giving nature a home

Seabird tracking at the Flamborough & Filey Coast:
Assessing the impacts of offshore wind turbines

Pilot study 2017
Fieldwork report & recommendations

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Executive summary

Hornsea Project One agreed to contribute to ornithological work at the Flamborough and Filey Coast potential Special Protection Area (pSPA), specifically a colony monitoring campaign and tracking work as part of a wider strategic study. It was agreed that the data would be made available for wider strategic research. The implementation of a strategic monitoring programme for the Hornsea Zone is to improve the understanding of the populations of key species (kittiwake, auks and gannet) at the pSPA and any possible dependence on the Hornsea Zone. The objectives of the strategic programme will be to improve understanding, through the collection and analysis of robust data, of:

1) abundance and trends in abundance of the species populations (and assemblage) of interest features of the pSPA. This would be achieved through contributions to whole colony counts that are more comprehensive and regularly undertaken than is currently the case.

2) population processes, which would include the collection of more data on the productivity and survivorship of key species breeding at the pSPA.

3) connectivity of the pSPA populations and the Hornsea Zone, through tagging which can reveal the movements of individuals between the colony and the zone and wind farm project areas within it.

As part of this package of monitoring, 20 adult kittiwakes breeding within the pSPA were fitted with lightweight, remote-download GPS-accelerometer tracking devices during the 2017 breeding season, just after their chicks hatched. Nest monitoring, for tracked and control birds, was also conducted in order to determine whether the tracking devices had any effect on bird welfare or breeding success. The three principal aims of the 2017 work presented in this report were:

(a) to collect baseline tracking data before turbines are in place (so that, in future, the behaviour and area-use of tracked birds can be compared before, during and after turbine construction);

(b) to pilot the use of this tracking system on this species and at the Flamborough and Filey Coast, and methods of data analysis, in order to refine methods for future strategic or post-consent tracking work; and

(c) to collect information on some of the parameters that feed into collision risk models in order to test the assumptions of these models and so that the models can be based on improved data in future.

All 20 tracking devices were deployed successfully at Flamborough, Filey and a new catching site at Speeton, and data were obtained from 18 of these. The new (for this species) medium-term tag attachment method we used worked very well and allowed tracking data to be collected for several weeks, and much later into the breeding season than has been achieved previously for kittiwakes (which had previously only been tracked for a few days at a time early in the chick-rearing period). The remote-download system also worked well in our study area, once we had determined suitable locations for the receivers. We were able to use an additional catching site at Speeton due to the system's ability to bounce data from a receiver near the nests at Speeton, to another on Filey Brigg 9km away, and then to a base station (connected to the internet) in a house 7km away from that. The two trackers that did not produce data were attributed to tag failure (potentially due to birds damaging the devices after attachment) rather than bird death, as

both birds were seen attending their nests in the colony (and within range of the receivers) during the weeks following tag attachment.

Stormy weather partway through the chick-rearing period had catastrophic effects on nesting success throughout the colony (tagged and control nests), with many nests failing at this time. However, many of the birds whose nests failed continued to visit the colony occasionally for some time after nest failure. This meant that we have collected world-first tracking data on the movements of kittiwakes after nest failure, which will be extremely valuable in understanding how birds at this life-stage behave at sea. The trackers did not have any obvious effects on adult welfare, but we are less certain about whether there are effects on nesting success of tracked birds. An initial comparison of tracked and control nests showed that nests of tracked birds were significantly more likely to have failed. However, once nest height was taken into account, this effect disappeared; it seems that lower nests (where we can catch birds) are more likely to fail, particularly at Flamborough, than those higher up the cliff, perhaps because of wave action from below compounding the effects of wind and rain on chicks.

Whilst the data collected were enormously valuable (e.g. ~30,000 GPS locations collected from 18 birds), we were unable to get as frequent GPS fixes as we had expected from the tags, due to issues with battery life caused primarily by the cliffs shading the tag solar panels for part of the day when birds were in the colony. Accelerometer data collection was very limited for this reason. We have spoken with the tag developers who are already working on modifications to the tracking system that should enable us to collect better data next year.

Data analysis is in progress and will continue until early 2018, but some initial results are included here. These results must be interpreted with caution since they represent only one year of study on 18 birds from a selection of nest sites within the large pSPA colony, and previous studies have shown that there is variation in the offshore areas used by kittiwakes both between individuals and years. Tagged birds from both Filey and Flamborough showed some use of the Hornsea wind farm zones, particularly Hornsea 1 and 2, largely for commuting, with the key foraging areas being to the north and south of the wind farm footprints. There was less overlap with the proposed wind farms of birds from Filey, which tended to forage to the north of the Hornsea developments, than those from Flamborough, which foraged further south. Given that birds at the north and south of the colony have different foraging distributions, it is important to understand the at-sea distribution and movements of birds at the centre of the colony, which represents the highest proportion of individuals. For this reason, one of our key recommendations for future years is to attempt to target more birds for tagging studies close to the centre of the colony within the Bempton cliffs RSPB reserve and at the new study site at Speeton.

We include recommendations for future work split into three sections: (i) data analysis/write up we intend to complete as part of the current contract; (ii) additional data analysis that would require new funding for staff time (but no additional data collection), largely due to potential collaborators offering to share data with us in recent weeks; and (iii) recommendations for further data collection in coming years. We recommend that in 2018 both kittiwakes and gannets are tracked using the current system, with the addition of barometric altimeters to allow more accurate flight height data to be collected.

Introduction

Background

The Flamborough and Filey Coast potential Special Protection Area (pSPA) is of international importance for breeding seabirds and contains the UK's largest mainland kittiwake and gannet colonies as well as important numbers of guillemot, razorbill, puffin and herring gull.

The Hornsea offshore wind farm development zones are situated in the North Sea, 63 km from the Flamborough and Filey Coast pSPA. The first two wind farm projects within the Hornsea zone have been granted planning consent and a package of strategic monitoring is being developed.

The potential impacts of the Hornsea wind farms on seabirds breeding in the pSPA include collision risk (particularly for kittiwake and gannet) and displacement (particularly for guillemot, razorbill and puffin), and there are also questions about the origin (breeding sites) of birds present in the Hornsea zone during the winter. However, there is a level of uncertainty associated with the predicted strength of these impacts on the population which, as highlighted in the Environmental Impact Assessment, requires further work. Therefore, the central aim of strategic monitoring is to reduce this uncertainty.

While there is a need to monitor impacts as part of the strategic monitoring for the Hornsea wind farms, there is a corresponding aim to conduct seabird population monitoring and understand potential effects on bird conservation in the area both by Natural England and the Flamborough Head European Marine Site Management Scheme in relation to monitoring the pSPA, and by RSPB as part of the reserve monitoring for the Bempton Cliffs reserve. To ensure a coordinated approach to seabird monitoring and conservation in the area, a voluntary seabird monitoring group has been set up comprising representatives of all the organisations listed above as well as Ørsted and their consultants (currently NIRAS). This group was involved in the concept development for the current strategic monitoring project.

Aims & Objectives

This project, funded as part of the strategic monitoring for Hornsea Project One, primarily addresses questions about kittiwake collision risk by tracking individual birds during the breeding season. However, the project was set up with the aim of collecting additional data in future years as part of a longer-term monitoring package to be developed. Here we report on the pilot / baseline kittiwake tracking work conducted during 2017; as such the aims and objectives have been split into long- and short-term (2017) aims below.

Long-term aims & objectives

Previous GPS and satellite tracking work conducted by RSPB has shown that the Hornsea wind farm zone is within the foraging range of kittiwakes and gannets breeding in the pSPA. Current collision risk modelling predicts that the wind farms will lead to collision mortality in both of these species, with uncertainty surrounding the likely magnitude of this impact and its significance for these populations. More widely, there are significant gaps in understanding of seabird collision risk from offshore wind farms, some of which could potentially be narrowed by this strategic work. As such, this project aims to collect information relevant to the Hornsea development, but which will also have broader relevance to the testing and refinement of collision risk models for offshore wind farms.

A key practical limitation of any project tracking kittiwakes is that we are unlikely to obtain a licence to use a long-term harness attachment of tags to this species, due to welfare considerations. Whilst harnesses have been used successfully (with evidence of no welfare implications) on species such as lesser black-backed and herring gulls, there have also been considerable problems with harness mounting on other species such as great skua (Thaxter *et al*. 2016) that spend the winter at sea. Because kittiwakes spend the winter at sea, we are concerned that they may be similarly adversely affected by a harness. This means that (unless using very small tags that can be attached to leg rings, such as geolocators) we are limited to temporary attachment of tags to feathers using glue or tape, which will last for a few weeks at most.

We use high quality GPS tracking devices developed by the University of Amsterdam (UvA) (http://www.uva-bits.nl/system/) to collect data on birds' locations at a high temporal frequency (between every 3 and 15 minutes). These tags also contain accelerometers, which allow us to detect the individual wing beats of birds and differentiate gliding/soaring from flapping flight. These accelerometers allow us to measure sudden changes in flight behaviour around turbines (i.e. changing from gliding to flapping flight in close proximity to a turbine could indicate micro avoidance). Furthermore, innovative analytical methods developed recently by the British Trust for Ornithology (BTO) have allowed robust modelling of flight height distributions from these tags, taking account of the error in altitude recorded by GPS (Ross-Smith *et al*. 2016[1]). These technical

[1] This method recognises that GPS tags record altitude with error and treats each recorded flight height as an observation with error. It then uses a state-space model that models the underlying flight height distribution and the error distribution in parallel. The error in the GPS tag altitude estimate is related to the number and position of satellites, captured by the Dilution of Precision (DOP) which is recorded by the tag for each GPS location. The error in altitudinal measurements is assumed to be normally distributed around the true altitude, with the standard deviation of the normal distribution linearly related to the DOP of each

specifications will allow us to address the following questions, which are of relevance to the monitoring of Hornsea wind farms, but also address some of the critical uncertainties in relation to the parameters used in collision risk modelling for offshore wind farms:

1. Provision of site-specific flight height information for kittiwake (a key part of testing whether the assumptions of collision risk modelling are correct)
2. Empirical measurement of flight speed, and variability in flight speed (the flight speeds currently used in collision risk models are based on very limited data and do not account for variability)
3. Empirical measurement of the tortuosity of flight lines (collision risk models currently assume birds fly in straight lines. We know they don't. This will allow us to quantify how much flight lines deviate from a straight line and test how this alters collision risk)
4. Empirical measurement of collision avoidance behaviour – this will be a longer-term output of the project, should tracking be continued in future years, but tracking during 2017 will be important to establish an appropriate baseline. Macro and meso avoidance would be detectable by examining high resolution GPS locations in relation to turbines. Previous tracking is not at sufficient resolution to allow these measurements (points were far enough apart in time that a bird could have flown into a wind farm and out the other side in between location fixes), hence the need for new work to establish a baseline ahead of future monitoring. Micro avoidance could be measured by combining the high-resolution GPS fixes with accelerometer data which allows the detection of individual wing beats. Once turbines are constructed, this would allow us to detect a sudden change to rapid flapping flight (from soaring or slower flapping flight) when birds are in the vicinity of turbines. We propose to use a before-after control-impact (BACI) design to compare the frequency of these types of sudden changes in flight patterns in the vicinity of turbines with control areas away from turbines, and to compare flight patterns before and after construction, to allow a measurement of micro avoidance to be developed, currently a critical gap in knowledge.

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observation. The error distribution varied between species (lesser black-backed gull and great skua), presumably because behavioural differences (more variable vs more constant flight height) change the modelled error and was wider when DOP was higher. The mean DOP was 3.3 (SD 1.6) for lesser black-backed gull, and the standard deviation of the altitude measurement error distribution was 8.9 m for DOP = 1 and 16.9 m for DOP = 10. For great skua the mean DOP was 3.7 (SD 1.6) and the standard deviation of the altitude measurement was much higher at 28.8 m for DOP = 1 and 38.5 m for DOP = 10.

Short-term aims and objectives (2017 work)

The pilot study of 2017 was to fulfil the short term aims of:

i. Collecting baseline data of the same quality as follow-up years of tracking during construction and operation of Hornsea Project One Offshore Wind Farm, and
ii. to pilot the methods of both data collection and analysis to be used in the future.

Data from the baseline year could be used to investigate long-term aims 1-3 above (though the analyses would be stronger once additional years of tracking are incorporated during and after construction), while long-term aim 4 (avoidance rates) could be answered once we have collected data using the similar tracking methods following construction of Hornsea Project One Offshore Wind Farm. In fulfilling the short term aims, the objectives of the pilot study in 2017 were to:

a) Track 20 individual birds from the colonies at Flamborough Head and Filey Brigg.
b) Conduct follow up fieldwork to monitor the 20 tagged birds and at least as many control birds, and to manage the download of data from the tags.
c) Use appropriate analytical methods to analyse the data in order to address the key questions set out above.

This preliminary report summarises the results of the first year of fieldwork and outlines proposals for the following year's work. In the longer term we will report the results of the study in peer-reviewed papers. We believe this is the best way to ensure that the findings are accepted as robust by the wider scientific and industry community, due to the rigorous nature of the peer-review process.

Methods

Field methods

Site selection

Flamborough Head and Filey Brigg were chosen as the main tagging locations within the Flamborough and Filey Coast pSPA as these are the safest places to catch kittiwakes in the area. At these locations, access to nests to catch birds is possible from the bottom of the cliffs without the need for boat access or working at height with ropes, both of which can cause safety issues for birds and people. In addition, both sites have previously been used by RSPB for kittiwake tracking, and hence there are data from other years against which to compare this year's results.

Selection of areas of cliff with groups of nests to monitor and catch birds from (sub-sites), in both Flamborough and Filey, was based on three main criteria:

1. Accessibility for tagging (i.e. numerous nests had to be reachable from ground with a 12 m noose pole)
2. A straight line of view to potential relay positions within 1 km to remotely download data via a network setup
3. Visibility for regular monitoring (i.e. safe and distant positions for observers that minimise disturbance of nests without compromising the ability to see nest contents)

Photographs from the bottom of the cliff as well as potential monitoring and relay positions were overlaid to select sub-sites that fulfilled all three criteria. This was done early in the breeding season when birds were incubating eggs. If there was more than one suitable option for relay positions in either Flamborough or Filey, the one that maximized the number of accessible/observable nests was chosen to account for predictable breeding failure during incubation (approximately 50%). In addition to nests suitable for tagging, at least the same amount of control nests had to be monitored to assess potential impacts of tagging on breeding performance. Therefore, only sub-sites that had at least double the amount of accessible and observable nest than needed for tagging in addition to the same number of control nests were chosen (i.e. If 10 birds are to be tagged at one sub-site, the site must have at least 40 nests).

Nests were further chosen based on their proximity to each other, their height and the direction of the cliff face to ensure comparable exposure to weather, predation etc. and thus the validity of controls. Using the photographs taken from the monitoring positions, all selected nests were numbered. At sites where the nest density was very high (Flamborough) only a subset of nests was selected and labelled to ensure the feasibility of frequent monitoring. These photographs were printed on photo paper and laminated as references. Monitored nests were divided into 6 monitoring plots (6 photographs) in Flamborough and into 2 monitoring plots (2 photographs) in Filey. See Table 1 for an overview of monitored and tagged nests in each of these sites.

As a trial, further two nests were tagged at an accessible site at Speeton cliffs to attempt collecting data from nests closer to the centre of the Flamborough and Filey Coast pSPA. Only limited post-deployment monitoring of tagged nests took place at this site due to more difficult access. No control nests were monitored at Speeton at any time.

All study sites are shown in Figure 1.

Table 1. Summary of sample sizes for monitored and tagged kittiwake nests. The "hatched" column refers to nests that successfully hatched a minimum of one chick. For exact locations of sites and subsites refer to Figure 1.

Site	Nests monitored	Hatched (%)	Tagged	Control
Flamborough	**249**	**226 (91%)**	**13 (+2 dummy)**	**211**
North	45	38 (84%)	2	36
Centre	84	75 (89%)	5	70
South	120	113 (94%)	6 (+2 dummy)	105
Filey	**84**	**78 (93%)**	**5**	**73**
North	72	69 (96%)	3	66
South	12	9 (75%)	2	7

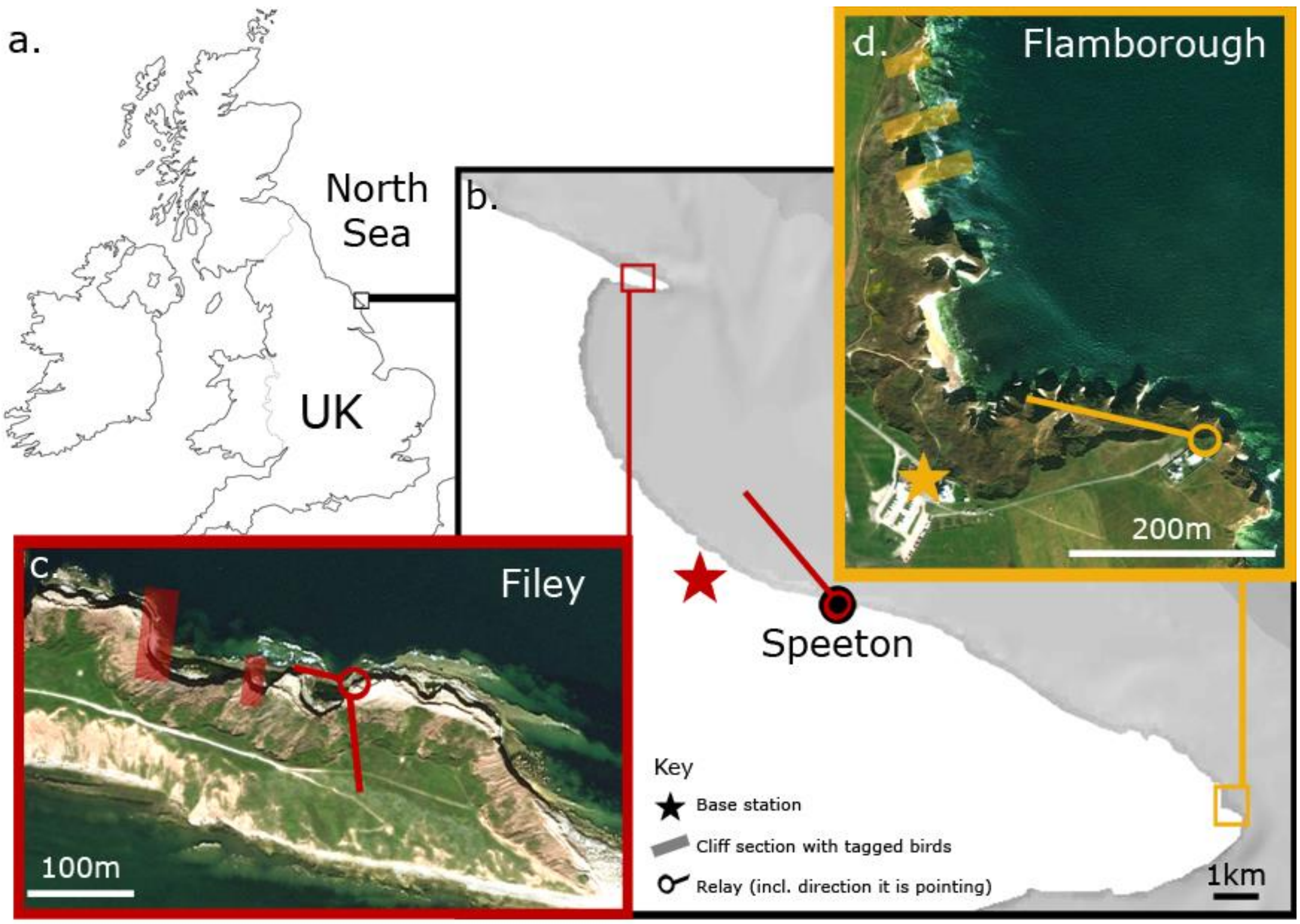

Figure 1. Location of field sites and network set-up. Stars indicate base-station locations. The black circle in map b. indicates the Speeton field site for which no close-up is shown. Circles with lines refer to relay locations; the angle of the line represents the direction the relay pointed (note there were two relays at the same location in Filey pointing in different directions). Shaded rectangles highlight monitored cliff sections (sub-sites) (North, Centre and South for Flamborough; North and South for Filey). Yellow symbols refer to the Flamborough network, Red symbols to the Filey network. Scale bars are shown. Individual maps were exported from ArcGIS 10.5 (ESRI 2016).

Network set-up

Network technology for remote download of data from deployed tags was provided by the University of Amsterdam (UvA) BiTS system and comprised of relay antennas and base stations (a laptop attached to an antenna for data download). Relays were connected to a battery which enabled free deployment in the field, whereas base-stations required access to electricity and, ideally, internet to (a) upload data to the BiTS server and to (b) remotely connect to the base station and change tag settings. One relay needed to face nests with tagged birds from a maximum proximity of 1 km. Additionally another relay at the same position (or the same relay, dependent on angles between cliff and base station) needed to face a base station up to 8km away to connect tags to the base station enabling the remote download of data and adjustment of tag settings. Detailed set-ups for sites are indicated in Figure 1.

Only one relay was needed in Flamborough to connect tags and base station due to a favourable angle between both, whereas in Filey two relays were used to transmit the signal from the tag to the base station. The Speeton relay connected to the Filey relays over approximately 9 km distance and data were subsequently downloaded to the Filey base station. In Flamborough the base station was positioned in very close proximity (~ 250 m) to the study site in a local shop with its antenna directly overlooking the relay. The Filey base station was positioned in the conservatory of a private house with its antenna facing the relay on Filey Brigg approximately 7 km across Filey Bay.

The first tags were deployed on 16th June 2017 and networks were installed before or shortly after the first tag deployment at each site. They were left in the field until mid-September 2017 to allow for potential data downloads from late returning birds.

Tag setup

Birds were tagged with UvA BiTS GPS and accelerometer tags equipped with two solar panels (Figure 2). Because tag data were remotely downloaded via the network, re-trapping of birds was not required. Tag settings could be altered via the network once the tag was on the bird and were adjusted to accommodate changes in battery voltage and maximize data collection. Tags needed to be in the colony or in 1 km proximity to one of the relays to download the updated settings from the base station.

In addition to the overall GPS and accelerometer sampling frequency it was also possible to change settings within geographic areas using a GPS fence (for example around the colony) and across time intervals (e.g. during day and night). Overall, GPS sampling frequency ranged from

3 to 15 minutes and accelerometer samples were taken every 10 minutes for 3 seconds at 20 Hz. Accelerometer sampling was started remotely towards the end of the deployment, after set-up and battery life had been thoroughly tested, to avoid draining batteries and damaging tags. At this stage some of the nests with tagged birds already failed and birds did not return regularly to download data and update tag settings. Consequently, accelerometer data collection was limited to a subset of individuals.

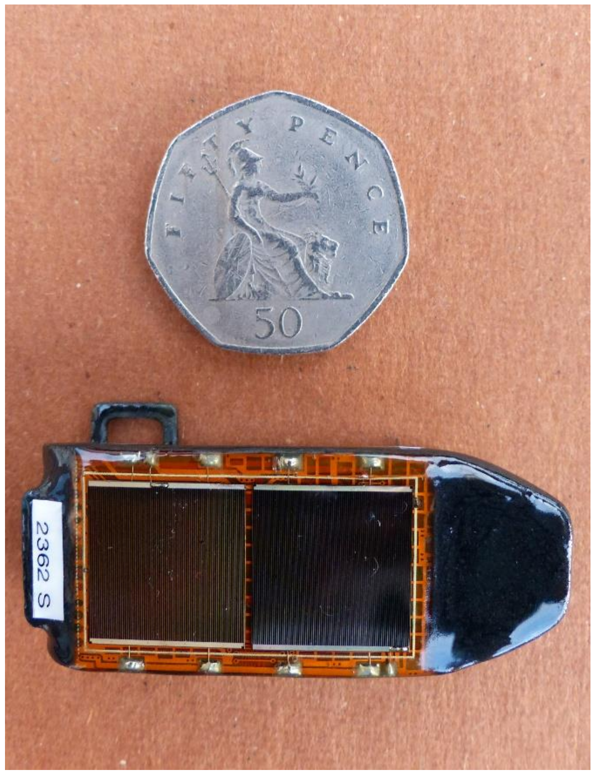

Figure 2. UvA BiTS tags used in this study. A 50 pence piece was used as scale. Picture courtesy of Saskia Wischnewski.

Tagging procedure

Thirteen adults were tagged in Flamborough, five in Filey and two in Speeton.

Tagging commenced on 16th June in Flamborough, just a week after the first eggs started hatching. The last birds were tagged on 8th July at Speeton. To ensure the catchability of adult birds while minimizing the chance of abandonment and nest failure, tagging concentrated on only one adult of a pair during early chick rearing rather than incubation.

Nests for tagging were approximately equally distributed across all monitoring plots at each site. The final selection for tagging was based on accessibility and proximity between each tagged nest to ensure that disturbance to the rest of the colony was equally spread and not all treatments nests were next to each other (Table 1). Adults were caught using a 12 m landing net pole with an attached snare that was moved over the bird's head. Thus, accessibility was mainly defined by nest height (<12 m) noting that increasing height made catching more difficult. However, an effort was made to not only trap birds at lowest nest but get a representative sample across the catchable height spectrum. Overhangs above and below nests as well as other cliff features that blocked the view of the bird from underneath could impede catching attempts and thus affected which nests were targeted.

Trapped birds were quickly moved into a cotton bag to reduce stress levels. Birds were then weighed (body condition), ringed with metal and engraved darvic rings (yellow with black writing; to enable later identification and re-sightings via telescope, without re-catching the bird), measured (wing, head and bill, bill; to be able to sex birds), colour marked with permanent marker on head feathers (to simplify identification of tagged birds from a distance) and tagged (Figure 3 d.).

Tags were glued (Super Glue) to trimmed back feathers of the birds. To increase the tag's surface area for attachment and simplify potential tag removal at a later stage (if necessary, not planned) a piece of muslin was glued to the bottom of the tag in preparation for fieldwork. Before deployment it was cut to extend approximately 0.5-1 cm beyond the tag's base (Figure 3 a.). The bird's body feathers were then trimmed to the shape of the muslin and wiped with acetone to remove any grease (Figure 3 b.). After waiting a few seconds for the acetone to dry the muslin was covered in superglue and the tag was carefully glued to the bird's back (Figure 3 c.).

This attachment method has previously been used in studies of various other bird species but had to our knowledge not yet been tried on this species, which is why detailed tagging impact studies including productivity and survival monitoring were necessary. However, it was chosen since it showed the potential to extend the deployment period compared to other short-term or long-term attachment methods which are either very quickly removed by the bird after a couple of days (Tesa tape) or are known to have negative effects on productivity and survival (harnesses).

To gain a more detailed understanding on the effects of the attachment method on the bird, 6 dummy tags (four in Flamborough and two in Filey) which matched the dimensions and weight of the original tag were deployed. The motivation was to re-trap these birds and assess the wear on the attachment and its interaction with the bird's skin and feathers. Unfortunately, either birds were not in the colony or bad weather jeopardized all re-trap attempts, but two dummy tags that were deployed within the monitored sites were added to the productivity comparison between tagged and control nests.

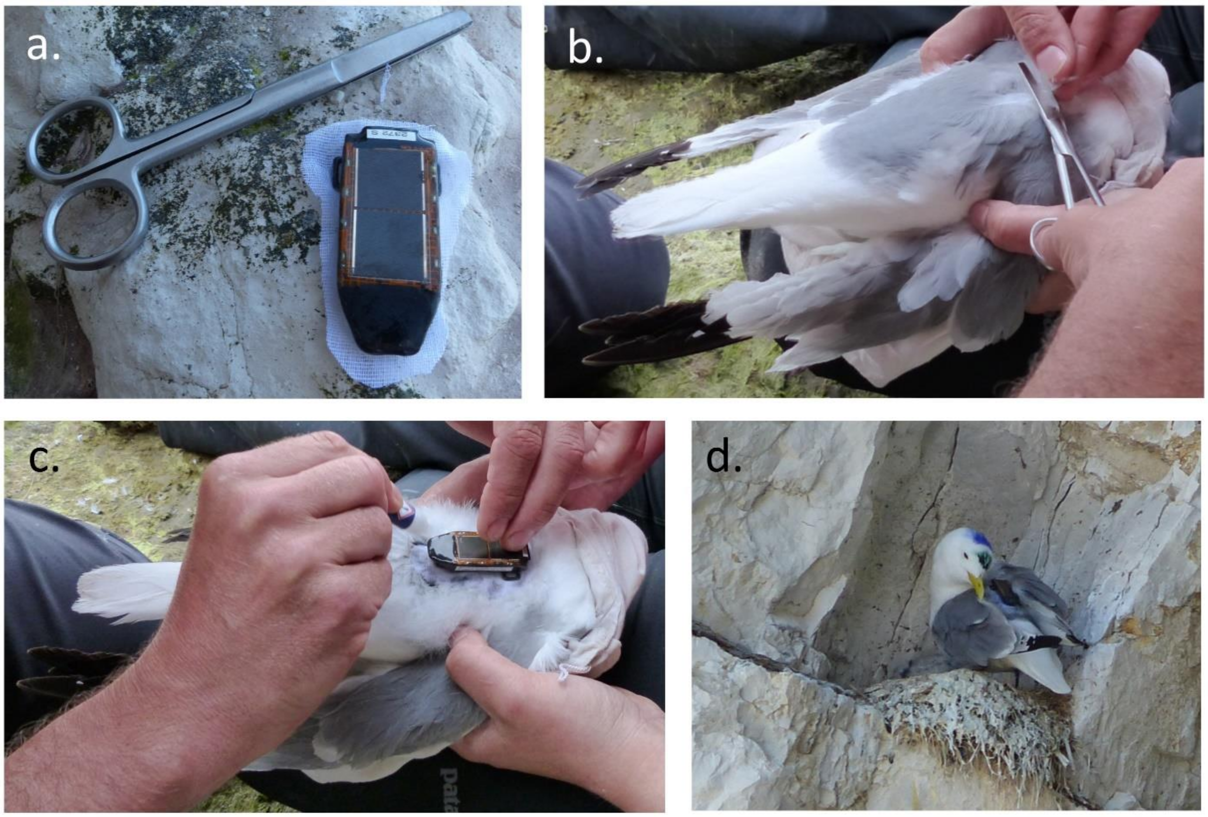

Figure 3. Photographs illustrating the tagging procedure. a. the tag just before deployment, attached to a layer of muslin cut to the shape of the tag. b. trimming the bird's back feathers, leaving short feather stubs that provide a secure base to glue the tag to. c. the tag is glued to the bird after feather trimming. d. the bird back at the nest shortly after release, preening its feathers and inspecting the tag. Note the colour markings on its head. Pictures courtesy of Saskia Wischnewski (a., d.) and David Aitken (b., c.).

Productivity monitoring

The monitoring of nest sites commenced on the 1st of June 2017 and sites were monitored every second day, or as frequently as possible if weather conditions were not favourable. Each monitoring session consisted of checking each nest for contents and present occupancy, and monitoring sessions were randomly distributed across daylight hours. Survey times and durations were recorded. Since adult occupancy was not the focus of this study, no particular time intervals for monitoring were chosen (e.g. to target periods of high nest attendance (such as early in the morning or late at night). Last monitoring took place on 10th August 2017 by which time the majority of nests had fledged and remaining chicks were fully grown and could therefore be considered successfully fledged. Clutch and brood sizes were reported as outlined in the JNCC Seabird Monitoring Handbook (Walsh *et al.* 1995). Chicks were divided into three development categories based on plumage characteristics, where small referred to downy chicks, medium to chicks with fully developed plumage markings, and large to chicks with down free wings with well-developed primary feathers. It was further noted when adults were not present, and nests were unattended. Hatch and fledge dates were determined by the average date between the last egg and first chick observation or the last chick observations and the first time the nest was unoccupied respectively. Empty nests were considered as successful if chicks were above 30 days and thus reached the minimum reported fledge age (Coulson 2011) while being well developed (large for more than the prior 3 observations). If a dead chick could be observed in the nest or these criteria were not fulfilled, and chicks were missing, nests were considered as failed.

Colour ringing

To compare adult survival over winter between tagged and non-tagged nests, a further 30 darvic rings were deployed later during chick rearing across Flamborough and Filey at non-monitored nests. Since kittiwakes are highly philopatric, birds are expected to return to a nest site in close proximity to this year’s. Consequently, next year’s re-sighting rates for tagged and non-tagged birds will be compared to determine whether tagging affected survival rates.

Analytical methods

Tracking data analysis

All data preparation and analysis were performed in R (R Development Core Team 2017), including most data visualization. In some cases, ArcGIS 10.5 (ESRI 2016) was used for mapping, which is highlighted in relevant figure legends. Only key R packages and functions that are central to understanding and ensuring the repeatability of the analytical approach are referenced within this report.

Data preparation

Tracking data were directly accessed via the BiTS server and extracted for each bird from the start of the deployment until the most recent data download. Tracks were visually examined and obvious outliers (likely inaccurate data) were removed; a standard procedure in tracking data analysis. If part of the analysis required projecting the tracking data, a Lambert Azimuthal Equal Area projection centred on the mid-point of all collected tracking data was used. This projection is commonly used for the analysis of tracking data of far ranging marine species to create a data specific projection that maximise the accuracy of distance and area measurements across the whole data set. All data points within a 1 km radius around each of the breeding colony sites were removed from subsequent analyses since they were expected to mainly include non-target behaviours such as rafting on water or resting on the cliff in close proximity to, or within, the pSPA. Individual foraging trips longer than 1 h between the bird's departure from the colony and its return were isolated. Due to varying sampling rates (between 3 and 15 minutes), shorter trips (<1 h) were excluded from the analysis of foraging trips since they may include less than the minimum of 4 data points that are required to calculate representative trip metrics and perform behavioural annotation of the tracking data.

Trip summaries

Trip duration, foraging range, travelled distance and mean speed were calculated for each trip and summarized for all the tracking data combined and by site. Since birds returned immediately to their nest site, spent at least one hour back at the nest or within 1 km of the colony before engaging in the next foraging trip (>1h), and there was no significant difference between the trip metrics (duration, range and distance) for the first and second trip conducted (Appendix I), we assumed that stress from capture and handling did not cause unusual behaviour during the first trip after deployment. Therefore, all foraging trips were included in the data set. To test whether foraging trip characteristics differ between sites, metrics were statistically compared using mixed effect models (*lmer*) with site and day of the year as predictors and bird id as random effect to account for pseudo-replication.

Behavioural annotation

Behavioural annotation is a method to infer different behaviours such as foraging, commuting and resting from simple GPS data when no direct measurements via accelerometers or time-depth recorders are available. Several different methods are widely used in tracking studies, each with their own assumptions and limitations.

Here we used Expectation Maximisation-based Clustering (EMbC) (Garriga *et al*. 2016) on the whole data set in the corresponding R package[2]. Since this annotation method mainly relies on assigning 4 behavioural states to patterns in tortuosity and speed, large gaps in the data or unequal sampling rates can heavily influence annotation. Before running the behavioural annotation algorithm, trips with gaps larger than one hour, which were caused by a break in the sampling regime due to a drop-in battery voltage usually linked to weather conditions or too high sampling frequencies, were therefore split into segments. Afterwards, each of these segment and trips without gaps were equalized to 10-minute intervals using the *redisltraj* function in the adehabitatLT package. Finally, the output of the behavioural annotation run on equalized trips and segments resulted in four output states of low tortuosity and low speed, low tortuosity and high speed, high tortuosity and low speed and high tortuosity and high speed. These were assigned to resting, commuting and two different foraging modes respectively, following Garriga *et al*. (2016). Finally, for each trip the mean minutes per hour a bird engages in commuting, resting and foraging (both modes together) were calculated and summarised for all the tracking data combined and per site. To test whether there are behavioural differences between trips from different sites, hourly rates of behaviour states were compared in a general linear mixed model with site and day of the year as predictors and bird id as a random effect to again account for pseudo-replication.

Kernel analysis

Kernel density analysis is a widely used and simple approach to infer utilization distributions (UDs) from locational data such as provided by GPS tracking using the density of relocations in space.

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[2] This is a new, cutting-edge and highly robust behavioural annotation method that has been ground-proofed on several seabird species with similar foraging behaviour as kittiwakes. Its key benefit to other methods is the binary clustering of input variables (in this case speed and tortuosity), which provides easily interpretable and meaningful results. It further does not require the input of often highly subjective parameters (as for example using First Passage Time) and has the ability to implement uncertainty in the data.

In simple terms, utilization distributions identify on a map the areas used by the birds (essentially their “home ranges”), and within that the areas that are used most frequently. The output is a three-dimensional probability surface. It uses a smoothing parameter to extrapolate the data and account for error, which can be determined using different estimators and methodologies.

In this case we followed the method outlined by Lascelles *et al. (*2016), which uses the mode of optimal search radii of all trips calculated by the *varlogfpt* function in the adehabitatLT package as smoothing parameter (4.1km). Afterwards the *KernelUD* function in the adehabitatHR package was used to calculate 50, 75, 90 and 95 % density contours for the whole data set, 50 and 95% contours for each of the sites and 50, 75 and 95% contours for each of the three behavioural states to a 1 km^2 resolution. Most commonly used contours are 50 and 95%, which for data of full trips are commonly associated with highly used areas (e.g. foraging locations) and the overall distribution/home range respectively. Therefore, the lower the percentage the higher the probability to encounter a bird in the area within the contour. To further examine differences in the spatial overlap between sites, the percentage overlap for each of the contours was calculated. Additionally, the percentage overlap between all determined contours and the Hornsea offshore development zones were calculated.

Accelerometer data

An inventory of all collected accelerometer data was taken, and a sample was plotted. Further analysis of this data will be completed subsequently (see recommended analysis section towards the end of the report).

Productivity analysis

Failure rates of control and treatment (tagged) nests during chick rearing were initially compared using the simple and widely used chi-squared test, which does not allow confounding variables to be included. A likely confounding factor affecting failure rates was nest height. To ensure results reflect tagging impacts, nest height (from the tide line) was measured using photographs of the study sites. A binomial model of failure rate with nest height, site, group (nest vs. control) and an interaction between the site (Flamborough or Filey) and nest height as predictors was fitted to test whether there was a difference in nest failure rates between tagged and untagged birds once nest height and site effects were accounted for.

Results

We successfully deployed 20 tags on adult kittiwakes during the early chick rearing period. Handling time of each bird from capture on the cliff to release was on average 12 (SD=±1) minutes (Range 9 - 16 minutes). Behavioural observations after deployment did not show any unusual behaviour and birds returned to the nest within 6 (SD=±2) minutes.

For 18 of the 20 deployments (all 13 in Flamborough, four in Filey and one in Speeton) we were able to download 168 foraging trips ranging from 3 to 24 trips per deployment/bird (Mean 9 (SD±6)) (Figures 4 and 5). For these birds we collected a total of 29,772 GPS fixes (including altitude estimates) and 755 three second accelerometer measurements (limited to 3 birds) (Figure 6). The first tag was confirmed to have been lost (bird seen in colony without tag) after being deployed for 20 days and the last data download happened after a deployment of 29 days.

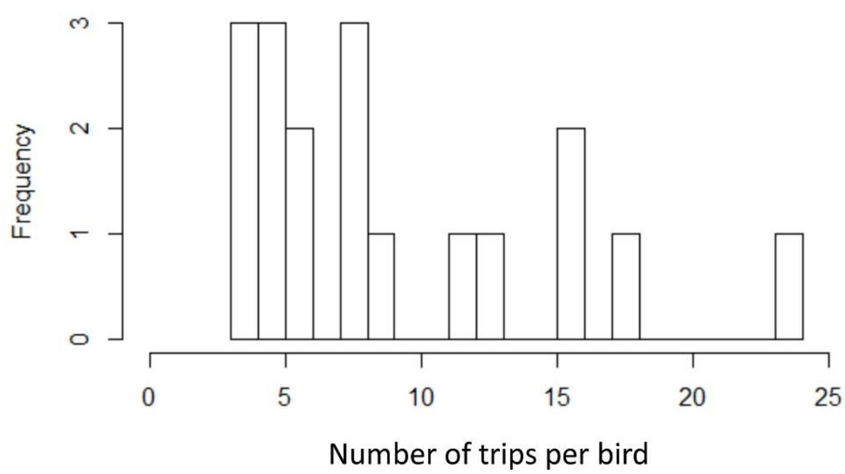

Figure 4. Frequency distribution of the number of trips tracked per tagged bird. Only trips that lead further than 1 km away from the colony and are longer than 1h are included. N=18.

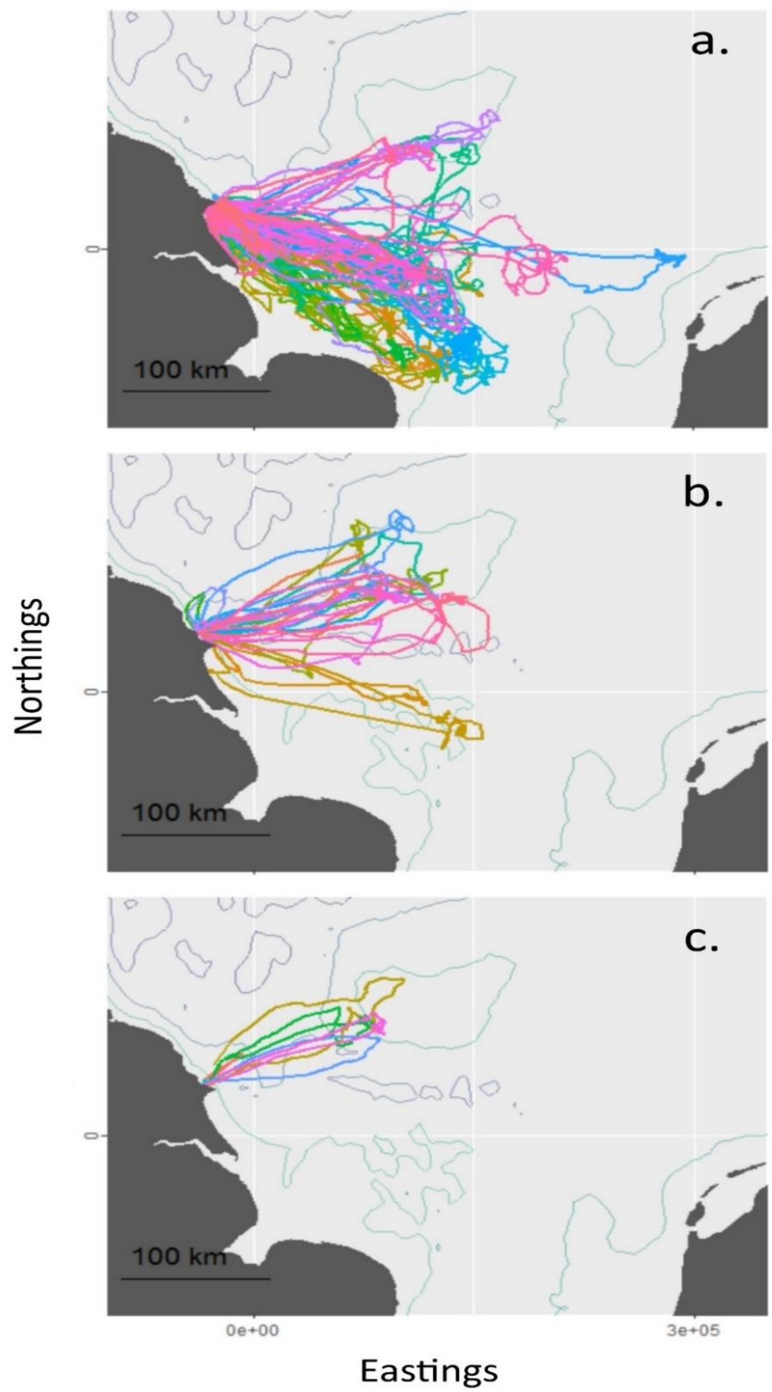

Figure 5. Individual Kittiwake GPS trips collected during the 2017 breeding season at the Flamborough and Filey Coast. All trips are shown from a. Flamborough (N=133 trips from 13 birds), b. Filey (N=29 trips from 4 birds) and c. Speeton (N=6 trips from 1 bird). Different shades represent individual trips. Bathymetric contours and scale bars are shown, with land in dark grey (UK, left; the Netherlands, right). The map is projected to the Azimuthal Equal Area centred on the mid-point of all the tracking data. The number of birds tracked per site is given in Table 1.

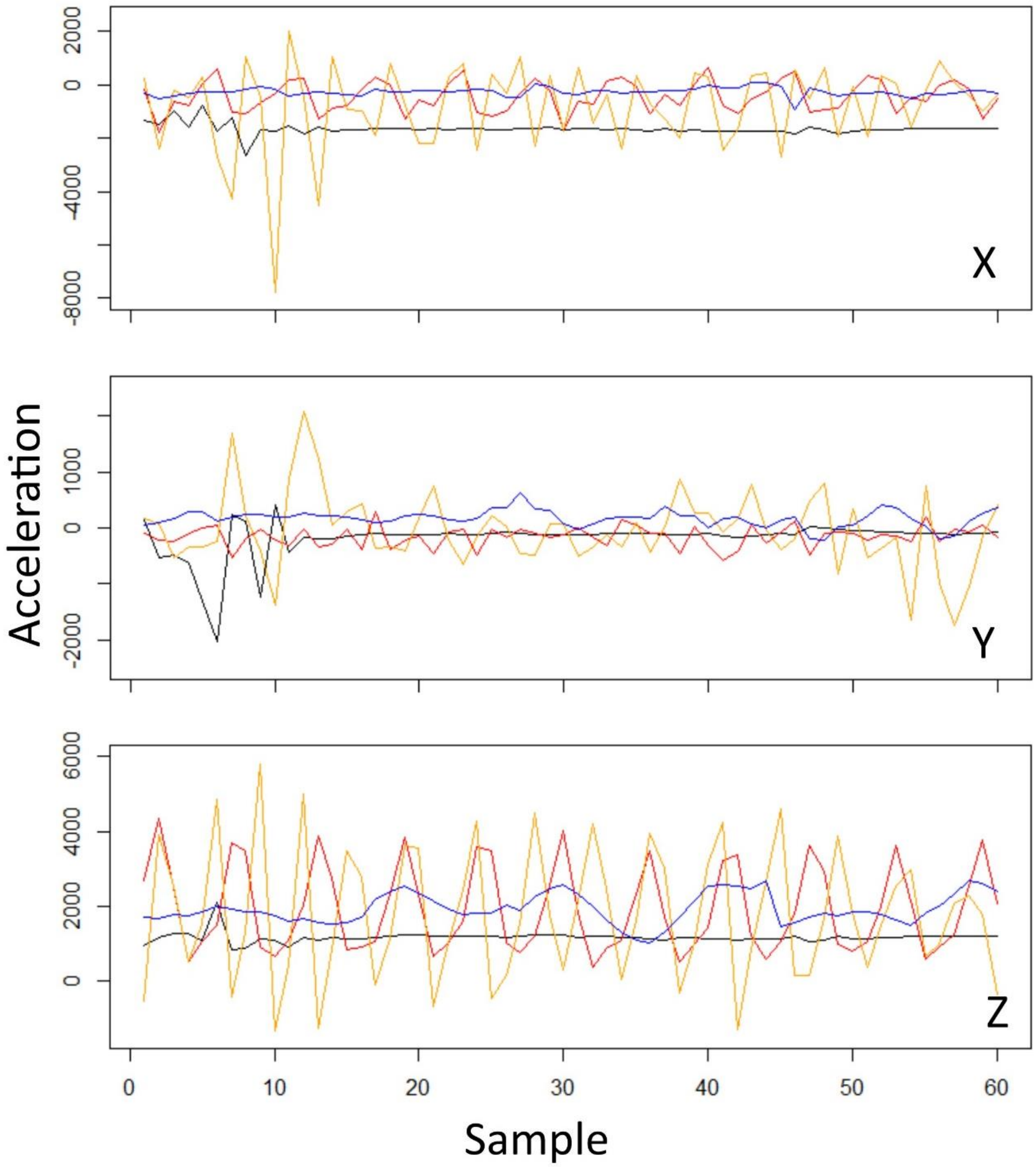

Figure 6. Sample of the acceleration data collected for one tracked individual at Flamborough. Each plot represents one accelerometer axis. Four sets of consecutive samples are shown, and colours across plots correspond to the same consecutive sample set. The 60 measurements (samples) taken reflect a three second consecutive sample set, at 20 Hz. Note the differences in amplitude between different measurements (e.g. the black and the orange line) which will be used to distinguish between behaviours such as flapping flight and resting.

Trip characteristics and behaviour

Trips metrics and hourly rates of the three target behaviours (commuting and two different foraging modes) are summarized in Table 2 and visualized in Figure 7 respectively. Linear mixed models comparing trip characteristics and behavioural composition across all three sites (Filey, Speeton and Flamborough) could not identify any statistically significant differences between any of these sites, but the hourly commuting time seems to decrease very slightly through the duration of the chick rearing period (-0.28 (SE=± 0.13), df=86, t=-2.25, p=0.02).

Table 2. Summary of the three trip metrics calculated for all 168 Kittiwake trips. Trips ranged over a maximum period of 29 days across the chick rearing period and also included trips from failed individuals. Note that the reported large standard deviations are due left skewed distribution of all three trip metrics. N=168 from 18 birds.

Trip metric	Mean (±SD)	Range
Trip duration (h)	22.12 (±28.69)	1.00 - 168.67
Foraging range (km)	88.65 (±74.22)	3.20 - 323.85
Travelled distance (km)	256.62 (±261.88)	7.91 - 1249.70

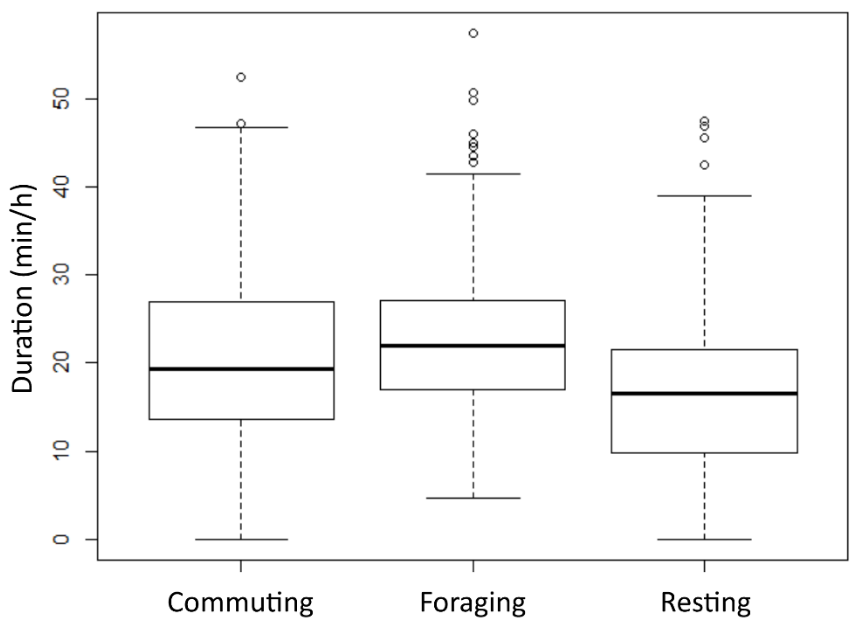

Figure 7. The relative contribution of the three different behaviour states to each foraging trip. Horizontal bars represent median values and whiskers 95% confidence intervals. All values are scaled to the duration of each individual foraging trip such that the mean minutes per hour a bird engages in each of the behaviours is used for each trip. N=168 trips from 18 birds.

Utilization distributions

Tracked birds spent most of the time during their foraging trips either in areas relatively close to the colony or in selected hot spots within 200 km of the colony (Figure 8). The utilization distributions of all three sites (Flamborough, Filey and Speeton) showed a substantial overlap with each other (Figure 9, Table 3). The distribution for foraging and resting show a similar pattern to the UD for all the tracking data (Figure 10 a. and c). However, distribution for commuting behaviour was much more widely spread, highlighting minor and major flight corridors from and to the colony and between hotspots that were not included in the overall or site-specific UDs (Figure 10 b). Note that utilization distributions include all trips collected in this study and thus cover foraging trips of chick rearing adults from just after hatching to when they are caring for chicks that are close to fledging size. They further also include trips collected after nests failed.

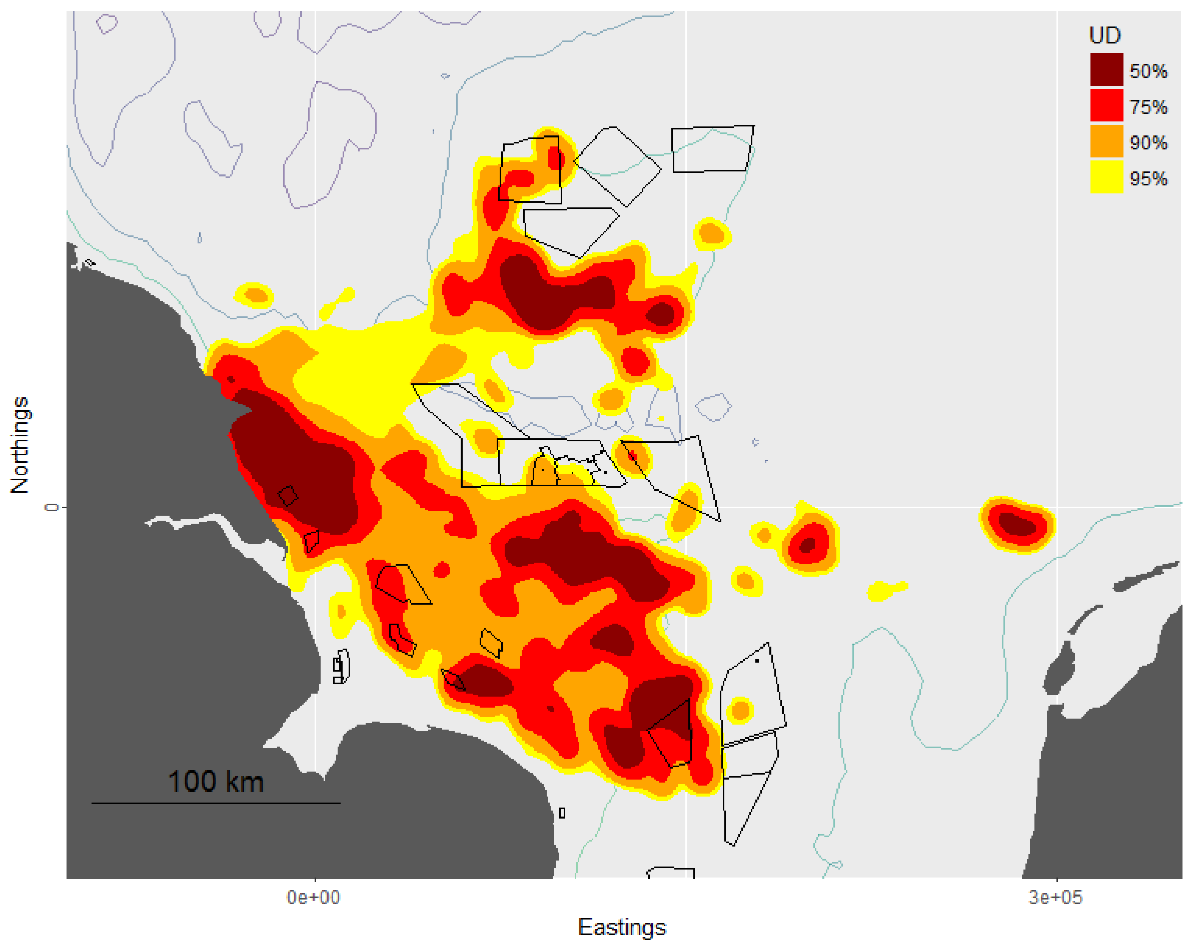

Figure 8. Utilization distributions of all kittiwakes tracked at Flamborough and Filey Coast during the 2017 breeding season. N=168 trips from 18 birds. 50, 75, 90and 95% contours are shown. Bathymetric contours, scale bar and outlines of all proposed, planned or active windfarm

zones are shown, with land in dark grey (UK, left; the Netherlands, right). The map is projected to the Azimuthal Equal Area centred on the mid-point of all the tracking data.

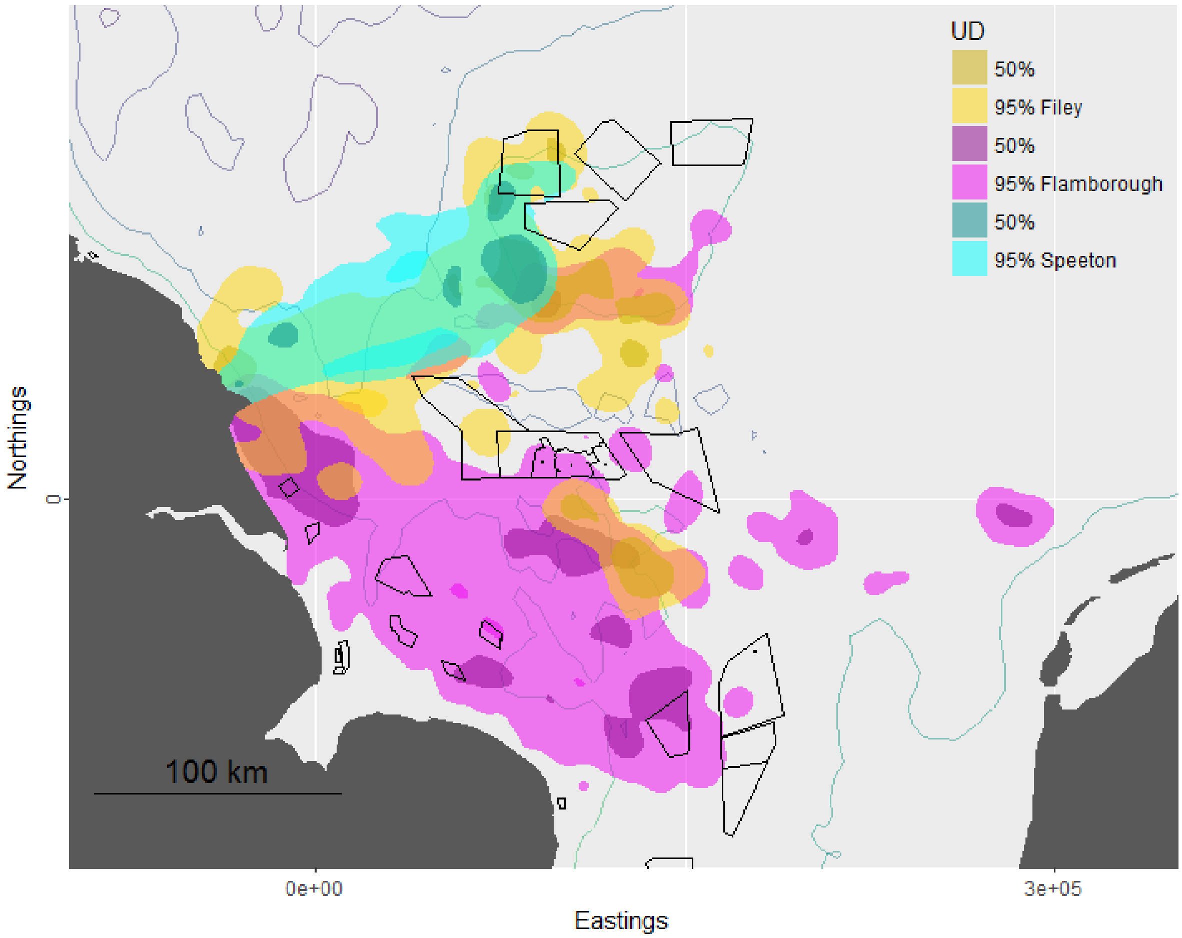

Figure 9. Utilization distributions of all kittiwakes tracked at Flamborough and Filey Coast during the 2017 breeding season by study site. 50 and 95% contours are shown. Pink tones refer to Flamborough (N=133 trips from 13 birds), yellow tones to Filey (N=29 trips from 4 birds) and green tones to Speeton (N= 6 trips from 1 bird). Bathymetric contours, scale bar and outlines of all proposed, planned or active windfarm zones are shown, with land in dark grey (UK, left; the Netherlands, right). The map is projected to the Azimuthal Equal Area centred on the mid-point of all the tracking data.

Table 3. Percentage overlap of Utilisation distributions off kittiwakes tracked at three sites within the Flamborough and Filey coast. Percentage overlap refers to the overlapping section of the total area covered by UDs from both sites. Overlap was calculated for 50% and 95% kernel density contours. Refer to Figure 9 for visualisation.

UD	Flamborough/Filey	Flamborough/Speeton	Filey/Speeton
50%	3.8%	0.2%	15.7%
95%	17.6%	2.9%	25.4%

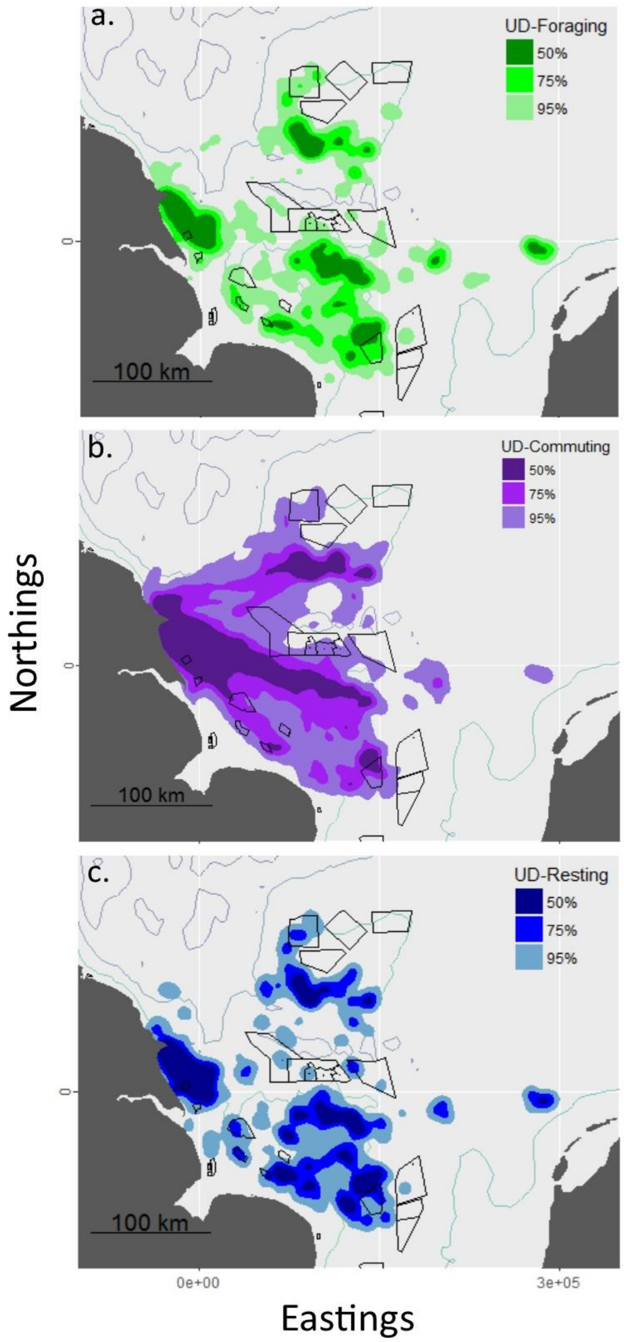

Figure 10. Utilization distributions for each of the behaviour states for all kittiwakes tracked at Flamborough and Filey Coast during the 2017 breeding season. N=168 trips from 18 birds. 50, 75 and 95% utilization distribution contours are shown for a. foraging locations, b. commuting locations and c. resting locations. Behaviour states were annotated using EMbC (see methods). Bathymetric contours, scale bar and outlines of all proposed, planned or active windfarm zones are shown, with land in dark grey (UK, left; the Netherlands, right). The map is projected to the Azimuthal Equal Area centred on the mid-point of all the tracking data. Note the large overlap between the UDs for foraging and resting compared to the commuting UD.

Overlap with Hornsea

The Hornsea project zones showed a certain degree of overlap with the all UDs assessed above, mostly with the 95% contours (Figures 8-10). All Hornsea project footprints overlapped to some degree with the 95% contours of the Flamborough tracking data and all behaviour-specific UDs (Figure 10, Table 4). The Filey UD only overlapped with the footprint of Hornsea projects 2 and 4, and the UD for the single bird successfully tracked at Speeton did not overlap with any of the Hornsea zones (Figure 9, Table 4).

Table 4. Percentage overlap between the Hornsea zones and the 95% utilisation distributions of Kittiwakes tracked on the Flamborough and Filey Coast in 2017. Overlap was assessed for the whole Hornsea zone (full zone footprint without buffer) and individual sub-zones (lease areas) as well as for the overall distribution and UDs per site and behaviour. a. shows the overlap as percentage of the UD, whereas b. shows the overlap as a percentage of the individual Hornsea zone assessed.

a.	Hornsea I	Hornsea II	Hornsea	Hornsea IV	All
Project area	407	462	696	846	2412
Site					
Flamboroug	1.1%	0.3%	0.9%	0.3%	2.7%
Filey	0%	0.3%	0%	2.3%	2.5%
Speeton	0%	0%	0%	0%	0%
Behaviour					
Foraging	0.8%	0.3%	0.9%	0.8%	2.7%
Commuting	1.1%	0.4%	0.2%	1.9%	3.6%
Resting	0.5%	0.4%	1.0%	0.9%	2.7%
All	0.8%	0.3%	0.7%	1%	2.7%

b.	Hornsea I	Hornsea	Hornsea	Hornsea IV	All
Project area (km^2)	407	462	696	846	2412
Site					
Flamborough	64.0%	15.5%	31.0%	7.9%	25.5%
Filey	0%	9.7%	0%	39.8%	15.8%
Speeton	0%	0%	0%	0%	0%
Behaviour					
Foraging	44.5%	14.1%	27.8%	20.7%	25.5%
Commuting	81.5%	26.2%	11.0%	71.4%	47%
Resting	24.7%	16.3%	30.1%	22.7%	23.9%
All	56.5%	16.9%	28.3%	33.4%	32.7%

Productivity and tagging effects

Overall 91% of all monitored nests (n=333) hatched at least one chick. The failure rate thereafter for all non-tagged nests was high with 58 % for Filey and 33 % for Flamborough, which were statistically different from each other (χ^2= 13.024, df = 1, p-value < 0.001). Additionally, total failure rates for control nests were significantly lower than for tagged nests (75%, χ^2= 8.5063, df = 1, p-value< 0.001) suggesting an effect of tagging. However, this effect was lost or weakened, dependent on site (Flamborough or Filey), when fitting a more complex binomial model, which also accounts for nest height (Figure 11). The height of tagged nests was approximately 1 meter lower than the average for controls (LM: -1.1672 ± SE 0.4194, t= -2.783, p= 0.006).

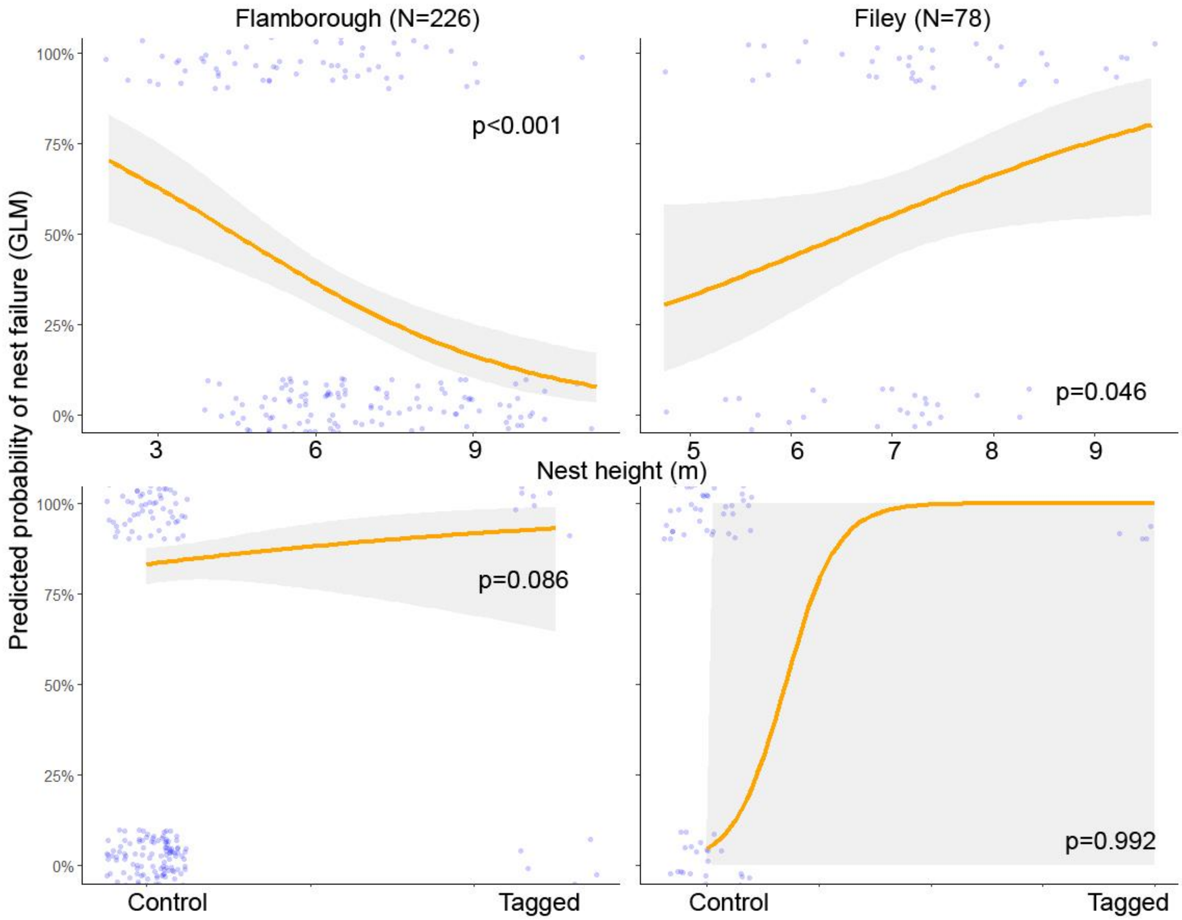

Figure 11. Nest failure probability for each of the monitored sites dependent on nest height and tagging. Raw data (with jitter[3]), model fit, sample sizes and confidence intervals are shown as are p-values for each model parameter.

[3]In this case "jitter" refers to the introduction of visual spread across the y-axis for the two top graphs and across both axes for the bottom ones. The aim is to improve the visualisation of data by making individual data points visible that would otherwise be plotted on top of each other. Here all the raw data on the y-axis refers to either 0 or 100% and x-axis data on the bottom two plot refers to either control or tagged nests.

Discussion

We successfully tracked 18 Kittiwakes in the Flamborough and Filey Coast pSPA to establish baseline data in reference to the planned Hornsea offshore developments. Two tags, one deployed at Filey and one at Speeton, did not provide any data, presumably due to technical problems with the tags following deployment, and perhaps due to tag damage caused by the birds. Both tags were tested prior to deployment and both birds were seen in the colony and well within range of the relays with their tags attached following deployment, so should have produced data. We piloted the use of the UvA BiTs tracking system at Flamborough, Filey and Speeton, and found that it generally worked well and was suitable for use at these sites. However, since the system is not usually used on cliff nesting seabirds that spend a large amount of time in shaded cliff areas we had initial trouble in adjusting settings so that solar panels were able to re-charge batteries before they ran out of power. Consequently, tags were not able to collect data at the very high temporal resolution originally planned (aimed to record GPS fixes every 3-30 seconds when birds were within the wind farm footprint) and, because of problems with battery life, accelerometer sampling this year was limited. Despite these issues, the data provide a unique and comprehensive insight into the foraging movements of breeding kittiwakes throughout chick-rearing, the period of the breeding cycle when seabirds are most constrained in terms of the foraging areas they can use, and thus most vulnerable to changes in their environment (e.g. Orians & Pearson 1979, Thaxter *et al*. 2012).

Overall trip characteristics and at-sea behaviour mirror previous observations from other studies and therefore support current expectations of foraging range and trip duration of kittiwakes during early chick rearing (Coulson 2011, Kotzerka *et al*. 2010), but the average foraging range and trip duration across the tracking period was larger than has been recorded previously. Based on our knowledge of seabird ecology and an initial examination of the tracks, we expect that this larger average foraging range compared to other studies is because we tracked kittiwakes for a longer part of the breeding season including when adults were provisioning large chicks (that can be left for longer than small chicks) or their nests had failed. An important part of our continuing analysis of this dataset will be to analyse trip characteristics separately for birds at different breeding stages (young chicks, older chicks, failed nests) and test for differences between these groups. Further analysis is also required to determine whether the risk of birds interacting with the Hornsea wind farms changes as the breeding season progresses. Speculatively, we think that if birds are behaving differently later in the season this is likely to change the likelihood of them encountering turbines, though we are not yet sure whether this will make a positive or negative difference to collision risk. We will investigate and quantify this difference as part of the further analytical work conducted during this contract (see below for details). The comparison of foraging characteristics and at-sea behaviour between sites suggests that foraging strategies are similar for birds from all breeding sites. However, comparing the key areas used by birds from different breeding sites showed that birds from Filey birds and the one bird tracked in Speeton tended to forage in similar areas to each other north-east of the colony, while Flamborough birds tended to go south-east. However, some individual birds from Filey and Flamborough did not follow this pattern. Similar foraging segregation has been observed previously in kittiwakes (Ainley *et al*. 2003, Paredes *et al*. 2012, Wakefield *et al*. 2017) and in other seabird species (e.g. Wakefield *et al*. 2013, 2017), but usually on a colony scale. Seeing such a pattern when comparing birds at either end of one colony emphasizes the need to include future tracking work on birds in the centre of the colony (in this case in Speeton or around Bempton) to ensure results are representative, particularly when informing post-consent monitoring or environmental assessments.

The analysis of the overlap of the key areas used by tracked kittiwakes (utilization distributions) with the Hornsea zones shows that all of the individual Hornsea project footprints sit outside the 50% utilization distributions of kittiwakes tracked during 2017. However there is an overlap of the 90% and 95% utilization distribution with all Hornsea zones and of the 75% one with only Hornsea III for all data combined. Whereas for the behaviour specific distributions for which 50, 75 and 95% contours were shown, only the 95% foraging contour overlaps with the overall Hornsea footprint, the 75% distribution of commuting and resting birds overlaps with small areas at the edges of the footprints of Hornsea Project 3 and 4. For the site specific analysis for which the core 50% and 95% percent contours were described, again only the 95% utilization distributions show an overlap for Flamborough and Filey birds. While this overlap for Flamborough birds covers varying degrees of all Hornsea project zones (Table 4), the overlap from Filey birds concentrates on Hornsea Project 2 (~10% coverage) and 3 (~40% coverage). It is important to note three aspects of the overlap of kittiwake area usage with the wind farm footprints:

1. Overlap approximately doubled when looking at the distribution of commuting behaviour compared to other behaviours or all data combined. This implies that although birds might not spend much time foraging or resting in the Hornsea zones they tend to pass through these areas frequently when commuting, which still puts them at risk and underlines the importance of collecting direct behaviour and flight height information from within the wind farm zones, as this project aims to do.

2. The spatial segregation outlined above shows that Filey birds on average tend to go north of the wind farm development zones while Flamborough birds tend to go south of them, which might not be representative for the overall pSPA colony. To exclude the possibility that the largest number of birds directly in the centre of the colony head out straight east into the Hornsea zone, further tracking work at the Speeton site (and potentially directly at Bempton) is needed.
3. The analysis is based on one year of data only and previous seabird tracking studies (including previous tracking conducted on kittiwakes breeding within the pSPA) has shown inter-annual variability in the birds' at-sea distribution and the location of core foraging areas.

The tagging approach successfully extended the deployment period compared to conventional short-term attachment methods. However, we are uncertain whether tags affected the likelihood of nest failure due to an overall low breeding success and confounding variables. A simple comparison of tagged and control nests (using a chi squared test) indicated a significant tag effect on nest failure rates, but more complex models that accounted for confounding factors such as nest height and site did not detect any significant effect of tagging. This highlights the importance of treatment and control nest choice in tagging studies and demonstrates that limited accessibility for tagging studies can lead to biased data. The attachment method therefore needs further testing before being recommended, particularly in direct comparison with more conventional methods such as short-term Tesa tape attachment. However, the trips collected after nest failure and later in the breeding season are extremely valuable since they represent data that cannot be collected using other deployment methods. Further analyses investigating how utilization distributions change during the chick rearing period and after nests fail is therefore warranted.

This year's pilot study successfully provides baseline pre-construction GPS tracking and distribution data from kittiwakes across the chick rearing period, and the first site specific analysis of behaviour budgets derived from behaviour annotation. Although the collection of directly measured behavioural data from accelerometers was limited this year, this first year of tracking enabled us to successfully trial the use of the UvA tracking system on kittiwakes in the Flamborough and Filey Coast pSPA and identified any site/species specific technological limitations. These were already successfully addressed to ensure the collection of GPS and behavioural base line data (derived from accelerometers and altimeters) in upcoming years, to eventually compare all data pre-, during and post-construction.

Recommendations for future work

Recommended data analysis

This report presents a first overview of the data that were collected during 2017 but is not intended to be an in-depth analysis. Numerous further analyses will be conducted during the ongoing contract between RSPB and Ørsted (Saskia is employed to work on this until early February 2018). These will be delivered either as submitted papers/short notes to peer-reviewed journals (Ørsted and the Flamborough and Filey Coast seabird monitoring group will have an opportunity to comment on drafts), or 1-2 page short reports to Ørsted that could be formatted as Annexes to this report (particularly if there is a desire to have all the outputs of this work in one place).

Further analytical ideas have emerged during the course of this work that would be highly beneficial for the strategic monitoring and environmental assessment of the various Hornsea projects. These would require additional staff time beyond that available in this contract, but no additional data collection, and as such would be relatively cheap. The most efficient way to do at least one to two of these additional analyses would be to extend Saskia's current contract by three to four months (all three analyses finalised and submitted as papers will take an additional 9 months), as she is already familiar with the dataset, so would do the work in less time than someone who has not worked with these data. This would also allow us to keep her employed during the few months between February and May 2018, ready to lead next year's fieldwork (assuming further tracking work goes ahead), which would give the project valuable continuity and be more efficient than training a new person to lead future fieldwork. If this is not possible, we recommend that these analyses could be included as part of the future package of strategic monitoring work that follows this contract. Fully costed proposals for the additional suggested analyses can be provided if they are of interest to Ørsted.

We have itemised our recommendations for future analytical work in two lists (one for the work included in the current contract, and one for the work that would require additional resource) below.

Analytical work included in the current contract

1. An investigation of the flight speed distribution of trips using and comparing speed estimates derived from GPS data. The main objective is to develop (spatially explicit) flight speed distributions that can help improve future collision risk models.

2. A paper on changes in the birds' trip characteristics and foraging distribution across the chick-rearing period, and comparison of trip characteristics between birds with active and failed nests, using some of the first tracking data available for kittiwakes whose nests have failed. This will be a crucial addition to the understanding of the temporal variation in at-sea distribution of seabirds in general, and how it is affected by breeding stage. Specifically, it will enable us to understand how kittiwake collision risk varies in relation to breeding stage; this has never previously been measured at any colony, or in relation to any wind farm.
3. A short note submitted to a peer-reviewed journal summarising our findings regarding the impact of nest height on breeding success. This will inform future tagging studies on the risks of introducing a bias by choosing nest sites based on accessibility. This is important to explain the apparent tag effect on nest failure rates observed in our study (which is largely explained by nest height) and will be vital to justify, and get a licence for, future tagging studies using the same methodology.

Analytical work that would require funding for additional staff time

4. A comparison of this year's tracking data with RSPB's tracking data from previous years to investigate annual variability of trip characteristics and at-sea distribution in relation to environmental parameters. Multi-year tracking data for kittiwakes is rare and our extensive dataset would not only allow us to look at the overall distribution across years, but also help us to understand what drives differences in annual distributions. This will help to estimate how kittiwake collision risk might vary between years.
5. An assessment of individual repeatability of kittiwake foraging trip characteristics and sites within one chick rearing period aiming to determine how degrees of site faithfulness affect breeding success. This will be the first study of its kind and will help us to predict the birds' ability to adjust to changes to their environments, such as new windfarms, by adapting their behaviour. This analysis could be extended using data from German collaborators who coincidentally performed longer-term tracking on chick rearing kittiwakes from Helgoland during 2017 and are willing to work with us. Using the additional data from Helgoland would allow us to determine whether site fidelity, and therefore the ability to adapt behaviour in response to new developments, differs between colonies.
6. An investigation of the overlap between the Hornsea development and the flight paths of prospecting juvenile gannets. Juvenile gannets have been tagged for the first time at three major sites in the North and Irish Sea (Grassholm, Bass Rock and Helgoland) by a

potential collaborator at the University of Glasgow who is willing to share data. Birds from all sites visited the Filey and Flamborough pSPA colony on their journey. This provides a unique opportunity to address a major gap in environmental assessments and to go beyond at-sea surveys and tracking data from breeding adults, enabling us to understand risks to juvenile non-breeders for the first time.

Recommended continuation of strategic seabird research

To address remaining gaps in our understanding of the at-sea distribution and behaviour of the two seabird species predicted to be most vulnerable to collision with the planned Hornsea wind farm developments, we recommend a further year of tracking work on both kittiwakes and gannets, as follows:

1. Another 20 kittiwakes should be tracked using an improved version of the tags used this season. These tags will include altimeters, potentially a slightly larger battery and the option to set up three rather than two geographically defined sampling regimes which will address problems with battery life and enable us to choose different sampling regimes within the colony, outside the colony and within the windfarm area. We have discussed these modifications with the tag developer, who will attempt to incorporate all of them alongside the addition of altimeters, subject to the altimeter development work being funded (as itemised in the current contract). Tracking data will therefore provide the most accurate flight altitude measurements for the species to date, more detailed behavioural data via accelerometers, and another opportunity to assess tag effects (which is important given the marginal tagging effect observed this year). We recommend the study should focus on Flamborough Head and the new site at Speeton to collect valuable tracking data of more birds in the centre of the colony, and to exclude Filey from the tracking work due to a high nest failure rate at this site, which limits data collection.
2. Twenty chick-rearing gannets should be tracked during 2018, which will provide the first high temporal resolution tracking data at the Bempton colony (previous gannet tracking at this site has used satellite tags that record positions less frequently). This baseline data collection will be vital if we are to compare gannet behaviour before and after wind farm construction in order to improve understanding of avoidance behaviour. Given construction timescales, 2018 is the only opportunity to collect this important data. This work could be performed using a larger version of the tags described above with more solar panels and a larger battery, due to the high body weight of gannets, which would allow more frequent GPS locations and accelerometer samples than we are able to collect

for kittiwake. Medium-term attachment of tags is easily achieved on gannets compared to kittiwakes by attaching them to the tail feathers, a proven method that has previously enabled tracking data collection over many weeks. As above, tags would feature an altimeter, accelerometer and the same option for sampling regimes, so the proposed tracking work would produce high resolution behavioural and altitude data for gannets across the whole chick-rearing period. This would provide important data on key parameters for collision risk models, including flight speed, flight height, and proportion of time spent (a) in flight, and (b) in the wind farm footprint, and would also provide the baseline against which to compare flight behaviour once turbines are constructed.

3. We must conduct re-sighting work to compare return rates of colour-ringed control and tagged kittiwakes to the colony in early-spring 2018. This will ensure that we can get approval for a licence to use the same tagging method for kittiwakes in future, and is a relatively small cost, particularly if done alongside other work.
4. Set up a project to colour ring kittiwakes to monitor survival rates as already suggested in this year's proposal. Although we did colour ring tracked individuals and a control sample close to the study site to estimate tagging impact on survival rate, we further suggest to set-up a larger scale project next year at an accessible site where no tagging will be conducted. Prospecting for potential sites during this field season highlighted other sites at Flamborough Head but also Flamborough North Landing as suitable choices which are accessible but not ideal for tagging work using relays/remote download tags. By colour ringing an initial sample of 200 birds at those sites and continuing to colour ring and re-sight birds over numerous years we could estimate adult survival rates between years for the colony, which will be an important component of population models assessing colony wide impact of local offshore developments.
5. In the longer-term, getting the best value from the data already collected will require further during- and post-construction tracking and monitoring work. We recommend tracking both species for at least one year during construction, two years immediately post-construction, and then at three-year intervals for the remainder of the post-consent monitoring period to determine whether habituation to the turbines occurs. We recommend that the long-term plan is discussed and agreed with the Flamborough and Filey Coast Seabird Monitoring Group, and that specific methodological details are refined throughout the course of the work, as rapid advances in tracking technology, analytical methods and other developments may bring improved, more efficient or more cost-effective methods to answer key questions in future years.

The recommended kittiwake and gannet tracking work during 2018 would provide more than double the amount of data than in 2017, including one additional species, but costs are likely to be similar, because this year's base-stations, antennas and other field equipment can be reused. Tracking both species would require a maximum of three additional relays, one additional month of salary for a senior research assistant compared to tracking only one species, and tag costs. We are able to provide a detailed, fully-costed research proposal on request.

We highly recommend that the development of a GPS tag with inbuilt barometric altimeter, as itemised in the current contract, is approved by Ørsted as a matter of priority, and by the end of October 2017 at the very latest, so that this work can be completed ahead of the 2018 breeding season. We can also confirm that the previously agreed colony monitoring (already in the current contract and with no further confirmation required) will go ahead next year.

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Appendix I.

Tagging studies sometimes omit the first trip conducted by an individual bird after tag attachment to exclude movements that are likely caused by stress from handling and are not representative of normal foraging behaviour. This is critical in species that are easily stressed and/or temporarily abandon their nest after tagging. In this case, tagged Kittiwakes returned to the nest within minutes and spent an average of 8 hours (N= 18, SD= ±9 hours, Range= 1-20 hours) at the nest or within 1km of the colony before engaging in the first foraging trip (longer than 1 hour). Therefore, we expect that birds returned to their chick rearing routine and direct stress from capture and handling does no longer influence the bird's foraging movements at sea. Consequently, it should not be necessary to exclude the first foraging trip from the sample.

To test this hypothesis, we compared the trip metrics of the first with the second trip conducted by an individual using general linear mixed models also including cofounding predictors that are likely to cause a change in trip metrics. Models included trip number (binomial), a factor indicating if the nest failed before or during the trip (binomial), day after hatching and Julian day as predictors and allowed the intercept to vary between individuals.

Although trip metrics were significantly different when nests failed before or during the second trip (all trip metrics increased), there was no difference in any of the metrics between the first and the second trip (Table), which supports our hypothesis. Therefore, we did not exclude the first foraging trip after deployment from our sample.

Table. Model outputs for the three different general linear mixed model run to assess differences in trip metrics between the first and second trip conducted after tagging. Models further allowed the intercept to vary by individual. Note that "Trip number" and "Failed" were both entered as binomial factors and estimates therefore predict change in intercept from the first to the second trip rather than changes in slope. The one tagged bird from Speeton was not included in the study since the nest was not monitored and co-founding predictors were therefore not available. N=34 from 17 birds.

Model 1:	**Predictor**	**Estimate ±SE**	**DF**	**F**	**Probability**
Duration	Trip number (binomial factor)	6.15±4.30	19	2.039	0.170
	Failed (binomial factor)	72.87±13.05	29	31.200	<0.001***
	Day after hatching	0.04±0.62	15	0.004	0.953
	Julian day	-0.02±1.32	16	0.027	0.873

Model 2:	**Predictor**	**Estimate ±SE**	**DF**	**F**	**Probability**
Range	Trip number (binomial factor)	14.61±23.55	19	0.385	0.543
	Failed (binomial factor)	238.76±71.91	28	11.026	0.002**
	Day after hatching	1.74±3.45	14	0.253	0.623
	Julian day	3.094±7.35	16	0.177	0.679

Model 3:	**Predictor**	**Estimate ±SE**	**DF**	**F**	**Probability**
Distance	Trip number (binomial factor)	65.08±61.41	19	1.123	0.302
	Failed (binomial factor)	725.61±188.74	28	14.780	<0.001***
	Day after hatching	3.22±9.18	14	0.123	0.731
	Julian day	4.10±19.54	16	0.044	0.836