *Ibis*, **148** S1, 29-42.

Eaton, M.A., Brown, A.F., Noble, D.G., Musgrove, A.J., Hearn, R., Aebischer, N.J., Gibbons, D.W., Evans, A. & Gregory, R.D. 2009. Birds of Conservation Concern 3: the population status of birds in the United Kingdom, Channel Islands and the Isle of Man. *British Birds*, **102**, 296-341.

Ellison, A.M. 2004. Bayesian inference in ecology. *Ecology Letters*, **7**, 509-520.

Ens, B.J., Barlein, F., Camphuysen, C.J., Boer, P. de, Exo, K.-M., Gallego, N., Hoye, B., Klaassen, R., Oosterbeek, K., Shamoun-Baranes, J., Jeugd, H. van der & Gasteren, H. van 2008. *Tracking of individual birds. Report on WP 3230 (bird tracking sensor characterization) and WP 4130 (sensor adaptation and calibration for bird tracking system) of the FlySafe basic activities project*. SOVON-onderzoeksrapport 2008/10. SOVON Vogelonderzoek Nederland, Beek-Ubbergen.

European Commission. 2007. *Guidelines for the Establishment of the Natura 2000 Network in the Marine Environment. Application of the Habitats and Birds Directives*. European Commission, Brussels.

Everaert, J. & Stienen, E.W.M. 2007. Impact of wind turbines on birds in Zeebrugge (Belgium) Significant effect on breeding tern colony due to collisions. *Biodiversity and Conservation,* **16,** 3345-3359.

Finn, J., Carlsson, J., Kelly, T. & Davenport, J. 2012. Avoidance of headwinds or exploitation of ground effect – why do birds fly low? *Journal of Field Ornithology*, **83**, 192-202.

Fox, A.D., Desholm, M., Kahlert, J., Christensen, T.K. & Petersen, I.K. 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. *Ibis,* **148,** 129-144.

Froese, R. & Pauly, D. (eds). 2011. FishBase. World Wide Web electronic publication. http://www.fishbase.org/

Furness, R.W. 1987. The Skuas. T & AD Poyser Ltd, Carlton.

Furness, R.W. 2003. Impacts of fisheries on seabird communities. *Scientia Marina*, **67 (suppl. 2)**, 33-45.

Furness, R.W., Crane, J.E., Bearhop, S., Garthe, S., Käkelä, A., Käkelä, R., Kelly, A., Kubetzki, U., Votier, S.C. & Waldron, S. 2006. Techniques to link individual migration patterns of seabirds with diet specialization, condition and breeding performance. *Ardea*, **94**, 631-639.

Furness, R., Wade, H., Masden, E.A. & Robbins, A. 2012. Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES Journal of Marine Science*, **69**, 1466-1479.

Furness, R.W., Wade, H.M. & Masden, E.A. 2013. Assessing vulnerability of marine bird populations to offshore wind farms. *Journal of Environmental Management*, **119**, 56-66.

Galván, I. 2003. Intraspecific kleptoparasitism in Lesser Black-backed Gulls wintering inland in Spain. *Waterbirds*, **26**, 325-330.

Garthe, S., Camphuysen, C. J. & Furness, R.W. 1996. Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. *Marine Ecology Progress Series*, **136**, 1-11.

Garthe, S. & Hüppop, O. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. *Journal of Applied Ecology*, **41**, 724-734.

Gilks W.R., Richardson S. & Spiegelhalter D.J. 1996. *Markov Chain Monte Carlo in Practice*. Chapman & Hall/CRC.

Gray, C.M. & Hamer, K.C. 2001. Food-provisioning behaviour of male and female Manx Shearwaters, *Puffinus puffinus*. *Animal Behaviour,* **62,** 117-121.

Greig, S.A., Coulson, J.C. & Monaghan, P**.** 1985. Feeding strategies of male and female adult Herring Gulls (*Larus argentatus*). *Behaviour,* **94,** 41-59.

Gyimesi, A., Boudewijn, T.J., Poot, M.J.M. & Buijs, R.J. 2011. *Habitat use, feeding ecology and reproductive success of Lesser Black-backed Gulls breeding in Lake Volkerak*. Final Report 10-234, Bureau Waardenburg.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R. & Watson, R. 2008. A global map of human impact on marine ecosystems. *Science,* **319,** 948-952.

Hamer, K.C., Furness, R.W. & Caldow, R.W.G. 1991. The effects of changes in food availability on the breeding ecology of Great Skuas *Catharacta skua* in Shetland. *Journal of Zoology*, **223**, 175-188.

Hamer, K.C. & Furness, R.W. 1993. Parental investment and brood defence by male and female Great Skuas *Catharacta skua*: the influence of food supply, laying date, body size and body condition. *Journal of Zoology*, **230**, 7-18.

Hamer, K.C., Phillips, R.A., Wanless S., Harris, M.P. & Wood, A.G. 2000. Foraging ranges, diets, and feeding locations of Northern Gannets *Morus bassanus* in the North Sea: evidence from satellite telemetry. *Marine Ecology Progress Series,* **200,** 257-264.

Hamer, K.C., Phillips, R.A., Hill, J.K., Wanless, S. & Wood, A.G. 2001. Contrasting foraging strategies of gannets Morus bassanus at two North Atlantic colonies: foraging trip duration and foraging area fidelity. *Marine Ecology Progress Series*, **224**, 283-290.

Hamer, K.C., Humphreys, E.M., Garthe, S., Hennicke, J., Peters, G., Grémillet, D., Phillips, R.A., Harris, M.P. & Wanless, S**.** 2007. Annual variation in diets, feeding locations and foraging behaviour of gannets in the North Sea: flexibility, consistency and constraint. *Marine Ecology Progress Series,* **338,** 295-305.

Harrison, P.J., Hanski, I. & Ovaskainen, O. 2011. Bayesian state-space modeling of metapopulation dynamics in the Glanville fritillary butterfly. *Ecological Monographs,* **81,** 581-598.

Hexter, R. 2009. High resolution video survey of seabirds and mammals in the Rhyl Flats Area. Report commissioned by COWRIE Ltd., HiDef Aerial Surveying Ltd., Available from: http://www.thecrownestate.co.uk/media/354799/2009-07%20High%20Resolution%20Video%20Survey%20of%20Seabirds%20and%20Mammals%20in%20the%20Rhyl%20Flats%20Area.pdf

Hudson, A.V. & Furness, R.W. 1989. The behaviour of seabirds foraging at fishing boats around Shetland. *Ibis*, **131**, 225-237.

Hüppop, O., Dierschke, J., Exo, K.M., Fredrich, E. & Hill, R. 2006. Bird migration studies and potential collision risk with offshore wind turbines. *Ibis*, **148** S1, 90-109.

Inger, R., Attrill, M.J., Bearhop, S., Broderick, A.C., Grecian, W.J., Hodgson, D.J., Mills, C., Sheehan, E., Votier, S.C., Witt, M.J. & Godley, B.J. 2009. Marine renewable energy: potential benefits to biodiversity? An urgent call for research. *Journal of Applied Ecology*, **46**, 1145-1153.

Irons, D.B. 1998. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. *Ecology,* **79,** 647-655.

Ito, M., Takahashi, A., Kokubun, N. Kitaysky, A.S. & Watanuki, Y. 2010. Foraging behavior of incubating and chick-rearing Thick-billed Murres *Uria lomvia*. *Aquatic Biology,* **8,** 279-287.

Johnston, A.J., Cook, A,S.C.P, Wright, L.J., Humphreys, E.M. & Burton, N.H.K. 2014. Modelling flight heights of marine birds to more accurately assess collision risk with offshore wind turbines. *Journal of Applied Ecology*, **51,** 31-41.

Jorge, P.E., Sowter, D. & Marques, P.A.M. 2011. Differential annual movement patterns in a migratory species: effects of experience and sexual Maturation. *PLoS ONE*, **6**, e22433.

Kemp, M.U., Shamoun-Baranes, J., Dokter, A.M., van Loon, E. & Bouten, W. 2013. The influence of weather on the flight altitude of nocturnal migrants in mid-latitudes. *Ibis*, **155**, 734-749.

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

King, R. 2012. A review of Bayesian state-space modelling of capture-recapture-recovery data. *Interface Focus* **2,** 190-204.

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

Krijgsveld, K.L., Akershoek, K., Schenk, F., Dijk, F., & Dirksen, S. 2009. Collision risk of birds with modern large wind turbines. *Ardea*, **97**, 357-366.

Kubetzki, U. & Garthe, S. 2003. Distribution, diet and habitat selection by four sympatrically breeding gull species in the south-eastern North Sea. *Marine Biology* **143,** 199-207

Langston, R.H.W. & Teuten, E. 2012; *Foraging ranges of northern gannets Morus bassanus in relation to proposed offshore wind farms in the UK: 2011*. RSPB Report to DECC, DECC URN: 12D/315.

Le Corre, M., Jaeger, A., Pinet, P., Kappes, M.A., Weimerskirch, H., Catry, T., Ramos, J.A., Russell, J.C., Shah, N. & Jaquemet, S. 2012. Tracking seabirds to identify potential marine protected areas in the tropical western Indian Ocean. *Biological Conservation,* **156,** 83-93.

Lewis, S., Sherratt, T.N., Hamer, K.C. & Wanless, S. 2001. Evidence of intra-specific competition for food in a pelagic seabird. *Nature*, **412**, 816-819.

Lewis, S., Benvenuti, S., Dall'Antonia, L., Griffiths, R., Money, L., Sherratt, T.N., Wanless, S. & Hamer, K.C. 2002. Sex-specific foraging behaviour in monomorphic seabird. *Proceedings of the Royal Society B: Biological Sciences,* **269,** 1687-1693.

Lewis, S., Schreiber, E.A., Daunt, F., Schenk, G.A., Orr, K., Adams, A., Wanless, S. & Hamer, K.C. 2005. Sex-specific foraging behaviour in tropical boobies: does size matter? *Ibis,* **147,** 408-414.

Lunn, D., Spiegelhalter, D., Thomas, A. & Best, N. 2009. The BUGS project: Evolution, critique, and future directions. *Statistics in Medicine,* **28,** 3049-3067.

Maclean, I.M.D., Wright, L.J., Showler, D.A. & Rehfisch, M.M. 2009. *A review of assessment methodologies for offshore windfarms*. Report BTO: British Trust Ornithology Report commissioned by COWRIE Ltd.

Martins, E.G., Araujo, M.S., Bonato, V. & Reis, S.F.D. 2008. Sex and season affect individual-level diet variation in the Neotropical marsupial *Gracilinanus microtarsus* (Didelphidae). *Biotropica,* **40,** 132-135.

Marsh, M. 2013. Here's one I made earlier: the Landguard gull RAS. *BTO RAS News,* **13**, 10-11.

Martin, G.R. 2011. Understanding bird collisions with man-made objects: a sensory ecology approach. *Ibis*, **153**, 239-254.

Masden, E.A., Haydon, D.T., Fox, A.D., Furness, R.W., Bullman, R. & Desholm, M. 2009. Barriers to movement: impacts of wind farms on migrating birds. *ICES Journal of Marine Science*, **66**, 746-753.

Mateos-Rodríguez, M. & Liechti, F. 2011. How do diurnal long-distance migrants select flight altitude in relation to wind? *Behavioral Ecology*, **23**, 403-409.

McCleery, R.H. & Sibly, R.M. 1986. Feeding specialization and preference in Herring Gulls. *Journal of Animal Ecology* **55,** 245-259.

Mellor, M. & Maher, M. 2008. *Full scale trial of high definition video survey for offshore windfarm sites*. HiDef Aerial Surveying Ltd Report commissioned by COWRIE Ltd.

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

Murray, D.L. & Fuller, M.R. 2000. A critical review of the effects of marking on the biology of vertebrates. In: Boitani, L. & Fuller, T.K. (eds) *Research Techniques in Animal Ecology*, pp. 15-64. Columbia University Press, New York.

Nemiroff, L. & Despland, E. 2007. Consistent individual differences in the foraging behaviour of forest tent caterpillars (*Malacosoma disstria*). *Canadian Journal of Zoology,* **85,** 1117-1124.

Newman, K.B., Fernández, C., Buckland, S.T. & Thomas, L. 2009. Monte Carlo inference for state-space models of wild animal populations. *Biometrics* **65,** 572-583.

Nussey, D.H., Wilson, A.J. & Brommer, J.E. 2007. The evolutionary ecology of individual phenotypic plasticity in wild populations. *Journal of Evolutionary Biology,* **20,** 831-844.

O'Brien, S.H., Webb, A., Brewer, M.J. & Reid, J.B. 2012. Use of kernel density estimation and maximum curvature to set marine protected area boundaries: identifying a Special Protection Area for wintering Red-throated Divers in the UK. *Biological Conservation,* **156,** 15-21.

Pettex, E., Bonadonna, F., Enstipp, M.R., Siorat, F. & Grémillet, D. 2010. Northern Gannets anticipate the spatio-temporal occurrence of their prey. *Journal of Experimental Biology,* **213,** 2365-2371.

Pettex, E., Lorentsen, S-H. Grémillet, D., Gimenez, O., Barrett, R., Pons, J-B., Le Bohec, C. & Bonadonna, F. 2012. Multi-scale foraging variability in Northern Gannet (*Morus bassanus*) fuels potential foraging plasticity. *Marine Biology*, **159,** 2743-2756.

Phillips, R.A., Thompson, D.R. & Hamer, K.C. 1999. The impact of Great Skua predation on seabird populations at St Kilda: a bioenergetics model. *Journal of Applied Ecology*, **36**, 218-232.

Plonczikier, P., & Simms, I.C. 2012. Radar monitoring of migrating Pink-footed Geese: behavioural responses to offshore wind farm development. *Journal of Applied Ecology*, **49**, 1187-1194.

Poore, A. & Hill, N. 2006. Sources of variation in herbivore preference: among-individual and past diet effects on amphipod host choice. *Marine Biology,* **149,** 1403-1410.

R Development Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://ww.r-project.org

Ramírez, F., Navarro, J., Afán, I., Hobson, K.A., Delgado, A. & Forero, M.G. 2012. Adapting to a changing world: unravelling the role of man-made habitats as alternative feeding areas for Slender-Billed Gull (*Chroicocephalus genei*). *PLoS ONE*, **7**, e47551.

Rappole, J.H. & Tipton, A.R. 1991. New harness design for attachment of radio transmitters to small passerines*. Journal of Field Ornithology,* **62,** 335-337.

Raven, S.J. & Coulson, J.C. 1997. The distribution and abundance of *Larus* gulls nesting on buildings in Britain and Ireland. *Bird Study*, **44**, 13-34.

Regular, P.M., Hedd, A., Montevecchi, W.A. 2011. Fishing in the dark: a pursuit-diving seabird modifies foraging behaviour in response to nocturnal light levels. *PLoS ONE*, **6**, e26763. doi:10.1371/journal.pone.0026763.

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

Ropert-Coudert, Y., Kato, A., Naito, Y. & Cannell, B.L. 2003. Individual diving strategies in the Little Penguin. *Waterbirds,* **26,** 403-408.

Scheidat, M., Tougaard, J., Brasseur, S., Carstensen, J., Petel, T.V., Teilmann J. & Reijnders, P. 2011. Harbour Porpoises (*Phocoena phocoena*) and wind farms: a case study in the Dutch North Sea. *Environmental Research Letters,* **6,** 10.

Schindler, D.E., Hodgson, J.R. & Kitchell, J.F. 1997. Density-dependent changes in individual foraging specialization of largemouth bass. *Oecologia,* **110,** 592-600.

Schmaljohann, H., Liechti, F., Bachler, E., Steuri, T. & Bruderer, B. 2008. Quantification of bird migration by radar – a detection probability problem. *Ibis*, **150**, 342-355.

Schwemmer, P. & Garthe, S. 2008. Regular habitat switch as an important feeding strategy of an opportunistic seabird species at the interface between land and sea. *Estuarine Coastal and Shelf Science,* **77,** 12-22.

Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J. & Gitzen, R.A. 1999. Effects of sample size on kernel home range estimates. *Journal of Wildlife Management,* **63,** 739-747.

Seys, J., Offringa, H., Van Waeyenberge, J. Meire, P., Vincx, M. & Kuijken, E. 2001. Distribution patterns of seabirds in Belgian marine waters. In: Seys, J. (ed) *Het gebruik van zee- en kustvogelgegevens ter ondersteuning van het beleid en beheer van de Belgische kustwateren*, pp. 22-39.

Shamoun-Baranes, J. & van Loon, E. 2006. Energetic influence on gull flight strategy selection. *Journal of Experimental Biology*, **209**, 3489-3498.

Shamoun-Baranes, J. Bouten, W. & van Loon, E. 2010. Integrating meteorology into research on migration. *Integrative and Comparative Biology*, **50**, 280-292.

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

Shealer, D.A. 2002. Foraging behaviour and food of seabirds. In: Schreiber, E.A. & Burger, J. (eds) *Biology of Marine Birds*. CRC Press, London.

Skov, H., Humphreys, E., Garthe, S., Geitner, K., Grémillet, D., Hamer, K.C., Hennicke, J., Parner, H. & Wanless, S. 2008. Application of habitat suitability modelling to tracking data of marine animals as a means of analyzing their feeding habitats. *Ecological Modelling*, **212**, 504-512.

Soanes, L.M., Atkinson, P.W., Gauvain, R.D. & Green, J.A. 2012. Individual consistency in the foraging behaviour of Northern Gannets: implications for interactions with offshore renewable energy developments. *Marine Policy*, **38**, 507-514.

Soanes, L.M., Arnould, J.P.Y., Dodd, S.G., Sumner, M.D. & Green, J.A. 2013. How many seabirds do we need to track to define home-range area. *Journal of Applied Ecology,* **50,** 671-679.

Stillman, R.A., Bautista, L.M., Alonso, J.C. & Alonso, J.A. 2002. Modelling state-dependent interference in Common Cranes. *Journal of Animal Ecology,* **71,** 874-882.

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

Syvitski, J.P.M., Vorosmarty, C.J., Kettner, A.J. & Green, P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science,* **308,** 376-380.

Tasker, M.L., Jones, P.H., Blake, B.F. & Dixon, T.J. 1985. Distribution and feeding habits of the Great Skua Catharacta skua in the North Sea. *Seabird*, **8**, 34-44.

Thaxter, C.B., Daunt, F., Hamer, K.C., Watanuki, Y., Harris, M.P., Grémillet, D., Peters, G. & Wanless, S. 2009. Sex-specific food provisioning in a monomorphic seabird, the Common Guillemot *Uria aalge*: nest defence, foraging efficiency or parental effort? *Journal of Avian Biology* **40,** 75-84.

Thaxter, C.B., Lascelles, B., Sugar, K., Cook, A.S.C.P., Roos, S., Bolton, M., Langston, R.H.W. & Burton, N.H.K. 2012b. Seabird Foraging Ranges as a Preliminary Tool for Identifying Candidate Marine Protected Areas. *Biological Conservation*, **156**, 53-61.

Thaxter, C.B., Ross-Smith, V.H., Clark, J.A., Clark, N.A., Conway, G.J., Masden, E.A., Wade, H.M., Leat, E.H.K., Gear, S.C., Marsh, M., Booth, C., Furness, R.W., Votier, S.C. & Burton, N.H.K. In prep. Effects of harness attachment for avian bio-logging research are species-specific and depend on temporal scale.

Thaxter, C.B., Ross-Smith, V.H., Clark, N.A., Conway. G.J., Rehfisch, M.M., Bouten, W. & Burton, N.H.K. 2011. *Measuring the interaction between marine features of Special Protection Areas with offshore wind farm development zones through telemetry: first breeding season report*. BTO Research Report No. 590. Thetford, Norfolk.

Thaxter, C.B., Ross-Smith, V.H., Clark, N.A., Conway. G.J., Wade, H.M., Masden, E.A., Rehfisch, M.M., Bouten, W. & Burton, N.H.K. 2012a. *Measuring the interaction between marine features of Special Protection Areas with offshore wind farm development zones through telemetry: second year report*. BTO Research Report No. 610. Thetford, Norfolk.

Thaxter, C.B., Ross-Smith, V.H., Johnston, A., Clark, N.A., Conway. G.J., Wade, H.M., Masden, E.A., Bouten, W. & Burton, N.H.K. 2013. *Measuring the interaction between marine features of Special Protection Areas with offshore wind farm development zones through telemetry: third year report*. BTO Research Report No. 639. Thetford, Norfolk.

Thaxter, C.B., Wanless, S., Daunt, F., Harris, M.P., Benvenuti, S., Watanuki, Y., Grémillet, & Hamer, K. C. 2010. Influence of wing loading on trade-off between pursuit-diving and flight in Common Guillemots and Razorbills. *Journal of Experimental Biology,* **213,** 1018-1025.

Torres, L.G., Thompson, D.R., Bearhop, S., Votier, S., Taylor, G.A., Sagar, P.M. & Robertson, B.C. 2011. White-capped albatrosses alter fine-scale foraging behavior patterns when associated with fishing vessels. *Marine Ecology Progress Series,* **428,** 289-301.

Vanermen, N. & Stienen, E.W.M. 2009. Seabirds & Offshore Wind Farms: Monitoring results 2008. Report INBO.R.2009.8, Research Institute for Nature and Forest, Brussels. In: Degraer, S. & Brabant, R. (eds) *Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring*. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Monitoring Unit. pp.151-221.

Vardanis, Y., Klaassen, R.H.G., Strandberg, R. & Alerstam, T. 2011. Individuality in bird migration: routes and timing. *Biology Letters*, **7**, 502-505.

Votier, S.C., Bearhop, S., Crane, J.E., Arcos, J.M. & Furness, R.W. 2007. Seabird predation by great skuas *Stercorarius skua* - intra-specific competition for food? *Journal of Avian Biology,* **38**, 234-246.

Votier, S.C., Bearhop, S., Fyfe, R. & Furness, R.W. 2008. Temporal and spatial variation in the diet of a marine top predator—links with commercial fisheries. *Marine Ecology Progress Series,* **367**, 223-232.

Votier, S.C., Bearhop, S., MacCormick, A., Ratcliffe, N. & Furness, R.W. 2001. Assessing the diet of Great Skuas, *Catharacta skua*, using five different techniques. *Polar Biology*, **26**, 20-26.

Votier, S.C., Bearhop, S., Ratcliff, N. & Furness, R.W. 2004a. Reproductive consequences for Great Skuas specializing as seabird predators. *Condor*, **106**, 275-287.

Votier, S.C., Bearhop, S., Witt, M.J., Inger, R., Thompson, D. & Newton, J. 2010. Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *Journal of Applied Ecology,* **47,** 487-497.

Votier, S.C., Crane, J.E., Bearhop, S., de León, A., McSorley, C.A., Minguez, E., Mitchell, I.P., Parsons, M., Phillips, R.A. & Furness, R.W. 2006. Nocturnal foraging by Great Skuas *Stercorarius skua*: implications for conservation of storm-petrel populations. *Journal of Ornithology*, **147**, 405-413.

Votier, S.C., Furness, R.W., Bearhop, S., Crane, J.E., Caldow, R.W.G., Catry, P., Ensor, K., Hamer, K.C., Hudson, A.V., Kalmbach, E., Klomp, N.I., Pfeiffer, S., Phillips, R.A., Prieto, I. & Thompson, D.R. 2004b. Changes in fisheries discard rates and seabird communities. *Nature*, **427**, 727-730.

Wade, P.R. 2000. Bayesian methods in conservation biology. *Conservation Biology*, **14**, 1308-1316.

Walls, R.J., Pendlebury, C.J, Budgey, R., Brookes, K. & Thompson, P. 2009. *Revised best practice guidance for the use of remote techniques for ornithological monitoring at offshore windfarms*. Report to COWRIE Ltd.

Wanless, S. & Harris, M.P. 1986. Time spent at the colony by male and female guillemots *Uria aalge* and razorbills *Alca torda*. *Bird Study*, **33**, 168-176.

Washburn, B.E., Bernhardt, G.E., Kutschbach-Brohl, L. Chipman, R.B. & Francoeur, L.C. 2013. Foraging ecology of four gull species at a coastal-urban interface, *Condor,* **115,** 67-76.

Watanuki, Y. 1992. Individual diet difference, parental care and reproductive success in Slaty-backed Gulls. *Condor,* **94,** 159-171.

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

Wilson, L.J., McSorley, C.A., Gray, C.M., Dean, B.J., Dunn, T.E., Webb, A. & Reid, J.B. 2009. Radio-telemetry as a tool to define protected areas for seabirds in the marine environment. *Biological Conservation,* **142,** 1808-1817.

Woo, K.J., Elliott, K.H., Davidson, M., Gaston, A.J. & Davoren GK. 2008. Individual specialization in diet by a generalist marine predator reflects specialization in foraging behaviour. *Journal of Animal Ecology,* **77,** 1082-1091.

Wood, S.N. 2006. *Generalized Additive Models: An Introduction with R*. Chapman & Hall/CRC.

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

Wright, L.J., Ross-Smith, V.H., Austin, G.E., Massimino, D., Dadam, D., Cook, A.S.C.P., Calbrade, N.A., & Burton, N.H.K. 2012. *Assessing the risk of offshore wind farm development to migratory birds designated as features of UK Special Protection Areas (and other Annex 1 species)*. Strategic Ornithological Support Services Project SOSS-05. BTO Research Report No. 592. BTO, Thetford.

Appendix 3.1 Outputs from all GAMMs and GAMs assessing, for Lesser Black-backed Gull, the extent of variation in (a) trips statistics, (b) time budgets, and (c) area usage through size and overlap of the 95% KDE – outputs here provide the significance of all effects tested.

(a) Trip statistics

TRIP STATISTICS		**TOTAL**			**DAY**			**NIGHT**		
Main effects	**Variable**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**
(i) Trip duration	Sex	1	15.46	< 0.001	1	8.38	< 0.001		24.7	< 0.001
	Year	2	58.08	< 0.001	2	18.23	< 0.001	1	6.44	0.0112
	s(Jdate)	4.328	56.79	< 0.001	4.359	20.91	< 0.001	4.344	62.21	< 0.001
	s(Jdate,Year)	4	84.45	sig	4	13.24	sig	4	763.47	sig
	s(Jdate,Sex)	2	30.4	sig	2	74.95	sig	2	154.81	sig
	s(Jdate,bird)	4	59.14	sig	Not run			Not run		
	bird*Year	2	118.77	< 0.001						
(ii) Foraging range	Sex	1	0.48	0.488	1	0.001	0.997	1	0.72	0.3979
	Year	2	3.36	0.035	2	4.10	0.0176	2	3.09	0.0463
	s(Jdate)	4.771	35.21	< 0.001	4.277	14.24	< 0.001	4.705	29.37	< 0.001
	s(Jdate,Year)	4	5.05	sig	4	1.11	ns	4	-12.13	ns
	s(Jdate,Sex)	2	11.53	sig	2	2.95	sig	2	6.35	sig
	s(Jdate,bird)	4	62.86	sig	Not run			Not run		
	bird*Year	2	32.036	< 0.001						
(iii) Total distance travelled	Sex	1	0.58	0.447	1	0.04	0.85	1	0.04	0.8397
	Year	2	5.18	0.006	2	20.01	< 0.001	2	2.53	0.0802
	s(Jdate)	4.785	67.25	< 0.001	4.778	36.86	< 0.001	4.644	42.80	< 0.001
	s(Jdate,Year)	4	83.46	sig	4	-15.83	ns	4	385.10	sig
	s(Jdate,Sex)	2	21.04	sig	2	-14.31	ns	2	146.09	sig
	s(Jdate,bird)	4	834.61	sig	Not run			Not run		
	bird*Year	2	179.98	< 0.001						

(b) Time budgets

TIME		**TOTAL**			**DAY**			**NIGHT**		
Main effects	**Variable**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**
(i) Time away from nest	Sex	1	0.04	0.842	1	0.012	0.915	1	0.45	0.504
	Year	2	68.39	< 0.001	2	90.54	< 0.001	2	31.05	< 0.001
	s(Jdate)	4.74	79.61	< 0.001	4.46	44.43	< 0.001	4.90	159.90	< 0.001
	s(Jdate,Year)	4	0.95	ns	4	-7.43	ns	4	14.35	sig
	s(Jdate,Sex)	2	38.21	sig	2	56.08	sig	2	-6.50	ns
	s(Jdate,bird)	83.37	395.28	sig	Not run			Not run		
	bird*Year	29	9.78	< 0.001						
(ii) Offshore usage	Sex	1	0.02	0.904	1	2.19	0.139	1	0.09	0.766
	Year	2	40.07	< 0.001	2	48.72	< 0.001	2	33.31	< 0.001
	s(Jdate)	4.92	25.07	< 0.001	4.85	24.60	< 0.001	4.71	37.97	< 0.001
	s(Jdate,Year)	4	2.75	sig	4	143.67	sig	4	-871.71	ns
	s(Jdate,Sex)	2	-23.19	ns	2	120.29	sig	2	-49.81	ns
	s(Jdate,bird)	62.72	264.74	sig	Not run			Not run		
	bird*Year	29	10.33	< 0.001						
(iii) Wind farm overlap	Sex	1	2.731	0.099	1	2.46	0.117	1	2.32	0.128
	Year	2	63.16	< 0.001	2	52.77	< 0.001	2	22.31	< 0.001
	s(Jdate)	3.81	23.07	< 0.001	3.61	17.31	< 0.001	3.61	7.27	< 0.001
	s(Jdate,Year)	4	-110.48	ns	4	-121.04	ns	4	-50.34	ns
	s(Jdate,Sex)	2	68.90	sig	2	54.99	sig	2	-2.68	ns
	s(Jdate,bird)	44.46	290.10	sig	Not run			Not run		
	bird*Year	29	8.67	< 0.001						

(c) Area usage

SPACE		**TOTAL**			**DAY**			**NIGHT**		
Main effects	**Variable**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**
(i) Total area usage	Sex	1	0.19	0.667	1	0.64	0.425	1	0.35	0.554
	Year	2	14.29	< 0.001	2	14.33	< 0.001	2	10.07	< 0.001
	s(Jdate)	4.75	12.36	< 0.001	4.72	10.66	< 0.001	4.64	9.46	< 0.001
	s(Jdate,Year)	4	-13.35	ns	4	-12.19	ns	4	4.33	sig
	s(Jdate,Sex)	2	21.82	sig	2	38.96	sig	2	22.68	sig
	s(Jdate,bird)	44.94	101.73	sig	Not run			Not run		
	bird*Year	29	7.75	< 0.001						
(ii) Offshore usage	Sex	1	0.14	0.706	1	0.03	0.864	1	0.01	0.928
	Year	2	39.73	< 0.001	2	41.30	< 0.001	2	25.71	< 0.001
	s(Jdate)	4.60	22.71	< 0.001	4.35	21.50	< 0.001	4.14	17.75	< 0.001
	s(Jdate,Year)	4	37.8	sig	4	29.09	sig	4	24.28	sig
	s(Jdate,Sex)	2	-9.98	ns	2	-1.64	ns	2	1.68	ns
	s(Jdate,bird)	55.83	167.30	sig	Not run			Not run		
	bird*Year	29	6.36	< 0.001						
(iii) Wind farm overlap	Sex	1	2.16	0.142	1	1.58	0.209	1	3.75	0.053
	Year	2	39.12	< 0.001	2	51.48	< 0.001	2	22.27	< 0.001
	s(Jdate)	3.71	15.64	< 0.001	3.73	20.10	< 0.001	3.44	7.82	< 0.001
	s(Jdate,Year)	4	-570.48	ns	4	-115.91	ns	4	-27.30	ns
	s(Jdate,Sex)	2	-53.20	ns	2	66.12	sig	2	-23.33	ns
	s(Jdate,bird)	72.47	202.81	sig	Not run			Not run		
	bird*Year	29	6.44	< 0.001						

Appendix 3.2 Outputs from GAMMs and GAMs assessing, for Lesser Black-backed Gull, the extent of annual, seasonal and sex-specific variation in (a) trips statistics, (b) time budgets, and (c) spatial usage through size and overlap of the 95% KDE – outputs here provide the β-coefficients of the effects tested. Missing variables in the list or dashes denote effects that were not significant for those particular models.

(a) Trip statistics

TRIP STATS			**Total**			**Day**			**Night**		
β-coefficients	**Variable**	**Level**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Trip duration	Year	2010	2.307±0.126	18.267	< 0.001	1.142±0.092	12.35	< 0.001	2.684±0.141	18.971	< 0.001
		2011	-0.637±0.122	-5.217	< 0.001	-0.024±0.089	-0.267	0.79	-0.598±0.134	-4.472	< 0.001
		2012	-0.244±0.129	-1.895	0.058	0.117±0.091	1.274	0.203	-0.210±0.142	-1.473	0.141
	Sex	Female	2.307±0.126	18.267	< 0.001	1.142±0.092	12.35	< 0.001	2.684±0.141	18.971	< 0.001
		Male	-0.428±0.087	-4.914	< 0.001	-0.282±0.066	-4.27	< 0.001	-0.291±0.115	-2.538	0.0112
	s(Jdate,Year)	2010	1	90.55	< 0.001	1	14.76	< 0.001	1	56.33	< 0.001
		2011	3.88	48.09	< 0.001	4.062	16.23	< 0.001	3.71	31.58	< 0.001
		2012	4.763	71.19	< 0.001	3.259	12.73	< 0.001	4.176	82.08	< 0.001
	s(Jdate,Sex)	Female	3.563	21.39	< 0.001	4.083	4.093	0.002	3.432	17.05	< 0.001
		Male	4.469	51.12	< 0.001	4.152	30.743	< 0.001	4.457	48.4	< 0.001
(ii) Offshore foraging range	Year	2010	3.030±0.163	-5.191	< 0.001	2.894±0.195	14.876	< 0.001	3.130±0.196	15.978	< 0.001
		2011	-0.049±0.166	-0.295	0.768	0.252±0.202	1.246	0.214	-0.157±0.196	-0.801	0.424
		2012	-0.257±0.183	-1.405	0.16	-0.018±0.226	-0.083	0.934	-0.399±0.218	-1.832	0.068
	s(Jdate,Year)	2010	1	20.98	< 0.001	-	-	-	-	-	-
		2011	3.861	17.02	< 0.001	-	-	-	-	-	-
		2012	3.473	27.14	< 0.001	-	-	-	-	-	-
	s(Jdate,Sex)	Female	4.758	27.23	< 0.001	4.024	15.363	< 0.001	4.614	19.81	< 0.001
		Male	4.451	41.48	< 0.001	1.914	3.069	0.051	4.397	39.38	< 0.001
(iii) Total distance per trip	Year	2010	3.351±0.128	28.168	< 0.001	2.746±0.159	17.24	< 0.001	-	-	-
		2011	-0.128±0.120	-1.062	0.288	0.134±0.147	0.91	0.363	-	-	-
		2012	-0.309±0.129	-2.39	0.017	-0.197±0.156	-1.26	0.208	-	-	-
	s(Jdate,Year)	2010	1	98.02	< 0.001	-	-	-	1	59.52	< 0.001
		2011	4.681	26.7	< 0.001	-	-	-	1	29.5	< 0.001
		2012	3.788	57.22	< 0.001	-	-	-	3.794	40.79	< 0.001
	s(Jdate,Sex)	Female	4.68	53.68	< 0.001	-	-	-	4.47	31.09	< 0.001
		Male	4.67	67.01	< 0.001	-	-	-	4.552	46.72	< 0.001

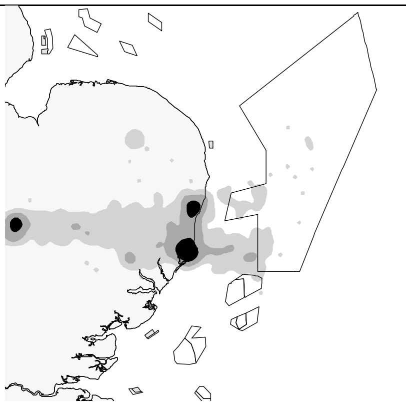
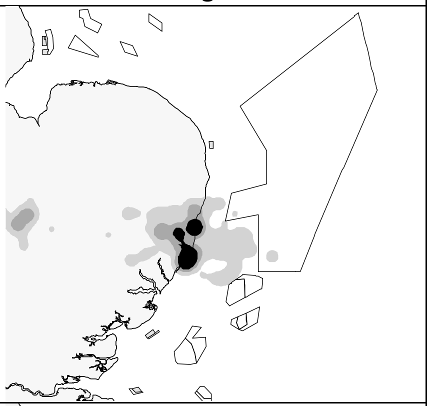
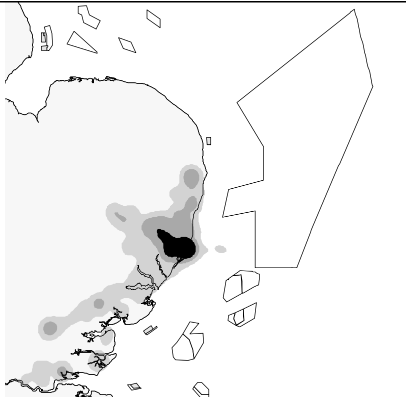
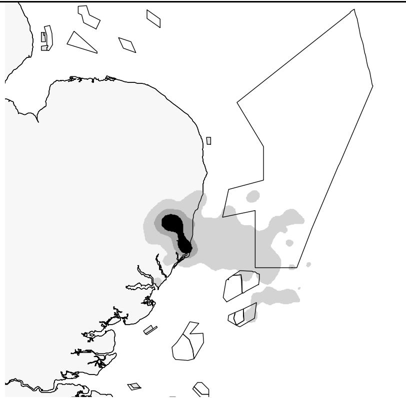
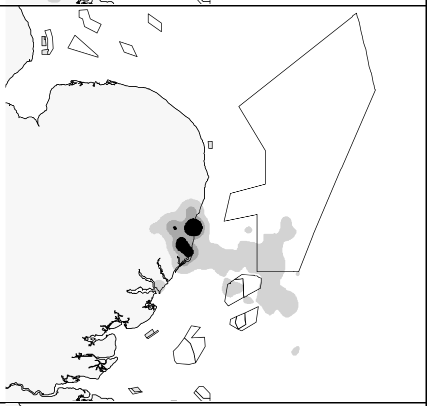
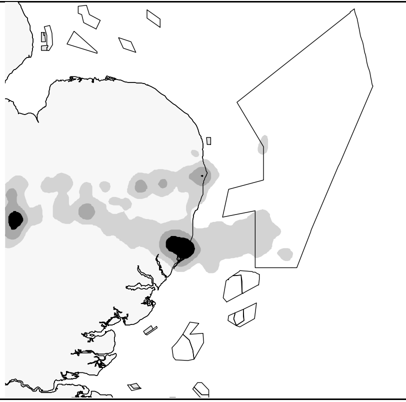
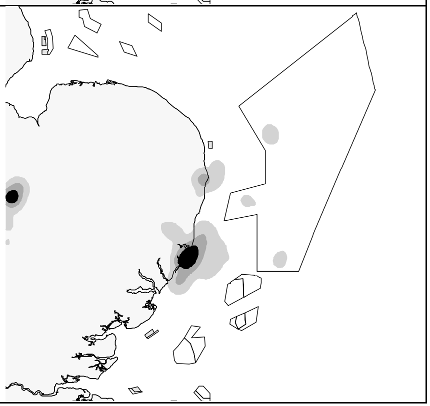
(b) Time budgets

TIME β-coefficients	**Variable**	**Level**	**Total**			**Day**			**Night**		
			β / edf	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Time away from nest	Year	2010	-0.330±0.063	-5.191	< 0.001	-0.864±0.065	-13.222	< 0.001	-1.263±0.084	-15.038	< 0.001
		2011	-0.305±0.063	-4.854	< 0.001	-0.301±0.061	-4.916	< 0.001	-0.370±0.086	-4.322	< 0.001
		2012	0.000±0.066	0.003	0.997	0.051±0.064	0.798	0.425	-0.090±0.091	-0.99	0.323
	s(Jdate,Sex)	Female	4.016	34.28	< 0.001	3.423	7.965	< 0.001	-	-	-
		Male	4.733	98.84	< 0.001	4.38	45.33	< 0.001	-	-	-
	s(Jdate,Year)	2010	-	-	-	-	-	-	1	5.782	0.0164
		2011	-	-	-	-	-	-	4.551	53.559	< 0.001
		2012	-	-	-	-	-	-	4.894	80.931	< 0.001
(ii) Time offshore	Year	2010	-2.427±0.313	-7.764	< 0.001	-3.835±0.334	-11.486	< 0.001	-2.199±0.503	-4.37	< 0.001
		2011	-1.370±0.205	-6.67	< 0.001	-1.371±0.175	-7.839	< 0.001	-2.479±0.407	-6.087	< 0.001
		2012	-2.238±0.251	-8.924	< 0.001	-2.211±0.225	-9.846	< 0.001	-3.508±0.448	-7.827	< 0.001
	s(Jdate,Year)	2010	3.078	28.03	< 0.001	3.085	2.566	0.052	-	-	-
		2011	4.299	11.6	< 0.001	4.556	6.68	< 0.001	-	-	-
		2012	4.748	24.67	< 0.001	4.16	1.771	0.13	-	-	-
	s(Jdate,Sex)	Female				3.654	11.712	< 0.001	-	-	-
		Male				4.763	29.23	< 0.001	-	-	-
(iii) Time in wind farm	Year	2010	-9.136±0.979	-9.332	< 0.001	-9.080±0.947	-9.585	< 0.001	-8.102±0.933	-8.684	< 0.001
		2011	-1.424±0.173	-8.218	< 0.001	-1.286±0.183	-7.017	< 0.001	-1.622±0.290	-5.604	< 0.001
		2012	-2.808±0.252	-11.141	< 0.001	-2.762±0.269	-10.255	< 0.001	-2.723±0.436	-6.249	< 0.001
	s(Jdate,Sex)	Female	3.469	11.449	< 0.001	3.11	9.768	< 0.001	-	-	-
		Male	2.75	4.685	0.004	2.795	4.839	0.003	-	-	-

(c) Spatial usage

SPACE			**Total**			**Day**			**Night**		
β-coefficients	**Variable**	**Level**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Total area usage	Year	2010	-0.418±0.175	-2.381	0.018	-0.452±0.167	-2.709	0.007	-0.696±0.186	-3.732	0.002
		2011	-0.266±0.149	-1.79	0.074	-0.371±0.137	-2.703	0.007	-0.210±0.151	-1.389	0.165
		2012	-0.717±0.170	-4.217	< 0.001	-0.748±0.157	-4.779	< 0.001	-0.599±0.171	-3.501	< 0.001
	s(Jdate,Sex)	Female	4.123	3.77	0.005	4.236	4.214	0.002	4.544	12.11	< 0.001
		Male	4.373	7.474	< 0.001	3.77	3.966	0.004	4.599	41.21	< 0.001
	s(Jdate,Year)	2010	-	-	-	-	-	-	2.272	3.819	0.0185
		2011	-	-	-	-	-	-	3.665	11.631	< 0.001
		2012	-	-	-	-	-	-	1	3.148	0.0765
(ii) Offshore usage	Year	2010	-0.694±0.145	-4.775	< 0.001	-0.926±0.1533	-6.039	< 0.001	-0.566±0.127	-4.444	< 0.001
		2011	-0.728±0.105	-6.945	< 0.001	-0.735±0.105	-7.033	< 0.001	-0.466±0.101	-4.623	< 0.001
		2012	-1.063±0.119	-8.908	< 0.001	-1.090±0.120	-9.08	< 0.001	-0.805±0.115	-6.976	< 0.001
	s(Jdate,Year)	2010	3.333	36.743	< 0.001	3.305	30.4	< 0.001	2.98	14.86	< 0.001
		2011	3.511	24.072	< 0.001	3.632	19.27	< 0.001	3.113	25.614	< 0.001
		2012	3.777	6.942	< 0.001	3.241	5.72	< 0.001	1	18.89	< 0.001
(iii) Wind farm overlap	Year	2010	-5.384±0.608	-8.851	< 0.001	-7.210±0.724	-9.957	< 0.001	-6.373±0.809	-7.875	< 0.001
		2011	-1.167±0.182	-6.405	< 0.001	-1.122±0.164	-6.851	< 0.001	-0.948±0.232	-4.085	< 0.001
		2012	-2.104±0.238	-8.826	< 0.001	-2.014±0.199	-10.137	< 0.001	-2.062±0.309	-6.663	< 0.001
	s(Jdate,Sex)	Female	-	-	-	3.3661	17.373	< 0.001	-	-	-
		Male	-	-	-	2.807	5.302	0.002	-	-	-

Appendix 3.3 Individual examples of day / night variation in movements of Lesser Black-backed Gulls away from the colony; shown are the 95% (light grey) representing total area usage, 75% KDEs (medium grey) and 50% KDE, representing core area usage. Also shown are polygons representing all wind farms in the nearby area (see Figure 3.1 for wind farm details).

Bird / Year	Day	Night
459 / 2011		
480 /2011		
482 / 2011		
493 /2012		

Appendix 4.1 Outputs from all GAMMs and GAMs assessing, for Great Skua, the extent of variation in (a) trips statistics (negative binomial errors), (b) time budgets (Poisson errors), and (c) area usage (Poisson errors) through size and overlap of the 95% KDE – outputs here provide the significance of all effects tested.

(a) Trip statistics

Main effects	**Variable**	**TOTAL**			**DAY**			**NIGHT**		
		df or edf	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**
(i) Trip duration	Sex	1	5.88	0.016	1	0.09	0.7597	1	10.86	0.001
	s(Jdate)	2.48	6.32	0.001	1.773	1.26	0.273	2.27	4.09	0.015
	s(chick age)	2.87	8.44	<0.001	2.015	2.40	0.092	2.601	5.81	0.002
	s(Jdate,sex)	2	-3.24	ns	2	-5.15	ns	2	-7.82	ns
	s(chick age,sex)	2	43.36	sig	2	-3.23	ns	2	7.47	sig
	s(Jdate,colony)	2	2.88	sig	2	4.71	sig	2	-14.87	ns
	s(chick age,colony)	2	-12.88	ns	2	7.27	sig	2	-15.16	ns
	s(Jdate,birdID)	44.644	547.39	sig	38.627	317.97	sig	33.553	218.06	sig
	s(chick age,birdID)	38.346	445.64	sig	34.281	334.65	sig	26.945	143.29	sig
(ii) Foraging range	Sex	1	0.39	0.53	1	0.14	0.709	1	5.06	0.026
	s(Jdate)	1	0.45	0.50	1	0.21	0.644	1	1.65	0.201
	s(chick age)	1	1.43	0.23	1	0.57	0.451	1	1.17	0.282
	s(Jdate,sex)	2	-2.51	ns	2	-13.65	ns	2	-2.71	Ns
	s(chick age,sex)	2	54.31	sig	2	11.57	sig	2	15.54	Sig
	s(Jdate,colony)	2	-3.00	ns	2	-3.71	ns	2	-0.80	Ns
	s(chick age,colony)	2	-4.76	ns	2	-6.12	ns	2	-6.63	Ns
	s(Jdate,birdID)	32.613	240.37	sig	34.065	183.93	sig	24.885	115.40	Sig
	s(chick age,birdID)	26.105	261.22	sig	30.645	209.89	sig	17.972	77.54	Sig
(iii) Total distance travelled	Sex	1	1.28	0.26	1	0.06	0.812	1	7.79	0.006
	s(Jdate)	1	0.01	0.91	1	0.04	0.839	1	0.31	0.579
	s(chick age)	1.342	0.19	0.73	1	0.16	0.688	1	0.07	0.796
	s(Jdate,sex)	2	-4.62	ns	2	-12.57	ns	2	-4.24	ns
	s(chick age,sex)	2	24.49	sig	2	-1.92	ns	2	2.52	sig
	s(Jdate,colony)	2	-4.69	ns	2	-3.94	ns	2	-3.86	ns
	s(chick age,colony)	2	-2.73	ns	2	-2.23	ns	2	-3.92	ns
	s(Jdate,birdID)	30.96	265.20	sig	34.7	181.36	sig	22.659	117.94	sig
	s(chick age,birdID)	25.832	276.31	sig	33.758	210.04	sig	17.3	86.59	sig

(b) Time budgets

Main effects		**TOTAL**			**DAY**			**NIGHT**		
	Variable	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**	**df or edf**	**F / dAIC**	**P**
(i) Time away from nest	Sex	1	7.27	0.007	1	4.30	0.039	1	7.64	0.006
	s(Jdate)	1	21.43	< 0.001	1	9.05	0.003	1.99	24.94	<0.001
	s(chick age)	1	25.57	< 0.001	1	12.82	<0.001	2.16	22.3	<0.001
	s(Jdate,sex)	2	-5.12	ns	2	-7.94	ns	2	-5.00	ns
	s(chick age,sex)	2	-4.82	ns	2	-6.54	ns	2	-9.37	ns
	s(Jdate,colony)	2	-3.93	ns	2	-4.08	ns	2	-4.01	ns
	s(chick age,colony)	2	-3.83	ns	2	-5.46	ns	2	-17.76	ns
	s(Jdate,birdID)	33.36	587.75	sig	36.44	309.97	sig	53.39	148.80	sig
	s(chick age,birdID)	28.15	543.07	sig	27.04	253.57	sig	45.44	131.90	sig
(ii) Wind farm overlap										
Combined Model	Sex	1	0.10	0.753	1	0.16	0.689	1	0.002	0.965
	s(Jdate)	1	0.14	0.708	1	0.19	0.666	1	0.41	0.522
	s(chick age)	1	0.34	0.560	1	0.35	0.555	1	0.08	0.784
	s(Jdate,colony)	2	1033.20	<0.001	2	1009.50	<0.001	2	4.15	0.042
	s(chick age,colony)	2	6.38	0.012	2	6.38	0.012	2	0.81	0.369
	s(Jdate,sex)	2	-12.44	ns	2	-14.49	ns	2	-10.82	ns
	s(chick age,sex)	2	-10.15	ns	2	-19.98	ns	2	-12.07	ns
	s(Jdate,birdID)	61.45	291.83	sig	59.46	274.68	sig	39.41	236.46	sig
	s(chick age,birdID)	29.41	205.56	sig	30.06	194.89	sig	34.28	213.79	sig
Foula model	s(Jdate)	1	1.21	0.273	1	1.24	0.267	1	0.97	0.326
	s(chick age)	1	1.92	0.168	1	1.96	0.163	1	0.55	0.459
Hoy model	s(Jdate)	1	7.82	0.006	1	6.12	0.014	1	0.13	0.714
	s(chick age)	1	8.45	0.004	1	5.58	0.019	1	0.13	0.719

(c) Area usage

Main effects	Variable	TOTAL			DAY			NIGHT		
		df or edf	F / dAIC	P	df or edf	F / dAIC	P	df or edf	F / dAIC	P
(i) Total area usage	Sex	1	0.05	0.833	1	0.22	0.642	1	0.06	0.814
	s(Jdate)	1	0.32	0.574	1	0.40	0.531	1	0.99	0.328
	s(chick age)	1	0.71	0.403	1	0.03	0.859	1	1.20	0.278
	s(Jdate,sex)	2	-3.75	ns	2	-3.60	ns	2	-3.21	ns
	s(chick age,sex)	2	-4.39	ns	2	-1.53	ns	2	-3.59	ns
	s(Jdate,colony)	2	-2.33	ns	2	0.15	ns	2	-4.02	ns
	s(chick age,colony)	2	-5.39	ns	2	-2.77	ns	2	-4.01	ns
	s(Jdate,birdID)	35.60	195.11	sig	38.58	185.69	sig	14.15	75.19	sig
	s(chick age,birdID)	31.66	177.82	sig	27.18	135.61	sig	16.11	105.14	sig
(ii) Wind farm overlap										
Combined model	Sex	1	3.76	0.057	1	3.25	0.077	1	15.44	<0.001
	s(Jdate)	1	0.04	0.836	1	0.13	0.725	1	0.70	0.411
	s(chick age)	1	0.41	0.525	1	0.54	0.466	1	0.01	0.909
	s(Jdate,colony)	2	-15.69	ns	2	-16.15	ns	2	-6.04	ns
	s(chick age,colony)	2	-15.15	ns	2	-16.54	ns	2	-3.66	ns
	s(Jdate,sex)	2	-4.87	ns	2	-4.65	ns	2	-6.49	ns
	s(chick age,sex)	2	-4.03	ns	2	-3.72	ns	2	-7.08	ns
	s(Jdate,birdID)	43.45	1496.70	sig	2.04	-19.04	ns	26.55	1339.80	sig
	s(chick age,birdID)	34.67	1473.50	sig	3.77	-7.36	ns	20.16	838.15	sig
Foula model	s(Jdate)	1	0.05	0.822	1	0	0.997	1	0	0.985
	s(chick age)	1	1.98	0.165	1	1.88	0.176	1	0.001	0.971
Hoy model	s(Jdate)	4.20	4.39	0.004	1	3.61	0.065	4.19	23.61	<0.001
	s(chick age)	4.82	7.87	0.001	1	4.61	0.039	1	0.37	0.557

Appendix 4.2 Outputs from GAMMs and GAMs assessing, for Great Skua, the extent of annual, seasonal and sex-specific variation in (a) trips statistics, (b) time budgets, and (c) spatial usage through size and overlap of the 95% KDE – outputs here provide the β-coefficients of the effects tested. Missing variables in the list or dashes denote effects that were not significant for those particular models.

(a)

TRIP STATS			**Total**			**Day**			**Night**		
β-coefficients	**Variable**	**Level**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Trip duration	Sex	Female	1.843±0.173	10.687	<0.001	-	-	-	1.736±0.278	6.252	<0.001
		Male	0.422±0.174	2.424	0.016	-	-	-	1.018±0.309	3.295	0.0012
	s(chick age,sex)	Female	1	1.056	0.305	-	-	-	1	0.445	0.506
		Male	2.941	7.544	<0.001	-	-	-	2.53	5.530	0.003
(ii) Foraging range	Sex	Female	-	-	-	-	-	-	3.889±0.278	13.986	<0.001
		Male	-	-	-	-	-	-	0.685±0.304	2.250	0.657
	s(chick age,sex)	Female	1	0.024	0.876	1	0.007	0.935	1	0.277	0.6
		Male	1.002	1.750	0.186	1.812	1.106	0.319	1	2.536	0.113
(iii) Total distance per trip	Sex	Female	-	-	-	-	-	-	4.748±0.259	18.334	0.001
		Male	-	-	-	-	-	-	0.789±0.283	2.790	0.006
	s(chick age,sex)	Female	1	0.061	0.805	-	-	-	1	0.001	0.982
		Male	1.931	1.724	0.179	-	-	-	1	1.048	0.307

(b)

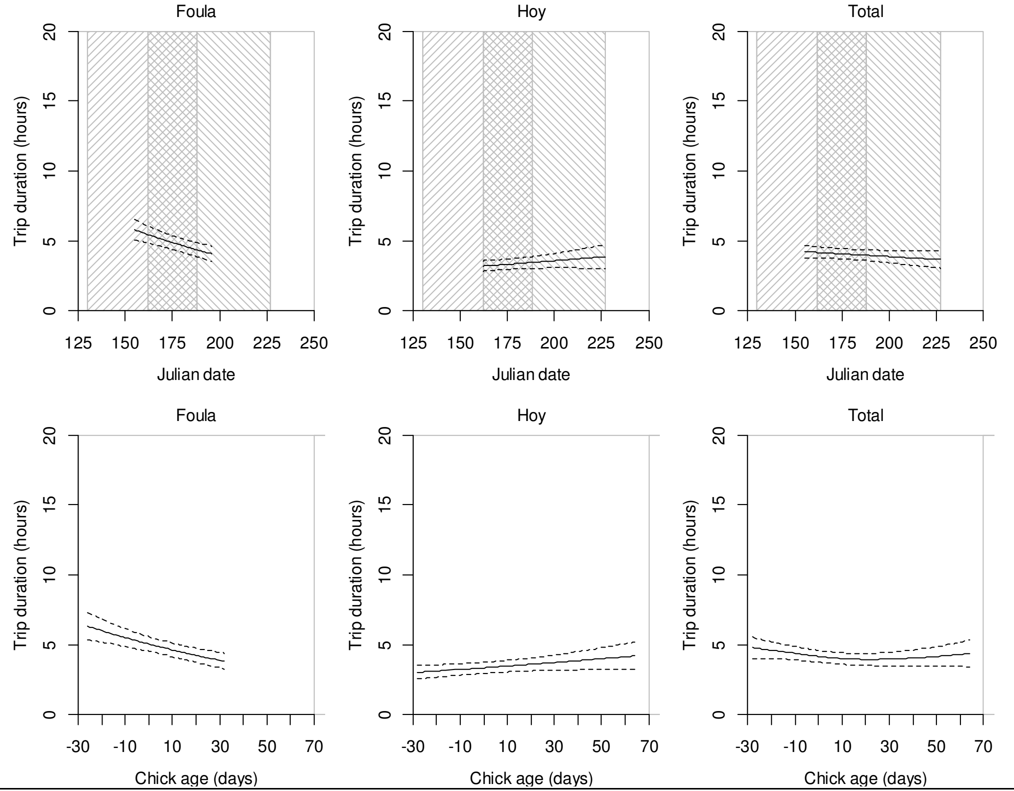
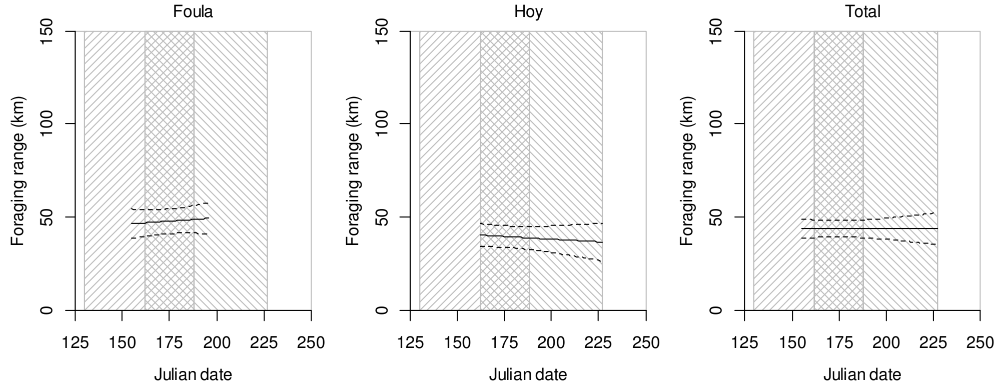
TRIP STATS			**Total**			**Day**			**Night**		
β-coefficients	**Variable**	**Level**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Time away from nest	Sex	Female	-1.225±0.128	-9.583	< 0.001	-1.446±0.108	-13.356	< 0.001	-3.186±0.290	-11.000	< 0.001
		Male	0.370±0.137	2.697	0.007	0.286±0.138	2.074	0.039	0.878±0.318	2.763	0.006
(ii) Time in wind farm	N/A	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-

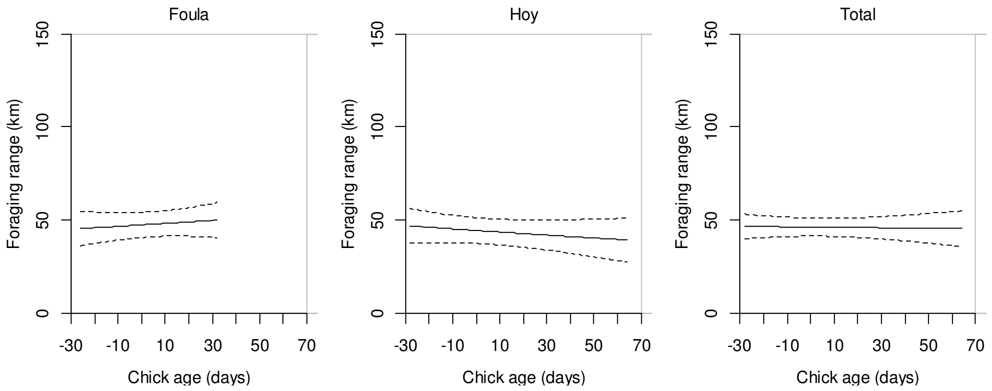
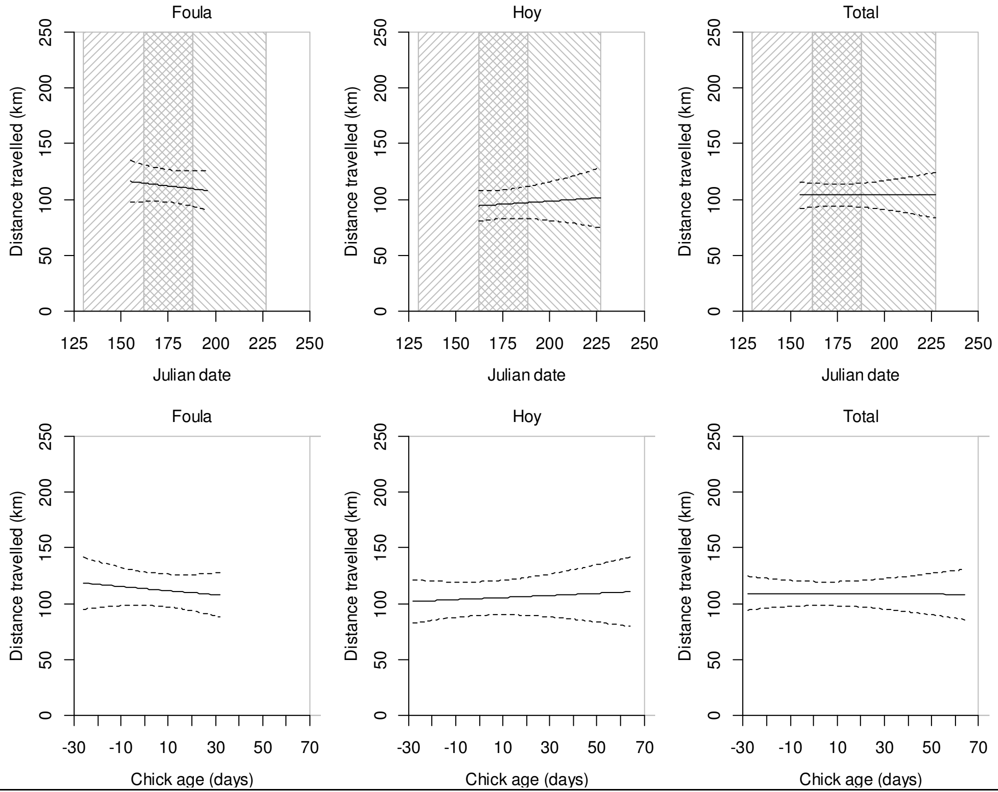
(c)

TRIP STATS			Total			Day			Night		
β-coefficients	**Variable**	**Level**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**	**β / edf**	**t / F**	**P**
(i) Total area usage	s(Jdate,colony)	Foula	1.843	4.353	0.018	1	8.927	0.003	1	0.089	0.766
		Hoy	1	2.863	0.093	1	2.043	0.156	1	0.034	0.855
	s(chick age,colony)	Foula	2.598	2.651	0.062	1	4.505	0.036	1	0.000	0.989
		Hoy	1	1.860	0.018	1	1.834	0.179	1	0.002	0.967
(ii) Wind farm overlap	Sex	Female	3.815±0.273	13.979	<0.001	-0.765±0.255	-3.002	0.004	3.368±0.118	28.531	< 0.001
		Male	-0.577±0.298	-1.938	0.057	-0.506±0.281	-1.802	0.077	-0.708±0.180	-3.929	< 0.001
	s(Jdate,colony)	Foula	1	0.304	0.583	1	1.535	0.218	1	0.299	0.587
		Hoy	1	4.715	0.032	1	1.710	0.194	1	0.976	0.327
	s(chick age,colony)	Foula	1	0.233	0.630	1	0.026	0.871	1	0.034	0.854
		Hoy	1	6.907	0.010	1	3.342	0.071	1	0.161	0.689

Appendix 4.3 Day / night differences in relationships for Great Skua (using data from Foula and Hoy combined) derived from GAMMs for: (a) Summary statistics – trip duration, foraging range, and distance travelled per trip, (b) Time budgets, time spent away from the nest, time spent offshore, and time spent in wind farm zones, and (c) Spatial use, total area usage (95% KDE size), overlap with offshore areas (of 95% KDE), and overlap with offshore wind farms; significance of effects are given in Table 4.4.

(a) Summary statistics

Measure	Day
Trip duration	
Foraging range	

	
Total distance travelled per trip	

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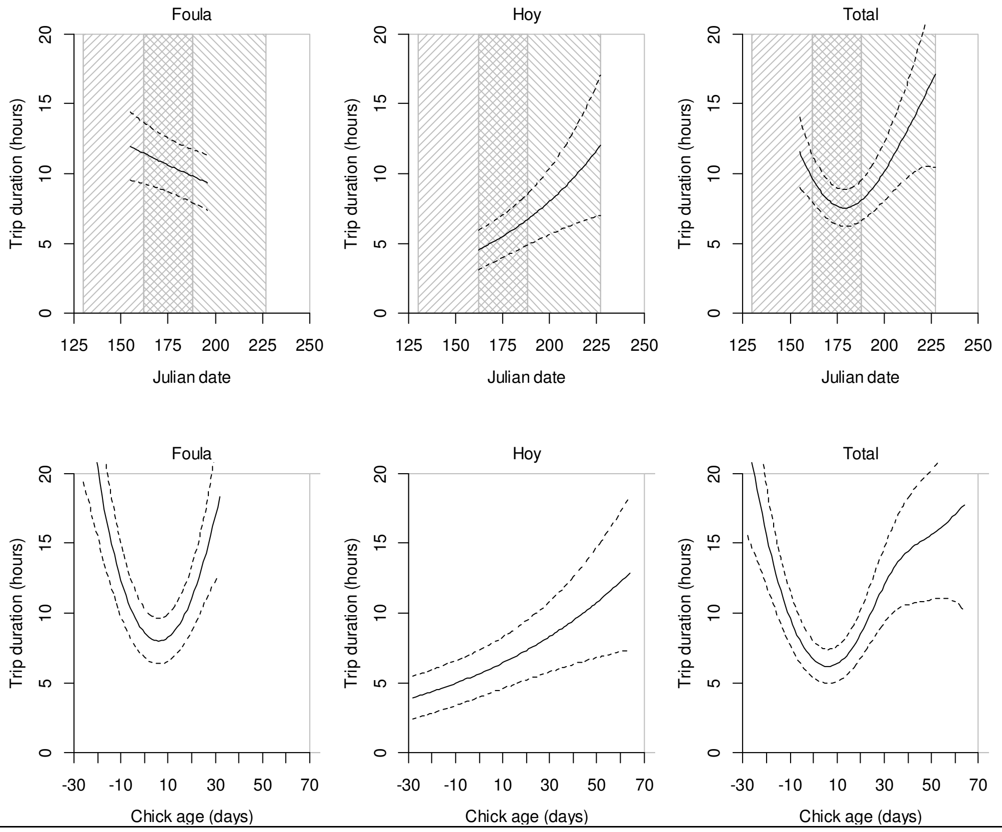
<tr><th>Measure</th><th>Night</th></tr>
<tr><td>Trip duration</td><td>
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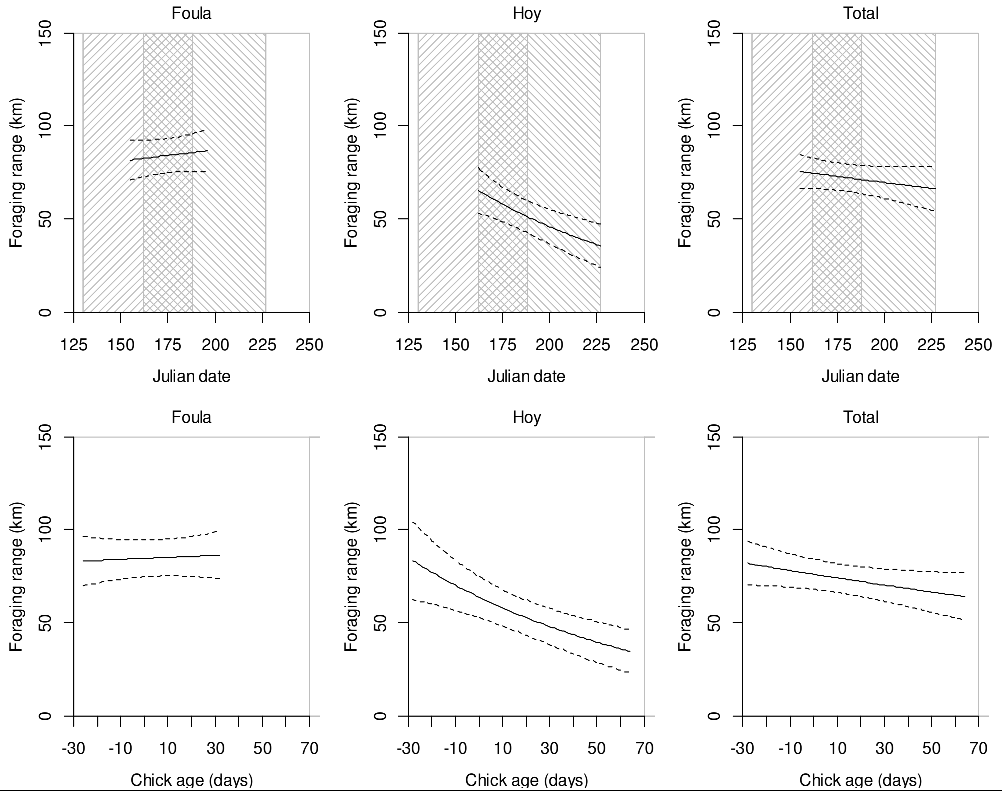
<tr><td>Foraging range</td><td>
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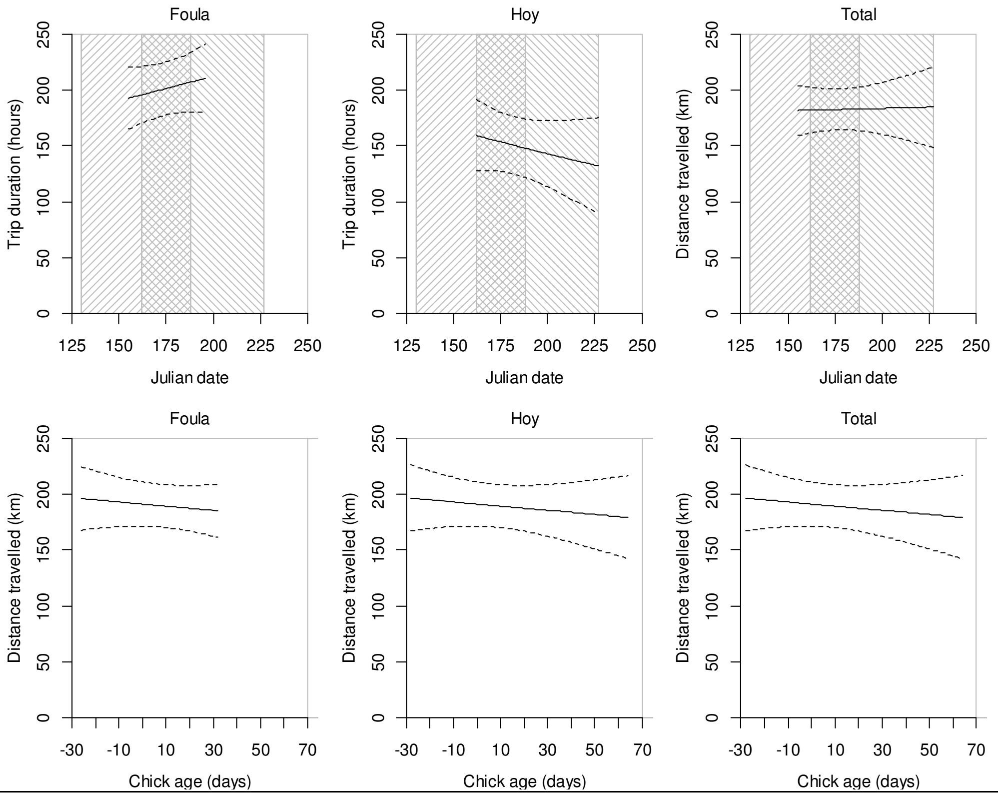
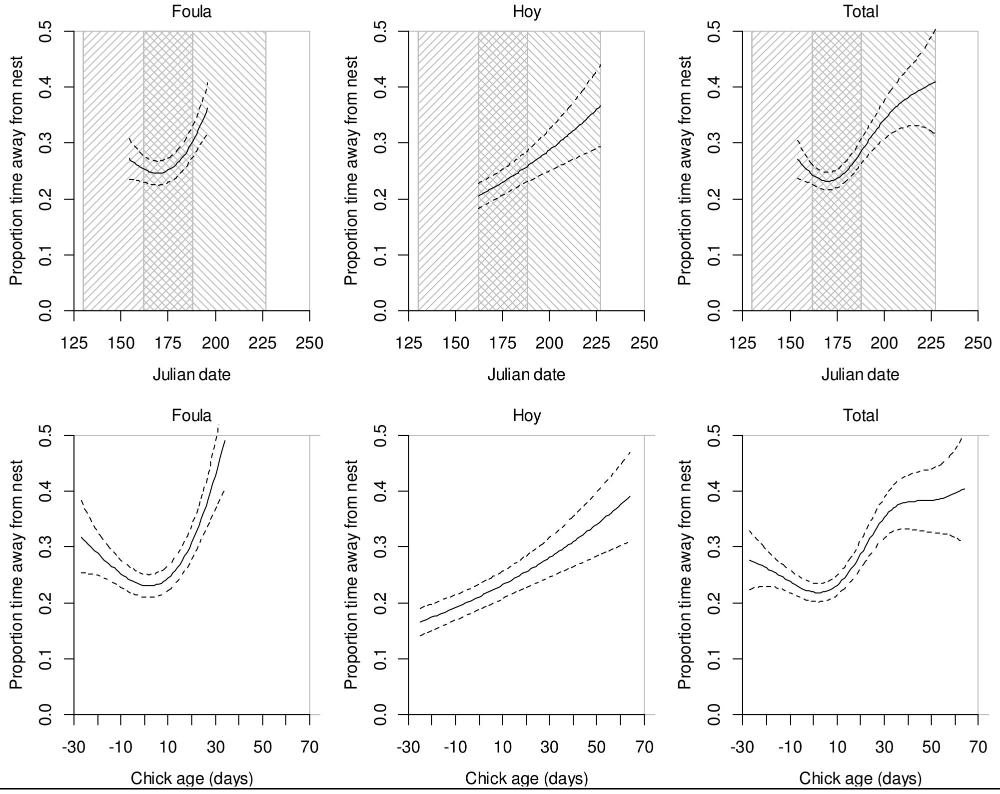
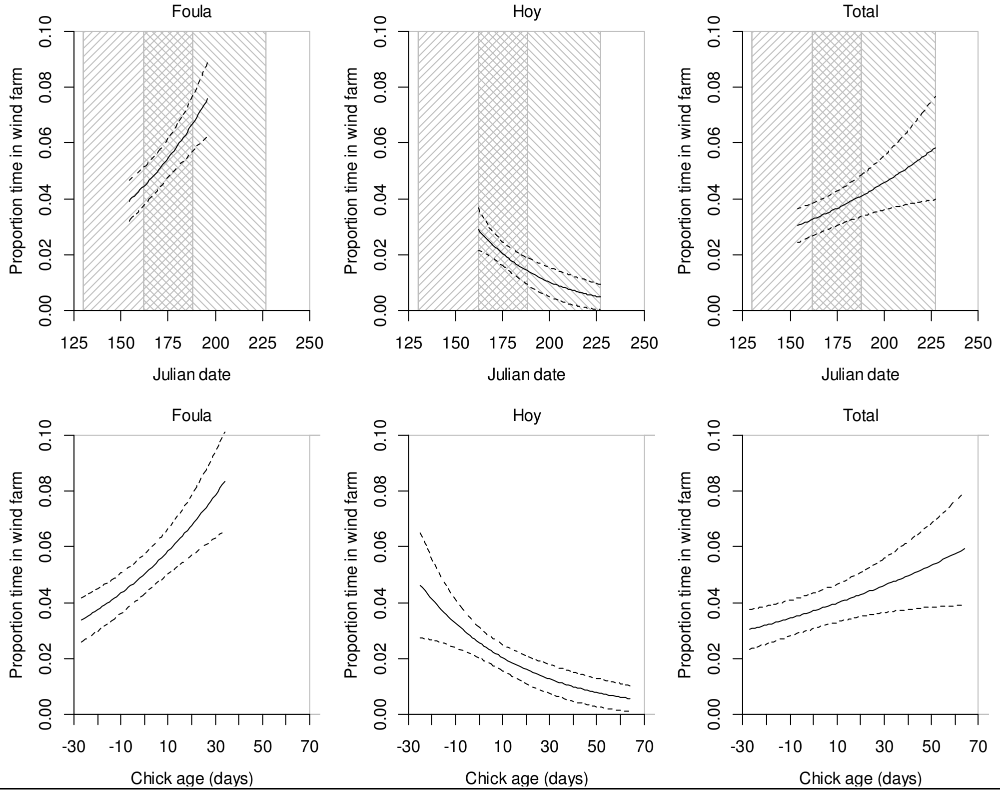
</table>

Total distance travelled per trip	

(b) Time budgets

<table>
<tr><th>Measure</th><th>Day</th></tr>
<tr><td>Time away from nest</td><td>
</td></tr>
<tr><td>Time spent in wind farm</td><td>
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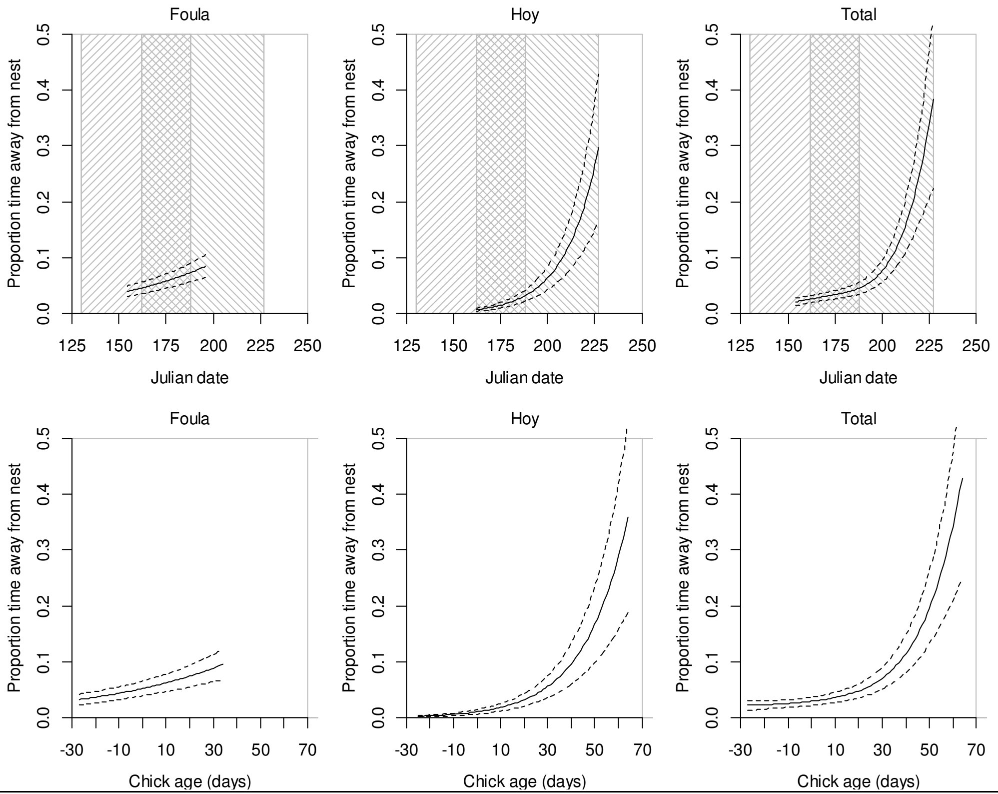
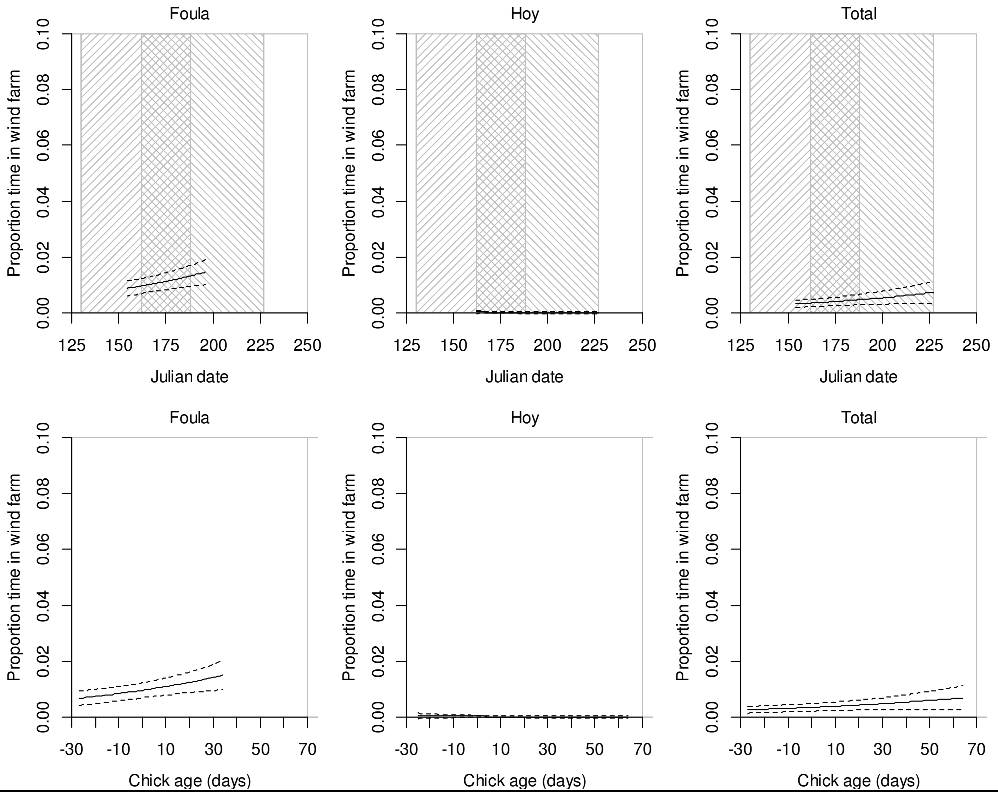
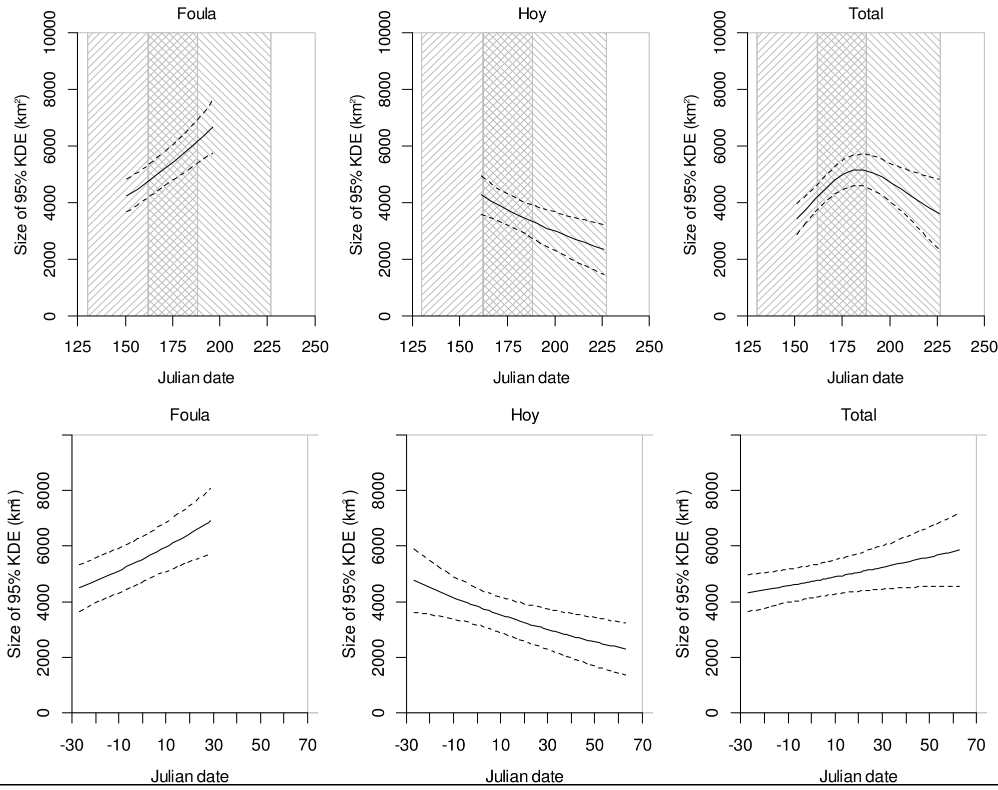
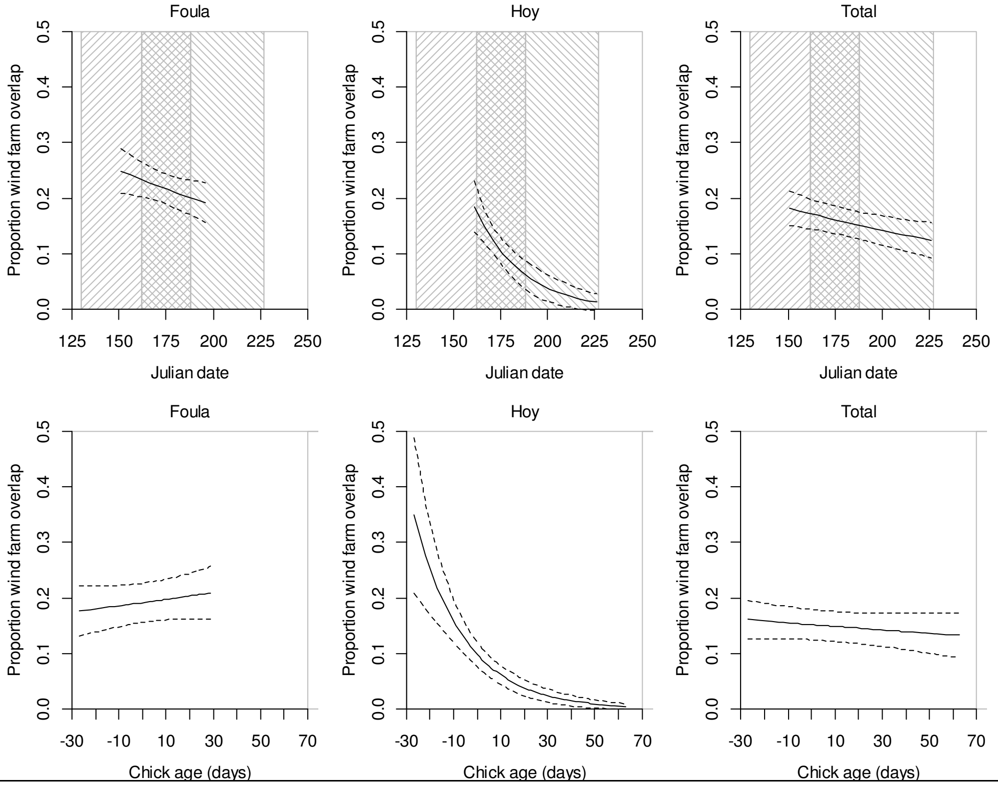
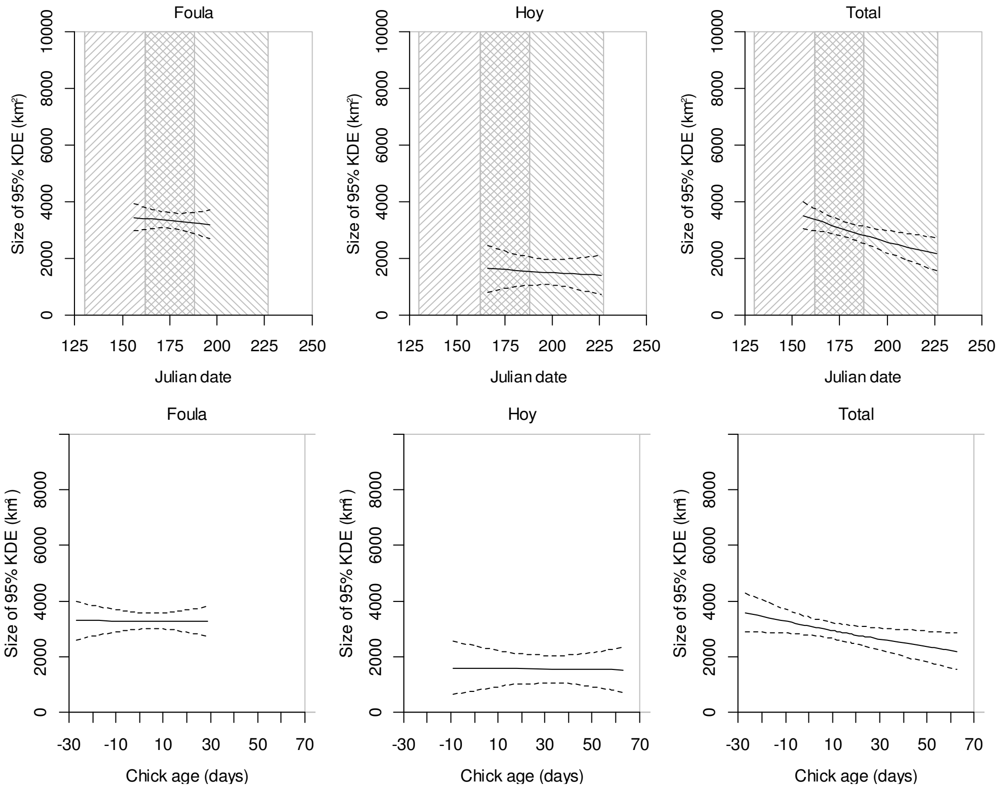
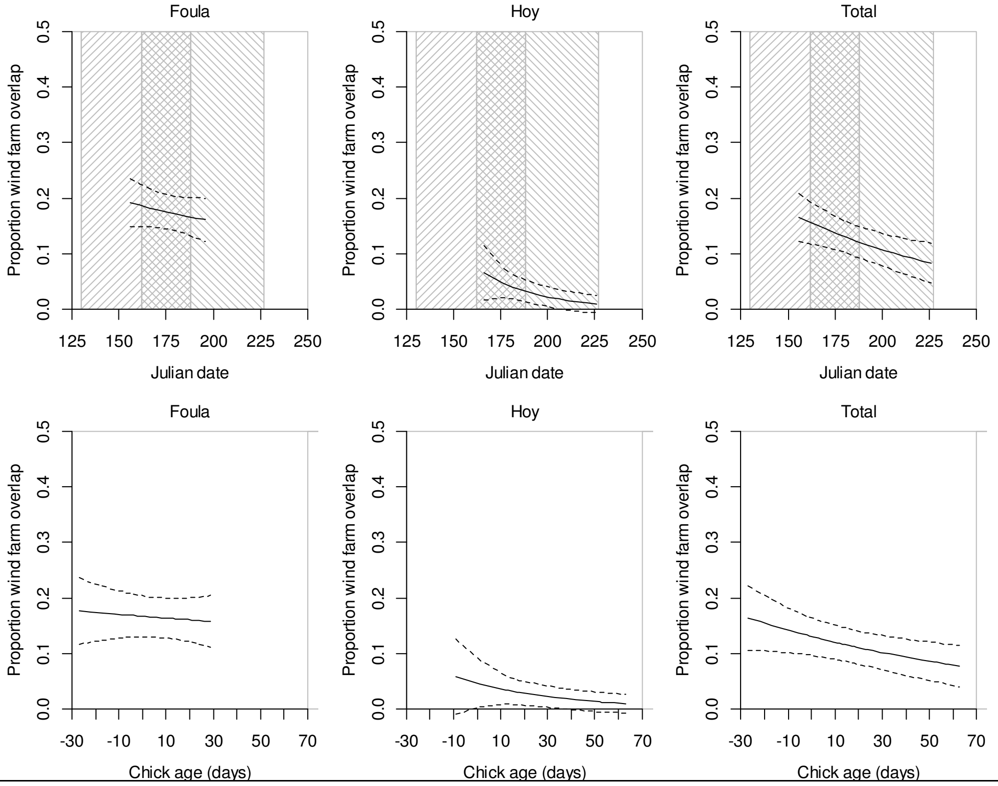
<table>
<tr><th>Measure</th><th>Night</th></tr>
<tr><td>Time away from nest</td><td>
</td></tr>
<tr><td>Time spent in wind farm</td><td>
</td></tr>
</table>

(c) Area usage

Measure	Day
Total area	
Wind farm area overlap	

Measure	Night
Total area	
Wind farm area overlap	

Appendix 7.1 Overlap of the tracks of individual Lesser Black-backed Gulls with offshore wind farm sites during the migration and wintering periods, expressed as the total distance travelled (km) within the site (Table 7.4, for means and percentages across all birds).

			Bird																	
Country	**Wind farm**	**Status**	**334**	**336**	**388**	**391**	**395**	**407**	**459**	**460**	**478**	**479**	**480**	**482**	**483**	**484**	**485**	**486**	**492**	**493**
Belgium	THV Mermaid	1																		0.05
Spain	HiPRWind	1				0.12	0.16		0.20							0.12				
	Proyecto EMERGE	1								0.10										
	Proyecto Idermar Phase 1	1		0.01																
	Proyecto Idermar Phase 2	1		0.01																
	Proyecto Idermar Phase 3	1		0.01																
	SeAsturLab Phase 2	1				0.53	0.13	0.27	0.08	0.06		0.02	0.09			0.17				
	SeAsturLab Phase 3	1				0.05	0.17	0.00		0.03			0.13							
France	Cherbourg	1	0.06				0.15	0.12					0.09					0.11		
	Cote d'Albatre II	1								0.05										
	Courseulles-Sur-Mer	1					3.10			7.63		4.12								
	d’Aïse	1		1.55		4.02	4.74	4.30		4.09		2.67						0.70		
	Des Minquiers	1		0.28		0.13		0.00				0.21								
	Fécamp	1							0.36	3.01		0.81								
	Haute Normandie	1							0.12	0.12										
	Le Tréport	1							0.92	0.26										
	Les Grunes	1		0.01			2.03	0.61				1.41								
	Neoen	1					0.19	0.06				0.13								
	Noirmoutier	1		0.12								1.24				5.52				
	Portes en Ré	1					0.02	0.15		0.14						0.15				
	Saint-Brieuc	1					0.01	4.93				3.04	6.62		4.68	6.25		7.82		
	Saint-Nazaire	1		0.63			0.43									3.18				
	Vendée	1		0.09								1.22				0.55				
	WIN 2	3							0.72	0.68										
	WINFLO Wind turbine	3					0.04									0.02				
Great Britain	East Anglia One	2																		0.75
	East Anglia rest	2																		39.54
	ETI Floating Offshore Wind Demonstrator	1													0.06					
	Galloper Wind Farm	3	14.77						5.11									1.20		1.55

			Bird																	
Country	**Wind farm**	**Status**	**334**	**336**	**388**	**391**	**395**	**407**	**459**	**460**	**478**	**479**	**480**	**482**	**483**	**484**	**485**	**486**	**492**	**493**
	Greater Gabbard	5	8.86						2.76									1.41		
	Gunfleet Sands 3 - Demonstration Project	5	0.13					0.02	0.07							0.14				
	Gunfleet Sands I + II	5	0.76	0.05				0.10	0.39	0.10						0.76				
	Inner Dowsing	5																	1.57	
	Kentish Flats	5	0.43						0.50											
	Kentish Flats Extension	3	0.36						0.42											
	Lincs	5																	6.75	
	London Array Phase 1	5	1.53	4.08					0.02	5.62										
	London Array Phase 2	3	1.26	0.86					0.46	0.48										
	Lynn	5																	1.58	
	Navitus Bay Wind Park 1	1				5.74	17.12	2.24				2.23			13.26	2.63				
	Rampion	2	1.98	0.06			26.11					0.72	1.00							
	Scroby Sands	5	0.15																	7.89
	Thanet	5								0.30										
Portugal	WindFloat - Phase 1	5	0.16	0.32	0.14	0.16	0.72	0.53	0.32	0.47		0.41	0.16		0.34	0.32		0.16		
	WindFloat - Phase 2	1	0.14						0.06							0.01				
	WindFloat - Phase 3	1	0.14						0.06							0.01				
	Total		30.73	8.06	0.14	10.75	55.12	13.31	12.58	23.15	0.00	18.23	8.09	0.00	18.34	19.82	0.00	11.39	9.90	49.78
	% total distance		0.15	0.03	0.00	0.08	0.13	0.05	0.03	0.09	0.00	0.06	0.04	0.00	0.09	0.07	0.00	0.06	0.08	0.33

Status: 1 – Concept/Early Planning; 2 – Consent Application Submitted; 3 – Consent Authorised; 4 – In construction; 5 – Fully Commissioned.

Appendix 7.2 Overlap of the tracks of individual Lesser Black-backed Gulls with offshore wind farm sites during the migration and wintering periods, expressed as the total time travelled (hrs) within the site (Table 7.5, for means and percentages across all birds).

			Bird																	
Country	**Wind farm**	**Status**	**334**	**336**	**388**	**391**	**395**	**407**	**459**	**460**	**478**	**479**	**480**	**482**	**483**	**484**	**485**	**486**	**492**	**493**
Belgium	THV Mermaid	1																		0.01
Spain	HiPRWind	1				0.00	0.02		0.00							0.00				
	Proyecto EMERGE	1								0.00										
	Proyecto Idermar Phase 1	1		0.00																
	Proyecto Idermar Phase 2	1		0.00																
	Proyecto Idermar Phase 3	1		0.00																
	SeAsturLab Phase 2	1				0.11	0.01	0.12	0.00	0.00		0.00	0.02			0.05				
	SeAsturLab Phase 3	1				0.02	0.01	0.00		0.00			0.01							
France	Cherbourg	1	0.00				0.00	0.00					0.00					0.00		
	Cote d'Albatre II	1								0.00										
	Courseulles-Sur-Mer	1					0.12			1.47		1.03								
	d'Aïse	1		0.03		0.08	0.14	0.07		0.21		0.26						0.11		
	Des Minquiers	1		0.08		0.02		0.00				0.04								
	Fécamp	1							0.01	0.04		0.06								
	Haute Normandie	1							0.01	0.00										
	Le Tréport	1							0.03	0.02										
	Les Grunes	1		0.00			0.27	0.08				0.06								
	Neoen	1					0.03	0.01				0.01								
	Noirmoutier	1		0.00								0.05				2.13				
	Portes en Ré	1					0.00	0.01		0.10						0.02				
	Saint-Brieuc	1					0.00	0.25				0.07	0.19		0.06	0.46		0.18		
	Saint-Nazaire	1		0.03			0.01									0.25				
	Vendée	1		0.00								0.07				0.10				
	WIN 2	3							0.08	0.02										
	WINFLO Wind turbine	3					0.00									0.00				
Great Britain	East Anglia One	2																		0.56
	East Anglia rest	2																		7.10
	ETI Floating Offshore Wind Demonstrator	1													0.01					
	Galloper Wind Farm	3	1.31						0.51									0.19		0.09

			Bird																	
Country	**Wind farm**	**Status**	**334**	**336**	**388**	**391**	**395**	**407**	**459**	**460**	**478**	**479**	**480**	**482**	**483**	**484**	**485**	**486**	**492**	**493**
	Greater Gabbard	5	0.64						0.28									0.22		
	Gunfleet Sands 3 - Demonstration Project	5	0.00					0.00	0.01							0.00				
	Gunfleet Sands I + II	5	0.02	0.00				0.00	0.03	0.01						0.02				
	Inner Dowsing	5																	0.27	
	Kentish Flats	5	0.14						0.10											
	Kentish Flats Extension	3	0.11						0.08											
	Lincs	5																	1.34	
	London Array Phase 1	5	0.06	0.15					0.00	0.78										
	London Array Phase 2	3	0.28	0.03					0.01	0.07										
	Lynn	5																	0.27	
	Navitus Bay Wind Park 1	1				0.12	0.71	0.08				0.04			0.25	0.27				
	Rampion	2	0.46	0.00			2.32					0.02	0.35							
	Scroby Sands	5	0.01																	2.97
	Thanet	5								0.01										
Portugal	WindFloat - Phase 1	5	0.01	0.01	0.00	0.00	0.25	0.02	0.01	0.02		0.02	0.00		0.08	0.01		0.00		
	WindFloat - Phase 2	1	0.00						0.01							0.00				
	WindFloat - Phase 3	1	0.00						0.01							0.00				
	Total		3.03	0.34	0.00	0.35	3.88	0.65	1.17	2.76	0.00	1.73	0.57	0.00	0.40	3.31	0.00	0.71	1.88	10.73
	% total distance		0.05	0.00	0.00	0.01	0.02	0.01	0.01	0.03	0.00	0.02	0.01	0.00	0.00	0.03	0.00	0.01	0.02	0.16

Status: 1 – Concept/Early Planning; 2 – Consent Application Submitted; 3 – Consent Authorised; 4 – In construction; 5 – Fully Commissioned.

Appendix 7.3 Migration routes of a single Lesser Black-backed Gull (bird 395) over 2010/11 (green), 2011/12 (blue) and 2012/13 (red).