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Pilot Tracking Study of the Migratory Movements of Shelduck to Inform Understanding of Potential Interactions with Offshore Wind Farms in the North Sea

Ros M.W. Green, Niall H.K. Burton and Aonghais S.C.P. Cook

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Pilot tracking study of the migratory movements of Shelduck to inform understanding of Potential interactions with offshore wind farms in the North Sea

Report of work carried out by the British Trust for Ornithology on behalf of the Department for Business, Energy and Industrial Strategy's Offshore Energy Strategic Environmental Assessment programme.

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EXECUTIVE SUMMARY

1. Following a review of current knowledge of the migratory movements of British and Irish Shelduck *Tadorna tadorna* in relation to the potential risks to the species associated with offshore wind farms (Green et al., 2019), a pilot tracking study was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS)'s Offshore Energy Strategic Environmental Assessment programme.

2. The objectives of the study were to catch and tag 10 Shelduck immediately preceding their departure on moult-migration across the North Sea in order to:
   - (i) Provide data to assess the routes and timing of movements of Shelduck during the early summer period on their migration between the UK and moulting sites in the Dutch/German Wadden Sea;
   - (ii) Provide data to assess the flight height and flight speed during these movements;
   - (iii) Assess potential connectivity with offshore wind farms (OWFs) within the southern North Sea during these movements; and
   - (iv) Assess suitable methodologies for a wider study, and tag performance.

3. In total, four adult Shelduck (two male and two female) were caught at the Alde-Ore Estuary Special Protection Area (SPA) in July 2019 and fitted with KITE BB 2S GPS-GSM tags manufactured by Ecotone Telemetry. All four subsequently migrated across the North Sea, initially to the Dutch Wadden Sea, with further onward movements to the German Bight shown by three individuals. Details of the birds' migration routes and data on flight timings, height and speed are presented. Only one data point occurred within an operational offshore wind farm, although other data points were recorded within planned offshore wind farms and an offshore wind farm under construction.

4. Conclusions on the success of the pilot study are presented and recommendations are provided on field methods, data analyses and the potential objectives and options for a future study that might build on the pilot.

1. INTRODUCTION

1.1 Background

The north-west European population of Shelduck *Tadorna tadorna* is estimated at 250,000 individuals (Wetlands International, 2020), and breeds on or near the coast from France through to Scandinavia and the Baltic (Hagemeijer & Blair, 1997). In the UK, as a breeding species it predominantly occurs on the coast, but with a significant inland breeding range (Balmer et al., 2013). It is also similarly widespread across UK coasts during passage seasons and the winter and is a non-breeding feature of 32 Special Protection Areas (SPAs) (Stroud et al., 2016).

A review project was conducted on behalf of the Department for Business, Energy and Industrial Strategy (BEIS) through which an overview of current knowledge of the migratory movements of British and Irish Shelduck was provided, in relation to the potential risk of offshore wind farm (OWF) effects for birds making migratory movements across the southern North Sea (Green et al., 2019).

The following information was provided within the review:

i. An overview of Shelduck distributions and movements within the north-west European population, highlighting existing knowledge of their migratory routes and timing, as well as the paucity of information available on their flight heights and speeds;
ii. An analysis of ring-recovery data from the British and Irish Ringing scheme, which broadly confirmed the information found within the literature review;
iii. A summary of key gaps in knowledge and recommendations for further work that could be conducted to fill these gaps.

As summarised in the review, a substantial proportion of the UK breeding Shelduck population migrates to the European continent annually in order to moult their flight feathers, before then returning to the UK to over-winter. In order to make this migration, the Shelduck must cross the North Sea and consequently there is the potential for them to interact with OWFs. However, the high resolution data on the birds' migratory pathways, flight heights and flight speeds needed to assess whether they do interact with OWFs, or to quantify the level of risk Shelduck may be exposed to whilst passing through OWFs, are currently lacking.

Given the current state of knowledge, a key recommendation of the review was for a pilot Global Positioning System (GPS) tracking study to better understand Shelduck movements and to evaluate suitable methodologies for further studies. A pilot tracking study was commissioned to be undertaken in summer 2019. The results of this pilot are outlined within this report and recommendations for future work are provided.

1.2 Project Objectives

The objectives of this pilot were to:

i. Provide data to assess the routes and timing of movements of Shelduck during the early summer period on their migration between the UK and moulting sites in the Dutch/German Wadden Sea;
ii. Provide data to assess the flight height and flight speed during these movements;
iii. Assess potential connectivity with OWFs within the southern North Sea during these movements;
iv. Assess suitable methodologies for a wider study, and tag performance.

Data on flight characteristics, such as flight height and speed, are key parameters for several collision risk models, and so gaining more quantitative detail on these parameters should help improve the quality of current collision risk assessments (Masden & Cook, 2016; Fijn & Gyimesi, 2018).

2. METHODS

2.1 Field Methods

2.1.1 Study site

In order to maximise the likelihood of achieving the aims of this pilot, it was identified that Shelduck should be caught from a site on the south Norfolk, Suffolk, Essex or Kent coasts. The initial review of the literature and ring recoveries analysis indicated that Shelduck in these areas were more likely to migrate east to the Wadden Sea, rather than stopping at UK moulting sites, and were also more likely to pass operational OWFs on this migration (Green et al., 2019).

The Alde-Ore Estuary SPA was identified as a suitable site for the pilot study, as it was known to have Shelduck present during the correct migratory time period, with numbers increasing in June and July and then falling, suggesting migratory activity. Shelduck also qualify as a feature of the SPA as part of an over-winter waterfowl assemblage[1]. Two potential catching sites within the Alde-Ore Estuary SPA were identified: Orford Ness NNR (National Trust) and Havergate Island (RSPB).

The Orford Ness NNR presented the better catching opportunity initially, as there were fewer other breeding species on the island that might be disturbed during the course of a catching attempt. A recce on 14th June found a suitable catching location where 20 Shelduck were roosting, but by the time the relevant permissions and consents had been granted (site permission from National Trust, and SSSI/SPA consent via a Habitats Regulations Assessment from Natural England) in late-June the Shelduck were no longer consistently roosting in groups exceeding 10 birds anywhere within the Orford Ness NNR. The decision was taken to place a cannon-net within the reserve on the 1st July, with wheat bait scattered regularly to try and entice Shelduck into the area in suitable numbers (~10 birds). However, no Shelduck responded to the bait and the number of Shelduck present across the entire reserve continued to decrease throughout July.

During the first week of July, wardens on Havergate Island informed us that Shelduck numbers had increased there from ~40 to ~200 between the end of June and 5th July, which was consistent with a pre-migration aggregation. It was assumed that the Shelduck which had been present on Orford Ness had either migrated or relocated to Havergate Island. The decision was taken to attempt to catch Shelduck on Havergate Island instead of Orford Ness NNR, and site visits with the wardens enabled us to find a suitable catching site that would minimise disturbance to other breeding bird species on the island. This target lagoon had nesting terns, but no other nesting species. The relevant extension to the SPA permission was sought, and site permissions from the RSPB were gained.

Reports from a volunteer on Havergate (Mike Matthewson) revealed that Shelduck numbers across the whole island were rapidly dropping (~200 on 5th July, ~100 on 7th July), which suggested Shelduck were already migrating away from the site. Dummy cannon-nets were laid on multiple islands within the target lagoon between 8th-11th July, for birds to habituate to, and a catching attempt was made on 12th July. On the 12th, three proper cannon-nets were set in orientations that maximised the chances of covering areas where Shelduck had been seen roosting regularly. No bait was laid, but feathered Shelduck decoys were placed in the middle of the catching area of one island, to

[1] JNCC – Alde-Ore Estuary SPA - http://archive.jncc.gov.uk/default.aspx?page=2010

encourage Shelduck to roost there. The locations of the sites described above are displayed in Figure 2.1.

Figure 2.1 Location of catching sites; with the original planned catching site (blue), two attempted catch sites (red and yellow) and the final successful catch site (green). The red and blue points are within Orford Ness NNR, and the yellow and green points are on Havergate Island.

2.1.2 Tag selection and licensing

Tag selection was informed by the data needs of the project and licensing criteria.

Licensing of the deployment of tags on birds in the UK is overseen by the independent Special Methods Technical Panel (SMTP) of the BTO Ringing Committee. Previous tracking studies of ducks have shown that they may not respond well to having tags fitted using a harness (Pietz, Krapu, Greenwood, & Lokemoen, 1993; Bergmann, Flake, & Tucker, 1994; Rogers, Petrie, & Baloyi, 1996; Lameris & Kleyheeg, 2017). Eight previous Shelduck tracking studies are known to have been conducted (Green et al., 2019), of which six used harnesses (Gyimesi et al., 2017; Wang et al., 2018;

Leander Khil (unpub.)[2]). The results of only one of these harness studies have been published (Wang et al., 2018), though issues with the harness design were not discussed, and communications with leaders of the other projects suggest the Shelduck did not respond well to harnesses. Due to these reported problems, the SMTP will not licence deployments of back mounted devices using harnesses on ducks, as they do not feel this method meets Home Office welfare standards. They will only licence this method if controlled studies on captive ducks are conducted, in order to prove welfare standards are not compromised. There are devices that can be attached to birds permanently using leg rings or neck collars, but none of these are capable of collecting data at the resolution needed to fulfil the objectives of this project. Therefore, the only suitable attachment method for this project was glue-mounting a tag to the mantle of the Shelduck.

Glue-mounted tags only remain attached to the bird for as long as it takes for new feathers to grow underneath and displace the tag. It is reported within moult guides (Baker, 1993; Demongin, 2016) that Shelduck undergo body moult once they have finished breeding, so it was not anticipated that the tags would stay attached to Shelduck for more than a month. Given that the birds were expected to migrate to an unknown location, it was assumed that manual retrieval of the tag in order to download data directly would not be possible. Therefore tags with remote downloading capabilities were required. Placing base stations close enough to birds migrating to unknown destinations in order to remotely download data via VHF/UFH would not be possible, so a tag capable of transmitting data remotely from any location within Europe was essential. GPS-GSM devices are the most widely available method for achieving this, whilst still collecting data at a suitable resolution to achieve the objectives of this project. Other remote downloading systems are available (satellite/PTTs/Argos) but these are more energy intensive and so require a large battery, which increases the tag weight beyond the licensable threshold. The SMTP generally only approve applications that have a device deployment weight that is less than 3% of the bird's weight.

For the purposes of this pilot it was agreed that the KITE BB 2S GPS-GSM tags manufactured by Ecotone Telemetry[3] were the most suitable option available. This is a GPS-GSM device that is capable of collecting up to 1440 GPS positions per day (1 per minute), as well as instantaneous speed data, and altitude data from both GPS data and barometric pressure sensors. The GPS fix rate can be controlled by an acceleration sensor, such that the tag collects data at a variable rate depending on whether the animal is moving or not. This functionality would enable battery power to be saved when the bird was stationary, ensuring enough was available to collect the highest resolution data possible during the migration. This model weighs ca. 20 g which is less than 3% of the species' average body mass (~1.2 kg, range 850-1560 g[4]), as required by licensing. The model is available at lighter weights, but it was decided that the inclusion of two solar panels for more efficient solar recharging, and a barometric pressure sensor were worthwhile to help achieve the objectives of the project. Temperature and accelerometry sensors were also integrated as standard. The tag would be affixed using glue to the Shelduck's mantle, which is the method recommended by the SMTP, and the mantle positioning minimised the risk of the additional weight affecting the flight dynamics (Vandenabeele et al., 2014; Lameris & Kleyheeg, 2017).

[2] Movebank study – https://www.movebank.org/movebank/#page%3Dstudies%2Cpath%3Dstudy522309921
[3] Ecotone Telemetry - http://www.ecotone-telemetry.com/en
[4] BirdFacts – Shelduck - https://app.bto.org/birdfacts/results/bob1730.htm

An alternative tag, the Ornitela OrniTrack-25[5], was also considered during the tag review process, and was capable of collecting the same data as the Ecotone Telemetry tag. It may have been capable of collecting location data at a higher frequency, but weighed 25 g+ so may not have been suitable for deployment on all captured Shelduck, as it may have weighed more than the 3% licensing weight threshold. As Shelduck are difficult to capture it was imperative that the tag was light enough to ensure it could be safely deployed on any bird captured, in line with the licensing conditions.

2.1.3 Catching and tagging

Shelduck are notoriously difficult to catch during the breeding season. During cold periods in the non-breeding season many individuals can easily be attracted into small, concentrated areas using bait (seed or wheat) and caught using traps, whoosh nets or cannon-nets. However, during the breeding season food is plentiful so they do not respond readily to bait, and individuals are territorial so rarely congregate in groups. This makes it challenging to catch a large enough sample for tagging, especially during the distinct time period aimed for as part of this pilot. Since 1963, UK national Ringing Scheme data indicate that 34.4 Shelduck on average per month have been caught between November – February (wintering), 15.6 between March – June (breeding), and just 5.4 between July – October (migratory period) (note, these figures only encompass individuals for which weight data were also available in the ringing database).

Shelduck had to be caught after they had finished breeding, but before they had migrated across the North Sea. They could not be tagged whilst still breeding for two main reasons:

i. Shelduck breed in holes – if a GPS tag is taken underground then it cannot communicate with satellites to get a location fix, and the battery is quickly drained attempting to do so. There is also a risk that a glue-mounted tag on the back would be dislodged as the Shelduck moves in and out of the hole;
ii. It is suggested in moult guides (Baker, 1993; Demongin, 2016) that body moult begins straight after breeding. There is a risk that any tag glued onto the bird whilst it is breeding would be shed before it begins its migration to the continent.

This meant that the most suitable catching and tagging period would be mid-June to early July, as identified from the literature review previously conducted (Green et al., 2019). Several potential catching methods were considered – see Appendix 1 for details of these.

For this pilot, given the catching sites, species, and licensed ringers available, cannon-netting was deemed the most appropriate catching method. It is recognised that this method may not be the most suitable for other catching situations, but was the most appropriate for this pilot.

On the day of the catch, three nets were set by three licensed individuals, with the assistance of two RSPB staff. Two feathered decoy Shelduck (taxidermy models) were placed within the catching area of one net to encourage Shelduck to roost with them. Once all nets were set, disturbance on the lagoon was kept to a minimum. The lagoon was watched by licence holders from a hide continuously, and when Shelduck numbers on the lagoon began to build the team of nine got into strategic positions so as to be ready to deal with the catch efficiently as soon as it was taken.

[5] OrniTrack-25 - https://www.ornitela.com/25g-transmitter

Shelduck returning to the lagoon after being disturbed by the setting process were initially reluctant to use the islands with cannon-nets on, but were instead actively feeding on algae within the lagoon, and resting on islands with no cannon-nets. Eventually one bird finished feeding and roosted on the island with the Shelduck decoys. This bird acted as a 'live' decoy which others soon came to join. Numbers steadily built up on the island, and as soon as the licence holders were satisfied that 10 birds were catchable, the nets were fired. It was hoped that more than 10 birds could be captured, since it was possible that some birds would be undergoing extensive body moult and would therefore be unsuitable for tagging. However, it appeared that no more than 10 birds were in the area at the time, perhaps due to the lateness within the migratory season. Of the 10 birds present when the nets were fired, four were captured, with the other six escaping from beneath the nets. All four birds caught were full adults (more than two years old) and were suitable for tagging. Tags SHEL01 and SHEL07 were fitted to two males and tags SHEL03 and SHEL08 to two females.

2.2 Data Analysis

2.2.1 Data categorisation

All data associated with flight were manually extracted from the complete deployment dataset using a decision process that utilised the GPS location, speed, and accelerometry data to identify flight data. At each data fix, if the speed figure was >12 knots and the accelerometry data showed a clear flight pattern (Figure 2.2, SHEL01) then the data were categorised as 'flight data'. If only one of the speed or accelerometry data met these criteria, then the GPS positions before and after the fix were taken into account to see if a substantial movement (>500 m) had taken place. If it had, then the data were categorised as 'flight data'. A time delay of 1 – 90 seconds between the accelerometry data collection and GPS/speed data collection was possible, which meant the two data types were not necessarily always associated with the same behaviour. In some cases it was not possible to logically determine whether the GPS, speed and height data (all taken at the same instant) were genuinely associated with flight; if there was any uncertainty then the data were not categorised as 'flight data'. For this relatively small dataset it was not possible to train models or algorithms to extract the flight data automatically. This manual process has ensured that all data presented as 'flight data' herein do genuinely represent data collected during flight, and has provided the dataset from which algorithms may be trained in future. Subsets of these flight data have been analysed to provide information on flight speed, whilst subsets of the entire deployment dataset have been analysed to provide information on flight height, North Sea migration timings, and routes.

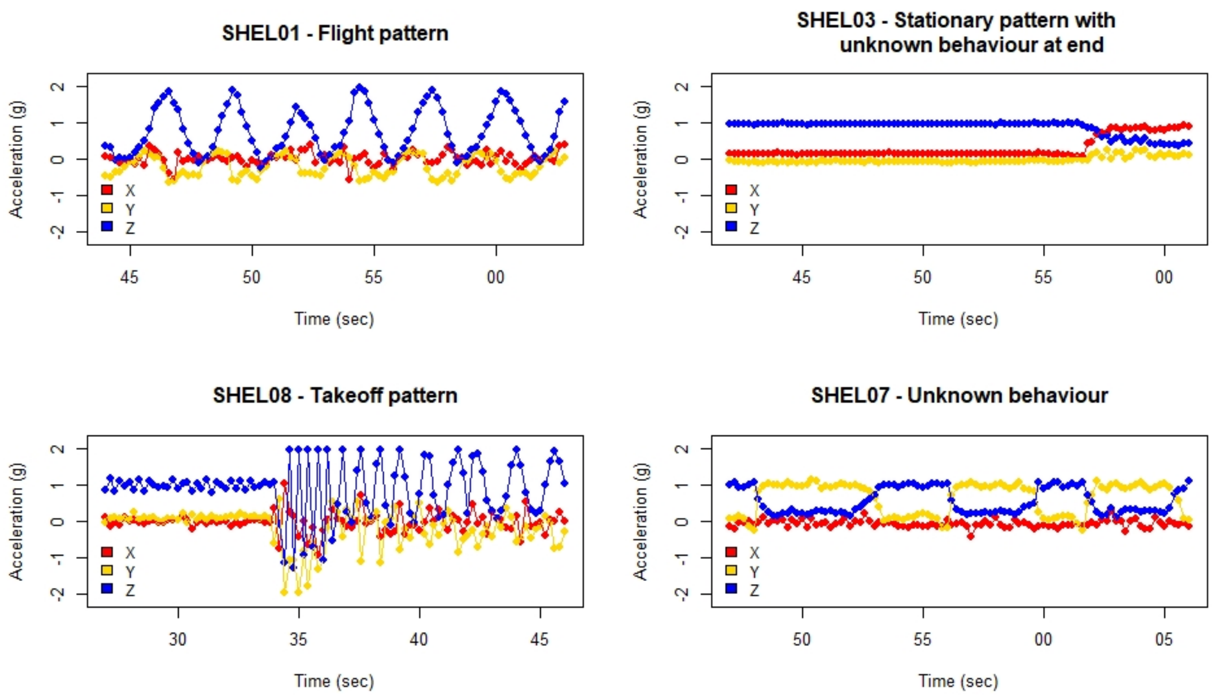


Figure 2.2 Example patterns from accelerometry data; collected shortly before each GPS fix (1-90 seconds prior). An example is displayed from each bird, for four different behaviours.

2.2.2 Speed data analysis

Data on instantaneous speeds for all Shelduck are presented, as well as subsets of these data that are associated with flight only. Instantaneous speed measurements are reported directly by the tags, and are calculated based on the time interval between sending and receiving the location information from the GPS-satellites. The mean error of similar devices that collect speed data in this way is generally between 0.01-0.82 m/s, and thus is a more representative speed estimate than those calculated from the time and distance between consecutive GPS fixes (Fijn & Gyimesi, 2018). Graphical representations of speed data have been plotted using a Kernel Density Estimation value on the Y axis, to help represent the spread of the speed data.

2.2.3 Flight height calculations

Data on altitude were collected by the tag in two separate formats; one from GPS satellite triangulation and the other from a barometric pressure sensor. The software provided by Ecotone Telemetry[6] calculated altitude from the GPS data and reported this value within outputted data files. The software also calculated altitudes using the barometric pressure sensor data and global pressure average data, and displayed this in graphical format. It did not output these data from the graph into data files because the estimates are deemed to be inaccurate, as they are calculated from uncalibrated sensors using global pressure averages rather than localised data sources. The altitude

[6] NGAnalyzer - http://nga.gps.ecotone.pl/ngaupdates/NGAnalyzerSetupComplete.exe

data calculated from these two data sources rarely agreed, which further suggests the estimates produced from them were not always accurate.

The altitude data reported here are those produced by the Ecotone Telemetry software, and should not be interpreted as precise. They do, however, provide representative information on the changes in relative altitude made by each Shelduck.

Further assessment of the precision and accuracy of altitude measurements is provided in the discussion, together with recommendations for calibration and possible future analysis.

3. RESULTS

3.1 Field Study and Tag Evaluation

3.1.1 Tag deployments

In total, four Shelduck were caught at the Havergate Island study site within the Alde-Ore Estuary SPA on 12th July 2019, from a total of 10 birds in the catching area. The other six birds either flew out from under the net before it landed, or pushed out of the side of the net after it had landed on top of them. Part of the net landed in water so some of the birds got damp; all birds were allowed time to dry off completely before tagging commenced. Due to the availability of catching sites, total number of Shelduck present, and potential disturbance to other species at the site, it was decided that any further catching attempts at that time of year would not be successful. Potential improvements to the catching method are discussed within the recommendations section.

All four birds caught were full adults (at least 2 years old), and comprised two males and two females (Figure 3.1). Immature Shelduck (1-2 years old) are also known to migrate to the Wadden Sea, so it was hoped one of these could also be tagged as part of the pilot to see if their migration routes, timing and flight characteristics differ from adults. No immatures were present on Havergate at the time of the catch attempt, so it is possible these had already migrated east, as suggested in the literature (Green et al., 2019).

Figure 3.1 Plumage differences in Shelduck. Left is a male with continuous black head plumage, uniform red bill and 'knob' ridge at the top of the bill; right is a female with white feathering around the base of the bill, mottled pink and black bill, and no 'knob'. Photos by Dave Fairhurst.

All four birds were fitted with BTO metal rings and a colour-ring. Full biometrics were taken (Table 3.1).

Table 3.1 Ring, colour-ring and biometric data from the four Shelduck tagged at the Alde-Ore Estuary SPA on 12th July 2019.

Bird/Tag ID	Ring number	Colour-ring code	Sex	Weight (g)	Wing (mm)	Bill length (mm)	Total head length (mm)	Tarsus length (mm)
SHEL01	GR55664	S3	Male	1368	336	55.4	102.9	59.2
SHEL03	GR55662	S6	Female	957	319	50.1	102.0	52.9
SHEL07	GR55661	S7	Male	1246	346	55.9	107.2	57.9
SHEL08	GR55663	S4	Female	999	310	49.3	95.6	54.3

All four birds were in active body moult, but this was not extensive on the mantle where the tag needed to be affixed. Mantle feathers were trimmed cautiously to ensure that active pin feathers (with strong blood supply) were not cut, and the tags were glued to the trimmed site ensuring no pin feathers were glued. Tags were checked for a firm and unrestrictive fit before the birds were released (Figure 3.2).

Figure 3.2 Images showing Shelduck with a glue-mounted tag fitted. The tag is positioned such that the forward edge is aligned with the rear edge of the chestnut mantle band.

All tags fell off within one month – see details in section 3.2 below – and all birds were still apparently able to fly at the time the tags dropped off. This suggests the mantle moult continued more heavily once the Shelduck reached the continent, thus moulting the tag off, and that their main moult (flight and tail feathers) had not yet begun before the tags were shed.

Tag weights were recorded, and the combined weight of tag and colour-rings was less than 3% of the overall mass of each bird in all cases. These data are summarised in Table 3.2.

Table 3.2 The additional weight added to each Shelduck (tag + colour-ring) expressed as a percentage of the birds mass before tagging. In all cases this was <3% of the mass, as stipulated by the licensing criteria.

Bird/Tag ID	Bird mass (g)	Tag weight (g)	Colour-ring weight (g)	Added weight as % of bird mass
SHEL01	1368	21.90	2.10	1.75
SHEL03	957	22.51	2.04	2.57
SHEL07	1246	22.12	2.05	1.94
SHEL08	999	22.72	2.01	2.48

On release all birds flew strongly, and appeared behaviourally unaffected by the tags. Each bird was watched for as long as possible, and three were seen to be actively feeding on mudflat areas within 10 minutes of being released. The fourth flew out of view before landing, so its behaviour after landing could not be monitored.

This glue-mounting method worked very well and performed as expected; no issues were experienced whilst deploying the tags. The tagging team were aware that extensive body moult at the tagging site could cause issues, so any pin feathers were noted and avoided. It is positive that it was possible to tag all four birds that were caught, and their body moult was not too extensive at the time of capture. This attachment method fulfilled the objectives of the project as the tags remained firmly attached to the birds for the duration of their migration across the North Sea (see below).

3.1.2 Tag performance

Generally the Ecotone Telemetry KITE-L BB 2S GPS-GSM tags performed as anticipated, and collected robust data on the parameters outlined above. This was the first time these tags had been deployed on Shelduck, and as expected a few operational issues were discovered during the deployment period. It is hoped that issues experienced this year may be avoided in future. Recommendations for doing so are made within the recommendations section.

The tags were initially programmed to collect data every 10 minutes, which pre-deployment tests had shown to be the highest continuous resolution achievable given the battery capacity and solar recharging rate of the tags. It became apparent after five days that two of the tags (SHEL01 and SHEL03) could not sustain this rate during extended periods of poor weather (heavy cloud) when little direct sunlight was available for solar recharging. As such these tags were reprogrammed to collect data every 15 minutes; this data collection rate was successfully sustained for the remaining duration of the deployment period. Tag SHEL07 sustained the 10 minute rate for 10 days, but then needed to be reprogrammed to a 15 minute rate. Tag SHEL08 sustained the 10 minute rate for 19 days, but then needed to be reprogrammed to the 15 minutes rate also. Consequently any future deployments of these tags made using a similar continuous scheduling system will be programmed to collect data every 15 minutes from the outset.

All four of the tags exhibited some form of change in functionality during or shortly after the North Sea crossing, which was unexpected. These issues have been reported to the manufacturer, and solutions are being found. It may be coincidental, but these issues only seemed to occur after sustained periods of flight, and did not occur during the rest of the deployment period. Further details of these problems and causes are outlined in Appendix 2.

3.2 Evaluation of Data

3.2.1 Data summary

All four of the tagged individuals migrated from the Suffolk coast to the Dutch Wadden Sea, crossing the southern North Sea. Data on location, timing, flight height (calculated from both GPS and atmospheric pressure), instantaneous flight speed, and accelerometry were collected during these North Sea movements, as well as other tag performance data.

A summary of the data collected during the deployment period is displayed in Table 3.3. Each data fix contained data on time and date, latitude and longitude, instantaneous speed, altitude from GPS triangulation, an atmospheric pressure reading, accelerometry data in three axes at 5Hz for 96 samples (i.e. 5 samples per second for 19 seconds), external and internal tag temperature, the time taken to calculate location from satellite data and the number of satellites used to calculate this, and battery voltage.

The table summarises the total data received, together with data associated with flight, with migration and with the flight across the North Sea. The data associated with migration (Table 3.3, column 4)include the last stationary fix on the UK mainland, all flight data across the North Sea, the stationary fixes during the birds first short stopover on the Dutch coast, and then the flight data to and first stationary fix at their first major stopover in the Sexbierum to Zwarte Haan area. The data reported for the flight across the North Sea (Table 3.3, column 5) include just those continuous fixes associated with flight across the southern North Sea, and do not include any stationary fixes, or data associate with flight beyond the first short Wadden Sea stop-over.

Table 3.3 Summary of deployment period, and number of data fixes collected during different periods of the deployment. *Issues with data collection during the North Sea crossing are outlined in Appendix 2.

	1	2	3	4	5
Bird ID	**Deployment period (days)**	**Total data fixes**	**Total data fixes associated with flight**	**Total data fixes associated with migration to first major stopover**	**Total data fixes associated with flight across North Sea***
SHEL01	18.09	1405	66	38	29
SHEL03	23.03	2315	53	20	9
SHEL07	32.63	3373	89	39	3
SHEL08	42.77	4846	92	46	25
Average	**29.13 ± 10.92**	**2984.75 ± 1478.64**	**75.00 ± 18.71**	**35.75 ± 11.09**	**16.50 ± 12.48**

3.2.2 Speed data summary

The tags collected information on instantaneous speed at each fix (see section 2.2.2 for further detail). As this is not a speed calculated from the time and distance between two GPS points, it should be an accurate reflection of the speed of the Shelduck at the time of the fix. With 15 minute intervals between fixes, a speed interpolated from the distance and time between fixes would not be accurate as the bird is very unlikely to have been travelling at a continuous velocity in one direction for the entire intervening 15 minutes.

The speed data collected during the entire deployment period for each Shelduck are displayed in Figure 3.3, with the density axis limited to ensure that the larger speed readings are visible. A bimodal pattern is evident, with the majority of data representing speeds between 0 and 5 knots, few data between 5 and 15 knots, then a substantial proportion of the data being between 15 and 40 knots. When looking at the other information associated with each fix (altitude, accelerometry, location), it is possible to deduce that speeds of 0-5 knots represent stationary or ground-level behaviours (feeding, walking, swimming, preening etc.), and those of 15-40+ knots represent flight. The speed values between 5-15 knots represent a suite of behaviours that are distinctly different from the stationary data but are hard to classify, though they do include taking off and accelerating to a full flight speed, and decelerating in order to land. Detailed observational studies would help elucidate the range of behaviours that these data represent.

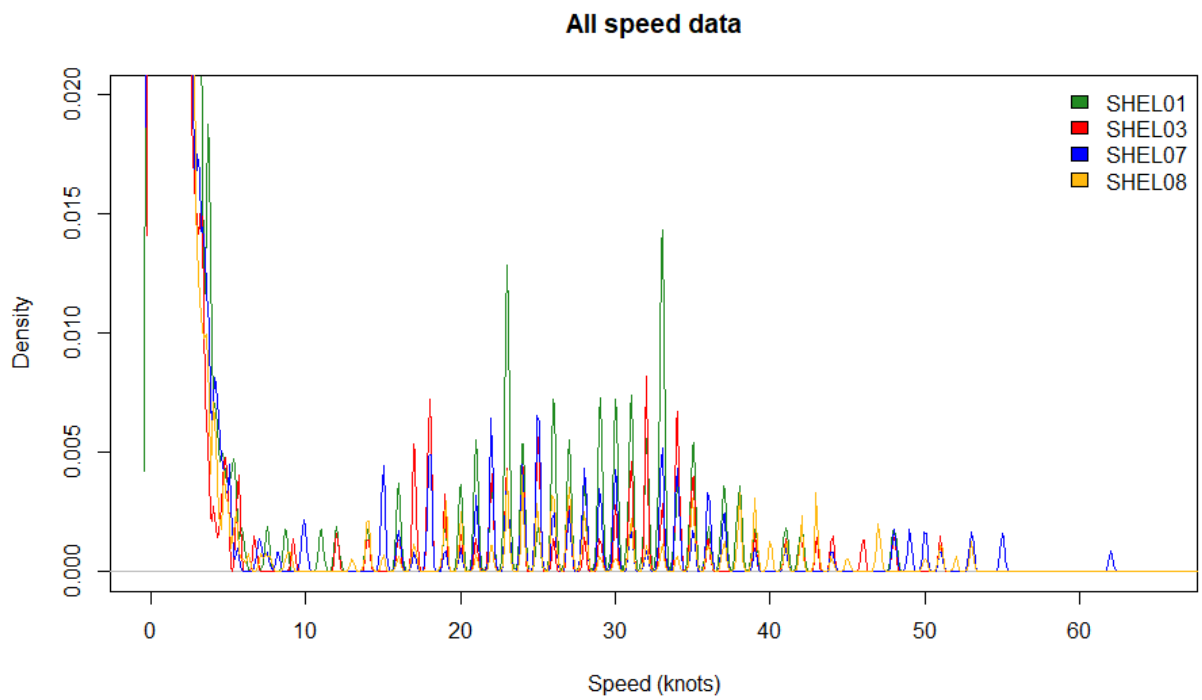


Figure 3.3 Speed data collected from all tags throughout the deployment period. The density axis has been limited for display purposes, so that the speeds >5 knots can be seen.

Using all the relevant information available (see methods 2.2.1), all data associated with flight behaviour were extracted from the full dataset. All flight speed data for each bird are presented in Figure 3.4. This confirms that the upper section of the bimodal pattern seen in Figure 3.3 does represent speeds associated with flight. The average flight speed was 30.3 ± 9.2 knots (n = 299, range: 8.7 – 55.0 knots).

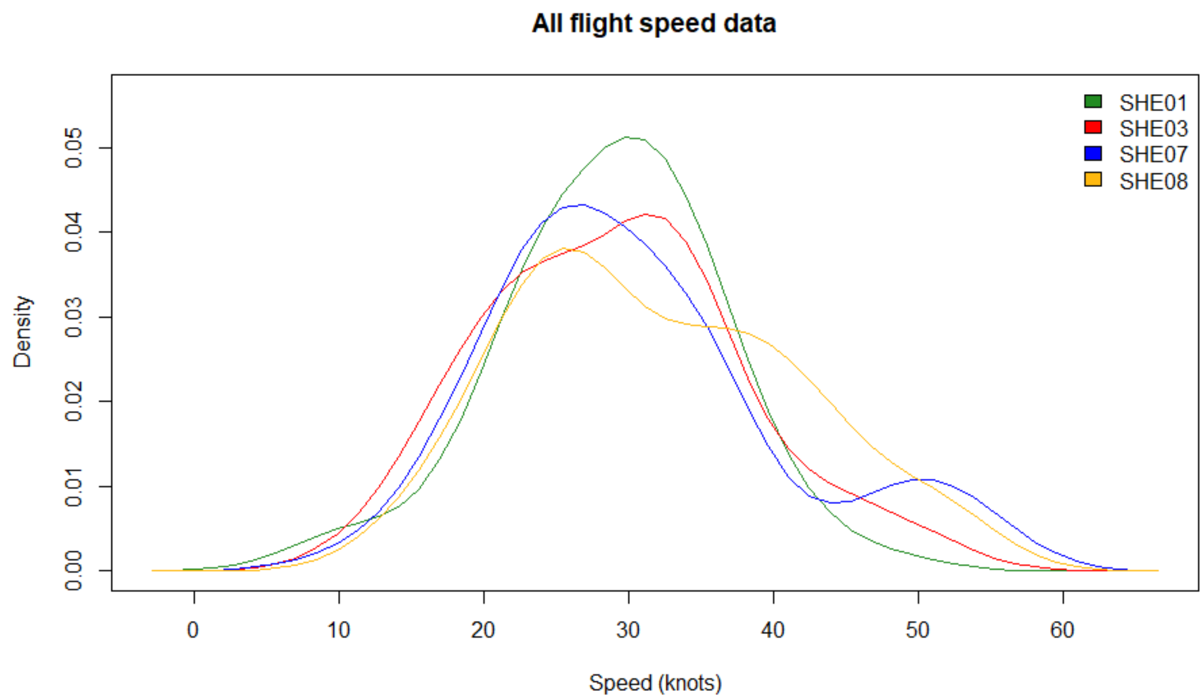


Figure 3.4 Speed values for data associated with flight only.

The flight speed data associated with the flight across the North Sea (Table 3.3, column 5) were then extracted from the full flight speed dataset. These data are displayed in Figure 3.5. The average flight speed for the North Sea migration was 35.4 ± 8.4 knots (n = 66, range: 14.0 – 52.0 knots), which is a higher average than for all flight speeds. This may suggest that on average, Shelduck fly faster when making a directed migration flight. This is confirmed when data for each individual are plotted as boxplots and compared (Figure 3.6).

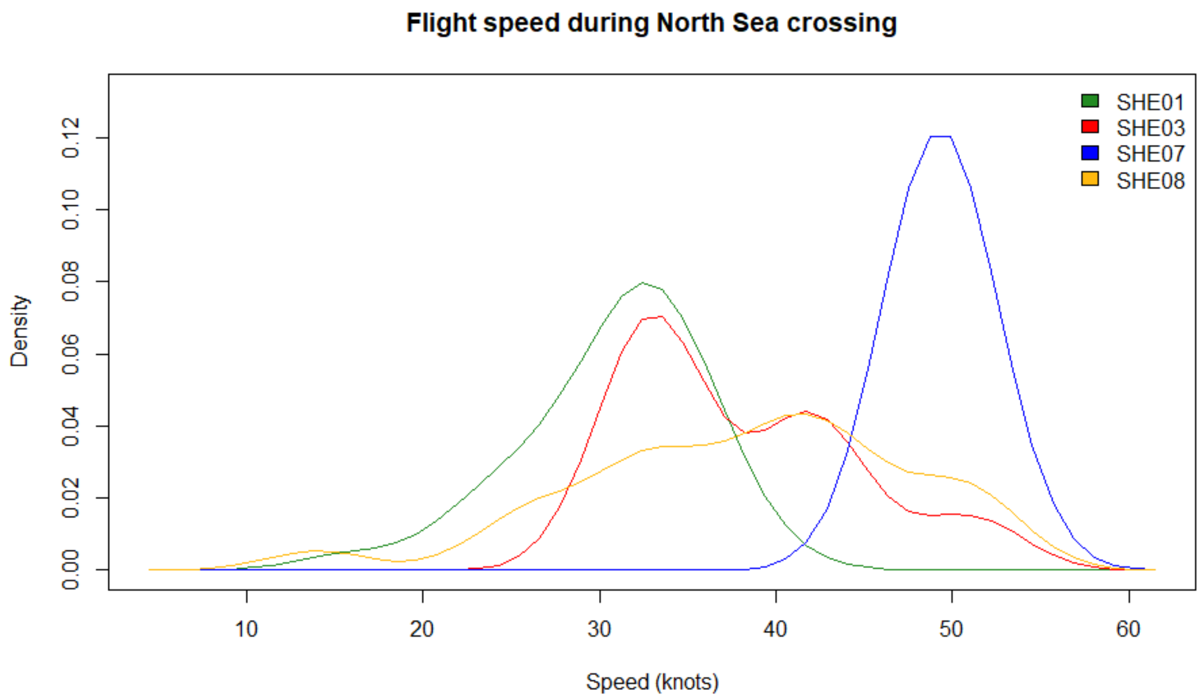


Figure 3.5 Flight speed data for the North Sea crossing period only.

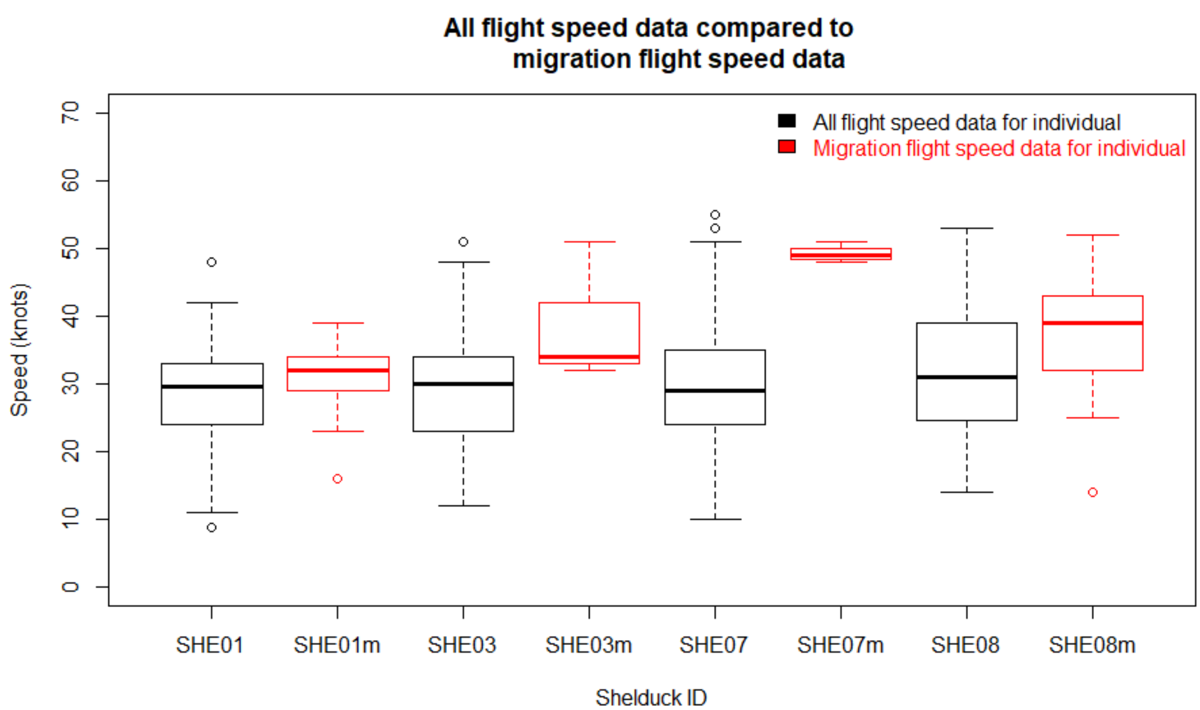


Figure 3.6 Data on all flight speeds (black) and migration flight speeds (red) for each individual tracked.

3.2.3 Migration timings and routes

All four birds migrated independently of each other, and took slightly different routes (Figure 3.7). The timings of migration for each bird are summarised in Table 3.4, with times presented in Coordinated Universal Time (UTC), which is one hour behind British Summer Time (BST).

Table 3.4 Timings of Shelduck moult migration from the UK to the Dutch Wadden Sea. All times are presented in Coordinated Universal Time (UTC). *Times for SHEL07 are only accurate to one hour due to the data fix rate during the migration period.

Bird ID	Final stationary fix in UK	Dutch coast reached	Wadden Sea entered	North Sea crossing duration (hours)	Migration to Wadden Sea duration (hours)
SHEL01	16th July 00:55	16th July 04:12	16th July 05:59	3.28	5.07
SHEL03	18th July 00:48	18th July 04:14	18th July 04:46	3.43	3.97
SHEL07*	22nd July 03:07	22nd July 06:03	22nd July 07:04	2.93	3.95
SHEL08	20th July 05:08	20th July 09:22	20th July 09:33	4.23	4.42
Average				**3.47 ± 0.55**	**4.35 ± 0.52**

In summary:

i. SHEL01 set off in the dark, in light north-westerly winds (<10 mph), with thin patchy cloud cover, arriving at the Dutch coast at dawn. It flew essentially due east until it reached the Dutch coast, then followed this northwards until it entered the Dutch Wadden Sea just north of Den Helder;

ii. SHEL03 set off in the dark, in light southerly winds (~10 mph), with thin cloud cover, arriving at the Dutch coast at dawn. It flew approximately north-east until it reached the Dutch coast, then followed this northwards until it entered the Dutch Wadden Sea just north of Den Helder;

iii. SHEL07 set off at dawn, in mild south-easterly winds (~20 mph), with thin patchy cloud cover, arriving at the Dutch coast by mid-morning (~08:00 Dutch time). It flew approximately north-east until it reached the Dutch coast, then appears to have followed this northwards until it entered the Dutch Wadden Sea just north of Den Helder. Data for this migration are less detailed than for the other Shelduck;

iv. SHEL08 set off in daylight as a rainy front moved from west to east across the North Sea with ~20 mph southerly winds. The Shelduck appears to have travelled with this front, so would most likely have been flying in rain, with complete, thick, cloud cover. It flew north up the Suffolk coast before turning east-south-east, and reaching the Dutch coast at Vlieland, where it then entered the Dutch Wadden Sea.

Figure 3.7 Routes taken across the North Sea by four tracked Shelduck.

The migration routes indicate apparent interactions with several OWF sites, though most of these sites are currently only at the planning or consenting phase. Only one data fix was apparently within an operational OWF, although it should be noted that the data freely available on the positioning of this wind farm are limited. SHEL07 was within the Egmond aan Zee wind farm at 06:03 (UTC) on 22nd July (Figure 3.7, blue line, operational wind farm near Alkmaar). At the time the Shelduck was flying at heights between ~30-85m, which would place it within the collision risk zone of Egmond aan Zee (25-139 m), and at rotor height (25-115 m), as reported by Krijgsveld et al., (2011).

There were also two instances where the straight line route between two data fixes passed through an operational OWF (Figure 3.7, SHEL01 through Luchterduinen, near Leiden; Figure 3.11d during post-migration movements, SHEL07 through Nordergründe, near Helgoland), but where the fixes themselves were outside the wind farms. It is not possible to state whether the actual flight path passed through the wind farm.

3.2.4 Altitude data summary for migration to first major stopover

Data on altitudes were available from both GPS measurements, and from data on atmospheric pressure. The variation in the raw altitude estimates produced by these two data sources is considerable, so in order to produce more accurate altitude estimates it is necessary to analyse the raw data output further. However, with the limited dataset from this pilot, this was not possible. Instead raw outputs of GPS altitude, and altitude data from pressure readings, analysed against global pressure averages, are presented for the period of migration to the first major stopover site (Figure 3.8). The migration period is here defined as including the data from the last stationary data fix on the UK mainland, to the first stationary data fix when the Shelduck reached their first major stop-over area. This included a period of stationary fixes in a short stopover when birds first reached the Dutch mainland (see 3.2.1 and Table 3.3, column 4). Approaches for future analyses are covered in the discussion.

The altitude estimates from these two data sources cover a range from 359.4 m down to -100.0 m. Negative altitude estimates represent part of the error distribution in estimates around the 'true' altitude. Future analyses would aim to capture this error and any inaccuracy in estimates in describing flight heights and their variation. The data from these two methods of estimation are presented in Figure 3.8. Here it can be seen that the GPS altitude estimates are reasonably well calibrated to a 0 m baseline, with the average altitude estimate for all birds being 36.7 ± 66.3 m. The altitude estimate calculated from air pressure is poorly calibrated to a consistent baseline, meaning that estimates across individuals were inconsistent. If calibrated to local air pressure values, rather than global averages, it may be possible to shift these to a consistent baseline, in line with the GPS estimates. However, it can be seen that, across individuals, data from the air pressure estimates broadly matched the GPS estimates, with data for individuals skewed higher or lower.

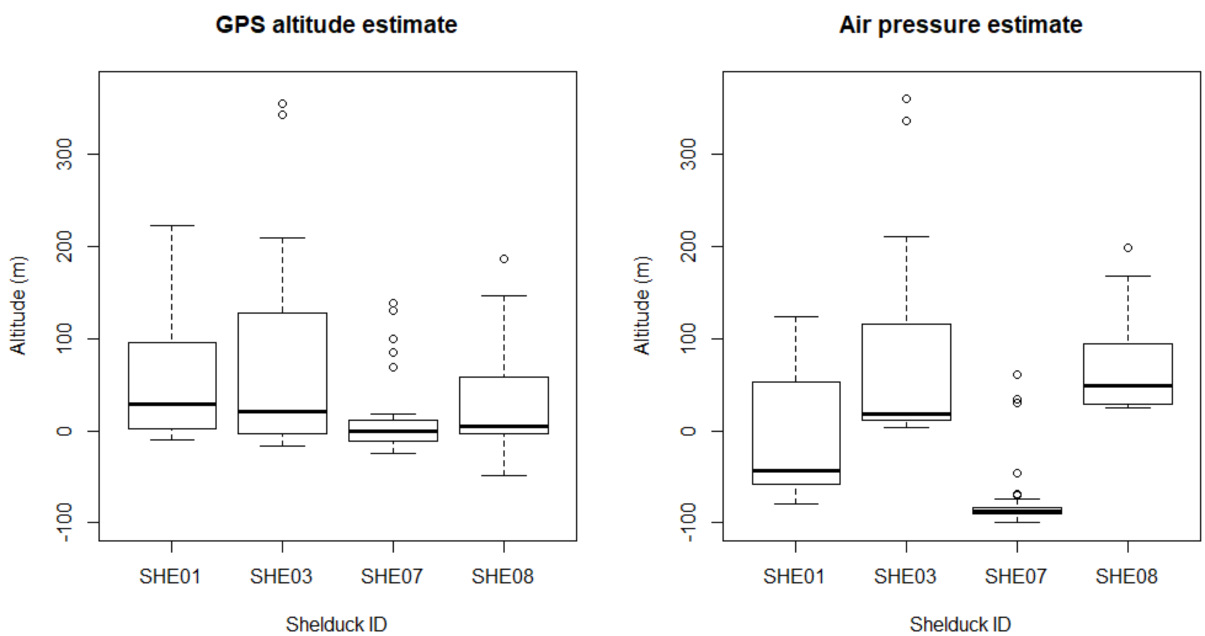


Figure 3.8 Variation in altitude estimates for four individuals tracked on migration across the North Sea. Estimates were calculated from two data sources; GPS altitude and altitude from air pressure.

On average the variation between the two forms of altitude estimate at each data fix was 55.2 ± 31.3 m (n = 143). The variation between the estimates was variable between the four individuals with SHEL01 having a variation of 64.9 ± 23.3, SHEL03 of 17.3 ± 15.4, SHEL07 of 87.1 ± 18.1 and SHEL08 of 36.8 ± 17.9. This is likely due to the variation in air pressure during the time when each bird migrated. In order to gain accurate altitude estimates from the pressure data, analysis against local air pressure and a method of initial calibration must be conducted. The altitude estimates produced from both the GPS altitude data and the barometric pressure sensor data for the migration period for each individual are presented in Figure 3.9. These represent only the data collected during the migration from the UK coast to the first major stop-over site in the Dutch Wadden Sea. These altitude data are plotted against longitude, to show the variation in height as the birds leave the UK coast (Longitude ~1.5), travel across the North Sea (~1.7 – 4.0), reach the Dutch coastline (~4.0 – 4.7), and then enter the Dutch Wadden Sea (>4.7). For individuals for which high resolution data (10-15min; SHEL01, SHEL03) were collected for the majority of the North Sea crossing, there appears to be a pattern where a substantial altitude increase occurred as the bird left the UK coast, and then again as it reached the Dutch coast, with the majority of the intervening flight occurring at lower altitudes. This pattern is not so evident for SHEL08, where 10 minute data were collected throughout the journey. This bird migrated at approximately the same time as a substantial low pressure front moved across the North Sea. It is suspected that this weather system affected both the route and altitude that the bird travelled. The data for SHEL07's migration is incomplete, and was only collected at a one hour resolution, due to a low battery voltage at the same time as the migration began.

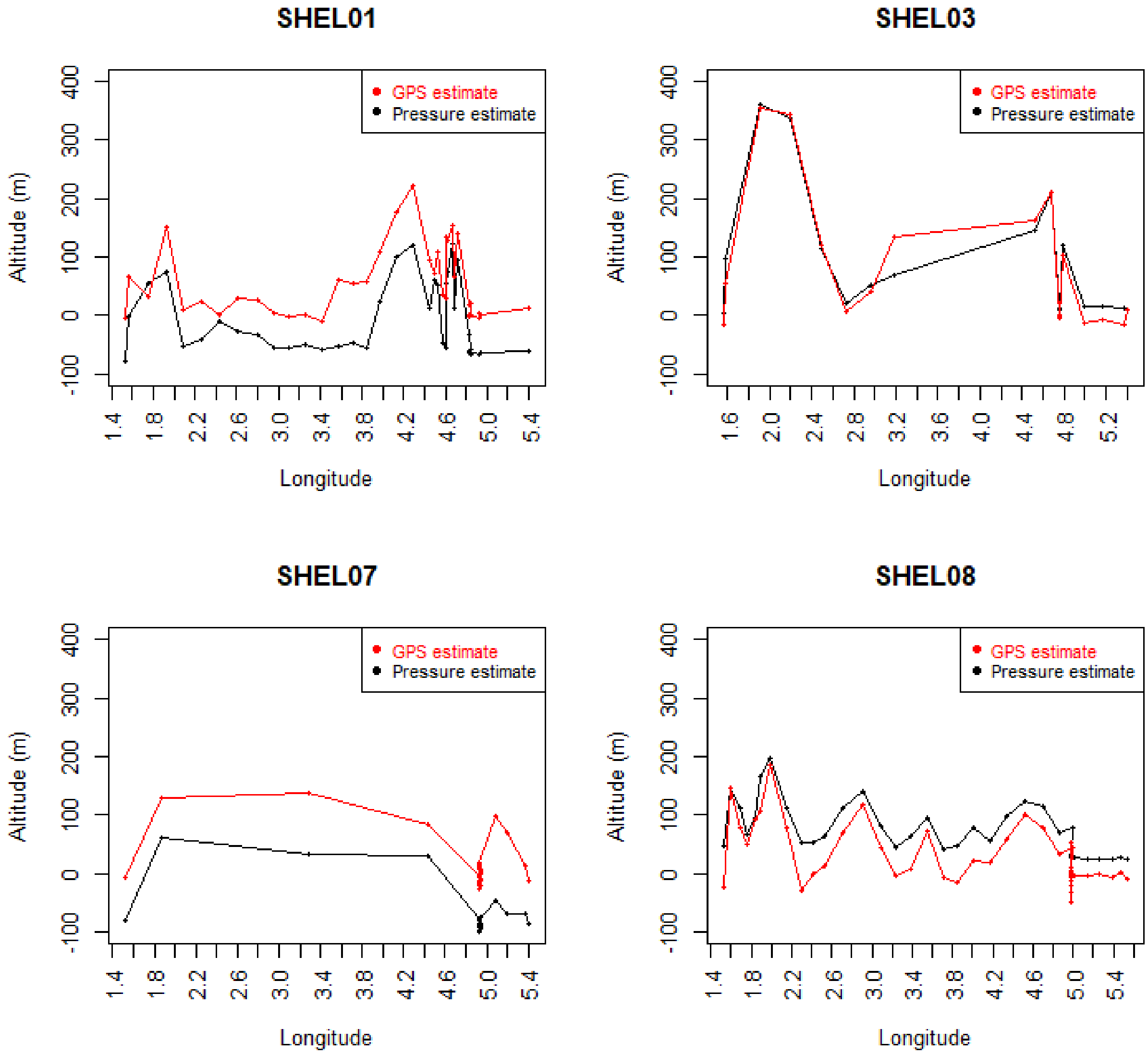


Figure 3.9 Altitude estimates in two formats (GPS: red; pressure: black) for the migration period of four tracked Shelduck.

3.2.5 Pre-migration data summary

As well as the data collected on the North Sea migration, additional data of interest were collected before and after this. The data collected suggest an interesting variation in pre-migration strategy, given that all four birds were caught together at the same time and place.

Despite being caught together, all four birds moved around the Suffolk coastal area as individuals thereafter, rarely occupying the same spaces at the same time, though using a similar range of sites. None returned to the catching lagoon after they were released, though all used other lagoons, saltmarsh and mudflat areas on Havergate Island. Three birds (SHEL01, 03 and 08) used roosting areas on Orford Ness, on the edge nearest Havergate, but none used the areas on Orford Ness previously intended for catching (see Figure 2.1). Three birds (SHEL03, 07 and 08) spent time within the Alde Estuary, 9 km to the north of Havergate, with SHEL03 and SHEL07 not returning to Havergate once they had moved to this estuary. SHEL01 and SHEL07 moved to the Butley Estuary 3 km to the north of Havergate at approximately the same time, remained for approximately one hour, before SHEL07 then flew north to the Alde Estuary, and SHEL01 flew south to the Deben Estuary, 12 km south-west of Havergate. From the Deben Estuary, SHEL01 apparently made an aborted migration attempt at dusk on 13th July, before returning to Havergate and eventually migrating from there on the 16th July (Figure 3.10, Table 3.5).

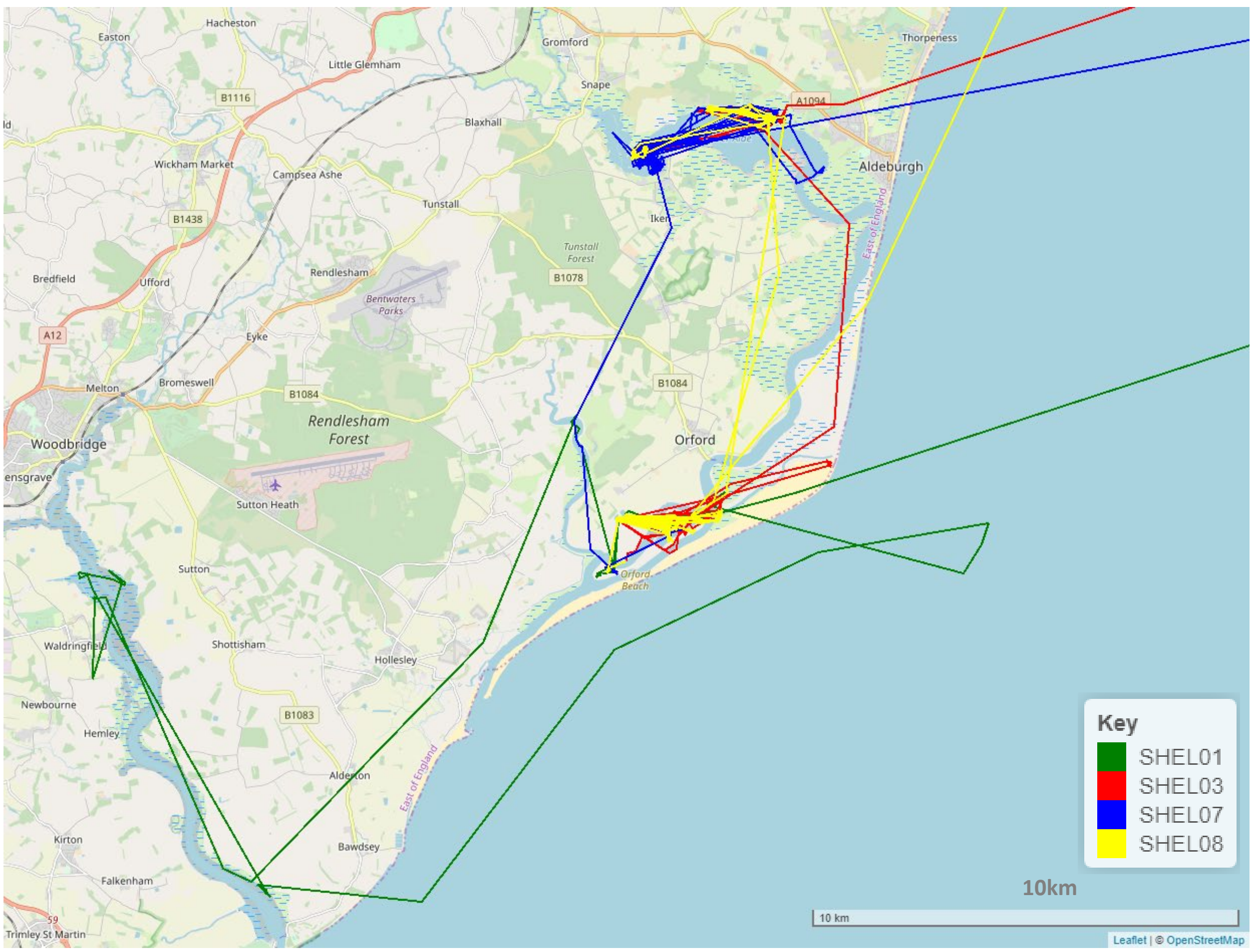


Figure 3.10 Pre-migration movements around the Suffolk coast. The timings of these movements are summarised in the Table 3.5. It is notable that almost all of these local movements of a distance >5 km happened at dawn, with one happening at dusk (SHEL01s return to Havergate). No large movements occurred during the day, and the only large movement that began in the dark was the North Sea migration of SHEL01 and SHEL03.

Table 3.5 Summary of pre-migration movements and timings; each location name represents the area they moved to from their previous location, with the time and date of the movement. All times are in UTC, which is one hour behind BST.

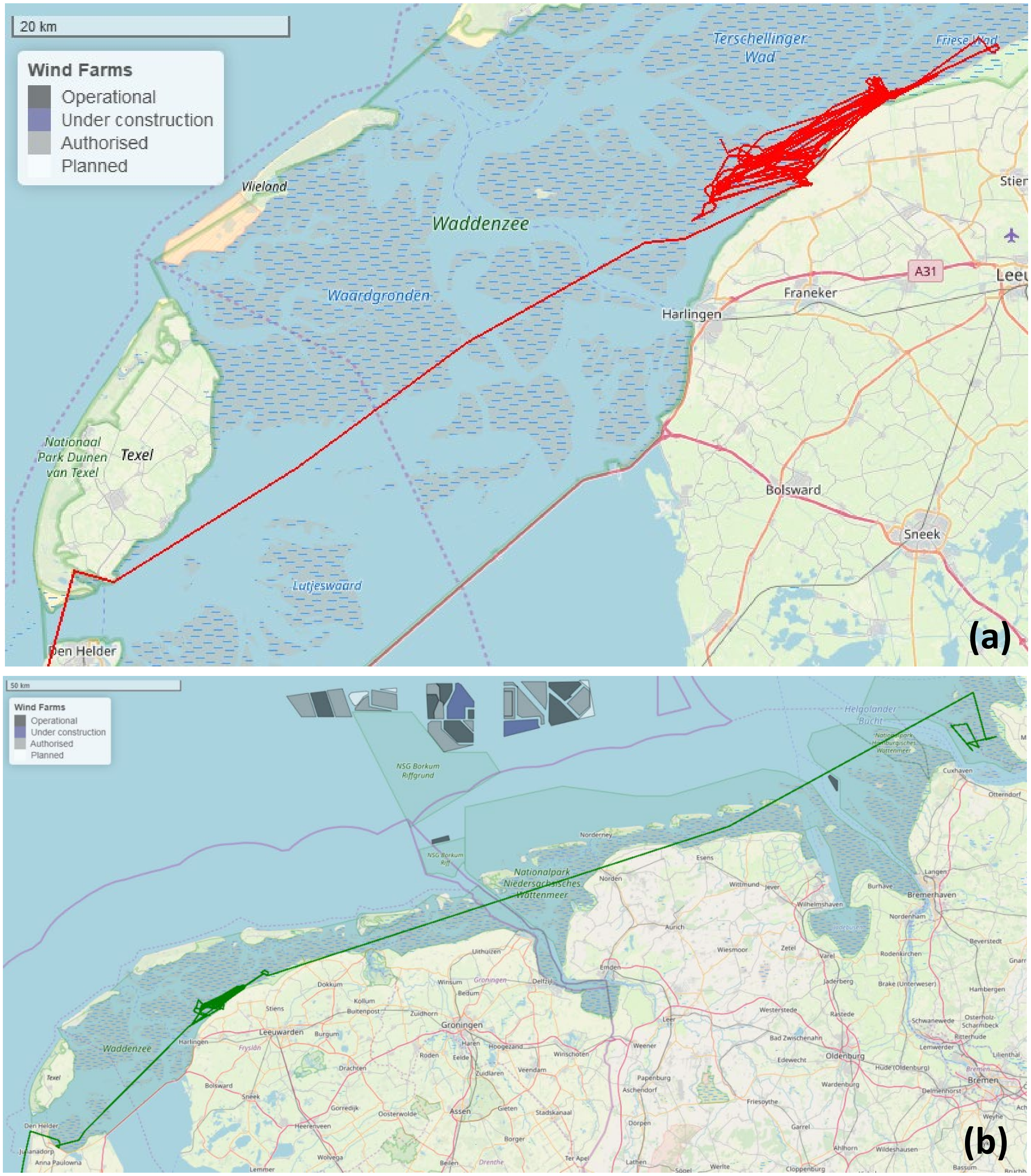
Shelduck ID	Havergate area	Butley estuary	Deben estuary	Alde estuary	Return to Havergate	Migration
SHEL01	12th July 15:50	13th July 03:05	13th July 04:54	-	13th July 20:33	16th July 00:55
SHEL03	12th July 15:05	-	-	15th July 03:14	-	18th July 00:48
SHEL07	12th July 14:40	13th July 03:09	-	13th July 04:02	-	22nd July 04:08
SHEL08	12th July 15:30	-	-	17th July 04:13	20th July 02:17	20th July 05:08

3.2.6 Post-migration data summary

Despite all taking different migratory routes and migrating on different days, all four birds ended their North Sea migration at almost exactly the same location. SHEL01, SHEL03 and SHEL07 all entered the Dutch Wadden Sea (DWS) around the gap between the Dutch mainland and Texel island (Figure 3.11), spent a short period 'resting' in this area and then all moved (independently) to the same area of mudflat, within 1 km of each other and ~3 km offshore from Sexbierum. SHEL08 took a more northerly migration route and entered the DWS over Vlieland. It had a short 'rest' on Vlieland and then moved east to an area of mudflat, 6.5 km north-east of where the other three birds ended their migration.

Regardless of the route taken into the DWS, all birds ended up spending an extended period in the 20 km stretch of coastline between Sexbierum and Zwarte Haan, no further than 5 km from land (Figure 3.11). Three birds (SHEL01, 07 and 08) then moved on to the area around the Elbe Estuary[7], within the German Wadden Sea (GWS). The tag on SHEL03 came off the bird whilst it was still in the DWS, but the bird was still apparently able to fly at this point so it was not possible to determine whether it moved onto the Elbe Estuary as well. This behaviour of stopping in the DWS for an extended period before continuing on to the GWS has not been reported previously (Green et al., 2019). The time periods that the birds spent within each stop-over area are summarised in Table 3.6 and 3.7

[7] https://northsearegion.eu/immerse/project-estuaries/the-elbe-estuary/


20 km
Wind Farms
Operational
Under construction
Authorised
Planned
Terschellinger Wad
Friese Wad
Vlieland
Waddenzee
Waardgronden
Stiens
A31
Leeu
Franeker
Harlingen
Nationaal Park Duinen van Texel
Texel
Bolsward
Sneek
Lutjeswaard
Den Helder
(a)
50 km
Wind Farms
Operational
Under construction
Authorised
Planned
NSG Borkum Riffgrund
Helgolander Bucht
Cuxhaven
Norderney
Nationalpark Niedersachsisches Wattenmeer
Norden
Esens
Wilhelmshaven
Bremerhaven
Aurich
Emden
Groningen
Leeuwarden
Waddenzee
Harlingen
Texel
Den Helder
Oldenburg
Bremen
(b)

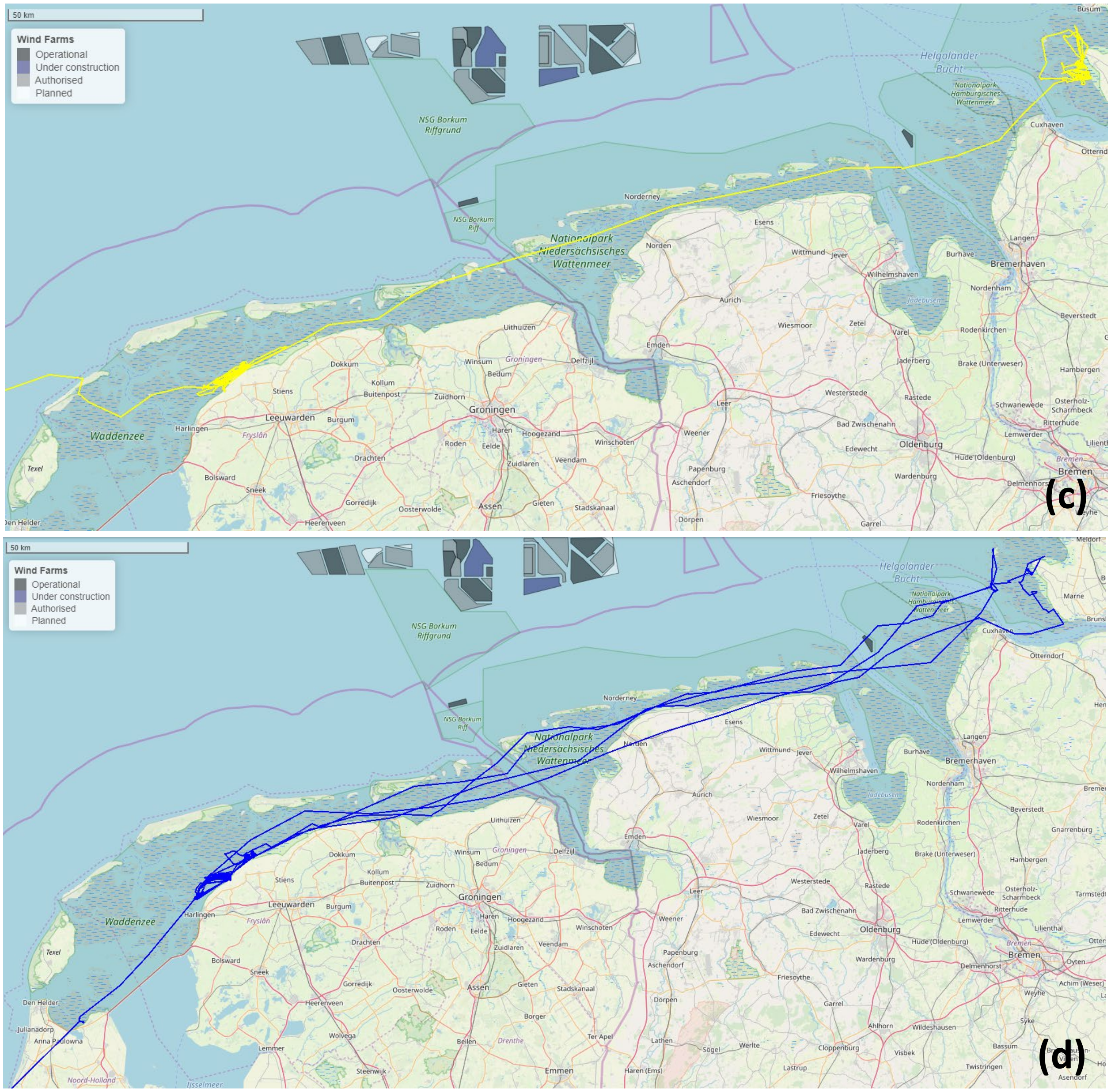


Figure 3.11 Post-migration movements throughout the Wadden Sea. Maps show movements for: (a) SHEL03; (b) SHEL01; (c) SHEL08; (d) SHEL07.

SHEL07 made some remarkable movements after its initial stop-over in the DWS. It made a day trip to the Elbe Estuary (~250 km) and then came back to the DWS. It stayed in the DWS for nine and a half days and then returned to the Elbe Estuary again, where it stayed for four days. It then returned to the DWS, where it remained until the tag fell off on the 14th August. The flight data received during its final return journey to the DWS are noticeably different to those on the previous flight (Table 3.7) being at lower speed, lower altitude and lower temperature than all previous journeys. The data received from the accelerometer were also less conclusive than for previous flights. This may suggest it was already losing flight feathers as part of its main moult, but may also be because the tag was coming loose from the bird's back and collected less reliable data. As far as we are aware, movements like this by Shelduck between known moulting locations within the Wadden Sea have not previously been recorded.

Table 3.6 Summary of stop-over periods and duration of three tracked Shelduck within the Dutch Wadden Sea. *Date at which the tag detached from the bird, rather than a genuine departure date, so stop-over period may have been longer.

Shelduck ID	Arrival in Waddenzee	Departure from Waddenzee	Stop-over duration (days)
SHEL01	16th July 13:02	27th July 18:00	11.2
SHEL03	18th July 07:26	*4th August 15:47	17.4
SHEL08	20th July 12:42	5th August 11:36	16.0
Average			**12.6 ± 5.2**

Table 3.7 Summary of stop-over periods and duration for tracked Shelduck SHEL07. *Date at which the tag detached from the bird, rather than a genuine departure date, so stop-over period may have been longer.

Stop over location	Arrival in area	Departure from area	Stop-over duration (days)
Dutch Wadden Sea	22nd July 18:32	28th July 18:16	6.0
Elbe Estuary	29th July 03:40	29th July 18:16	0.6
Dutch Wadden Sea	29th July 23:58	8th August 13:06	9.5
Elbe Estuary	8th August 16:14	12th August 16:07	4.0
Dutch Wadden Sea	13th August 08:59	*14th August 06:00	0.9
Average			**4.2 ± 3.7**

Table 3.8 Summary of flight data from SHEL07 during the four flights it made to and from the Dutch (DWS) and German (GWS) Wadden Sea stop-over areas. See Table 3.7 for dates of movements between stop-over areas.

Trip order	Sample size (n=)	Speed (knots)	Tag temperature (°C)	GPS altitude (m)
DWS -> GWS	16	27.0 ± 4.9	29.1 ± 1.8	21.6 ± 45.5
GWS -> DWS	14	34.4 ± 2.7	25.8 ± 1.8	49.6 ± 67.3
DWS -> GWS	9	47.9 ± 8.5	28.9 ± 1.3	143.4 ± 121.1
GWS -> DWS	19	24.0 ± 3.8	19.0 ± 2.6	5.7 ± 30.0

3.2.7 Tag retrieval

When the tags were purchased and deployed, it was not anticipated that it would be possible to retrieve them after becoming detached from the Shelduck. It was expected that they would detach and then sink into the mudflats of the Wadden Sea where the Shelduck were likely to moult. However, all four tags apparently floated on the tide after they detached, and washed ashore, providing opportunities to retrieve them.

The tag SHEL01 detached on 30th July at ~18:00 in the Elbe Estuary, floated on the tide for ~18 days, moving into the Weser Estuary to the east, then north across the German Bight until it washed ashore on the south coast of the Nordstrand peninsula in north-west Germany. It is believed to have been picked up by a member of the public, who then transported it to an accommodation complex near Schwackendorf north-east Germany. Despite communications with the accommodation owners via email and telephone, it was not possible to locate the person with the tag, and no further data transmissions have been received.

The tag SHEL03 detached on 4th August at ~15:50 in the DWS, floated on the tide for ~2 days, then washed ashore on a section of saltmarsh on the south-east coast of Terschelling, ~2.5 km from the nearest settlement (Oosterend). It must have landed upside down initially, because it did not transmit the data it held until the 27th August, when a subsequent high tide series must have flipped it over, allowing the batteries to re-charge and GPS data to be transmitted. It was possible to contact a bird watcher living in Oosterend, and on the 28th August Jacob de Vries ventured across the saltmarsh and was able to retrieve the tag, and then post it back to the BTO. The tag appears to be functioning normally so, following tests by Ecotone Telemetry, it may be possible to redeploy this tag next year.

The tag SHEL07 detached on 14th August at ~06:00 in the DWS, floated on the tide for ~1 day and then washed ashore very close to where it detached, just east of Zwarte Haan on the western Dutch shore. It must have initially landed upside down, but it did transmit its location on the 12th September when a subsequent high tide series must have flipped it to expose the solar panels. Three people in the area were contacted and were willing to retrieve the tag. Unfortunately the tag had washed up in a field with an extremely dangerous bull. Despite retrieval attempts, no-one could get close to the tag without risking their safety. The bull was removed on the 15th October but, unfortunately, a high tide series in the intervening period caused the entire saltmarsh to flood, and the tag stopped transmitting, presumably because it had been moved and landed upside down again. Retrieval attempts were made in the area after the bull was removed, but the tag could not be relocated. It has not transmitted its location since the 24th September.

The tag SHEL08 detached on 24th August at ~09:53 in the GWS, floated on the tide for ~11 days, travelling half way out to Helgoland, then washing ashore on the north-west coast of Germany near Sankt Peter-Ording. It transmitted its location on the 17th September, and a staff member (Klaus Günther) from the local National Park (Rastvogel-Monitoring im Nationalpark) made an attempt to find it on the 19th September, but was unsuccessful. Further GPS transmissions gave a more detailed location, and the tag was retrieved on 23rd September, and then posted back to the BTO. The tag appears to be functioning normally so, following tests by Ecotone Telemetry, it may be possible to redeploy this tag next year.

3.2.8 Other available data

As previously mentioned in section 2.2.1 and displayed in Figure 2.2, data on accelerometry were also collected by the tags throughout the duration of the deployment. These data were extremely useful for accurately categorising flight data, as well as other behaviours, as there is a distinct shape to accelerometry data when birds are flying (Shepard et al., 2008; Berlincourt, Angel, & Arnould, 2015; Williams, Shepard, Duriez, & Lambertucci, 2015). Using these data, and the knowledge gained about likely minimum flight speeds, it may be possible in future to develop algorithms to define and automatically extract data associated with flight.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Evaluation of the pilot study

Although only four of the planned 10 tags were deployed on Shelduck in this study, as a proof of concept the pilot has been successful. It has been shown that migrant Shelduck can be caught at the right time of year, and that a tag can be fitted which satisfies all UK licensing and welfare requirements. The tags remained attached for the duration of the North Sea migration and the data received from these provided information on flight timings, routes, speed and height, as well as other useful behavioural data, as hoped (project objectives i and ii). It has also been shown that the tags can be retrieved after they have fallen off the Shelduck, and may be usable for future deployments. The data collected during the pilot also provided some initial evidence of connectivity with offshore wind farms within the southern North Sea during these movements (objective iii).

The migration tracks collected show that Shelduck may migrate using different routes, which apparently cover a wide area of the southern North Sea, even though they all appear to end the North Sea migration at a similar location. This variation has been seen from birds departing from a single location, so it may be assumed that birds from other locations could display a similar variation in flight paths. Expanding the geographical range of tagged birds would help test whether this hypothesis is correct. It also appears that weather and wind may affect the routes taken, as seen by the migration route of SHEL08 (Figure 3.7). The sample size from this pilot is too small for testing this hypothesis, but analyses against weather data may be valuable if larger migration datasets are collected.

The data obtained during the pilot also provided valuable information on tag performance and methods (objective iv). Recommendations on field methods, data analyses, and the potential objectives and options for a future study that might build on the pilot are provided below.

4.2 Recommendations

4.2.1 Field methods

Catching and tagging

Ideally, in future, a catch attempt would be made a few weeks earlier in the season (mid to late June), and dummy cannon-nets would be laid at least a couple of weeks prior to this (early June), in order for target birds to habituate to them. The sudden rise and fall in numbers of Shelduck using Havergate Island suggests that migrating flocks may move into a new area quickly, but also move on quickly. It would be advantageous to have dummy cannon-nets laid well in advance of these movements, so that a catch attempt could be made as soon as numbers build in a target area. If cannon-nets had been laid on Havergate Island on the 1st July, instead of Orford Ness, then it may have been possible to make a catch attempt on the 5th/6th July when Shelduck numbers were at their peak. This would have helped maximise the chances of catching the planned sample of 10 birds.

In future it would be advisable to lay material that mimics cannon-nets in as many potential catching locations as possible by June 10th. An observer could then check these locations daily and alert the cannon-netters when Shelduck numbers increase at particular sites. A cannon-net team could then be quickly mobilised and be able to catch in the most optimal location. This approach would allow many potential catching locations to be made available in areas where it is not certain which particular locations Shelduck prefer to roost in.

We would also propose modifying the cannon-nets to maximise the likelihood of catching all birds that are present when the net is fired. By increasing the width of the 'skirt' around the edge of the cannon-net, it should be possible to ensure that the birds cannot escape from the net after being caught. It would also be advantageous to have a larger mesh size that catches them more securely, but this would necessitate purchasing an entirely new cannon-net, which may not be feasible.

Tagging methods

The glue mounting method used in this pilot was entirely successful and fulfilled the expected aims of the pilot. However, it is worth noting that this is a short-term deployment method, which limits the potential duration of data collection. A long-term deployment method would allow data to be collected from individuals for their entire annual cycle, which could mean capturing data for multiple North Sea crossings. It is known that harnesses (a long-term method) have been deployed on Shelduck in Mongolia (Wang et al., 2018), Austria[8], Belgium and Germany (Gyimesi et al., 2017), although none of these studies have published an assessment of the effect of the harnesses on the welfare of the Shelduck. Previously reported issues with harnesses on duck species (Lameris & Kleyheeg, 2017) have made the Special Methods Technical Panel (SMTP) wary of licensing this tagging method on any duck species within the UK, so there is currently a general ban on this method for ducks. The SMTP have stated that they would reconsider their position if evidence could be presented showing that the harnessing method does not have a detrimental welfare impact. This could be achieved via controlled studies on captive bred ducks, or by gaining evidence from countries where this method can be licensed, and where specific data on welfare with a matched control cohort have been collected. It is possible these data have been collected by the known Shelduck harness studies listed above, but these have not been formally reported. Even if suitable welfare evidence could be presented, it is likely that any trials on wild birds would only be licensed for small numbers initially until it could be thoroughly proven that there are no significant detrimental welfare impacts.

Tag options and tag settings

The Ecotone Telemetry tags used in this pilot study provided the data required on the birds' migration across the southern North Sea. Now that these have been tested on wild Shelduck, improvements can be made for future deployments:

1) Tag settings will be set such that tags transmit data at 12:00 each day. This will ensure the battery has had time to charge from solar energy in the morning, and will have time to recover energy lost during data transmission before sunset. This should ensure there is sufficient battery voltage to enable complete data collection for the duration of overnight migrations.
2) The accelerometry assisted data collection setting will be enabled. This allows a lower frequency data collection rate whilst the bird is stationary, and then a higher rate when it is

[8] Movebank study – https://www.movebank.org/movebank/#page%3Dstudies%2Cpath%3Dstudy522309921

flying. This should ensure the battery remains full before the bird migrates, and has enough energy to collect high frequency (1-10 minute interval) data during the migration. It is only possible to enable this setting once information has been collected on the accelerometry signature of a flying and stationary Shelduck. These data have been collected as part of the pilot.

3) If accelerometry assisted data collection cannot be used for any reason, the tags' basic continuous data collection rate will not be set at a higher frequency than every 15 minutes. The tags can perform consistently at this rate even during periods of extended poor weather, so this rate will ensure the battery retains enough voltage to collect data during the full migration also, avoiding the issues seen in SHEL01 and SHEL07 (see Appendix 2).
4) Tags will be fitted with a label that displays a contact email address and finding reward. This will help ensure that all tags that are found by the public can be returned. If the pilot tags had had this label then tag SHEL01 may have been returned by the member of the public that found it.
5) Efforts will be made to change the software within the tags, such that the accelerometry data is collected immediately after the location data fix, instead of before it. The current programming means that there is a delay between the accelerometry data and all the other data, which led to inconsistencies in determining behaviour from the different data associated with a location fix. This made it difficult to categorise flight data consistently in some instances.

The Ecotone Telemetry tags worked well and are recommended for future deployments. Since the tag procurement process for this pilot study, Ornitela have also released GPS-GSM models as light as 9 g[9] and which include settings, such as a GPS 'fence' that would allow the collection of more frequent fixes while birds are crossing the North Sea. It would thus be valuable to consider the utility of these newly available models for future deployments on Shelduck, noting that testing of a sample of tags may again be required to fully determine their applicability to delivering the project's objectives.

4.2.2 Future analysis techniques

Flight heights

Data on altitude were derived both from GPS and pressure sensor data; however, analyses of the data collected during this pilot were limited by sample size.

GPS altitude was automatically recorded in the tags as a component of the birds' three-dimensional position. However, the positional method for estimating altitude is known to suffer from a degree of error (precision and accuracy), in comparison to the horizontal xy positional component. GPS altitude data have previously been used to estimate flight altitudes in Lesser Black-backed Gulls *Larus fuscus* (e.g. Corman and Garthe, 2014) and also analysed in a Bayesian state-space framework, to account for such known sources of bias such as the number of satellites and dilution of precision (Ross-Smith et al., 2016). GPS altitude is typically measured in relation to the ellipsoid representation of the earth, which requires further transformation, using a mathematical geoid to approximate mean sea-

[9] OrniTrack-9 - https://www.ornitela.com/9g-transmitter

level, and a digital elevation model to in turn derive a height above ground level. These steps can also introduce error, including accuracy bias in relation to the geoid.

To provide an alternate measure of flight altitude, the tags were also equipped with a pressure sensor. Altimeters provide a potentially useful means to measure flight heights (e.g. Cleasby et al., 2015), but need robust calibrating. By analysing the data collected on air pressure against local air pressure data, it should be possible to calibrate the data to a consistent baseline in order to produce more accurate height estimates. Comparison can then be made with the altitude estimates from the two methods in order to provide a better assessment of flight heights.

Analyses would need to take into account tidal height measurements in order to gain an estimate of height above sea level. Previous studies have suggested that Shelduck fly just above the sea when migrating (Patterson, 1982; Kruger & Garthe, 2001), although the provisional results presented here suggest that there is variation in flight heights during birds' migrations.

Weather data

With a larger sample size it may also be possible to analyse the migratory routes against weather patterns to see if there are correlations between timings and route and the weather systems occurring. It is suspected that SHEL08 took a more northerly route across the North Sea because of the frontal system it was travelling with. The other three birds took fairly direct routes from their start point to the Dutch coast, and migrated at a time when weather conditions were fairly stable. With a larger sample it may be possible to detect correlations between weather systems and routes taken, and thus provide a better understanding of likely interactions with offshore wind farms.

Behaviour

In this study, a combination of GPS location, speed, and accelerometry were used to understand Shelduck behaviour. A wide variety of methods exist for analysing animal movement behaviour, ranging from classifications using simple track metrics such as speed and turning angle (e.g. Hidden Markov Models, McClintock et al., 2018) to more complex pattern recognition methods and accelerometry. For the latter more complex treatments of data, typically field-based observations of tagged birds are used to ascribe behaviours to a sample of the movement data (annotation) to in turn feed into supervised machine-learning approaches (such as random forests or artificial neural networks, see Shamoun-Baranes et al., (2016) for an example in Lesser Black-backed Gulls). In this way, models can be trained on a subset of the annotated data, validated and then projected onto unclassified data. In this study, the flight signature of Shelduck was distinctive enough to carry out classification of data through manual inspection, but for larger volumes of information could become increasingly problematic. Given our confidence in annotations of flight and resting activity of Shelduck was high, machine-learning methods can still be used in a supervised manner, as above, to predict such behaviours, albeit without independent field-based assessment. Dependent on tag sampling rates, simpler methods using speed and turning angle could also be useful. Together, such behavioural analyses would yield a robust picture of Shelduck behaviours in relation to offshore wind farms. In order to classify data where behaviours were unknown (from visual inspection) it would be necessary to conduct further field observations of the birds. This would naturally help ensure that flight data have also been correctly categorised, and could provide extra data on the behavioural repertoire of Shelduck.

4.2.3 Future study aims and options

The objectives of the pilot study have been met in providing initial data on the routes and timing of movements of Shelduck on their migration between the UK and moulting sites in the Wadden Sea, their flight heights and speeds, and on connectivity with offshore wind farms, as well as informing on tag performance and methods. Nevertheless, only four of the planned 10 tags were deployed, and the data obtained are representative only of the movements of birds present at one SPA just prior to their migration.

The Shelduck has a wide breeding distribution within the UK, while it is also a non-breeding feature of 32 SPAs across the country (Stroud et al., 2016). However, as outlined by the previous review of the literature and British and Irish ringing data (Green et al., 2019), little is known about which individuals from the UK breeding range migrate to the Wadden Sea, with some birds from the same breeding area evidently remaining in the UK to moult, whilst others cross the North Sea to moult on the continent.

In addition to deploying the outstanding tags from the pilot, as well as potentially those retrieved during the study, the principal objective of a future study that might build on the pilot should thus be increased geographical representation. This would provide information both on where within the UK birds which migrate to the Wadden Sea might originate from, and on the variation in routes that they might follow, and thus the wind farms that might present most risk to their migrations.

We recommend that the outstanding tags from the pilot, as well as potentially those retrieved during the study (if fully functional) are deployed at Havergate.

There are a number of SPAs around the coast of south-east England (East Anglia, London, Kent) from which Shelduck might migrate to the Wadden Sea. **We thus also recommend that it would be valuable to consider additional tagging from other sites in south-east England**. Based simply on straight-line paths, catching sites further south of Havergate would maximise the likelihood of recording interactions with operational offshore wind farms, with up to ~20 operational wind farms between this area and the Dutch coast. Areas of the Essex coast around Wallasea Island in the Crouch and Roach Estuaries (Mid-Essex Coast Phase 3) SPA or Foulness (Mid-Essex Coast Phase 5) SPA are worthy of consideration.

To further broaden geographical representation, it is also recommended that tracking from sites in the north and west of the UK should be considered. In north-east England, an option is the Teesmouth and Cleveland Coast SPA, where Shelduck have been ringed for a number of years by the Tees Ringing Group. On the north-west coast, the WWT Martin Mere reserve has a long running colour-ringing study on Shelduck, and presents an ideal site for tagging work. Although not a feature of the Martin Mere SPA, Shelduck is a feature of the nearby Ribble and Alt Estuaries SPA. Shelduck are caught at Martin Mere throughout the year, and a good proportion of the local population is already ringed. This opens up opportunities for tagging birds of known age and that are known to leave the area during the migration period. Tagging birds from the west coast may help provide information on whether birds from this side of the country remain in the UK to moult, or whether they also migrate to the Wadden Sea, as we have shown for birds leaving from the east coast.

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References

Baker, K. (1993). *Identification guide to European non-passerines: BTO guide 24.* Thetford: British Trust for Ornithology.

Balmer, D. E., Gillings, S., Caffrey, B., Swann, R. L., Downie, I. S., & Fuller, R. J. (2013). *Bird atlas 2007-11: the breeding and wintering birds of Britain and Ireland*. Thetford: British Trust for Ornithology Books.

Bergmann, P. J., Flake, L. D., & Tucker, W. L. (1994). Influence of brood rearing on female mallard survival and effects of harness-type transmitters. *Journal of Field Ornithology*, **65**, 151–159.

Berlincourt, M., Angel, L. ., & Arnould, J. P. Y. (2015). Combined use of GPS and accelerometry reveals fine scale three-dimensional foraging behaviour in the Short-Tailed Shearwater. *PLoS ONE*, **10**, e0139351.

Cleasby, I. R., Wakefield, E. D., Bearhop, S., Bodey, T. W., Votier, S. C., & Hamer, K. C. (2015). Three-dimensional tracking of a wide-ranging marine predator: flight heights and vulnerability to offshore wind farms. *Journal of Applied Ecology*, **52**, 1474–1482.

Corman, A.-M., & Garthe, S. (2014). What flight heights tell us about foraging and potential conflicts with wind farms: a case study in Lesser Black-backed Gulls (*Larus fuscus*). *Journal of Ornithology*, **155**, 1037–1043.

Demongin, L. (2016). *Identification guide to birds in the hand*. Beauregard-Vendon.

Fijn, R. C., & Gyimesi, A. (2018). Behaviour related flight speeds of Sandwich Terns and their implications for wind farm collision rate modelling and impact assessment. *Environmental Impact Assessment Review*, **71**, 12–16.

Green, R. M. W., Burton, N. H. K., & Cook, A. S. C. P. (2019). *Review of the migratory movements of Shelduck to inform understanding of potential interactions with offshore wind farms in the southern North Sea*.

Gyimesi, A., Evans, T. J., Linnebjerg, J. F., De, J. W., Collier, J. M. P., & Fijn, R. C. (2017). *Review and analysis of tracking data to delineate flight characteristics and migration routes of birds over the Southern North Sea. Report to Rijkswaterstaat WVL.*

Hagemeijer, W. J. M., & Blair, M. J. (1997). *The EBCC atlas of European breeding birds : their distribution and abundance*. London: T & A D Poyser.

Krijgsveld, K. L., Fijn, R. C., Japink, M., Van Horssen, P. W., Heunks, C., Collier, M. P., … Dirksen, S. (2011). *Effect studies Offshore Wind Farm Egmond aan Zee: Final report on fluxes, flight altitudes and behaviour of flying birds. Bureau Waadenburg report nr 10-219*.

Kruger, T., & Garthe, S. (2001). Flight altitudes of coastal birds in relation to wind direction and speed. *Atlantic Seabirds*, **3**, 203–216.

Lameris, T. K., & Kleyheeg, E. (2017). Reduction in adverse effects of tracking devices on waterfowl requires better measuring and reporting. *Animal Biotelemetry*, **5**, 24.

Masden, E. A., & Cook, A. S. C. P. (2016). Avian collision risk models for wind energy impact assessments. *Environmental Impact Assessment Review*, **56**, 43–49.

McClintock, B. T. & Michelot, T. (2018) momentuHMM: R package for generalized hidden Markov models of animal movement. *Methods in Ecology and Evolution*, **9**, 1518-1530.

Patterson, I. J. (1982). *The shelduck : a study in behavioural ecology*. Cambridge: Cambridge University Press.

Pietz, P. J., Krapu, G. L., Greenwood, R. J., & Lokemoen, J. T. (1993). Effects of harness transmitters on behavior and reproduction of wild Mallards. *The Journal of Wildlife Management*, **57**, 696–703.

Rogers, K. H., Petrie, S. A., & Baloyi, F. R. (1996). Effects of harness-attached satellite transmitters on captive whitefaced ducks Dendrocygna viduata : short communication. *South African Journal of Wildlife Research*, **26**, 93–95.

Ross-Smith, V. H., Thaxter, C. B., Masden, E. A., Shamoun-Baranes, J., Burton, N. H. K., Wright, L. J., … Johnston, A. (2016). Modelling flight heights of Lesser Black-backed Gulls and Great Skuas from GPS: a Bayesian approach. *Journal of Applied Ecology*, **53**, 1676–1685.

Shamoun-Baranes, J., Bouten, W., van Loon, E. E., Meijer, C. & Camphuysen, C. J. (2016) Flap or soar? How a flight generalist responds to its aerial environment. *Phil. Trans. R. Soc. B*, **371**, 20150395.

Shepard, E. L. C., Wilson, R. P., Quintana, F., Laich, A. G., Liebsch, N., Albareda, D. A., Macdonald, D. W. (2008). Identification of animal movement patterns using tri-axial accelerometry. *Endangered Species Research*, **10**, 47–60.

Stroud, D. A., Bainbridge, I. P., Maddock, A., Anthony, S., Baker, H., Buxton, N., Wilson, J. D. (2016). *The status of UK SPAs in the 2000s: the Third Network Review*. Peterborough.

Vandenabeele, S. P., Grundy, E., Friswell, M. I., Grogan, A., Votier, S. C., & Wilson, R. P. (2014). Excess baggage for birds: inappropriate placement of tags on gannets changes flight patterns. *PLoS ONE*, **9**, e92657.

Wang, X., Cao, L., Batbayar, N., & Fox, A. D. (2018). Variability among autumn migration patterns of Mongolian Common Shelducks (Tadorna tadorna). *Avian Research*, **9**, 1–11.

Wetlands International. (2020). Waterbird population estimates - CSR7.

Williams, H. J., Shepard, E. L. C., Duriez, O., & Lambertucci, S. A. (2015). Can accelerometry be used to distinguish between flight types in soaring birds? *Animal Biotelemetry*, **3**, 45.

Appendix 1 Catching methods considered

Methods of capturing Shelduck considered as part of this pilot. The positive and negative points of each method are discussed.

1) **Duck traps** – cheap and easy to set. Usually set along the edge of a water body where the ducks would feed naturally, and baited to attract them inside it. Many traps could be deployed in one area to increase the likelihood of catching. However, Shelduck do not respond readily to bait when other food sources are available, and are wary of entering unfamiliar enclosed spaces. The traps must also be monitored continuously so trapped birds can be removed immediately. This method had a low chance of success at the catching sites considered for this pilot study, and would require many fieldwork hours in order to catch ten Shelduck.
2) **Swan pipe** – this is a very large open-ended walk in trap that is baited all year round so birds can become habituated to it. When a catch is planned the rear entrance to the pipe is closed off and birds are herded inside and then captured. For this to work it must be a permanent structure, and it requires many licensed individuals to operate successfully. You would also expect to catch many species other than the target species. This method is only practical at a site where a swan pipe is already available (i.e. WWT Martin Mere).
3) **Lamping** – this involves walking around in the dark with a high powered torch and a hand net. Target birds are dazzled so they don't fly away then the ringer sneaks close enough to catch them with a hand net. This is a highly inefficient method of capture and would likely cause disturbance to many other roosting species at the same time. No reports have been found of this method working successfully for Shelduck.
4) **Mist-netting** – this is a widely utilised capture method by bird ringers, but Shelduck are not known to be caught in them regularly. They would need to be set in an area Shelduck are known to fly regularly, and then Shelduck would need to be flushed so that they flew into them. It is likely that only a very few (1-4) Shelduck could be caught in this way, and many other species would also be caught in the meantime.
5) **Whoosh-netting** – this is a good method for catching large numbers of birds at once when they are in a concentrated area. The netting can be fired over birds from a remote triggering location, so the catch need only be taken when a suitable sample is catchable. The netting is propelled out using elastic ropes, which are stretched beyond the catching area. This does mean that birds have to walk over the elastic and pegs to enter the catching area. This method generally works better for birds that fly into the catching area, which would not happen with Shelduck. This method requires special licensing in addition to a standard ringing permit.
6) **Cannon-netting** – this method is highly specialised and requires rigorous training in order to gain a licence for it; consequently few ringing permit holders are licensed to use it. However, it is an extremely useful technique for catching large numbers of birds in one go and, like whoosh-netting, a catch need only be taken once a suitable sample is present. The cannon-nets can also cover a larger area when fired than whoosh-nets, and do not have anything other than the netting as features on the surface. Therefore birds can comfortably walk into the area without having to cross over anything, which is more suitable for Shelduck.

Appendix 2 Functionality changes associated with North Sea migration

Detailed below are the functionality changes observed in each of the four tags around the period when the Shelduck migrated across the North Sea. It is likely that some of these changes were coincidental (SHEL01 and SHEL07), but some could have been caused by the sustained period of flight.

SHEL01 – This tag had been sustaining a 10 minute fix rate prior to the migration, though the battery voltage was steadily decreasing. It sustained this rate during the migration (16th July 00:00-06:00), but the extra energy required when it transmitted data at 06:00 reduced the battery voltage to a point where it could no longer sustain a 10 minute rate, and it defaulted to a 1 hour data rate to conserve battery. New settings were transmitted to change the tag to a 15 minute fix rate at 10:00 on the 16th, which were received at 06:00 on the 17th, and the tag regained normal 15 minute functionality at 13:00 on the 17th. More energy is required to connect to satellites during directed flights, and the combination of this and the energy required to download were the cause of the voltage falling too low.

SHEL03 – This tag sustained a 15 minute fix rate for the first half of the North Sea crossing, but then failed to connect with any satellites for the second half of the crossing, so no location data were collected during this period. When stationary again in the Dutch Wadden Sea, it regained connection and continued to take location fixes as normal. This issue was potentially caused by the way in which the tag connects to satellites to triangulate its position. When the tag switches on it 'anticipates' what constellation of satellites will be available based on the previous fix, and attempts to connect to these. If those satellites are not available, because the tag is not where it anticipated it would be, then it takes more time for it to connect to the satellites that are available. The tag is set to stop searching for satellites after 90 seconds. If the anticipated constellation is not available, and it cannot find new satellites within the remaining time, then it fails to take a fix. The manufacturer is aware of this issue and has suggested increasing the 90 second time limit, or reducing the time between fixes so that anticipated constellations are still available. Both of these solutions risk using more battery power per fix, but there are mechanisms available to ensure enough battery power is available for this.

SHEL07 – This tag had a low battery voltage on the day prior to the migration. New settings were sent to combat this which were received by the tag at 00:00 22nd July, three hours before the bird began its migration. The combination of connecting to the server, transmitting data, and retrieving new settings caused the battery to fall below the minimum voltage threshold and the tag reverted to a default one hour fix mode to preserve the battery. It maintained this one hour fix rate for the duration of its migration (03:00 – 06:00), and had recovered enough battery power by 11:00 to collect 15 minute data again. Therefore, high resolution data were not collected for the migration. This was a battery voltage issue, and methods have been developed to avoid this happening again in future.

SHEL08 – This tag collected high resolution data as normal, but failed to transmit the data for four days after its migration. The tag data suggested GSM signal was too weak to transmit data, but the tag was in the same area as other tags that had strong GSM connection. The manufacturer cannot ascertain why this problem should have occurred, but again it seems to have happened straight after a long flight, and once a connection had been made normal functionality resumed for the duration of the deployment.

We are working with the manufacturer to ensure these issues are unlikely to happen again in future. As the primary aim of the project is to collect flight data during the North Sea crossing, it is disappointing that issues seem to have arisen during and after this crossing, but not during any other part of the tag deployment.

Image: Edmund Fellowes. Cover image: Philip Croft

Pilot Tracking Study of the Migratory Movements of Shelduck to Inform Understanding of Potential Interactions with Offshore Wind Farms in the North Sea

Following a review of current knowledge of the migratory movements of British and Irish Shelduck *Tadorna tadorna* in relation to the potential risks to the species associated with offshore wind farms (Green et al., 2019), a pilot tracking study was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS)'s Offshore Energy Strategic Environmental Assessment programme.

The objectives of the study were to catch and tag 10 Shelduck immediately preceding their departure on moult-migration across the North Sea in order to: (i) Provide data to assess the routes and timing of movements of Shelduck during the early summer period on their migration between the UK and moulting sites in the Dutch/German Wadden Sea; (ii) Provide data to assess the flight height and flight speed during these movements; (iii) Assess potential connectivity with offshore wind farms (OWFs) within the southern North Sea during these movements; and (iv) Assess suitable methodologies for a wider study, and tag performance.

Four adult Shelduck (two male and two female) were caught at the Alde-Ore Estuary Special Protection Area (SPA) in July 2019 and fitted with KITE BB 2S GPS-GSM tags. All four subsequently migrated across the North Sea, initially to the Dutch Wadden Sea, with further onward movements to the German Bight shown by three individuals. Details of the birds' migration routes and data on flight timings, height and speed are presented. Only one data point occurred within an operational offshore wind farm, although other data points were recorded within planned offshore wind farms and an offshore wind farm under construction. Conclusions on the success of the pilot study are presented and recommendations are provided on field methods, data analyses and the potential objectives and options for a future study that might build on the pilot.

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