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Tracking Curlew and Redshank on the Humber Estuary

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EXECUTIVE SUMMARY

1. The Humber Estuary is designated as a Special Protection Area (SPA) due to its internationally important numbers of wintering waterbirds. To be able to assess the potential impacts of any effects associated with development under the Humber Strategic Economic Plan and to inform any compensation or mitigation measures proposed, it is important that the best possible evidence is available.

2. While there is good understanding of the numbers of birds that use different areas of the estuary, notably through Wetland Bird Survey (WeBS) counts, it is uncertain how this usage varies by day and night and according to the tide, and how dependent birds are on particular habitats or areas within the estuary. Such questions are best informed by detail study of individual birds, e.g. through colour-ringing or tracking. Together data from ringing and tracking can inform Individual-Based Models, designed to predict the impacts of habitat change associated with disturbance, development or sea-level rise. Further, they can be then used to monitor and assess impacts resulting from consented developments and the success of mitigation. Such studies thus have much to offer both in improving baseline understanding of species' use of the Humber Estuary and, as an integral component of wider work packages, in informing on the potential impacts of particular developments associated with the Humber Strategic Economic Plan.

3. Here we report on a successful collaborative pilot project between the British Trust for Ornithology (BTO) and Humber Wader Ringing Group (HWRG) that was conducted during winter 2015/16, to test the feasibility of GPS-tracking waders on the Humber Estuary Special Protection Area (SPA), with the volunteers of the HWRG leading on the fieldwork. The study aimed to gather high resolution data on wader habitat use over a monthly tidal cycle (fixes every 1.5 hours for 28-30 days) in mid-winter, to establish and refine efficient methods for conducting the work (e.g. finding the best locations for the base stations to which tags download data), and to demonstrate the value of the data that can be gathered from this type of study on the estuary.

4. Between 24th of January 2016 and 2nd of March 2016, we obtained records of 3,330 locations from eight birds – three Curlew *Numenius arquata* and five Redshank *Tringa totanus*. The tags recorded the location of each individual bird approximately once every 90 minutes over the study period. All tags downloaded at least 180 GPS fixes to the base station with the GPS tags for four of the five birds caught on 24th January providing or exceeding the 500 fixes expected (the tag for a fifth bird produced 438 fixes). On the first two visits to retrieve data from the base stations (on 9th and 23rd February 2016), data had been downloaded to the base station at Welwick within the preceding 24 hours. This indicates that tags were downloading their data regularly to this base station, and therefore this base station location and system worked extremely well. This level of data return is at the top end of our expectations for performance from remote-download tagging studies, based on a wide range of BTO experience with this technology on a variety of species.

5. Our initial analyses suggest that Redshank covered a greater area than Curlew. Whilst Curlew appeared to move mostly in relation to the tide, Redshank movements appeared to be much more spread out along the estuary. However, for both species there was a strong variation in the area of habitat used by individuals with Curlew home ranges during the study period covering between 4.4 and 9.6 km^2 and Redshank between 2.1 and 14.1 km^2.

6. Habitat use in both species varied in relation to both the tidal and diurnal cycles. Redshank used a greater area during the night than during the day, a finding consistent with previous studies of this species on the Severn Estuary. In contrast, Curlew appeared to cover a greater area during the day than during the night. The reasons for this are unclear, but may relate to

roosting patterns. As might be expected, both species ranged more widely during periods of low tide than was the case during periods of high tide, when birds were constrained to high tide roosts. The Welwick managed realignment area appeared to be an important high tide roost site for both species, but was particularly important for Curlew. There was also evidence to suggest that birds made greater use of the managed realignment area as a high tide roost during the day than during the night.

7. The pilot project has successfully demonstrated that high quality, valuable data to aid the long-term conservation of wading birds can be gathered by this type of study on the estuary. It has provided useful experience for all concerned, and allowed us to refine our methods to allow future wader GPS-tracking work on the Humber Estuary to be conducted very efficiently. The next step is to refine proposals for a full-scale project in collaboration with members of the Humber Nature Partnership and the wider bird-conservation community, and to seek funding for the continuation of this important work.

1. INTRODUCTION

The Humber Estuary is designated as a Special Protection Area (SPA) as it supports internationally important numbers of wintering waterbirds (a total assemblage of 153,934 wintering waterbirds in the period 1996/97 to 2000/01 according to the Natura 2000 standard data form for the site: JNCC 2015, although current numbers are slightly lower, with the average for 2010/11-2014/15 being 119,375: Frost *et al*. 2016). There is also a large amount of commercial/industrial development around the Humber Estuary, with more growth envisaged under the Humber Strategic Economic Plan, and this may affect the habitats on which waterbirds depend. The Humber Estuary also contains a number of existing managed realignment sites (where parts of the sea wall have been removed, allowing the land behind to flood to create new intertidal areas). More, and much larger, managed realignment sites are planned on the estuary as mitigation for intertidal habitat loss to sea-level rise due to climate change, and this may also be one of the options for creating mitigation habitat as a result of any planned developments.

Given this background, it is important that the best possible evidence is available to inform the assessment of the potential impacts of any effects associated with development and to inform any compensation or mitigation measures proposed. However, at present, although we have a good understanding of the numbers of birds that use different areas of the estuary, notably through Wetland Bird Survey (WeBS) counts (Ross-Smith *et al*. 2013, Frost *et al.* 2016), it is uncertain how this usage varies by day and night and according to the tide, and how dependent birds are on particular habitats or areas within the estuary. In addition to baseline data on numbers and distributions of birds, it is thus important to understand:

- The habitat characteristics of areas that are used by birds;
- The distances that birds commute between feeding and roosting sites on the estuary, i.e. individual home ranges;
- Individual site fidelity to feeding and roosting locations;
- How birds use the area at night, and in poor weather conditions (during which surveys would not normally be conducted), in comparison to their use of areas during the day.

Such questions are best informed by detail study of individual birds, either through marking birds, usually by colour-ringing, or through tracking (e.g. Burton & Armitage 2005, https://wadertales.wordpress.com/2016/01/11/tracking-waders-on-the-severn/). In addition to providing information on birds' movements and use of the estuary, ringing studies can also inform on individual fitness of birds, i.e. their body condition and survival rates. Together these data can inform the baselines for and help to validate Individual-Based Models, designed to predict the impacts of habitat change associated with disturbance, development or sea-level rise (e.g. Stillman 2008, Stillman *et al.* 2005, Stillman & Goss-Custard 2010, West *et al.* 2002, 2011). Further, they can be then used to monitor and assess impacts resulting from consented developments and the success of mitigatory habitat creation, such as managed realignment (e.g. Burton & Armitage 2008, Burton *et al.* 2006, Goss-Custard *et al.* 2006). Such studies thus have much to offer both in improving baseline understanding of species' use of the Humber Estuary and, as an integral component of wider work packages, in informing on the potential impacts of particular developments associated with the Humber Strategic Economic Plan.

The timescales and costs of a tracking study on wintering waterbirds will depend on its scope and specific objectives, but might be expected to include tagging of a minimum of 20 individuals of each species of interest at a given site over a wintering period. Waterbird species vary in their within and between winter site-fidelity and their movements in different areas of the estuary are also likely to be dependent on the relative location of feeding and roosting habitat.

Here we report on a pilot project conducted during winter 2015/16, which aimed to GPS tag 10 waders to gather high resolution data on their habitat use over a monthly tidal cycle (fixes every 1.5 hours for 28-30 days) in mid-winter in order to demonstrate the feasibility of tracking birds on the Humber, to establish the most efficient methods for conducting the work (e.g. finding the best locations for the base stations to which tags download data), and to demonstrate the value of the data that can be gathered from this type of study on the estuary. Assuming that this work is considered successful, funding will be sought for a continuation and expansion of the project (i.e. a larger sample size and more species) in future winters.

The Curlew *Numenius arquata* is a high conservation priority species due to widespread population declines (Eaton *et al.* 2015), and has recently been described as 'the most pressing bird conservation priority in the UK' (Brown *et al*. 2015). WeBS data also show that wintering Curlew numbers are declining on the Humber Estuary at a faster rate than in the surrounding region (Ross-Smith *et al*. 2013). As a species of high conservation interest for the site, therefore, we aimed to track 10 Curlew in this pilot study. The Redshank *Tringa totanus* is also a high conservation priority species on the Humber Estuary (and would be a species that we would want to extend this work to if the pilot is successful), and is much more reliably catchable. Therefore if it proved infeasible to catch Curlew for this work, we agreed that the pilot study would be conducted on Redshank instead, or a combination of the two species.

2. METHODS

2.1 Field methods

Five birds – three Curlew and two Redshank – were caught in mist nets set in the dark over wet features on the saltmarsh at Welwick (Ordnance Survey grid reference approximately TA333190) during the early hours of 24th January 2016 and a further three Redshank on 14th February 2016. Each bird was fitted with a numbered metal ring and an individual combination of colour-rings to aid subsequent identification in the field, its age (adult or first-winter) determined by plumage characteristics and then measured and weighed by trained and qualified members of the HWRG, or by trainees supervised by qualified group members, in accordance with their standard practice.

Each bird was fitted with a GPS tag. The tags used were Pathtrack NanoFix low power GPS tags with UHF download, weighing around 4g (model number NanoFix_GEO+RF_LP_2B_4TS). The tags had been set up using Pathtrack's specialist software a few hours prior to catching birds, and were set to start recording GPS locations between 9.00am and 10.00am on the morning after the birds had been caught (i.e. within a few hours of birds being released) and to subsequently record a location every 90 minutes until the battery ran out, and to attempt to communicate with nearby base stations (and download data if in range) once per hour. This gave an expected lifespan of at least 28 days for each tag, which would cover two spring-neap-spring tidal cycles. Tags were set to start recording at slightly different times from each other (with 5 minute intervals between tags) so that there were not several tags attempting to communicate with the base station at the same time, which can increase the time taken to download data and therefore the power consumption by the tags, reducing their lifespan. Tags were glue-mounted to the back of the bird in between the wings, ensuring that the tag was central over the spine and high enough up the back to avoid the preen gland and low enough down to avoid the tightest bend in the spine between the back and the neck of the bird. Tags had a small piece of muslin, extending 5-10mm beyond the footprint of the tag, attached to their base with superglue prior to catching the birds. We trimmed an area of feathers on the back of the birds corresponding to the footprint of the tag plus its muslin; feathers were trimmed to ~5mm long which helps to ensure that the tag is well attached close to the bird's body and not stuck to the ends of long feathers which could allow it to wobble and cause welfare issues, or make it easier for birds to remove the tag. The base of the tag and muslin were then attached to the area of trimmed feathers on the back of the bird using superglue to ensure a good join with no lose edges on the muslin.

Following the first catching attempt, three base stations were deployed at the following locations:

- Stone Creek: 53°39'08' N 0°08'03' W
- Welwick: 53°38'46' N 0°00'58' E
- The Warren, Spurn Peninsula: 53°36'43' N 0°08'38' E

Tags would download data when the bird was within 200-1000 metres of the base station, with the range improved if the base station was situated as high up as possible. The base station at Welwick was situated in an ideal location, high up and near the edge of the saltmarsh close to where the birds were caught. The other base stations were situated further away to either side of the catching site (but also high up and close to regular wader roost sites) in case birds from roosts further along the coast had been pulled into the catching site by the tape lure used and later returned to these areas, though this proved not to be the case, and all data for all eight of the tagged birds were subsequently downloaded via the Welwick base station.

The base stations were visited on 9th February, 23rd February and 2nd March to download data.

2.2 Analytical methods

To assess the space use / home ranges of Curlew and Redshank tagged in the Humber Estuary, we used kernel density analysis within the R package adehabitatHR (Calenge 2006). Kernel density analysis assesses space use by determining the area in which each bird (or all birds combined) spent a certain percentage of time during the study period (for example the 50% kernel denotes the core area in which a bird spent 50% of its time). Initially, we analysed the distribution of each individual bird over the period in which it was tracked. In order to assess distribution in relation to time of day, we then split the dataset for each individual into points recorded during daylight and points recorded during night using the R package RAtmosphere (Biavati 2014).

For each species, we then combined data for all individuals. In order to investigate how the distribution of each species was influenced by the state of the tide, we obtained data describing tidal height at 15 minute intervals for Immingham from the British Oceanographic Data Centre (http://www.bodc.ac.uk/). We classified periods where the tides reached heights of 5.5 m or greater as being high tide and periods when the tides were 2.5m or less as being low tide. For each species, we then repeated the kernel density analysis for all individuals at high tide and at low tide during daylight and during the night.

3. RESULTS

3.1 Fieldwork

Between 24th of January 2016 and 2nd of March 2016, we obtained records of 3,330 locations from the eight birds tagged – three Curlew and five Redshank. The tags recorded the location of each individual bird approximately once every 90 minutes over the study period. All tags downloaded at least 180 GPS fixes to the base station with the GPS tags for four of the five birds caught on 24th January providing or exceeding the 500 fixes expected (the tag for a fifth bird produced 438 fixes) (Table 1). It is important to note that on the first two visits to retrieve data from the base stations (on 9th and 23rd February 2016), data had been downloaded to the base station at Welwick within the preceding 24 hours. This indicates that tags were downloading their data regularly to this base station, and therefore that this base station location and system worked extremely well. This level of data return is at the top end of our expectations for performance from remote-download tagging studies, based on a wide range of BTO experience with this technology on a variety of species.

One of the tags deployed on 14th February only produced 181 locations, and there is some indication that the battery on this tag might not have performed as well as the others, although it still had sufficient charge at the time of its last fix on 25th February to continue functioning, therefore it is also possible that the bird left the area after this date, or was predated.

The raw track data for each bird, and for all birds combined, are mapped in Appendix 1.

Table 1 Summary of data for each tagged bird. A 'fix' refers to a recorded GPS location.

Species	Tag ID	Ring number	Age	Date of first fix	Time of first fix	Date of last fix	Total fixes	Days tracked
Curlew	13701	FP85203	Adult	24/1/2016	09.40	26/2/2016	537	34
Curlew	13751	FP85202	Adult	24/1/2016	09.45	25/2/2016	522	33
Curlew	13760	FP85130	Adult	24/1/2016	09.50	1/3/2016	627	38
Redshank	13411	DD49243	1st-winter	24/1/2016	09.20	20/2/2016	438	28
Redshank	13418	DD49242	1st-winter	24/1/2016	09.25	22/2/2016	501	30
Redshank	13108	DD49245	1st-winter	14/2/2016	09.05	25/2/2016	181	12
Redshank	13141	DD49246	Adult	14/2/2016	09.10	2/3/2016	276	18
Redshank	13143	DD49247	1st-winter	14/2/2016	09.15	28/2/2016	248	15

3.2 Redshank – Individuals

There was broad variation in the area of habitat exploited by individuals (Figures 1-5). Whilst some, e.g. 13108 (95% kernel 14.1 km^2; Figure 1, Table 2), appeared to cover a wide area over the study period, others were far more restricted in the area they used, e.g. 13143 (95% 2.1 km^2; Figure 3, Table 2). In general, there did not appear to be much difference between areas used during the day and those used during the night, although the total area used by birds during the day appeared to be smaller than that used during the night (Table 2).

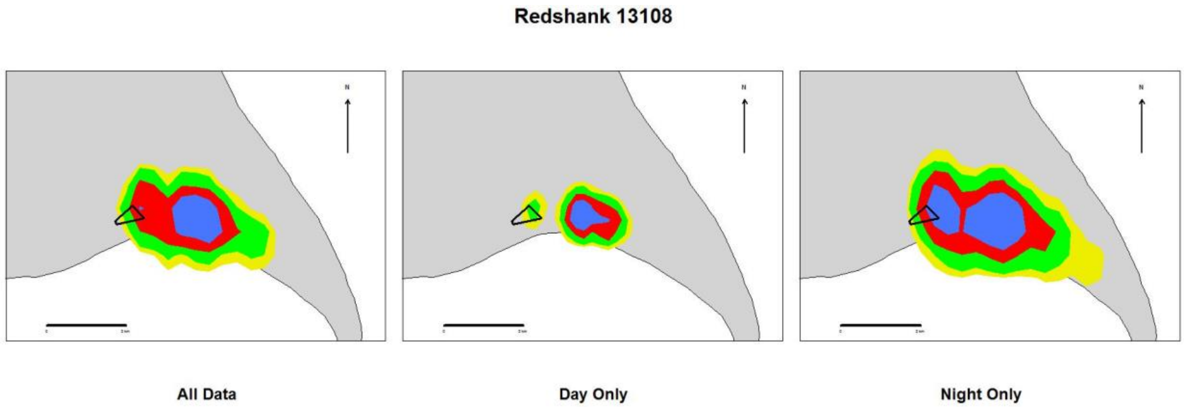

Figure 1 Kernel density analysis of the movements of Redshank number 13108. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

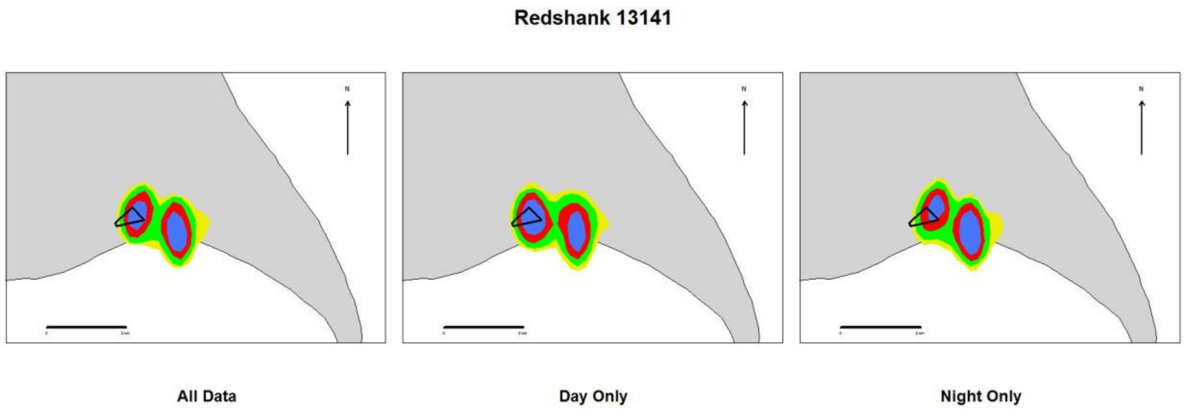

Figure 2 Kernel density analysis of the movements of Redshank number 13141. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

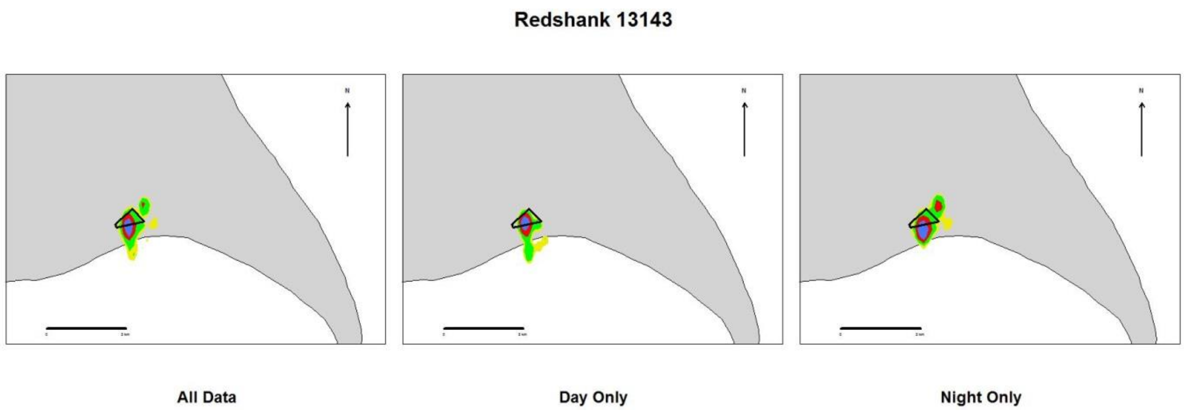

Figure 3 Kernel density analysis of the movements of Redshank number 13143. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

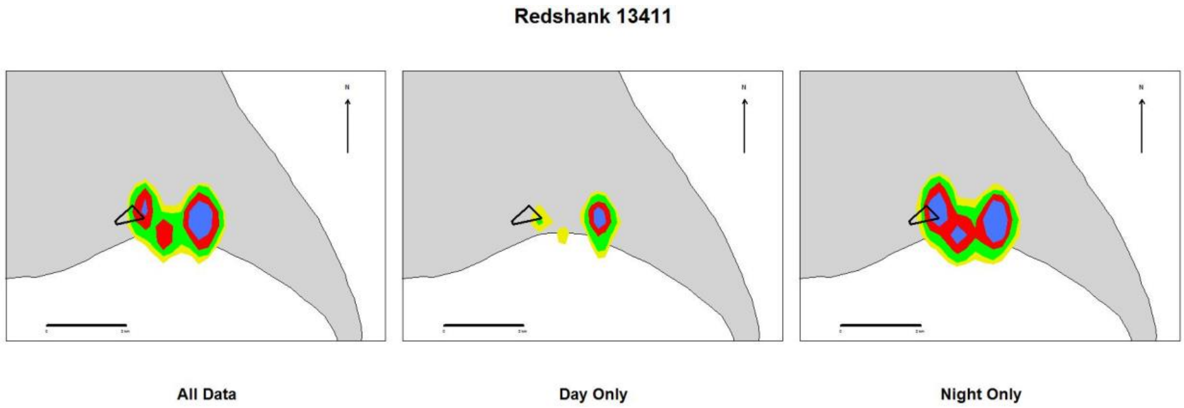

Figure 4 Kernel density analysis of the movements of Redshank number 13411. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

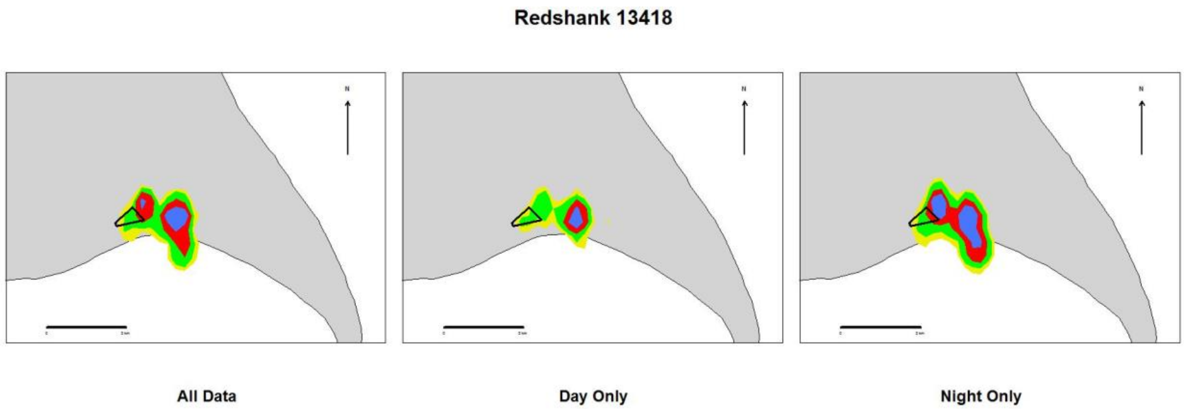

Figure 5 Kernel density analysis of the movements of Redshank number 13418. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

Table 2 Area of core habitat (km^2) used by tagged Redshank as assessed using 95%, 90%, 75% and 50% kernels based on all tracks, tracks during the daytime only and tracks during the night-time only.

Tag ID	All Tracks				Day Only Tracks				Night Only Tracks			
	95%	90%	75%	50%	95%	90%	75%	50%	95%	90%	75%	50%
13108	14.1	11.0	6.1	2.1	4.9	3.4	1.9	0.7	20.5	15.6	9.5	4.2
13141	6.9	5.4	3.3	1.5	7.0	5.5	3.4	1.4	7.3	5.7	3.5	1.6
13143	2.1	1.2	0.6	0.2	1.6	1.1	0.4	0.2	1.9	1.3	0.7	0.3
13411	7.8	6.3	3.2	0.9	3.2	1.9	0.7	0.2	9.2	7.3	4.7	1.9
13418	6.1	4.6	2.1	0.6	3.0	1.8	0.6	0.2	7.4	5.6	3.3	1.3

Use of the managed realignment area varied strongly between individuals with some, e.g. 13143, using it a significant proportion of the time and others, e.g. 13411, using it rarely (Table 3). Of the birds which spent a significant proportion of time in the area, usage of the managed realignment area was higher during the day than the night.

Table 3 Percentage of time spent in the managed realignment area by each individual in total, during the day and during the night.

Tag ID	All tracks	Day Only Tracks	Night Only Tracks
13108	4%	4%	4%
13141	25%	46%	10%
13143	34%	55%	16%
13411	2%	1%	3%
13418	4%	3%	4%

3.3 Redshank – All Birds

As might be expected, Redshank were distributed over a broader area during periods of low tide than periods of high tide (Figure 6, Table 4). This pattern was consistent regardless of whether periods of high and low tide occurred during the day or night. During periods of low tide, birds appeared to range over a wider area at night than was the case during the day (Table 4). However, the reverse was the case for periods of high tide.

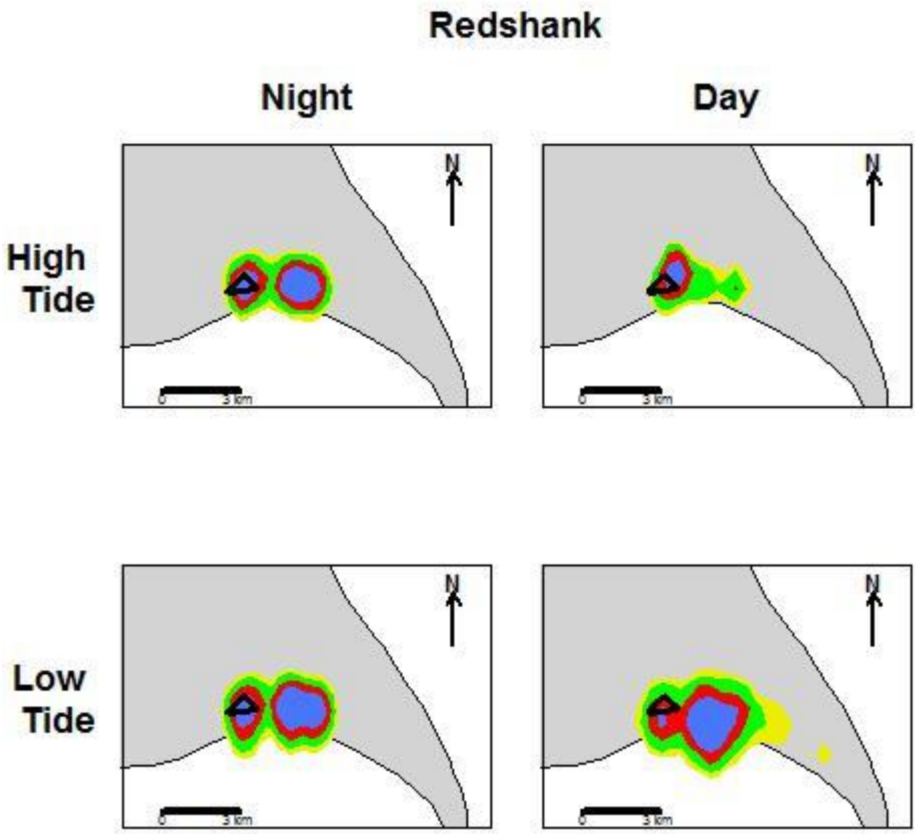

Figure 6 Kernel density analysis of the movements of Redshank during the day and night and in relation to high and low tide. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

Table 4 Area of core habitat used by all Redshanks at high and low tide during the day and night assessed using 95%, 90%, 75% and 50% kernels.

		95%	90%	75%	50%
High Tide	Day	7.4	5.9	3.6	1.7
	Night	5.6	4.1	1.7	0.5
Low Tide	Day	11.5	9.2	5.7	2.6
	Night	14.7	10.7	6.3	2.5

Use of the managed realignment area varied between day and night and between high and low tide (Figure 6, Table 5). Overall, birds spent a greater proportion of their time in the managed realignment area during periods of high tide and during the day.

Table 5 Percentage of time spent in the managed realignment area by Redshank during periods of high and low tide and during the night and day.

	Night	Day
High	17%	27%
Low	2%	17%

3.4 Curlew – Individuals

There was some variation in the area of habitat used by individuals. Curlew 13760 covered a broader area (95% kernel 9.6 km^2) than was the case for either Curlew 13751 (95% kernel 6.9 km^2) or Curlew 13701 (95% kernel 4.4 km^2). There was also a tendency for birds to use a wider area during the day than during the night (Table 6, Figures 7-9).

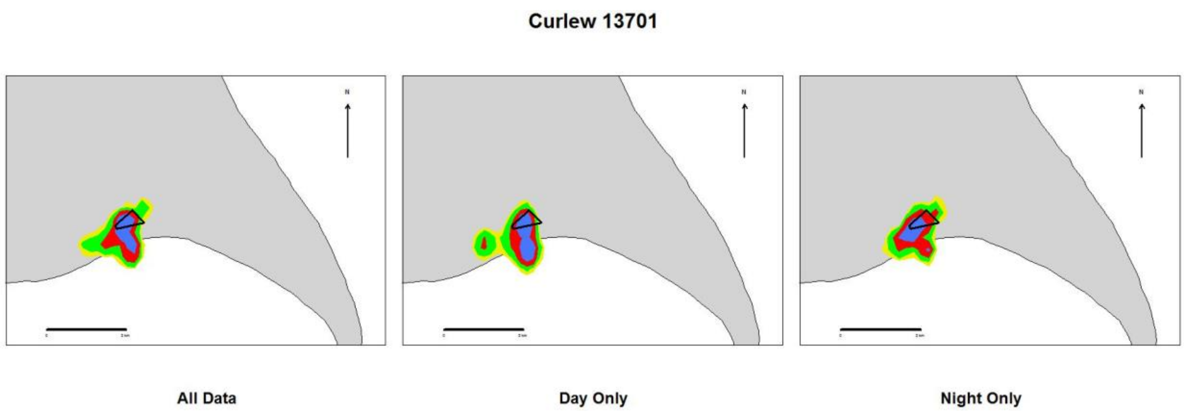

Figure 7 Kernel density analysis of the movements of Curlew number 13701. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

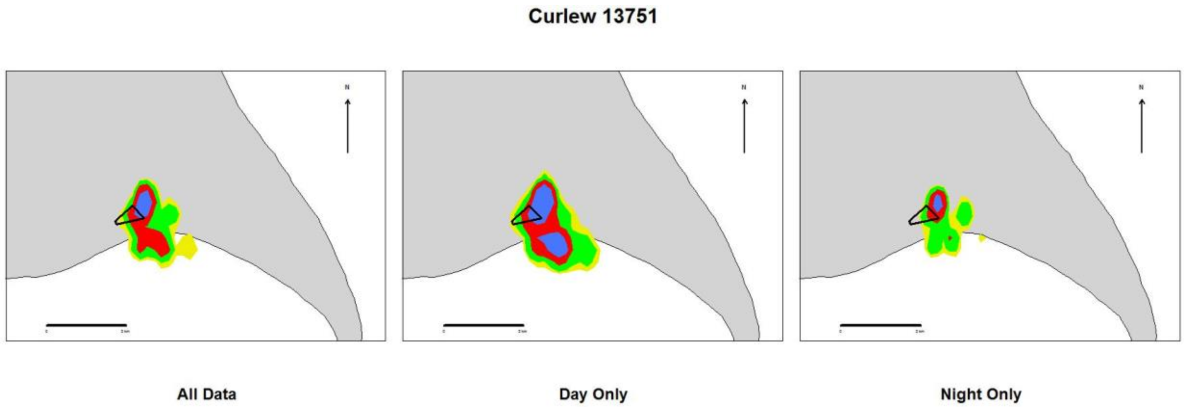

Figure 8 Kernel density analysis of the movements of Curlew number 13751. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

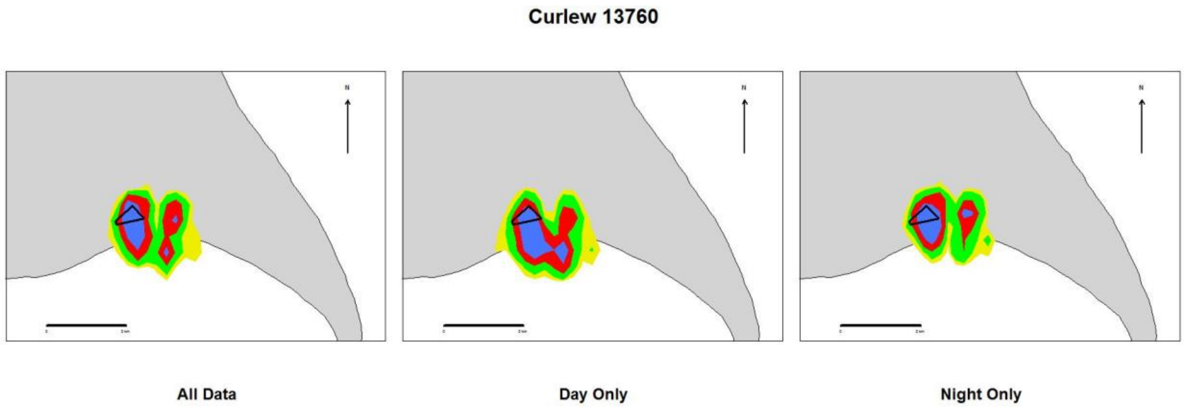

Figure 9 Kernel density analysis of the movements of Curlew number 13760. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

Table 6 Area of core habitat (km^2) used by tagged Curlew as assessed using 95%, 90%, 75% and 50% kernels based on all tracks, tracks during the daytime only and tracks during the night-time only.

Tag ID	All Tracks				Day Only Tracks				Night Only Tracks			
	95%	90%	75%	50%	95%	90%	75%	50%	95%	90%	75%	50%
13701	4.4	3.4	2.0	0.7	4.5	3.6	2.1	0.9	4.0	3.2	1.9	0.7
13751	6.9	5.1	2.5	0.6	9.1	7.4	4.5	2.0	4.7	3.3	1.0	0.3
13760	9.6	7.6	4.0	1.5	10.3	7.9	4.3	2.0	8.2	6.8	3.1	1.2

Use of the managed realignment area varied between individuals. Curlew 13701 spent up to 43% of its time in the managed realignment area. In contrast, Curlew 13751, only spent 9% of its time in the area (Table 7). Of the two birds which spent a significant proportion of their time in the managed realignment area, they tended to make greater use of it during the night than during the day.

Table 7 Percentage of time spent in the managed realignment area by each individual in total, during the day and during the night.

Tag ID	All tracks	Day Only Tracks	Night Only Tracks
13701	43%	36%	48%
13751	9%	13%	6%
13760	28%	24%	31%

3.5 Curlew – All Birds

As might be expected, Curlew were distributed over a broader area during periods of low tide than periods of high tide (Figure 10, Table 8). This pattern was consistent regardless of whether periods of high and low tide occurred during the day or night. During periods of low tide, birds appeared to range over a wider area at night than was the case during the day (Table 8). However, the reverse was the case for periods of high tide.

Use of the managed realignment area varied between day and night and between high and low tide (Figure 10, Table 9). Overall, birds spent a greater proportion of their time in the managed realignment area during periods of high tide and during the day.

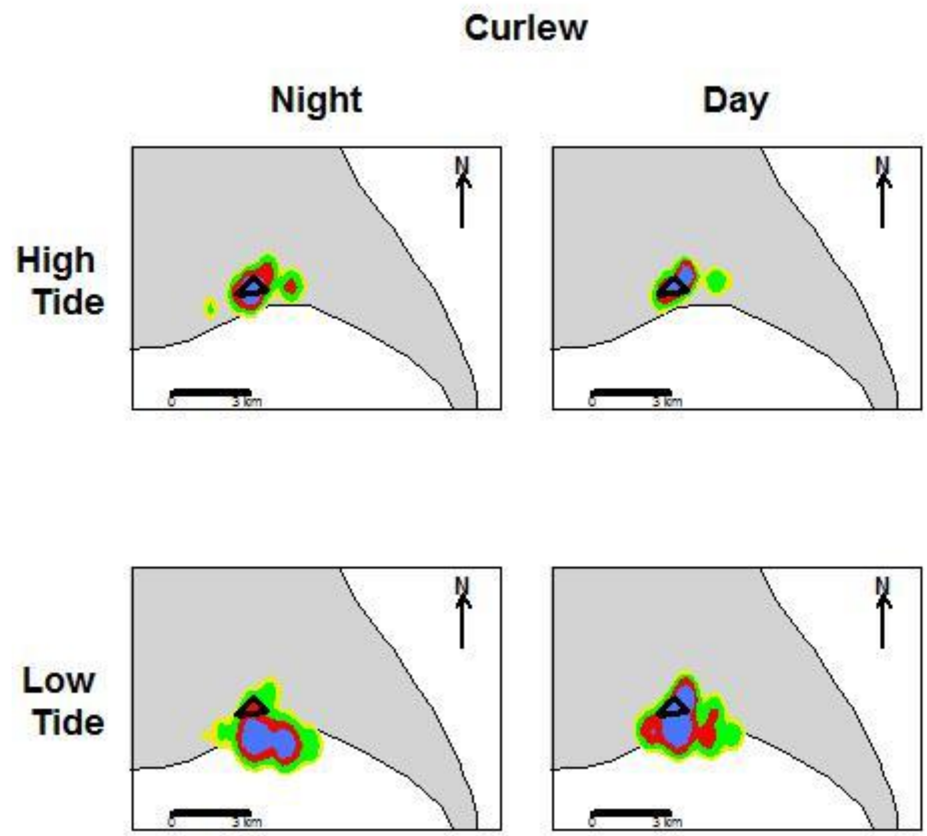

Figure 10 Kernel density analysis of the movements of Curlew during the day and night and in relation to high and low tide. Maps show distributions based on all data, data from the day only and data from night only. Blue = 50% kernel, Red = 75% kernel, Green = 90% kernel and Yellow = 95% kernel. Outline of the managed realignment area also shown, note that coastline reflects the mid tide mark.

Table 8 Area of core habitat used by all Curlew at high and low tide during the day and night assessed using 95%, 90%, 75% and 50% kernels.

		95%	**90%**	**75%**	**50%**
High Tide	Day	4.7	3.4	1.6	0.6
	Night	3.1	2.2	1.1	0.2
Low Tide	Day	9.7	7.3	3.8	1.6
	Night	10.0	8.2	4.7	2.1

Table 9 Percentage of time spent in the managed realignment area by Curlew during periods of high and low tide and during the night and day.

	Night	**Day**
High	45%	63%
Low	9%	6%

4. DISCUSSION

Overall, our initial analyses suggest that, in this part of the Humber Estuary, Redshank cover a greater area than Curlew. Whilst Curlew appeared to move mostly in relation to the tide (Figure 10), Redshank movements appeared to be much more spread out along the estuary (Figure 6). However, for both species there was a strong variation in the area of habitat used by individuals with Curlew covering between 4.4 and 9.6 km^2 and Redshank between 2.1 and 14.1 km^2. The reasons for this variation are unclear with the sample sizes available, but may be linked to factors such as age. For example, age-related foraging segregation has been demonstrated in the Redshank, with adult birds feeding in areas with a lower predation risk (Cresswell 1994).

Habitat use in both species varied in relation to both the tidal and diurnal cycles (Tables 3 and 7, Figures 6 and 10). Redshank were found to cover a greater area during the night than during the day, a finding consistent with a previous study of this species on the Severn Estuary (Burton & Armitage 2005). This was thought to reflect greater use of the open mudflats during the night when predation risk in these areas was lower, but predation risk nearer the shore high. The data shown in Figure 6 appear to offer some support to this finding, as this shows some evidence of greater use of mudflats during the night. However, more data are needed to support this hypothesis. In contrast, Curlew appeared to cover a greater area during the day than during the night. The reasons for this are unclear, but may relate to roosting patterns. At present, the resolution of the tagging data is insufficient to investigate movement patterns at a sufficiently fine scale to infer the extent to which birds are roosting or actively foraging.

As might be expected, both species ranged more widely during periods of low tide than was the case during periods of high tide, when birds were constrained to high tide roosts. The managed realignment area appeared to be an important high tide roost site for both species (Tables 4 and 8), but was particularly important for Curlew. There was also evidence to suggest that birds made greater use of the managed realignment area as a high tide roost during the day than during the night.

This pilot study provides some insights into how both Curlew and Redshank make use of the estuary. However, there are two key areas where further investigation is required. The first of these is an investigation of the fine-scale habitat used by each species. Characteristics of mudflats, such as the location of drainage channels, are known to influence the distribution of feeding waders (Lourenco *et al.* 2005). Given the apparent importance of the managed realignment areas for both Curlew and Redshank, a better understanding of how the fine scale habitat influences species distributions is important in order inform the hydro-dynamic models that can be used to assess the impact of managed realignment areas on the distribution of waders.

The second area which requires further investigation is an understanding of the role of disturbance in influencing wader distributions on the estuary. Disturbance can have a significant population level impact on wintering waders (West *et al.* 2002). Disturbance has been cited as a potential explanation for the redistribution of wintering waterbirds elsewhere (e.g. Burton *et al.* 2002, Austin & Calbrade 2010). Tracking data could be related to information about human activity within the Humber Estuary in order to understand how disturbance was influencing wader distribution and, potentially, what the population-level consequences of this may be.

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Appendix 1

This appendix provides maps showing the raw data for each of the birds tracked and for all birds combined. Two versions of each map have been provided (i) with lines showing movements between consecutive GPS locations, and (ii) with the GPS locations only (with no lines linking consecutive locations), which makes it easier to see areas of frequent usage, but less easy to identify movement patterns.

Figure A1 Raw track data for a first-winter Redshank with tag number 13108. This bird was tracked from 14th February – 25th February 2016 (12 days), with 181 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

Figure A2 Raw track data for an adult Redshank with tag number 13141. This bird was tracked from 14th February – 2nd March 2016 (18 days), with 276 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

Figure A3 Raw track data for a first-winter Redshank with tag number 13143. This bird was tracked from 14th February – 28th February 2016 (15 days), with 248 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

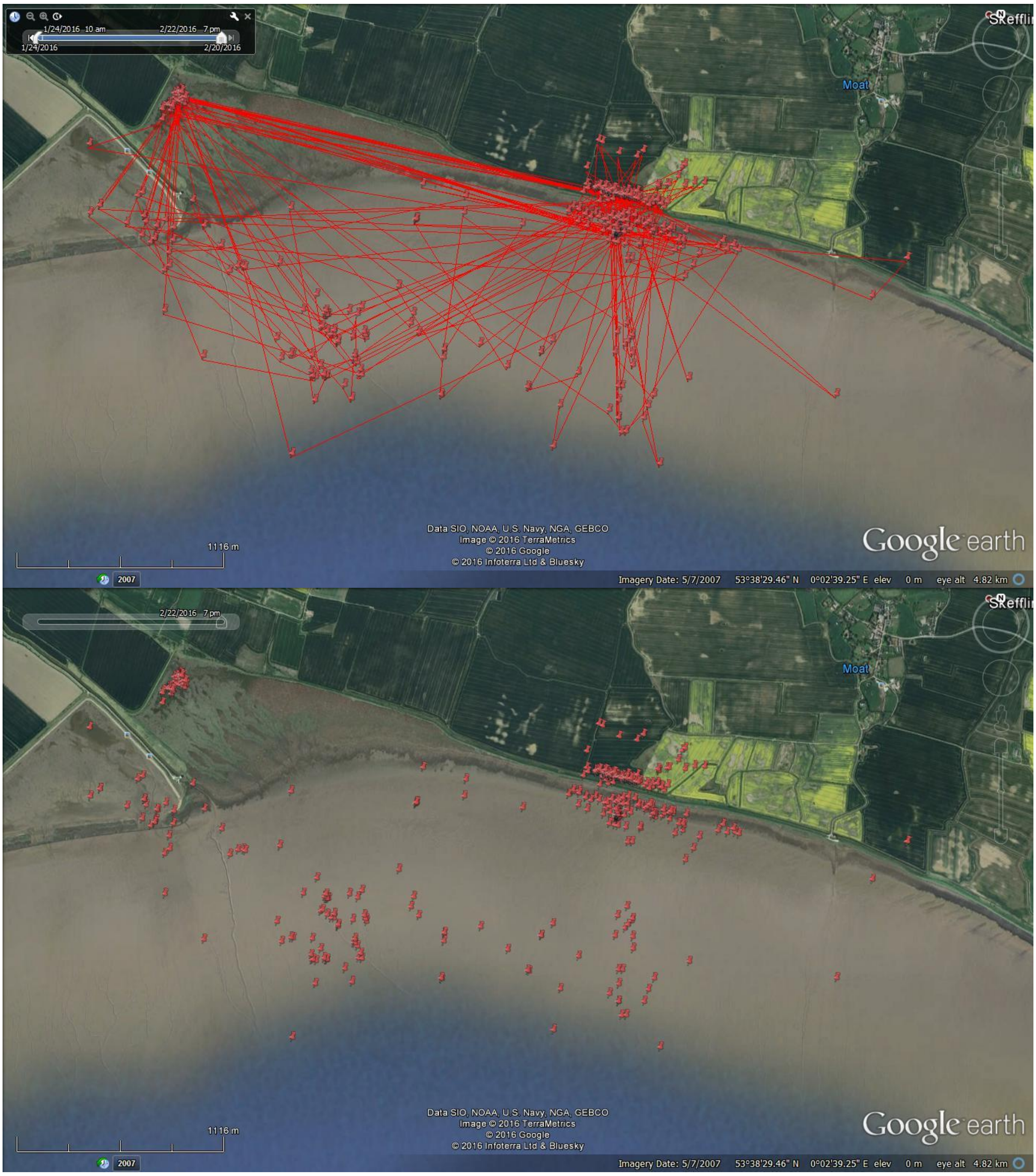

Figure A4 Raw track data for a first-winter Redshank with tag number 13411. This bird was tracked from 24th January – 20th February 2016 (28 days), with 438 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

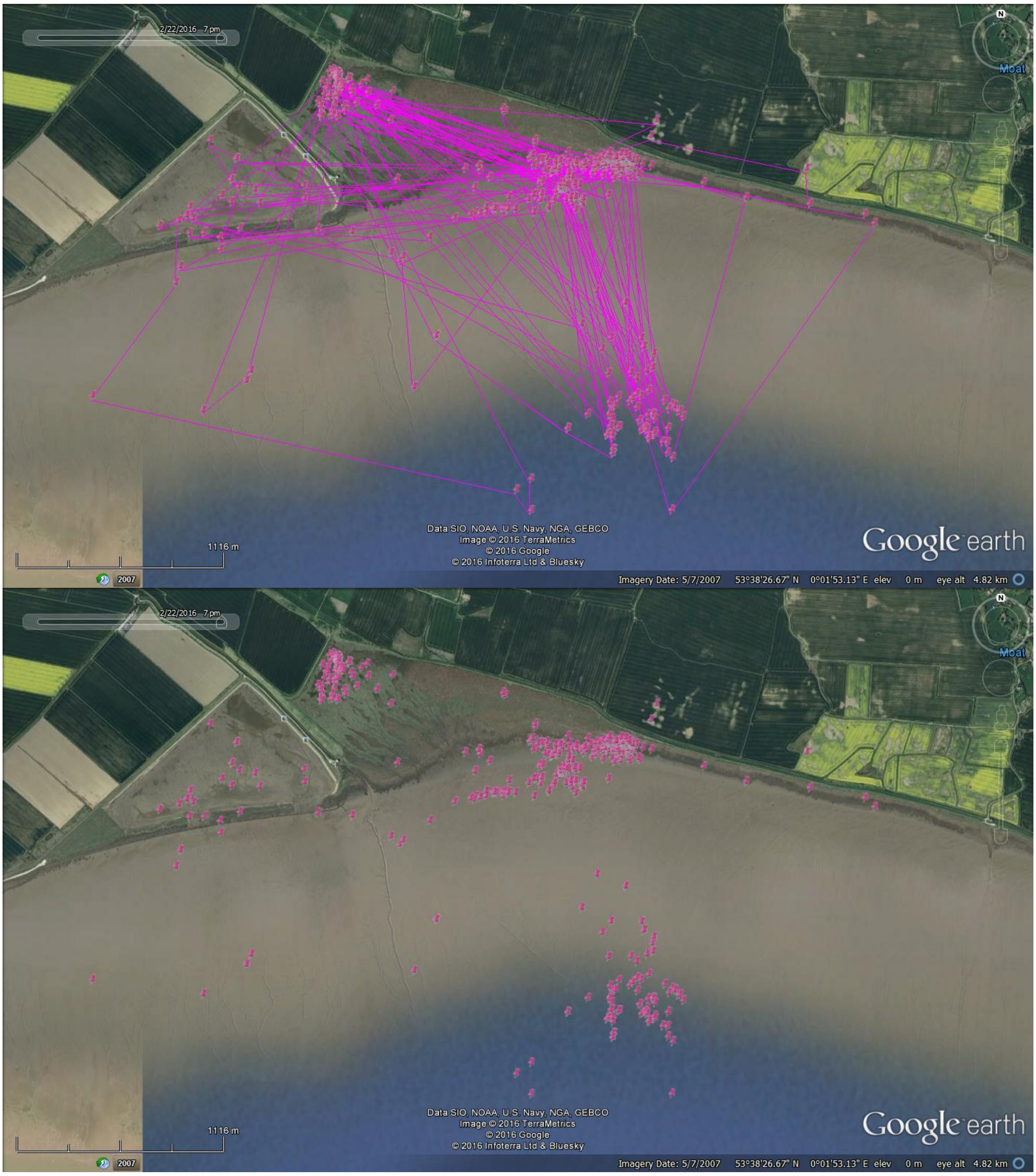

Figure A5 Raw track data for a first-winter Redshank with tag number 13418. This bird was tracked from 24th January – 22nd February 2016 (30 days), with 501 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

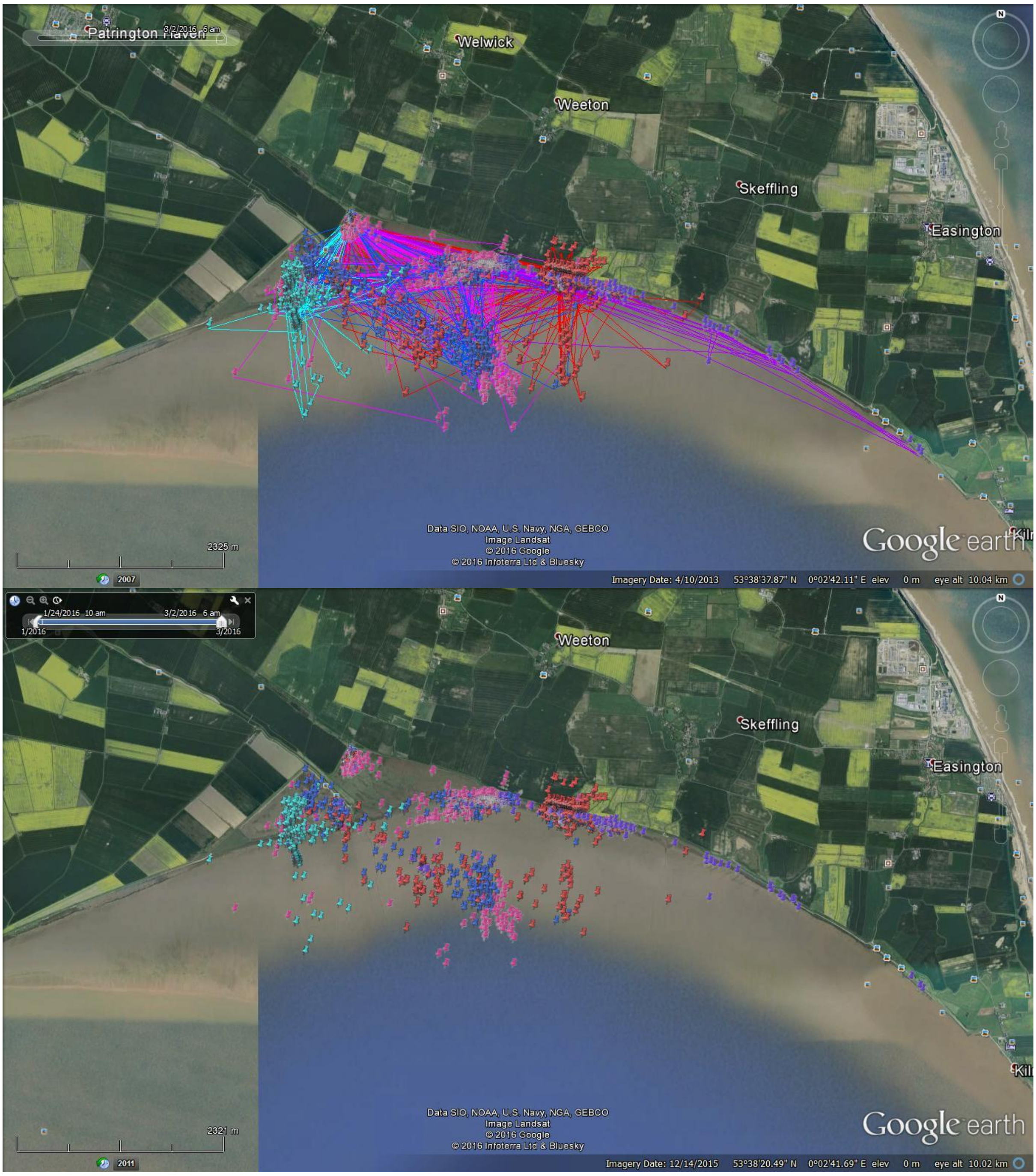

Figure A6 Raw track data for all five Redshank combined. Each bird is shown using a different colour, corresponding with the colours used in Figures A1-A5 (Purple = 13108; Dark Blue = 13141; Pale Blue = 13143; Red = 13411; Pink = 13418). The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

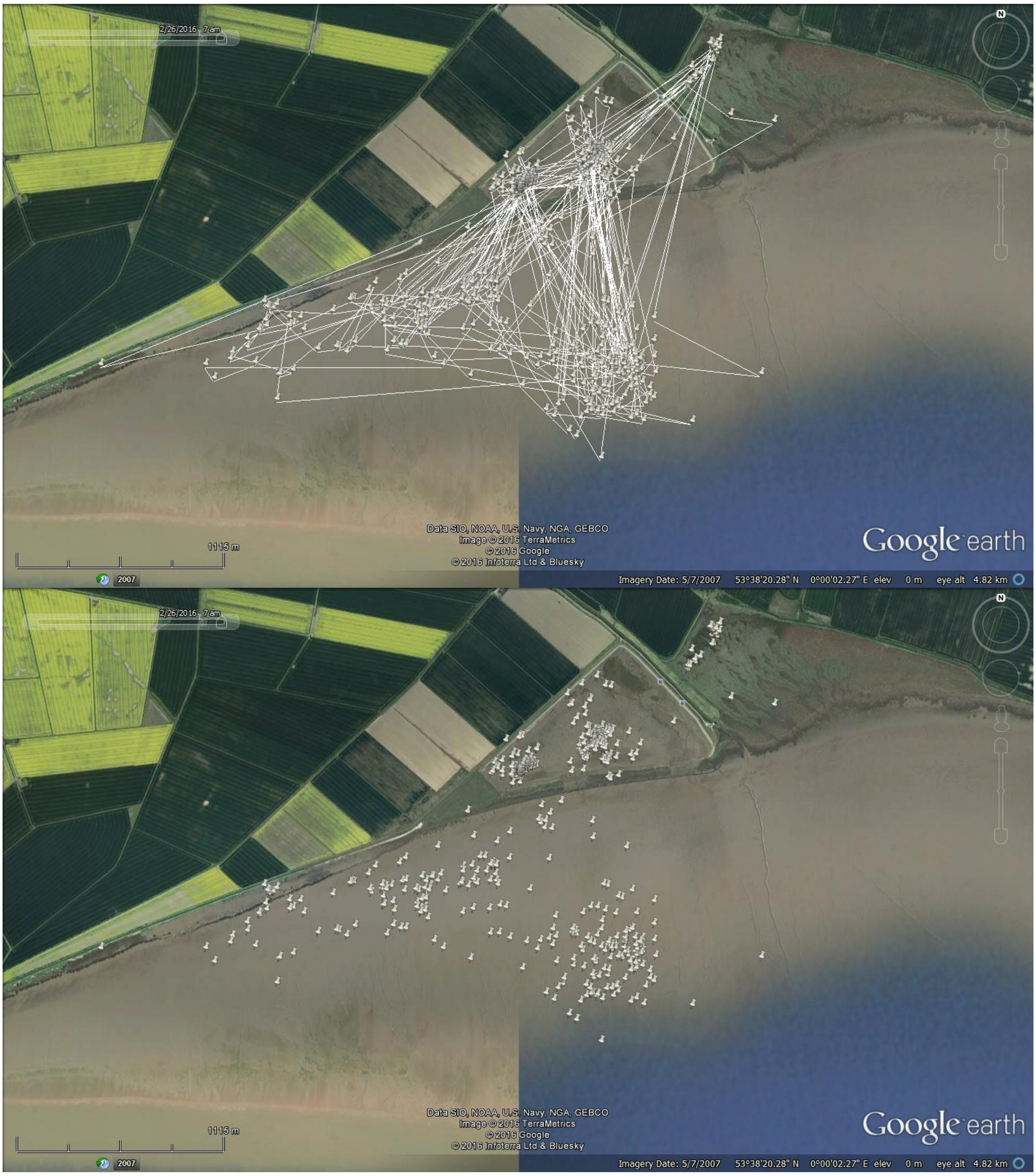

Figure A7 Raw track data for an adult Curlew with tag number 13701. This bird was tracked from 24th January – 26th February 2016 (34 days), with 537 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

Figure A8 Raw track data for an adult Curlew with tag number 13751. This bird was tracked from 24th January – 25th February 2016 (33 days), with 522 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

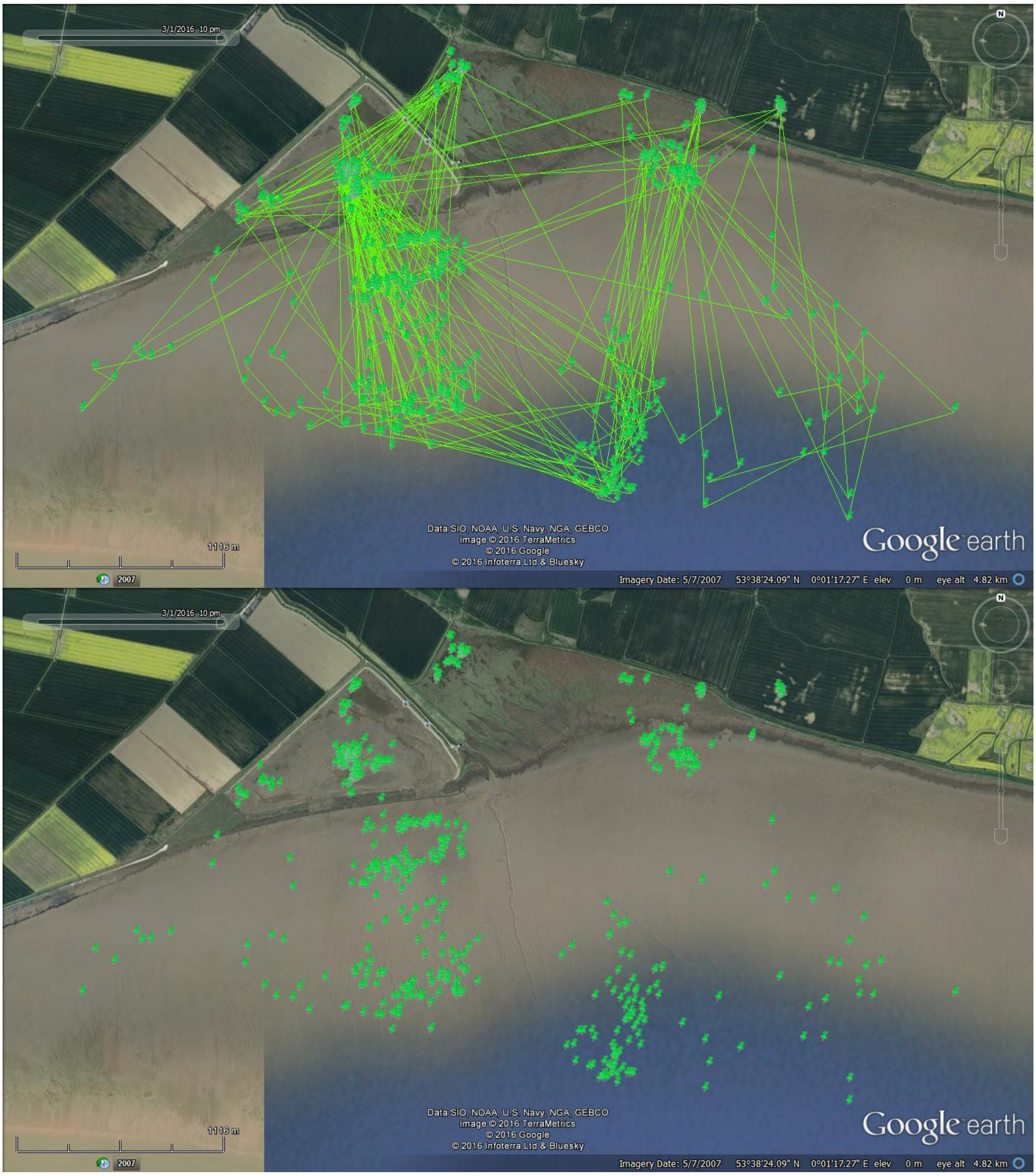

Figure A9 Raw track data for an adult Curlew with tag number 13760. This bird was tracked from 24th January – 1st March 2016 (38 days), with 627 GPS locations recorded during this period. The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

Figure A10 Raw track data for all three Curlew combined. Each bird is shown using a different colour, corresponding with the colours used in Figures A7-A9 (White = 13701; Yellow = 13751; Green = 13760). The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.

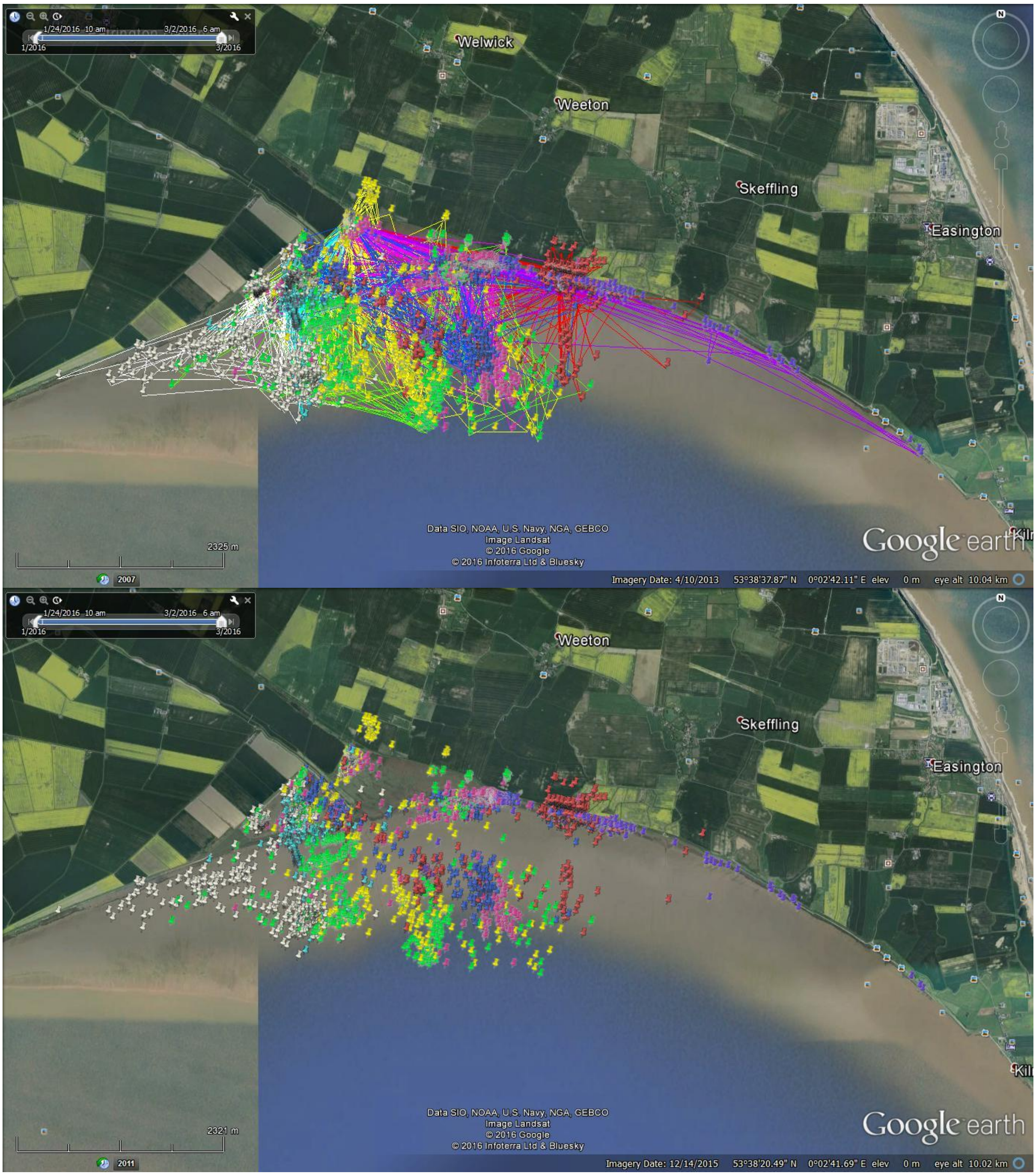

Figure A11 Raw track data for all birds (five Redshank and three Curlew) combined. Each bird is shown using a different colour, corresponding with the colours used in Figures A1-A10 (Redshank: Purple = 13108; Dark Blue = 13141; Pale Blue = 13143; Red = 13411; Pink = 13418. Curlew: White = 13701; Yellow = 13751; Green = 13760). The upper map includes lines showing movements between consecutive GPS locations, while the lower map shows only the GPS locations.