moray offshore renewables ltd

Environmental Statement

Technical Appendix 4.5 C - Seabird Tracking and Modelling Report

Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement

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APPENDIX 4.5 C

SEABIRD TRACKING TECHNICAL REPORT (DRAFT)

30th August 2011

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SUMMARY

- During May, June and July 2011 the at-sea movements and behaviour of four species of seabird (black-legged kittiwake *Rissa tridactyla*, common guillemot *Uria aalge*, razorbill *Alca torda*, northern fulmar *Fulmarus glacialis*) breeding along the East Caithness cliffs was studied using bird-borne GPS loggers.
- 248 device deployments resulted in collection of 171 foraging tracks. The low recover rate suggests some devices effects.
- Of 77 devices deployed on black-legged kittiwakes, 25 were recovered containing data on 30 foraging trips.
- Of 92 devices deployed on common guillemots, 26 were recovered containing data on 62 foraging trips.
- Of 31 devices deployed on razorbills, 18 were recovered containing data on 58 foraging trips.
- Of 48 devices deployed on northern fulmars, 17 were recovered containing data on 28 foraging trips.
- All four species showed qualitatively similar central place foraging trip characteristics; few long directed commuting flights interspersed with many short highly tortuous movements. The latter are consistent with area-restricted search behaviours.
- Razorbills travelled to inshore foraging grounds mostly in the south and west of the Moray Firth and none passed through the proposed development site.
- Guillemots travelled to mostly inshore foraging grounds in the south and the south west of the Moray Firth, with one bird foraging along the coast of North East Scotland. Two birds (10%) passed through the proposed development site, but no birds foraged there.
- Kittiwakes travelled to mostly inshore foraging grounds in the west and the south west of the Moray Firth, with one bird travelling east to Peterhead. Three birds (20%) passed through the proposed development site, but no birds foraged there.
- Fulmars travelled over a much wider areas compared with the other three species, heading to more offshore foraging grounds. Birds travelled to a range of different foraging locations throughout the Moray Firth, and one bird had an incomplete track that stopped in the middle of the North Sea. Twelve birds (80%) passed through the proposed development site, and three birds (20%) foraged there.

INTRODUCTION

Recent developments in bio-logging technology have seen an exponential increase in the use of miniaturised logging and transmitting devices to study the fine scale movements and behaviour of free-living animals (Ropert-Coudert& Wilson 2005). In the context of the proposed Round 3 Zone 1 Offshore Wind Farm development in the Moray Firth, this approach has been identified as an appropriate technique to inform the Environmental Impact Assessment with regard to the large numbers of cliff-nesting seabirds that breed along the east coast of Caithness.

This individual-level approach to studying interactions between seabirds and Marine Renewable Energy Installations (MREIs) provides the opportunity to specifically draw spatial links between seabird breeding colonies and offshore developments, to better understand potential positive or negative impacts. Moreover, analysis of tracking data enables the location of specific behaviours (such as commuting and foraging) to better inform the nature of habitat use by seabirds in response to the location of MREIs.

Here we describe the results of a tracking study of the four most abundant seabird species nesting along the Caithness Coast (black-legged kittiwake *Rissa tridactyla*, common guillemot *Uria aalge*, razorbill *Alca torda*, northern fulmar *Fulmarus glacialis*) using GPS loggers during the incubation and early chick-rearing 2011.

METHODOLOGY

Fieldwork took place May - July 2011 in seabird colonies along the East Caithness cliffs between Helmsdale (58^{o}07’N, 03^{o}40’W) and Dunbeath (58^{o}25’N, 03^{o}42’W)

Bird selection and capture

We selected birds breeding in areas with safe access and there was a mixture of birds caught on the edge and in the centre of colonies. All tracked birds were reproductively active. Kittiwakes, Guillemots and Razorbills were either on eggs or small chicks, while Fulmars, because of risk of abandonment, were caught on small chicks. Multiple areas within suitable colonies were used to prevent unnecessary disturbance.

All birds were caught (under licence from Scottish Natural Heritage) using an adjustable carbon fibre pole (maximum length 11m) equipped with a noose made from fishing line (tensile strength of 60 – 100lb).

Device deployment

On initial capture birds were fitted with a single iGotU GPS logger. In all cases the original plastic housing removed to reduce weight and then re-housed in waterproof heat-shrink plastic. The devices were numbered to aid the identification after recapture. For each species modifications to this basic attachment method were required to improve recapture and reduce any potential device effects.

(1) Kittiwake device deployment

Initially, the standard GPS device was attached to the dorsal surface of the birds with black Tesa tape, this technique yielded a poor return (12 devices deployed, 1 retrieved). The devices were then packaged differently to elongate their shape, with the intention of spreading the weight of the devices along the dorsal surface of the Kittiwakes. Black tape was used and the devices attached to the dorsal surface of the birds (18 devices deployed, 5 retrieved) (Fig. 1).

Fig. 1. Kittiwake with GPS logger attached with black Tesa tape. A green identification mark is visible on the head.

A further change was made to the method of device attachment in an attempt to reduce device loss and therefore increase retrieval rate. An elastic harness was made from a single piece of elastic. This harness was looped around the chest and wings of the bird and the device attached to this elastic so that it was positioned on the dorsal surface of the bird. Adjustments were made to ensure that the harness was not too tight across the chest and so that it did not impede wing movement (9 devices deployed, 3 retrieved) (Fig. 2). This modification in device attachment was to avoid the use of tape which the birds appeared to preen excessively, leading to the loss of the devices.

Fig. 2. Kittiwake fitted with an elastic harness to attach the GPS device. Excess elastic is visible in front of both wings; this was trimmed prior to release.

The elongated device design was then reused (see Fig. 1), with white Tesa tape instead of black tape. This change in was to negate any potential effects of increased preening at the site of device deployment due to the contrast between the bird's light coloured plumage and the black tape (14 devices deployed, 4 retrieved) (Fig. 3).

Fig. 3. Kittiwake fitted with an elongated GPS logger attached using white Tesa tape.

The final stage of the method deployment was to reduce the weight of the GPS device and to employ a different attachment technique. Fitting a smaller battery to the device did this; the standard 3.7V 230mAh battery was replaced with a lighter 3.7V 90mAh battery (overall device weight 11g). These lighter-weight devices were attached under the tail feathers with two translucent cable ties (24 devices deployed, 15 retrieved) (Fig. 4).

Fig. 4. The underside of a Kittiwake showing a GPS device with a smaller battery deployed on the tail feathers. The device is covered in white Tesa tape and attached with two translucent cable ties. Green identification marking is visible on the tail feathers.

This final method of attachment, coupled with the lighter device yielded the best rates in terms of device retrieval. This reduction in weight had a trade-off as the smaller battery reduced the number of GPS points that the device could store compared to when the standard battery was used (the standard battery had a operational duration of c.100hrs, the smaller battery was c. 30hrs). Devices were deployed on Kittiwakes from the last week of May until the first week of July.

(2) Common guillemot device deployment

Standard GPS devices were attached to the dorsal surface of guillemots using black Tesa tape (92 devices deployed, 26 retrieved) (Fig. 5). Devices were deployed on Guillemots from the first week of June until the first week of July.

Fig. 5. The final stage of the deployment of a device on a Guillemot. The bird is being marked green with a Paintstik on the chest. The GPS device is just visible on the dorsal surface.

(3) Razorbill device deployment

Standard devices were attached to the dorsal surface of the Razorbills using black Tesa tape (31 devices deployed, 20 retrieved) (Fig. 6). Devices were deployed on Razorbills from the first week of June until the third week of June.

Fig. 6. Razorbill with a standard GPS device attached with black Tesa tape to the back.

(4) Fulmar device deployment

Elongated devices were attached to the dorsal surface of the Fulmars using white Tesa tape (31 devices deployed, 20 retrieved) (Fig. 7). White tape was used to reduce the contrast between the tape and the plumage of the bird. Devices were deployed on Fulmars from the first week of July until the third week of July.

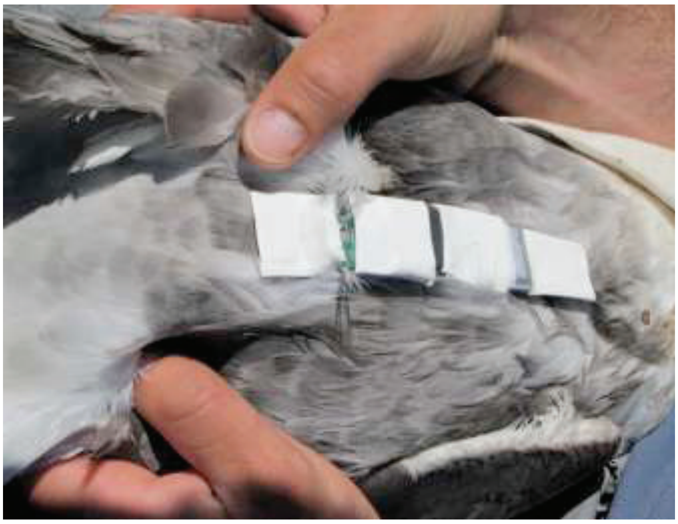

Fig. 7. Fulmar with an elongated GPS logger attached using white Tesa tape to the back.

For all species handling time was kept to an absolute minimum and the birds were protected from direct sunlight during device deployment to reduce stress. All tagged birds were marked with a green non-toxic semi-permanent waterproof marker (All Weather Paintstik) on the head, breast or tail feathers (i.e. where the plumage is white) to allow subsequent identification of individuals in the field. The tagged birds were released in the same area where they were captured.

Device Recovery

Tagged birds were left for a minimum of 36 hrs to allow them to complete one or more a foraging trips. During this time the appropriate areas of the colonies were avoided to reduce disturbance. Where possible tagged birds were re-captured using the same technique for device deployment. After device removal the bird was marked using a pink non-toxic semi-permanent waterproof marker (All Weather Paintstik) to prevent erroneous re-captures.

Data analysis

Following device retrieval, data was downloaded using the manufacturers software (@trip PC). Individual movements were then reconstructed from GPS fixes and checked for location errors. To examine the movements of individuals away from the colony we split the data into trips, defined as the occurrence of more than one GPS fix at least one kilometre from the colony. Each "trip" from the colony therefore began and finished as the individual passed a 1 km buffer around the colony of capture.

To identify commuting and foraging behaviours we took a two-stage approach. Firstly, the scale at which individuals' search for prey was identified using First Passage Time (FPT). Recent work has linked increased diving rates (as identified using Time Depth Recorders) with area-restricted search (ARS) behaviours, indicating that these behaviours are a reliable indication of prey capture (Hamer *et al.* 2009). These ARS behaviours and the scale at which they occur can be identified by calculating the time it takes an individual to fly through a circle of varying radius (Pinaud& Weimerskirch 2005). We did this for a sub-sample of individuals (three razorbills, and two individuals for the remaining three species) to define the scale at which each species adjust their searching to inform the second step of the process.

To examine the distribution of GPS locations and identify areas of importance at-sea for these four species we then used the scale of ARS behaviour to bin positional information into equidistant grids. All fixes obtained from an individual were summed into an overlaid grid of 3 km x 3 km (Razorbills, Guillemots and Kittiwakes) and 7 km x 7km (Fulmars). Those grid squares with a high number of fixes would therefore indicate a high level of space use by individuals, or by the species as a whole. Data are presented as percentage of fixes within each grid cell to allow comparison between individuals and species. This approach was adopted instead of determining ARS behaviours for all individuals because it produces figures that are easier to interpret at the study population level.

All analyses were carried out in ArcGIS 9.3 and 10 (ESRI, USA), MATLAB R2009b (The Mathworks, USA), and R 2.11.1 (R Development Core Team, Austria), FPT was calculated using ade4 and adehabitat packages for R.

RESULTS

Device recovery

There was a low rate of device recovery for the Kittiwakes, Guillemots and Fulmars (Table 1). For the Kittiwakes this was due to a combination of a low re-sighting rate of the tagged birds combined with a significant number of devices being lost from the birds. Kittiwakes that were tagged on the dorsal surface appeared to preen the area of the device attachment and in some cases they did so vigorously. When the tail deployment method was used, combined with the lighter weight device, far fewer birds preened the area of device attachment. This preening action may have accounted for the significant number of devices lost from tagged Kittiwakes. As there was only a 50% re-sighting rate for tagged Kittiwakes there must have been a significant effect of device attachment on the behaviour of the birds leading to nest abandonment.

The low device retrieval rate for the Guillemots and Fulmars was due to a low re-sighting rate of tagged birds rather than from loss of devices. Again it can be assumed that the devices had an impact on the natural behaviour of the birds, leading to nest abandonment.

Table 1 Number of GPS devices deployed, retrieved, trip data available and approximate re-sighting and device loss rates for four species of seabird tracked from the East Caithness Cliffs.

Species	Tags deployed	Tags retrieved	Tags containing trip data	Total trips	Approx. target bird re-sighting rate (%)	Tags seen lost from target birds (%)
Kittiwake	77	25	19*	30	~50%	>60%**(large tag) <1% (small tag)
Guillemot	92	26	20	62	~50%	<5%
Razorbill	31	20	18	58	>80%	<1%
Fulmar	48	17	17	28	~40%	<1%
Totals	**248**	**87**	**74**	**171**	**-**	**-**

***** Some tags deployed with smaller batteries (3.7 volt 90mAh) have partial trips due to the reduced duration of the power supply (~30 hrs for 90mAh batteries compared to ~100hrs for 230mAh batteries). ****** The majority of large devices that had stayed attached to kittiwakes did not contain a long foraging trip indicating these birds had stayed on their nest or gone on short bathing trips.

<u>Razorbill *Alca torda*:</u>

The mean duration of trips for razorbills was 10.9 $\pm$ 5 h (range = 0.2 – 21.4 h, n = 58 trips from 18 birds), with a mean distance covered per trip of 83.2 $\pm$ 41.3 km (range = 3.2 – 202.5 km) and a mean foraging range of 30.3 $\pm$ 11.2 km (range = 1.3 – 57.7 km).

The majority of GPS tracks for razorbills (Figure 8 & 9) showed “commuting” behaviour, with evidence of area-restricted search behaviour at the distal portion of the track. Most birds only showed single area-restricted search behaviour per foraging trip.

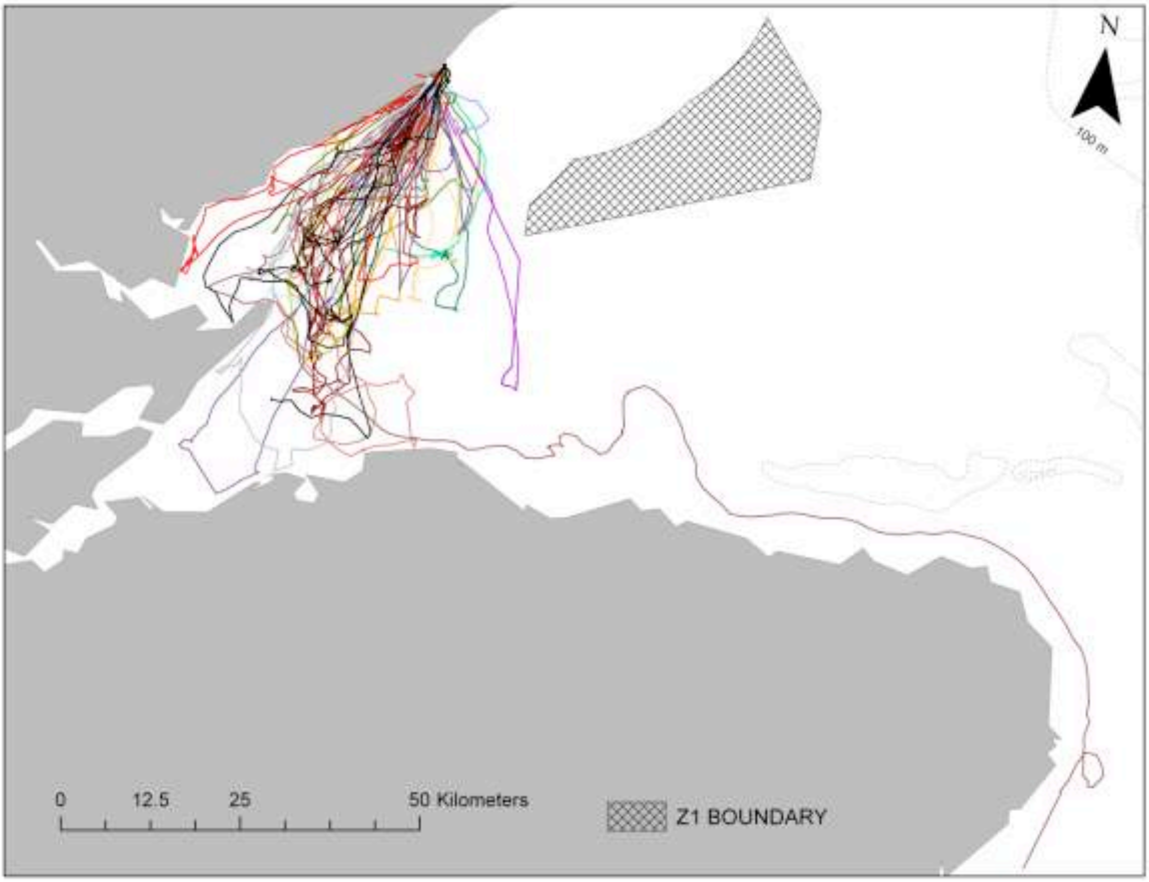

Fig. 8. GPS tracks of razorbill trips from colonies on the Sutherland/Caithness coast and their proximity to the proposed wind farm development (n=18 individuals, n=58 foraging trips).

All birds headed east or south from the breeding site and all but one stayed within the Moray Firth (Figures 8 & 9). One bird travelled around the Aberdeenshire coast, close to Peterhead (Figure 9c), although the device stopped working before the return leg began. No birds headed north or north-east or entered/passed through the proposed development area.

There were repeat tracks for a number of individuals and these suggest a certain degree of repeatability in terms of track location (Fig. 9.).

The GPS position binning for razorbills was on a 3 x 3 km scale (taken from the highest log (FPT variance) from FPT analysis). Comparison of the location of these high usage grids with ARS determined from FPT revealed that they showed qualitatively very similar results (Appendix 1). Therefore we assume that areas shaded dark represent foraging zones.

Foraging zones were found mainly in inshore waters indicating foraging in relatively shallow waters (Figure 10). No birds foraged in the proposed development.

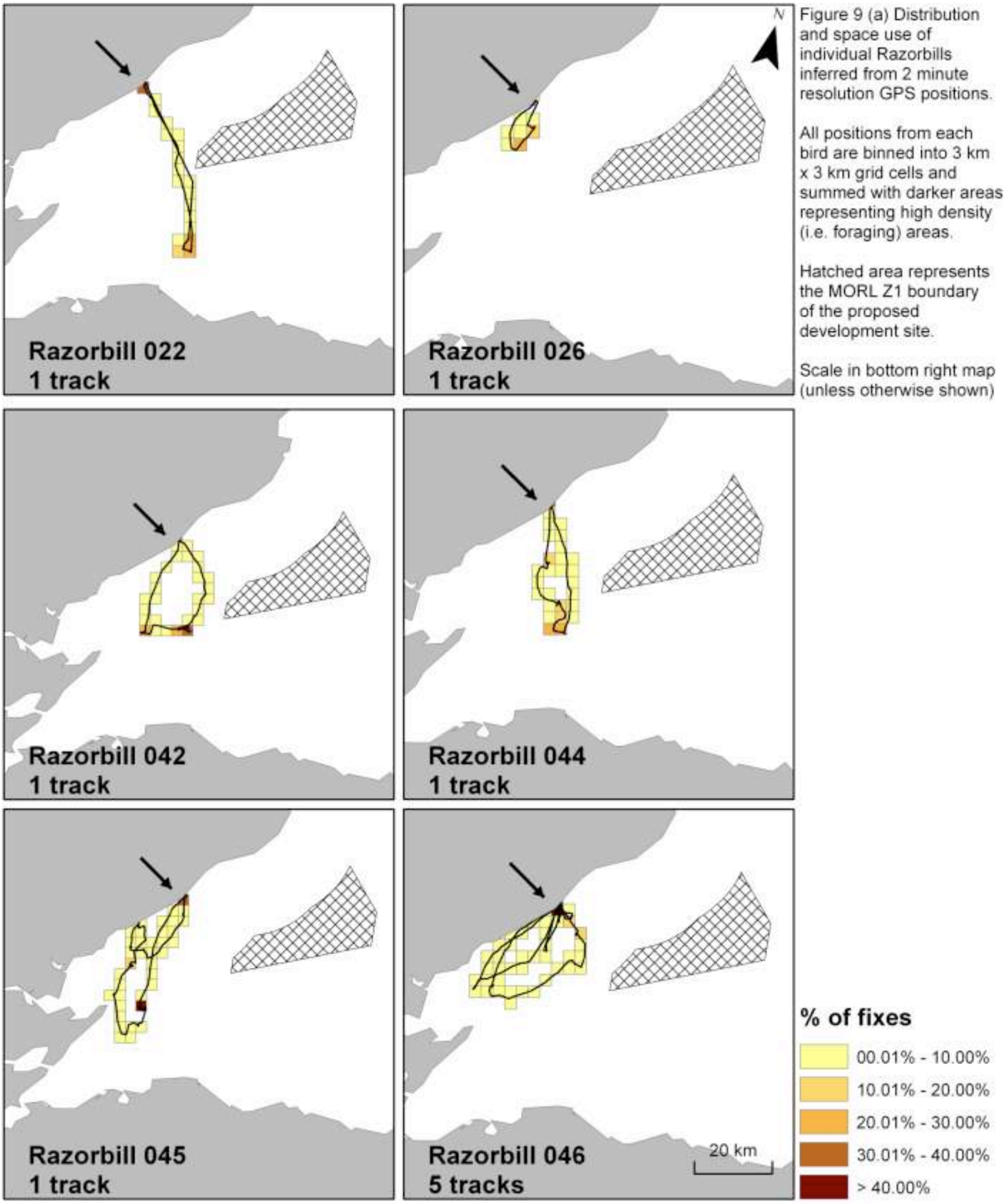

Figure 9 (a) Distribution and space use of individual Razorbills inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

Figure 9 (b) Distribution and space use of individual Razorbills inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

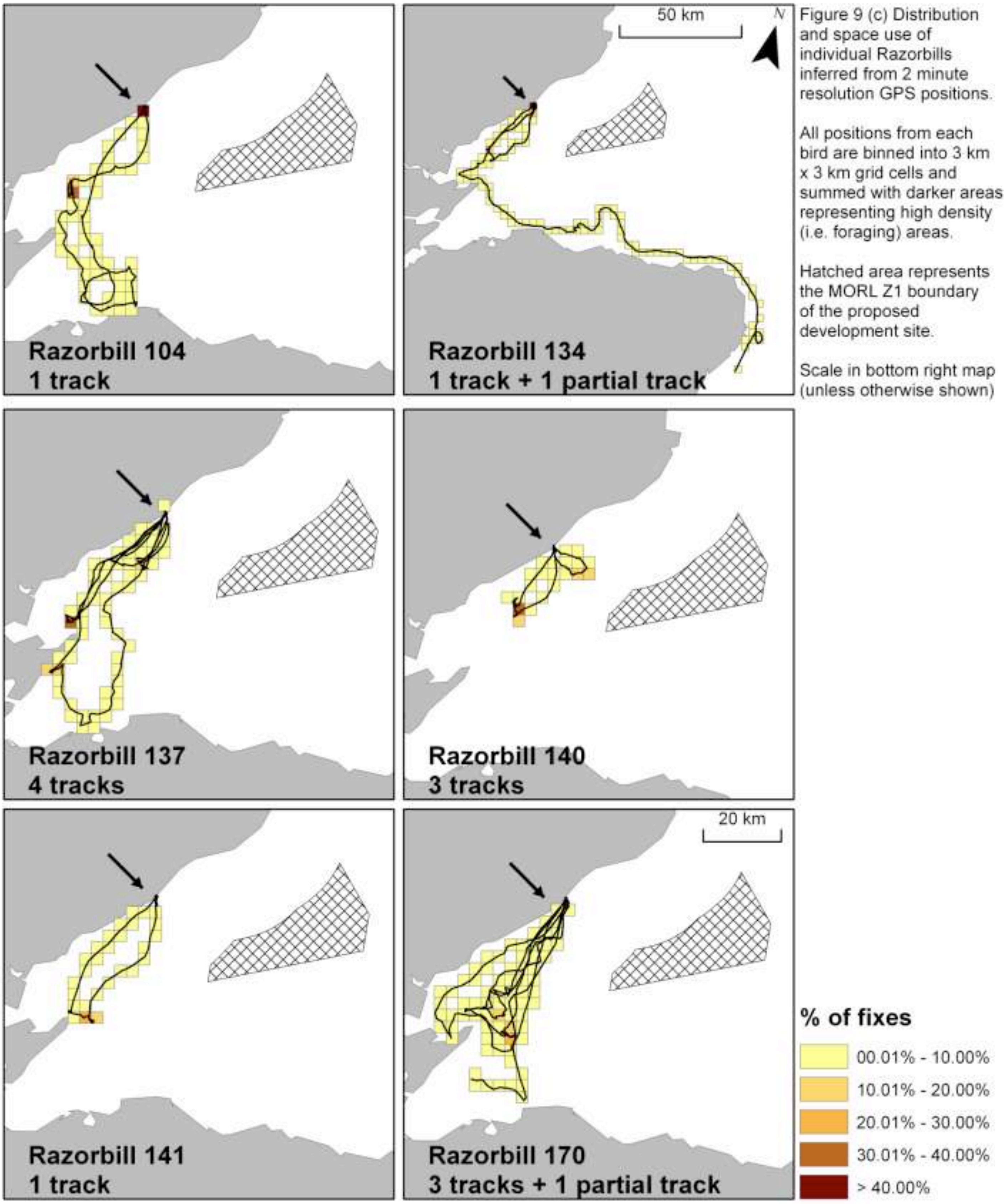

Figure 9 (c) Distribution and space use of individual Razorbills inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

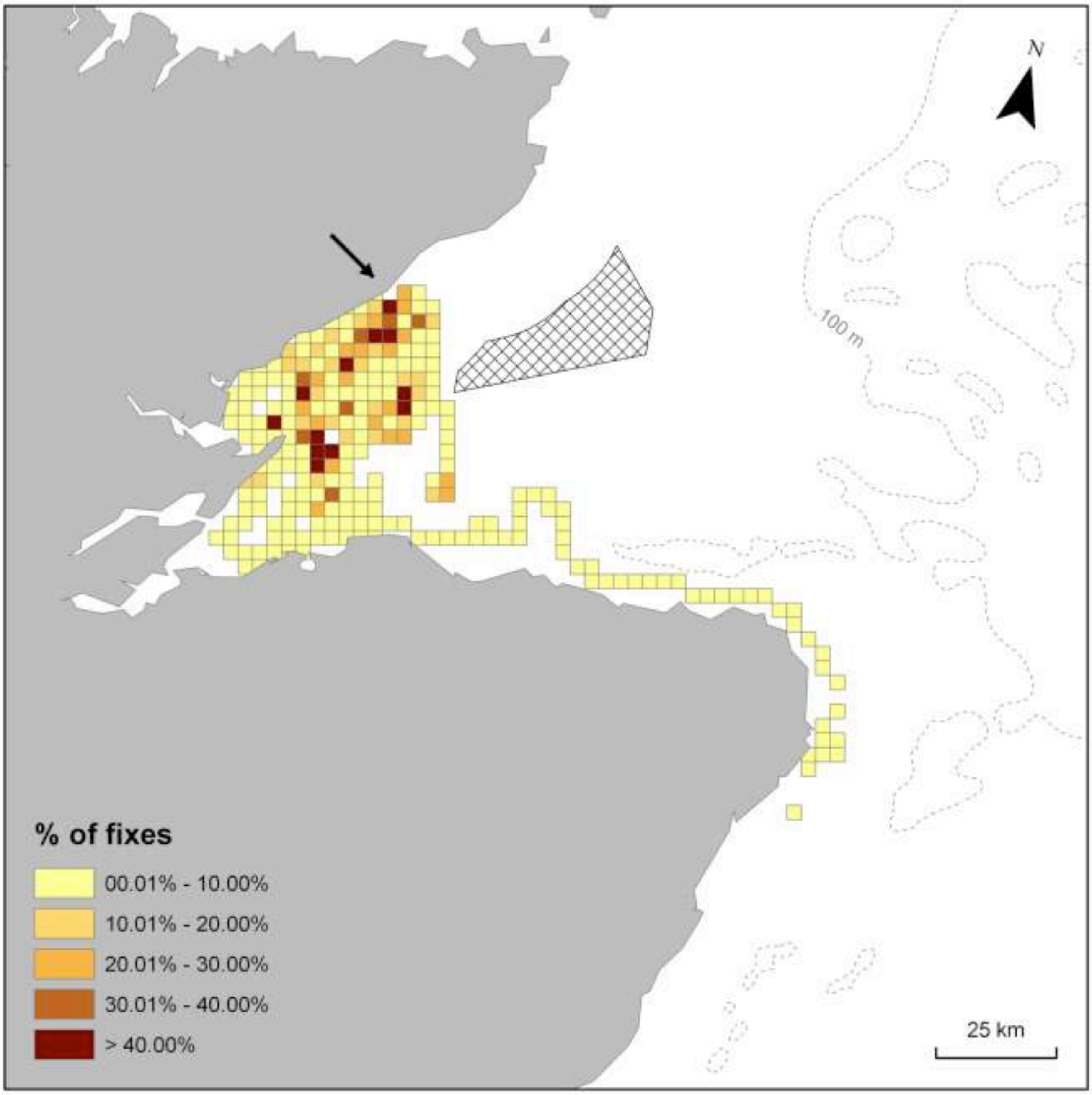

Figure 10. Distribution and space use of all Razorbill inferred from 2-minute resolution GPS positions. Positions from all birds are binned into 3 km x 3 km grid cells and summed with darker areas representing areas of more intense use consistent with foraging behaviour (n=18 individuals, n=58 trips).

<u>Guillemot *Uria aalge*:</u>

The mean duration of trips for guillemots was 13.7 ± 10,8 h (range = 0.3 – 48.3 h, *n* = 62 trips from 20 birds), with a mean distance covered per trip of 119.4 ± 105.1 km (range = 1.3 – 496.2 km) and a mean foraging range of 40.2 ± 32.1 km (range = 1.1 – 156 km).

The majority of GPS tracks for guillemots showed long directed commuting flights followed by intensive searching at a restricted scale (Figures 11 & 12).

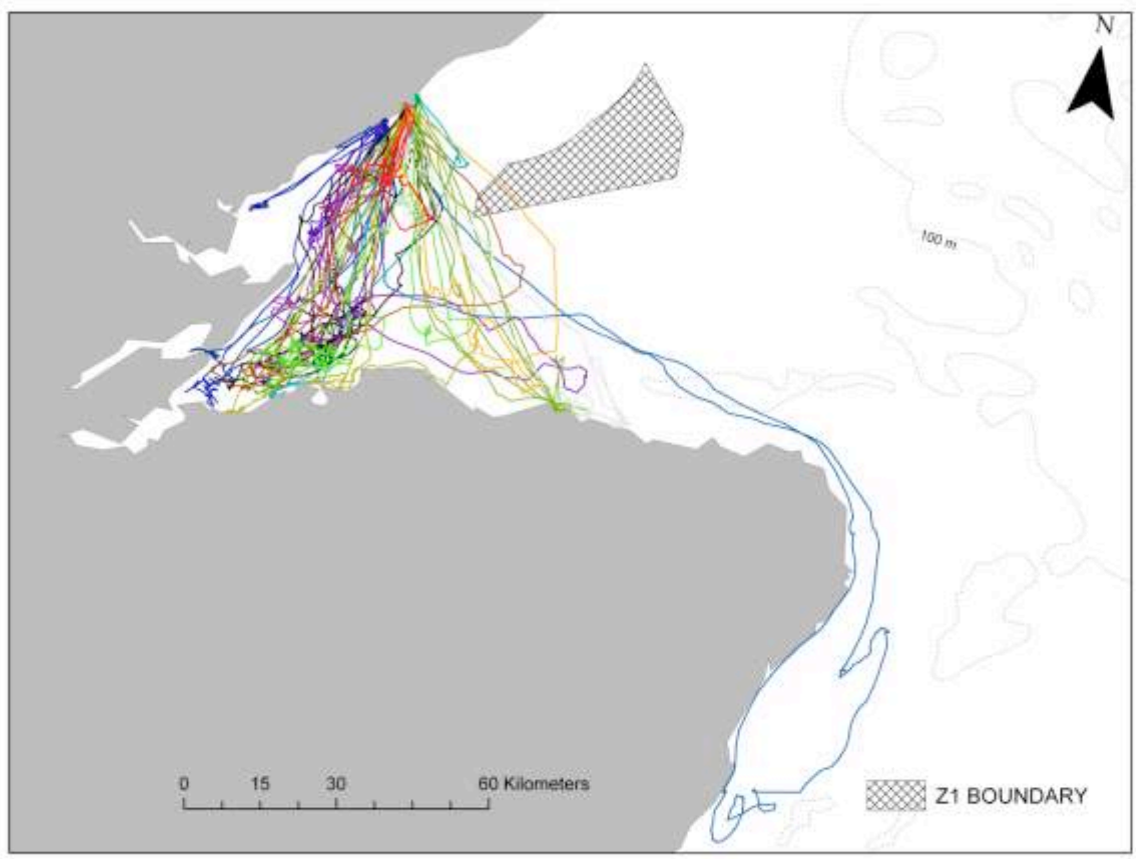

Figure 11. GPS tracks of guillemot trips from colonies on the Sutherland/Caithness coast and their proximity to the proposed wind farm development (n=20 individuals, n=62 foraging trips).

At-sea distribution was very similar to razorbills. As with the razorbills, all birds headed east or south of the colonies staying within the Moray Firth (Figures 11 & 12), except one bird that travelled to the Aberdeenshire coast, down to the waters off Aberdeen and returned via similar route (Figure 12b). No trips headed north or north-east and only one track passed through the proposed development area (Figure 12a).

For several individuals repeat foraging tracks showed a high degree of individual repeatability (Fig. 12).

The GPS position binning for guillemots was on a 3 x 3 km scale (taken from the highest log (FPT variance) from FPT analysis), with the darker grid cells in Figures 5 representing areas with high position density. The highest density of shaded grids (indicating foraging) was mainly inshore, close to the colonies, near Cromarty, between Nairn and Burghead, and between Buckie and Banff. There was also an area further offshore of high activity, similar to the razorbills (see Figure 10), east-southeast of Helmsdale (Figure 13). No birds foraged in the proposed development.

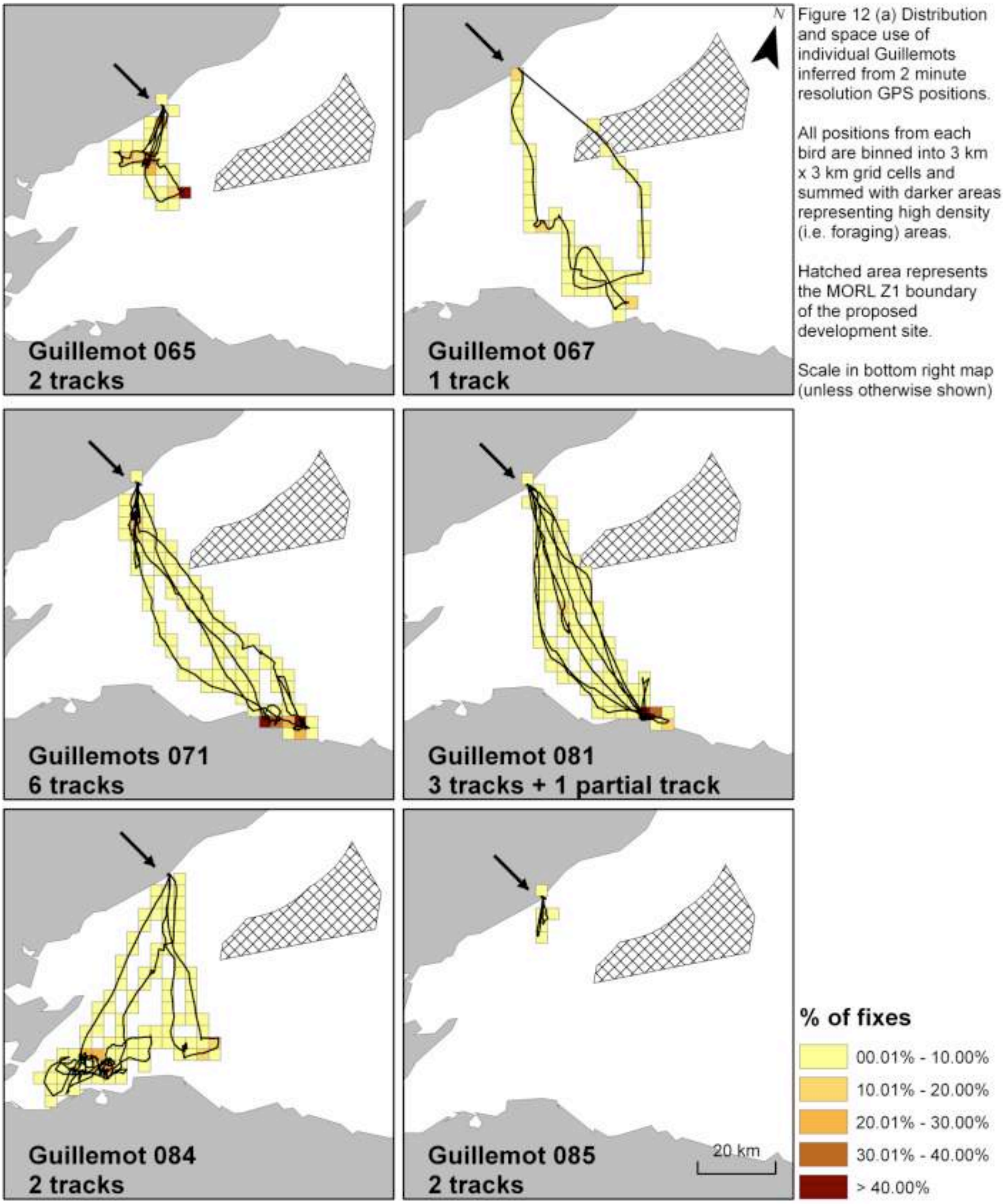

Figure 12 (a) Distribution and space use of individual Guillemots inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

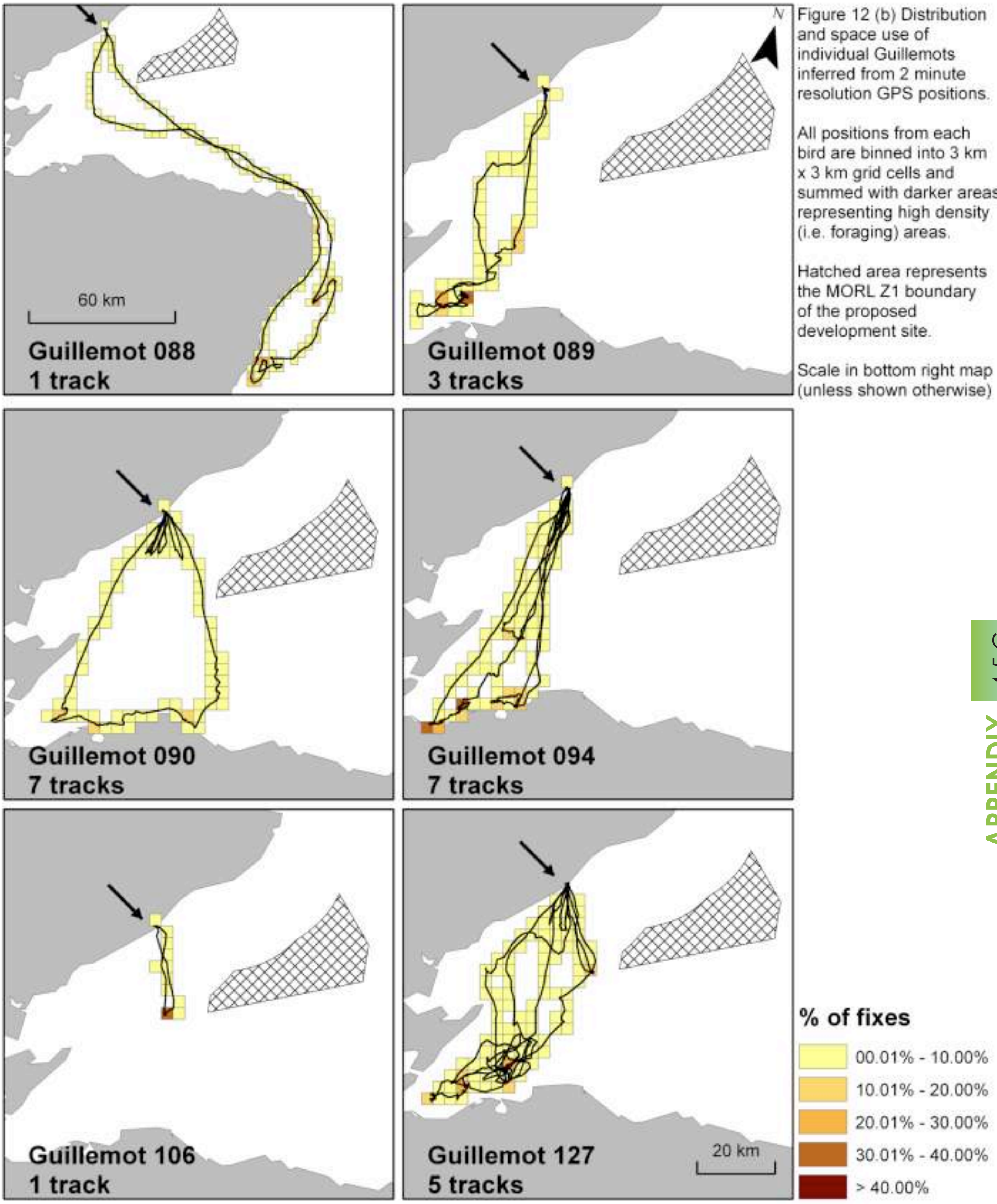

Figure 12 (b) Distribution and space use of individual Guillemots inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless shown otherwise)

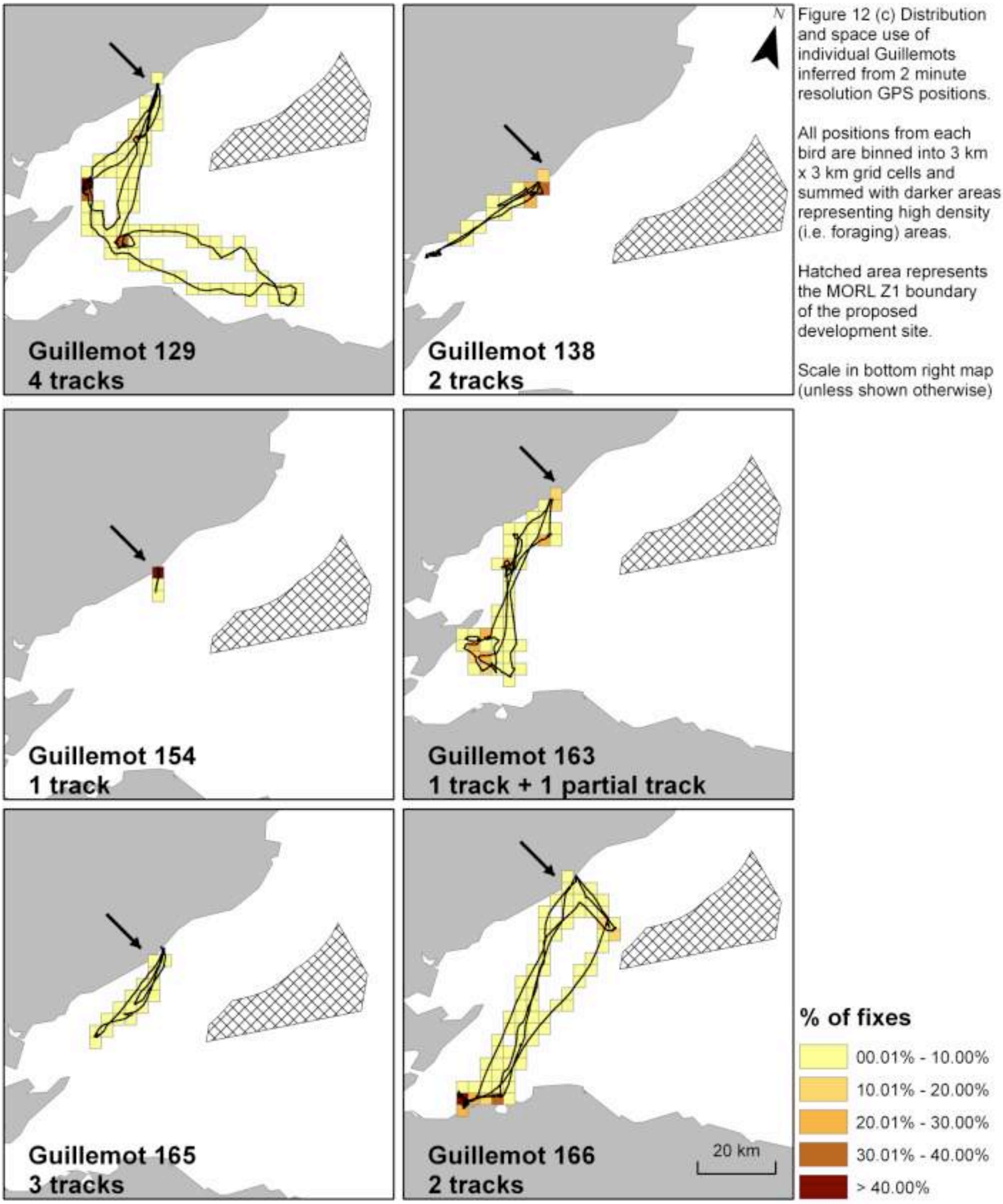

Figure 12 (c) Distribution and space use of individual Guillemots inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless shown otherwise)

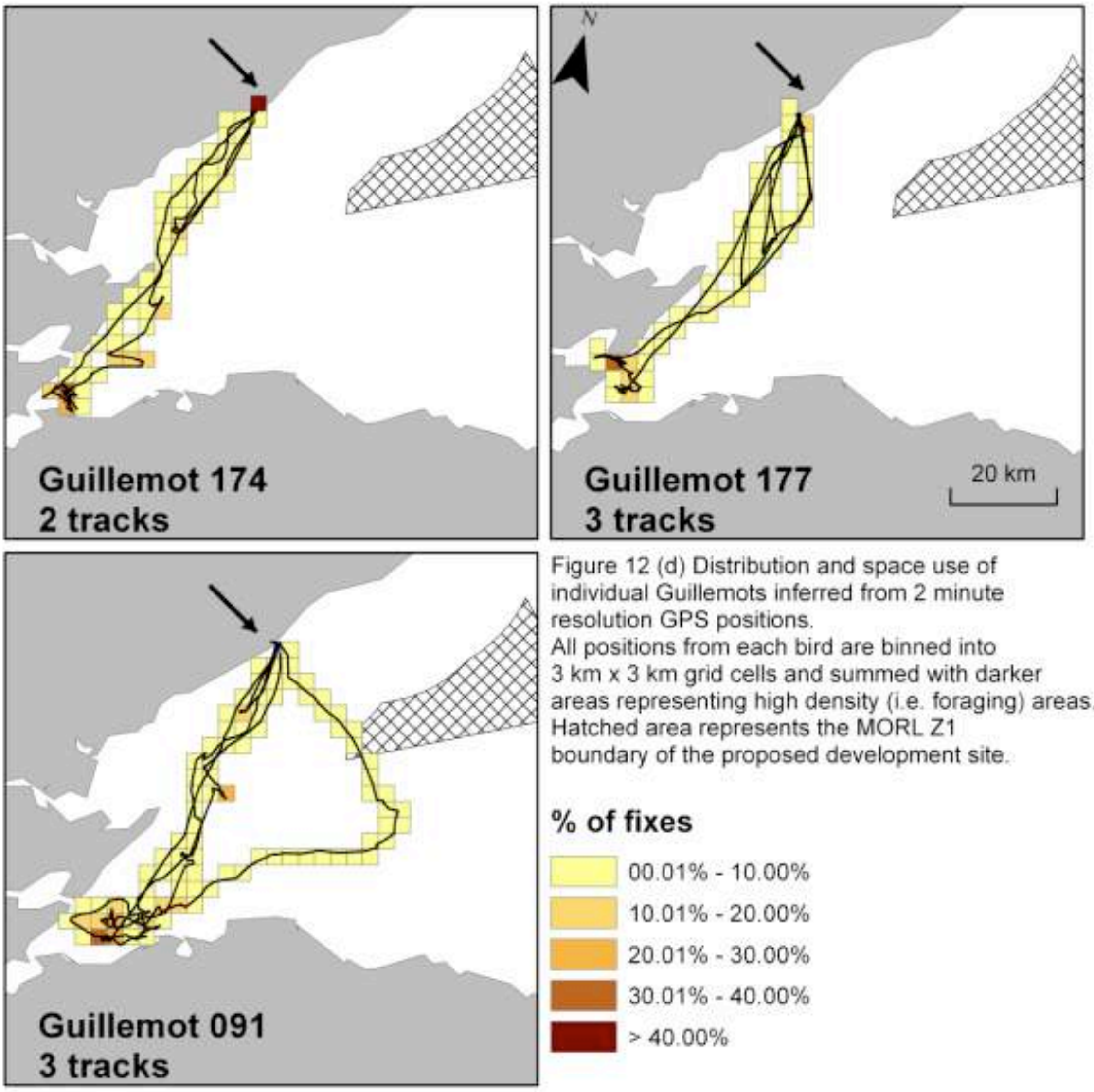

Figure 12 (d) Distribution and space use of individual Guillemots inferred from 2 minute resolution GPS positions. All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas. Hatched area represents the MORL Z1 boundary of the proposed development site.

APPENDIX 4.5 C

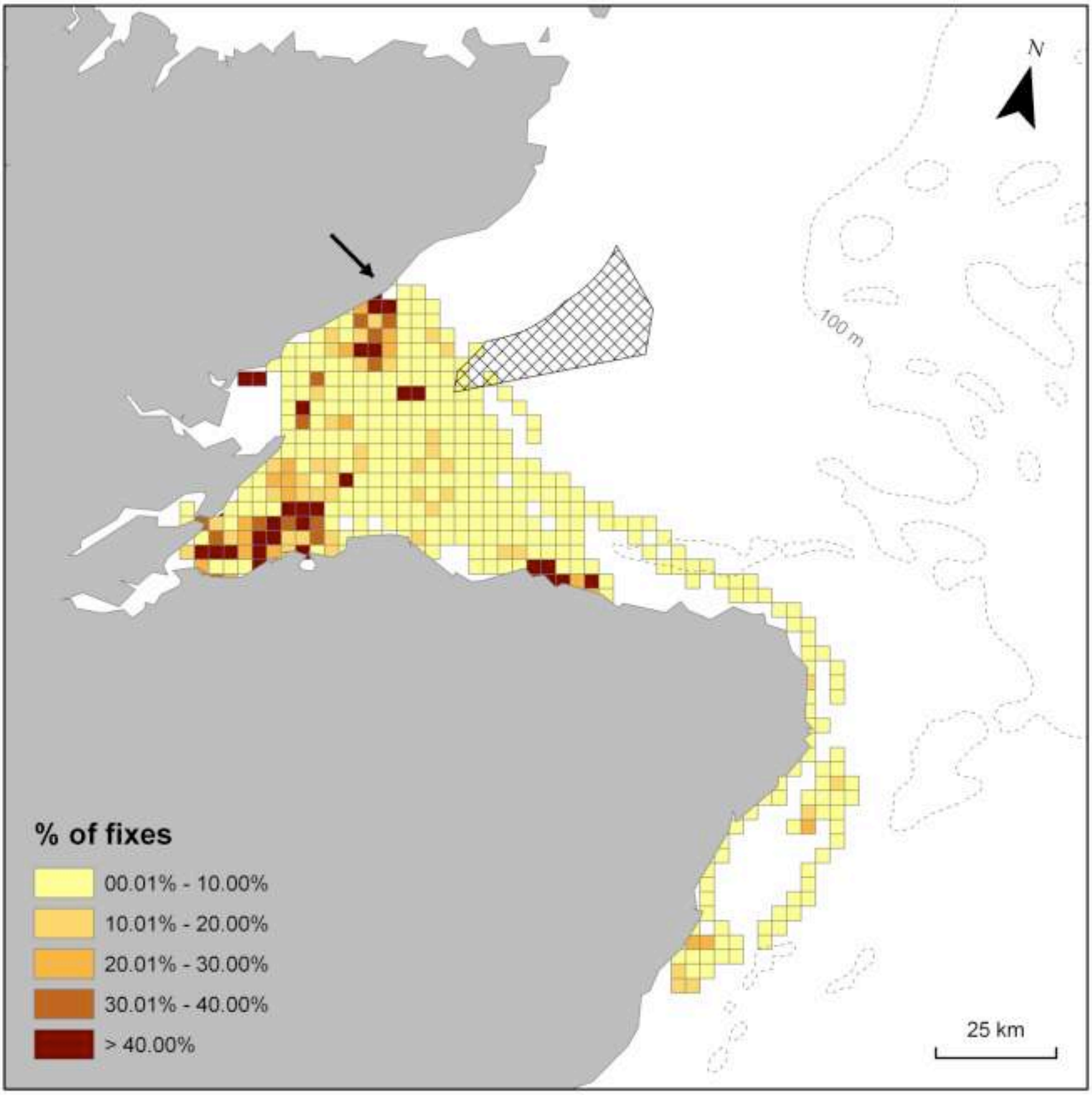

Figure 13. Distribution and space use of all Guillemots (n=20 individuals, n=62 foraging trips) inferred from 2-minute resolution GPS positions. Positions from all birds are binned into 3 km x 3 km grid cells and summed with darker areas consistent with foraging activity.

<u>Kittiwake *Rissa tridactyla*:</u>

The mean duration of trips for Kittiwakes was 13.3 ± 8.2 h (range = 0.1 – 46.4 h, *n* = 28 trips from 15 birds), with a mean distance covered per trip of 128.8 ± 92.7 km (range = 1.4 – 478.4 km) and a mean foraging range of 41.9 ± 36.9 km (range = 1.1 – 119.6 km).

The majority of GPS tracks for kittiwakes showed long directed commuting flights followed by intensive searching at a restricted scale (Figures 14 & 15).

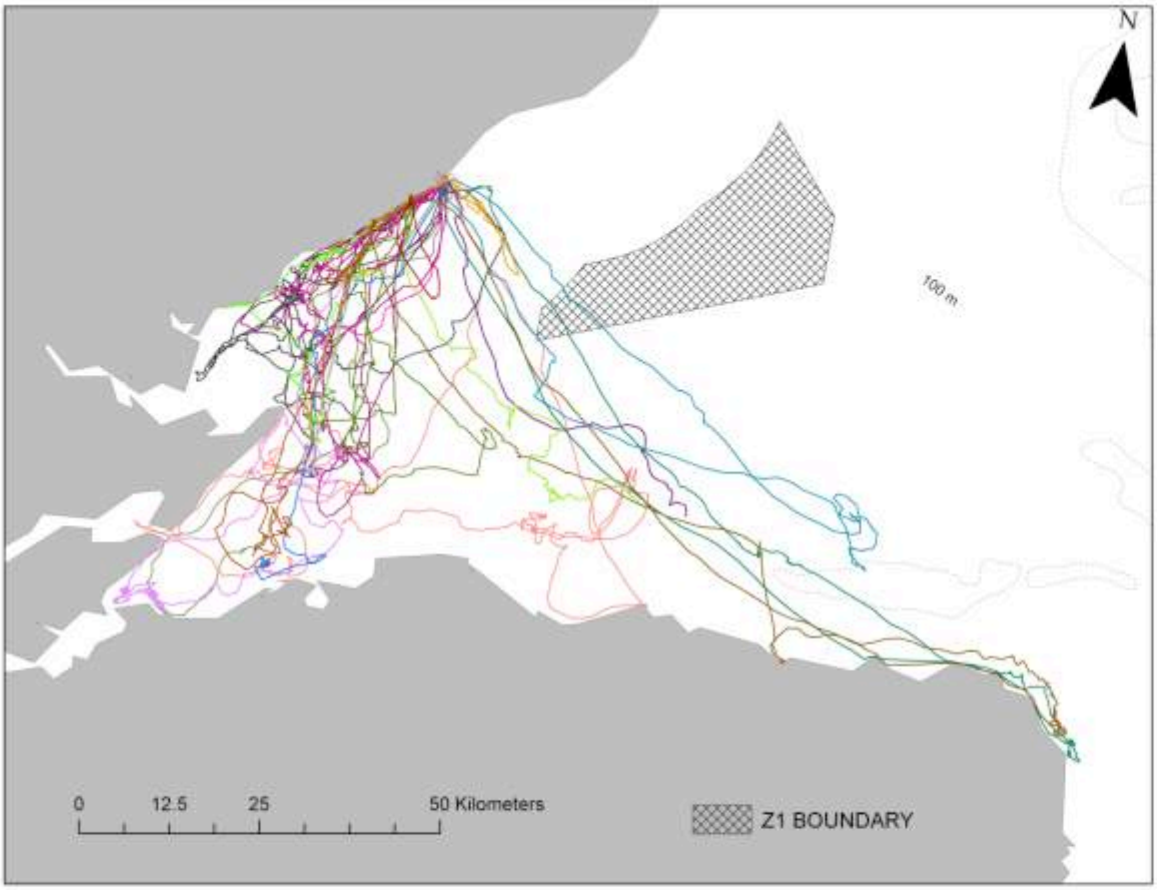

Figure 14. GPS tracks of Kittiwake foraging trips from colonies on the Sutherland/Caithness coast and their proximity to the proposed wind farm development (n=15 individuals, n=28 trips).

As with the razorbills and guillemots, all birds headed east or south of the colonies staying mainly within the Moray Firth (Figures 14 & 15). Two birds travelled to inshore waters close to Peterhead (Figure 15 b & c). No trips headed north or north-east and only two tracks passed through the proposed development area (Figure 15 b).

Multiple foraging tracks from the same individuals indicated a certain degree of repeatability (Fig. 15).

The GPS position binning for Kittiwakes was on a 3 x 3 km scale (taken from the highest log(FPT variance) from FPT analysis), with the darker grid cells in Figure 16 representing foraging areas. The highest density of foraging were generally found in inshore waters to the south and west of Helmsdale, with some foraging activity more widely spread in the south and east of the Moray Firth. No birds foraged in the proposed development.

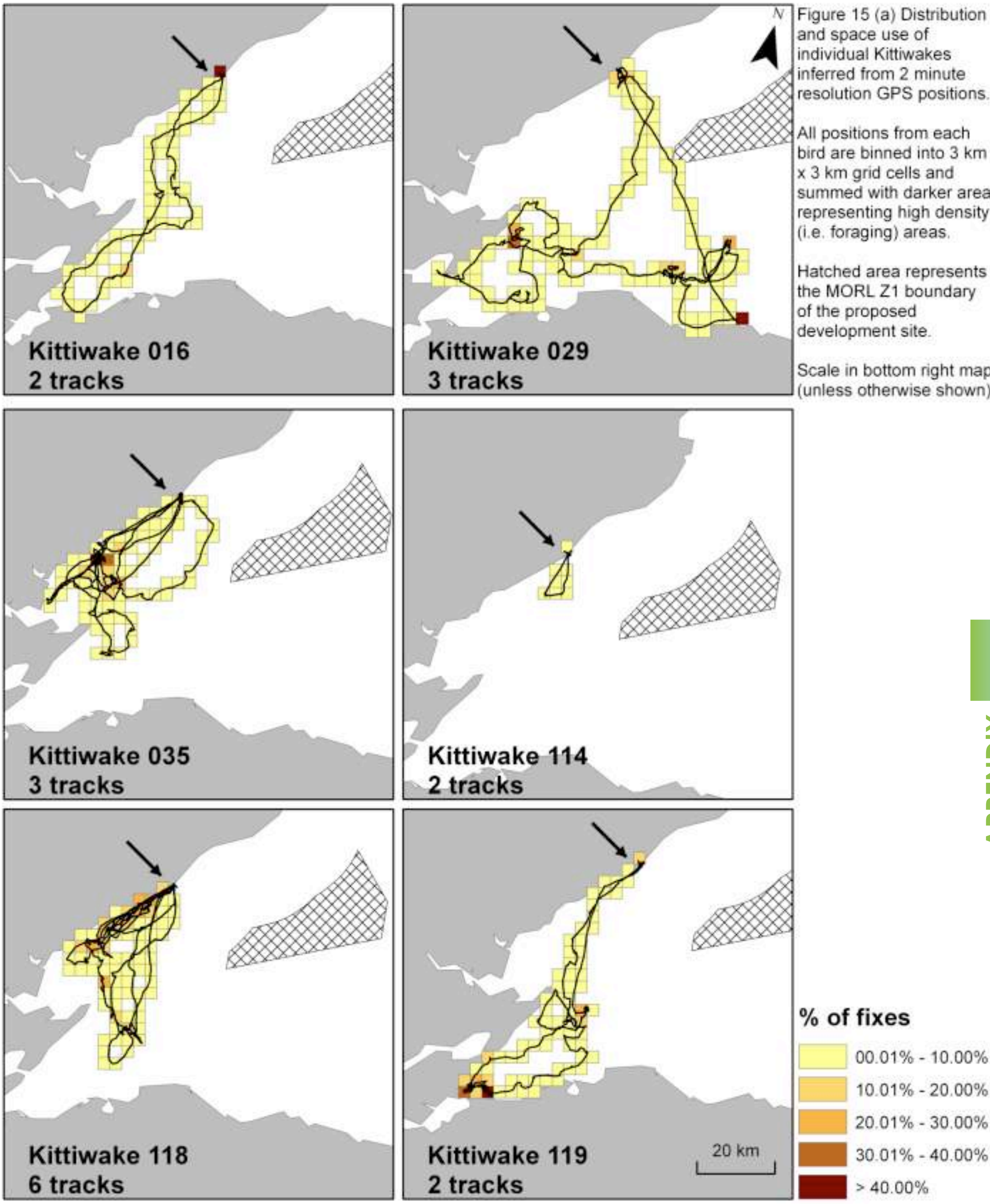

Figure 15 (a) Distribution and space use of individual Kittiwakes inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

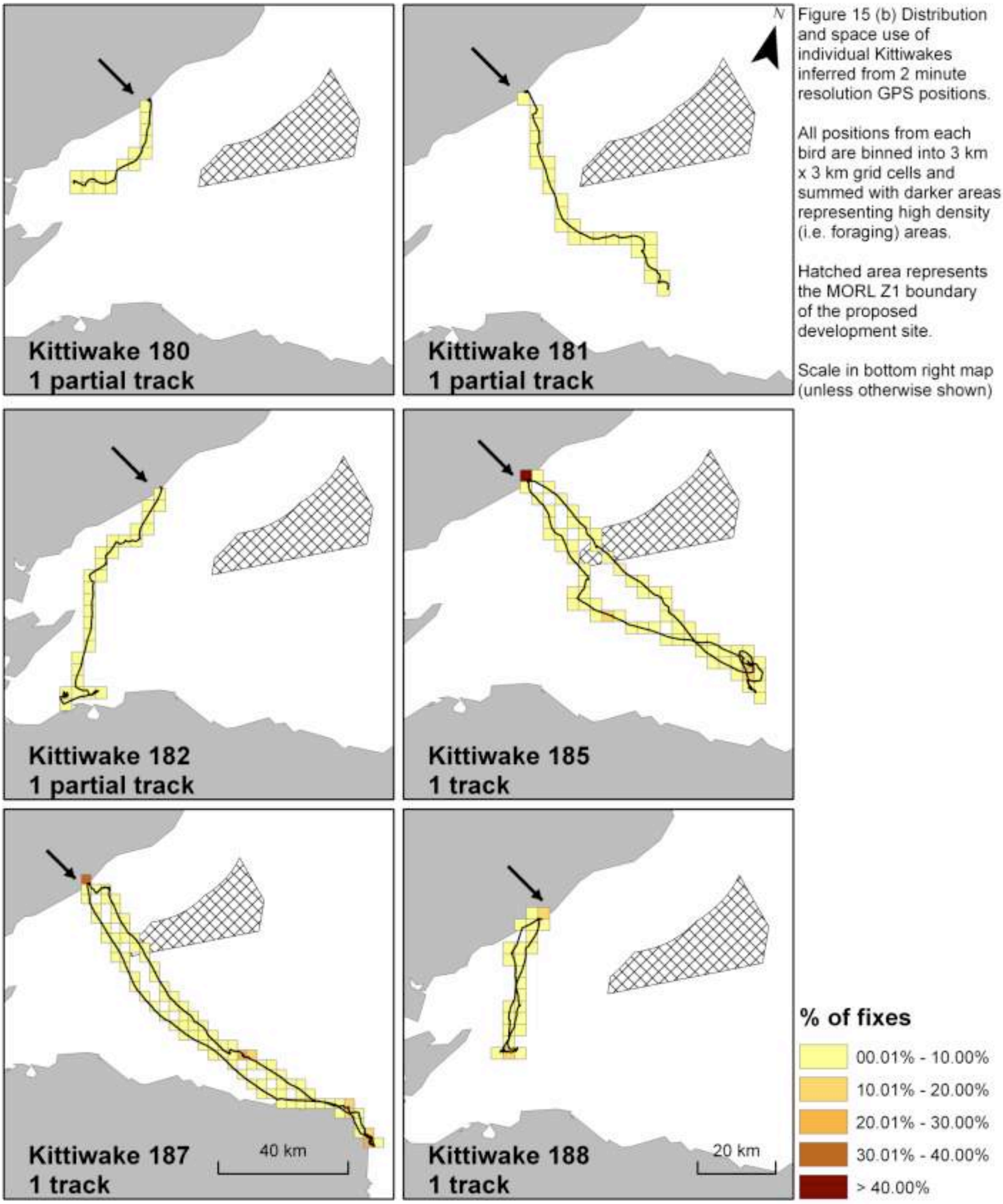

Figure 15 (b) Distribution and space use of individual Kittiwakes inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

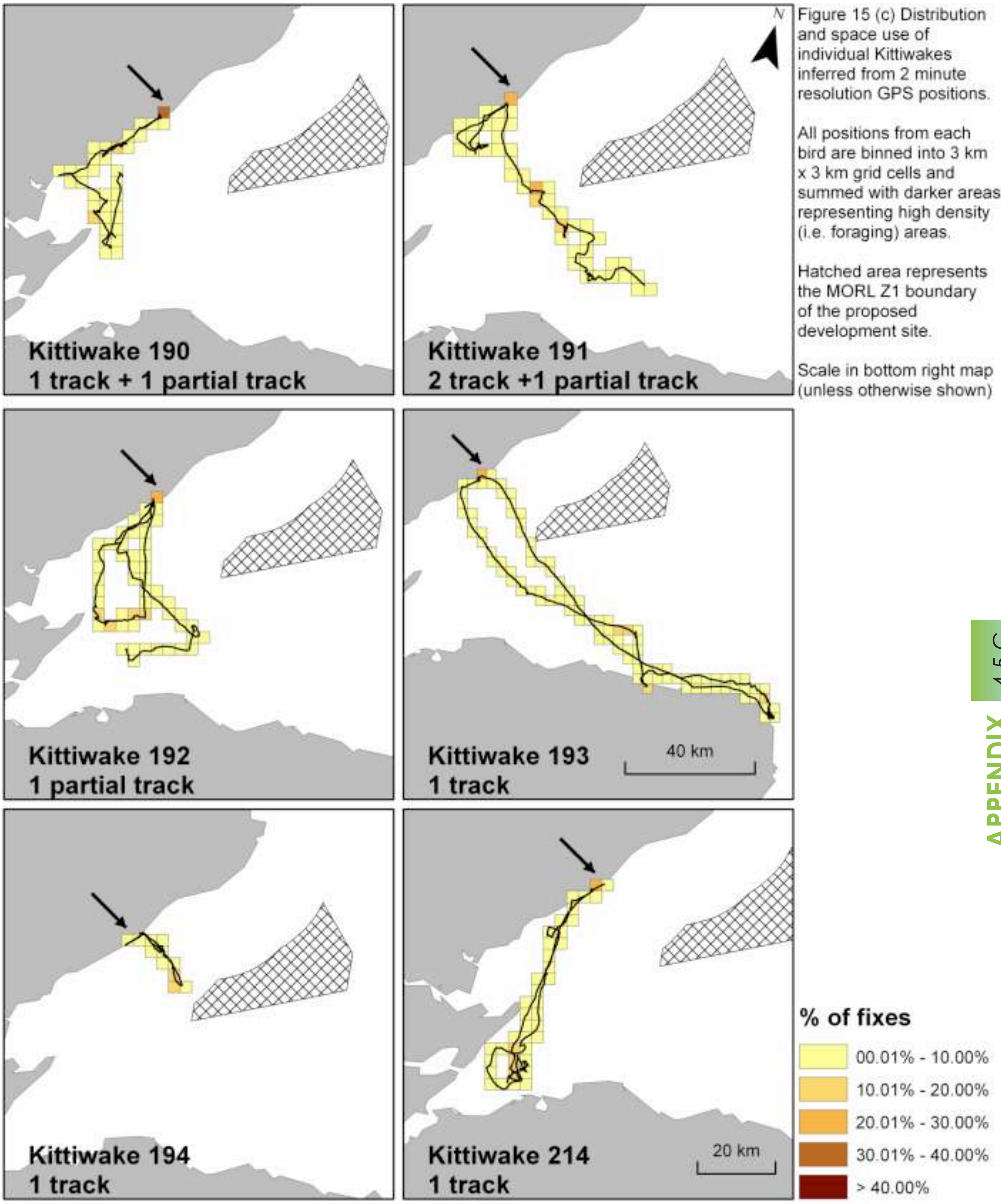

Figure 15 (c) Distribution and space use of individual Kittiwakes inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

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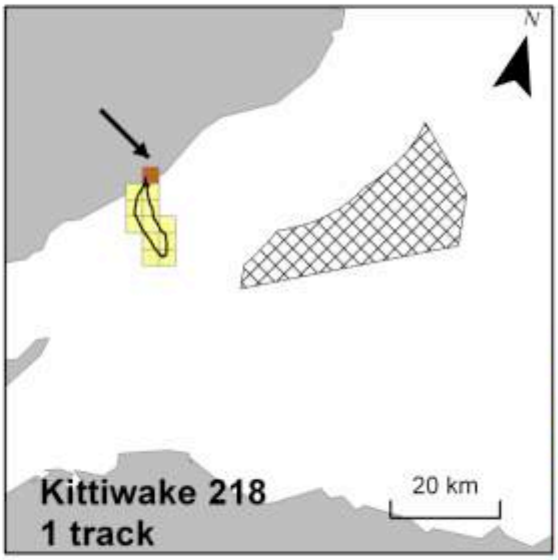

Figure 15 (d) Distribution and space use of an individual Kittiwake inferred from 2 minute resolution GPS positions. All positions are binned into 3 km x 3 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

% of fixes

- 00.01% - 10.00%
- 10.01% - 20.00%
- 20.01% - 30.00%
- 30.01% - 40.00%
- > 40.00%

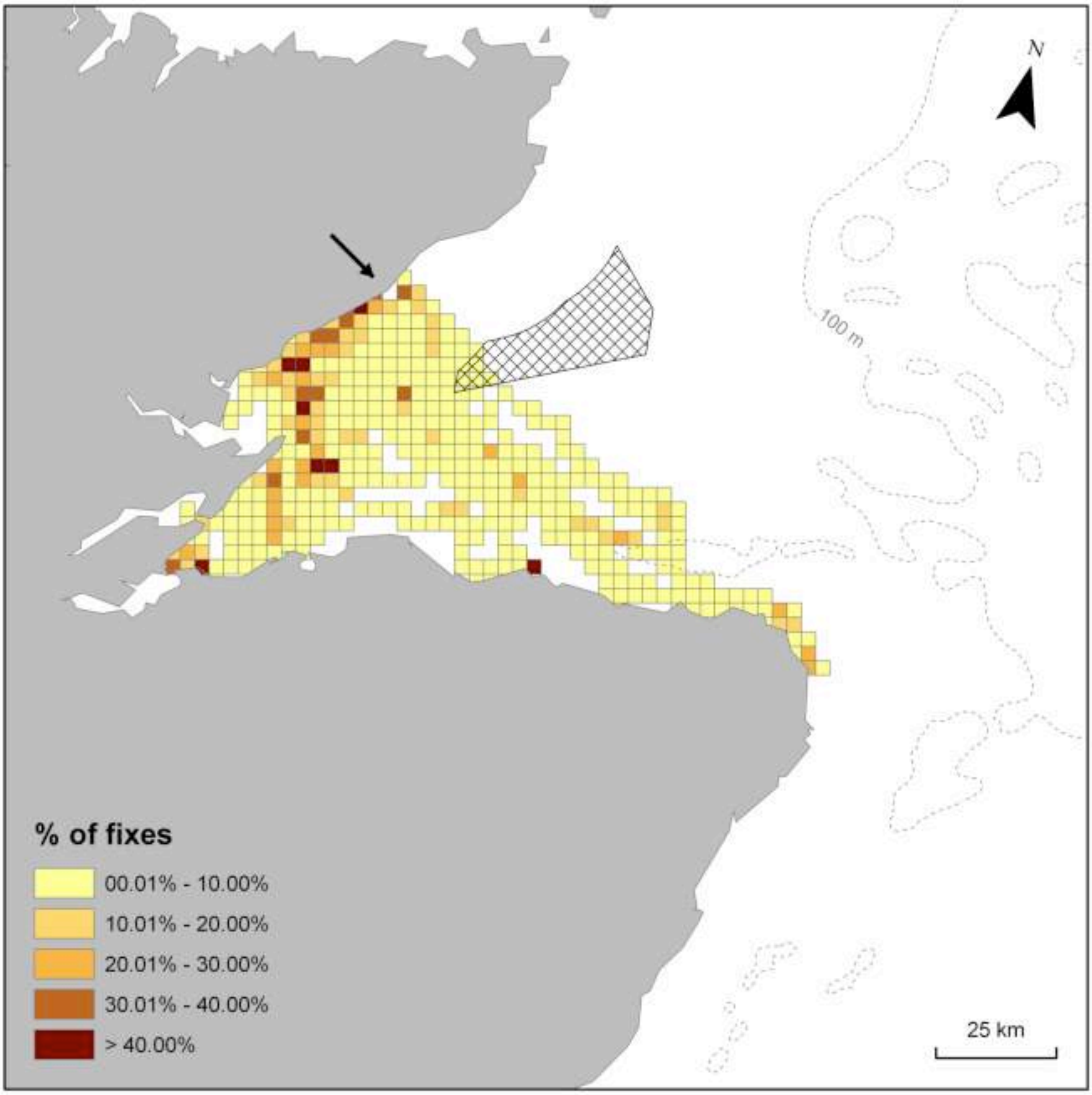

Figure 16. Distribution and space use of all Kittiwakes inferred from 2-minute resolution GPS positions. Positions from all birds are binned into 3 km x 3 km grid cells and summed with darker areas representing high density areas (n=15 individuals, n=28 trips).

Fulmar *Fulmarus glacialis*:

The mean duration of trips for Fulmars was 12.6 $\pm$ 13.9 h (range = 0.4 – 51.6 h, n = 28 trips from 15 birds), with a mean distance covered per trip of 133.4 $\pm$ 176.9 km (range = 0.9 – 683.4 km) and a mean foraging range of 47.4 $\pm$ 59.5 km (range = 1.2 – 218 km).

The majority of GPS tracks for fulmars showed long directed commuting flights followed by intensive searching at a restricted scale (Figures 17 & 18).

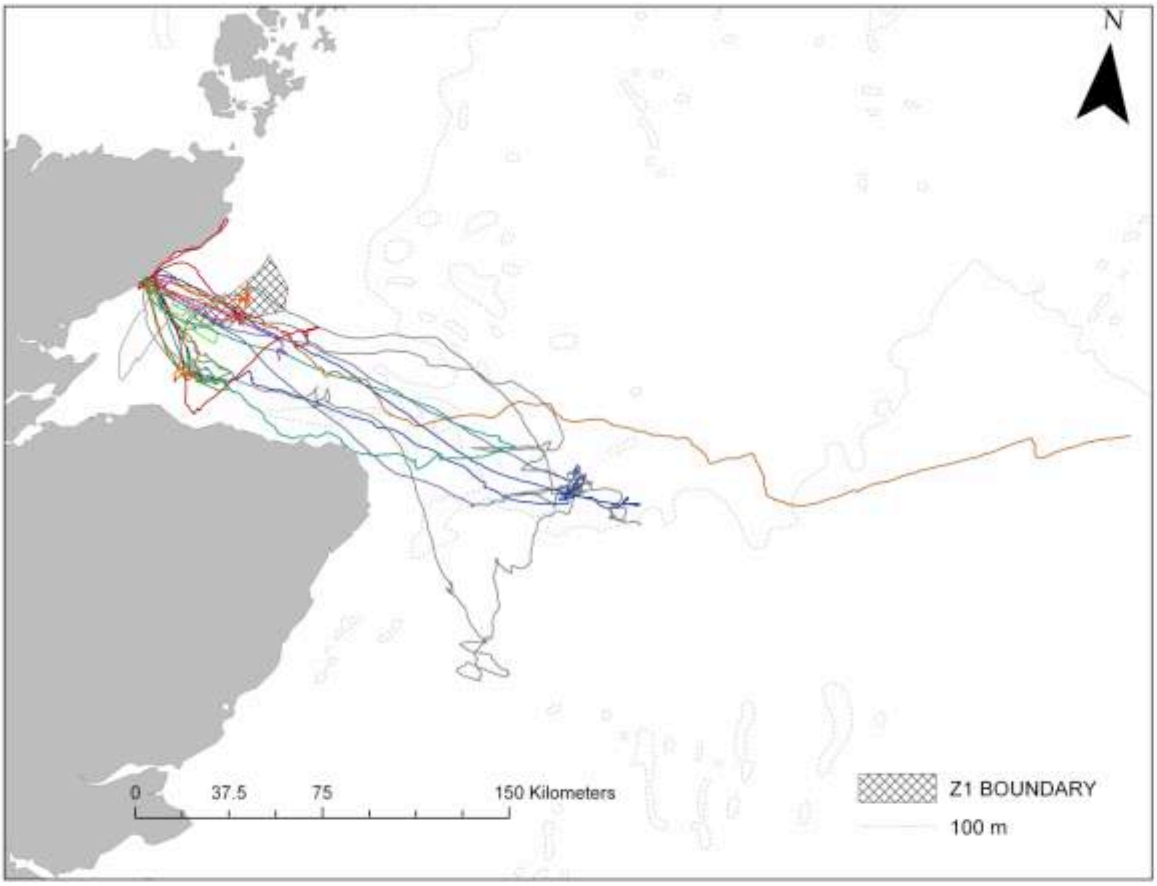

Figure 17. GPS tracks of Fulmars trips from colonies on the Sutherland/Caithness coast and their proximity to the proposed wind farm development (n=15 individuals, n=28 trips).

The majority of birds headed east of the colonies to within the Moray Firth or further into the North Sea (Figures 17 & 18), and on one occasion a partial track detailed movement across the sea towards Norway (Figure 18c). Thirteen of the trips passed through the proposed development area, and two birds spent time within the Z1 area (Figure 18 a & b).

Multiple foraging tracks from the same individual suggest a certain degree of site fidelity, although there were a number of tracks of greatly varying length and also some individuals that showed low levels or track repeatability (Fig. 18).

The GPS position binning for fulmars was on a 7 x 7 km scale (taken from the highest log(FPT variance) from FPT analysis), with the darker grid cells in Figures 19 representing foraging areas. There are 4 main foraging: Inshore close to the colonies, within the ZI boundary, north of Lossiemouth and approximately 75 kilometres northeast of Peterhead, in the North Sea (Figure 19).

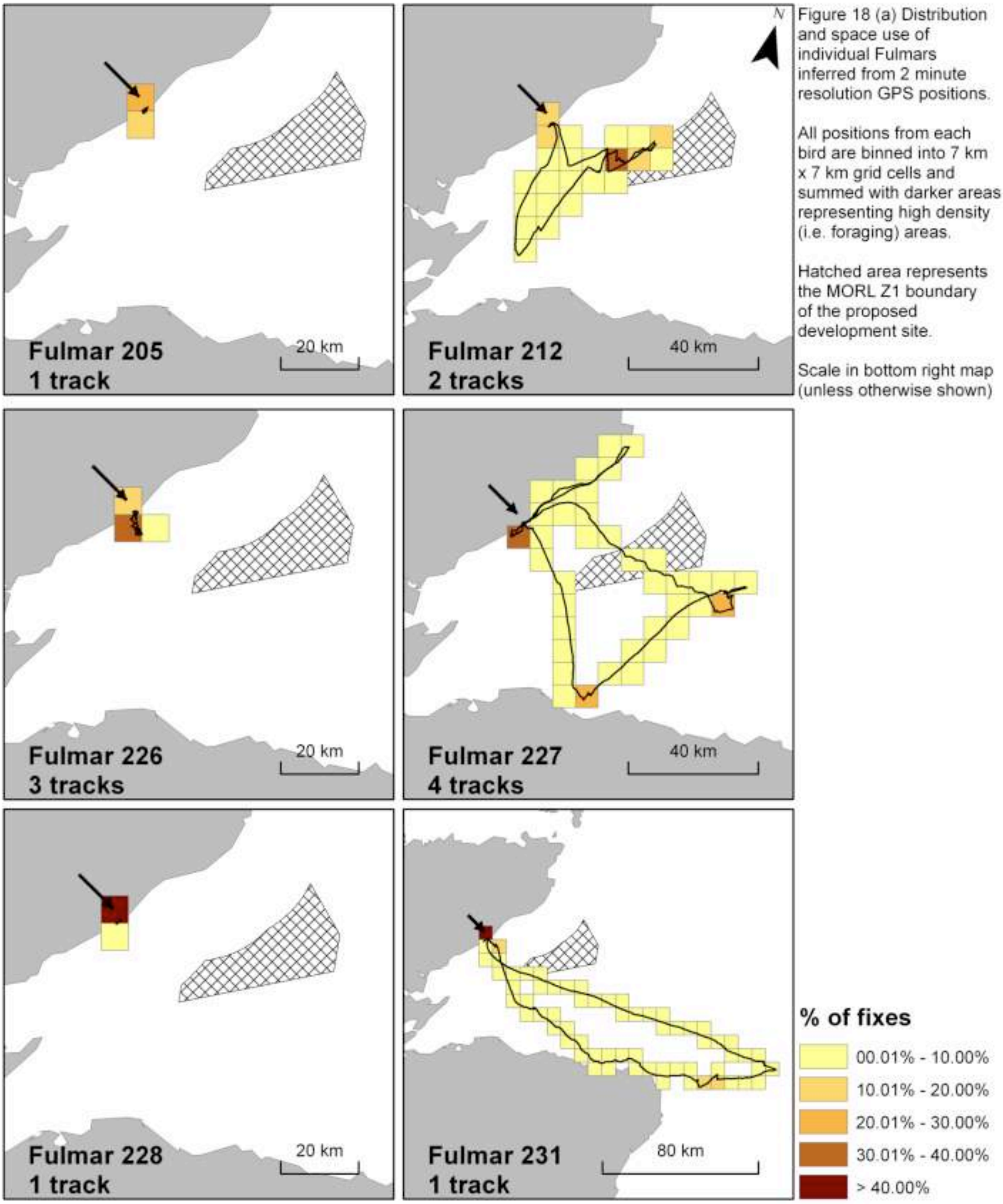

Figure 18 (a) Distribution and space use of individual Fulmars inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 7 km x 7 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

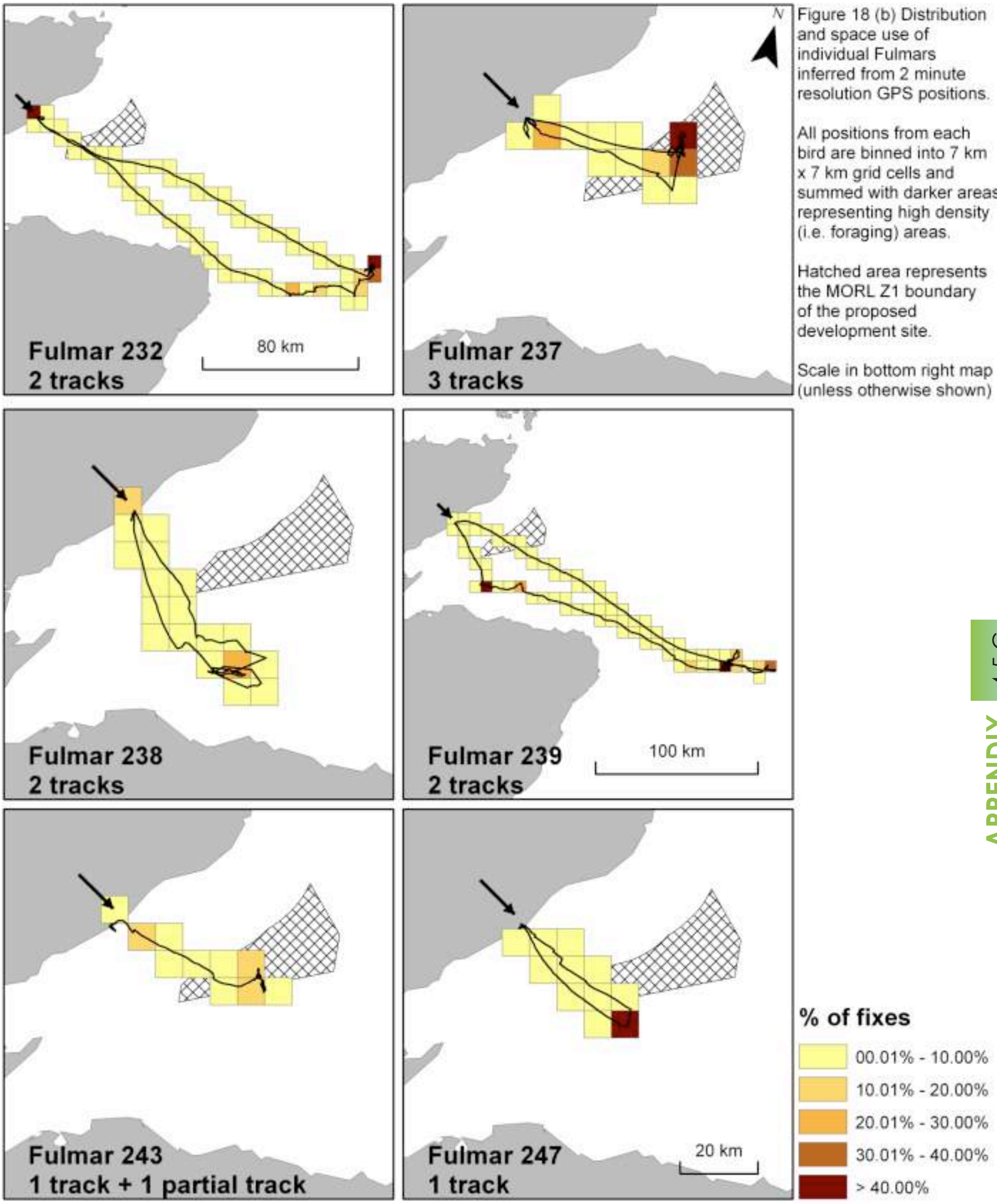

Figure 18 (b) Distribution and space use of individual Fulmars inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 7 km x 7 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in bottom right map (unless otherwise shown)

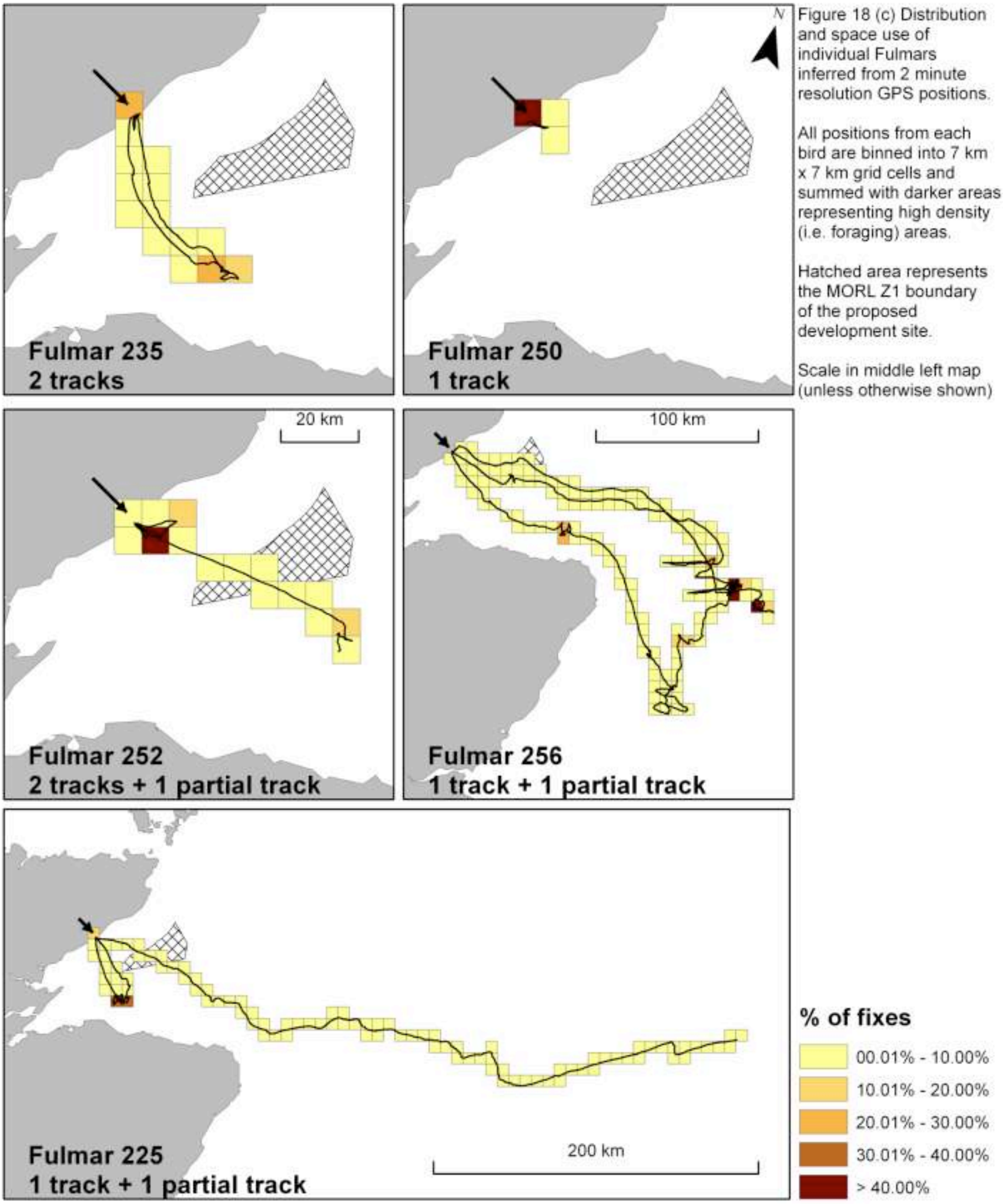

Figure 18 (c) Distribution and space use of individual Fulmars inferred from 2 minute resolution GPS positions.

All positions from each bird are binned into 7 km x 7 km grid cells and summed with darker areas representing high density (i.e. foraging) areas.

Hatched area represents the MORL Z1 boundary of the proposed development site.

Scale in middle left map (unless otherwise shown)

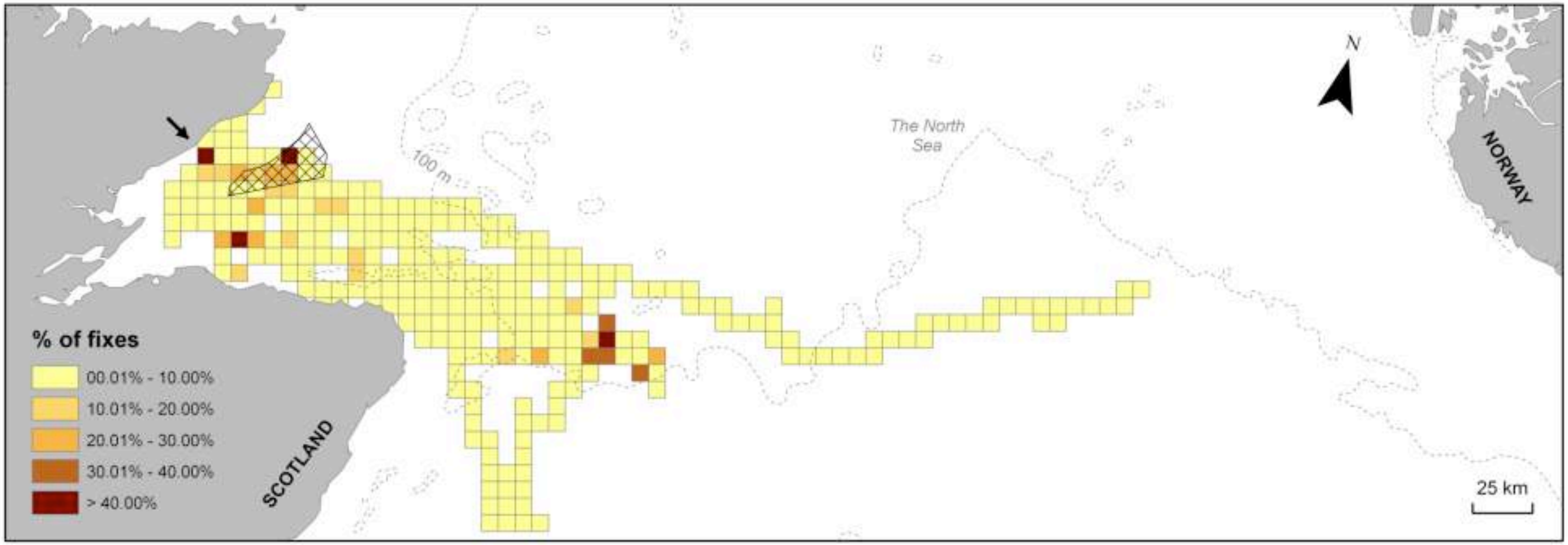

Figure 19. Distribution and space use of all Kittiwakes inferred from 2-minute resolution GPS positions. Positions from all birds are binned into 3 km x 3 km grid cells and summed with darker areas representing high-density areas (n=15 individuals, n=28 trips).

DISCUSSION

Here we have provided details of the at-sea distribution and foraging behaviour of four species of cliff-nesting seabird (breeding along the East Caithness Cliffs between Helmsdale and Dunbeath. Using GPS loggers we have tracked centrally placed movements and using a combination of FPT and by binning GPS fixes identified areas that most likely represent foraging zones.

Device effects

It seems clear from this work that the attachment of GPS loggers had some deleterious effects for at least some of the species. Re-sighting rates of ~50% for kittiwakes and guillemots and ~40% for fulmars suggest nest abandonment or at least prolonged periods of absenteeism, which is not typical. There is a possibility that these birds were simply undertaking very long foraging trips followed by short visits to the colony or that returning birds had lost their device and coloured dye, but this seems unlikely. Razorbills showed a re-sighting rate of 80%, suggesting that any levels of abandonment were low.

The differences among species are not easy to interpret however. The low body mass of kittiwakes (~450-700g) may be associated with the low return rate of this species and it was interesting to note a reduction of the device mass from 15g to 11g had a marked improvement on recovery rates (Table 1) suggesting that the device to body mass ratio is relevant. However despite the relatively similar body mass of razorbill (~500-900g) compared with guillemot (~500-900g) and fulmar (~600-1000g), razorbills showed much higher recovery rates suggesting that body mass alone is not necessarily a good indication of potential device effects.

A key issue here is whether the foraging data gathered he provides a representative characterisation of the foraging behaviour of these three species. This is a key question in the field of bio-logging that has not currently been satisfactorily been addressed. The key issue here is that currently we cannot track free-living animals without using devices so it is not possible to provide a control.

At-sea behaviour in relation to the Round 3 Zone 1 Offshore Wind Farm development

With respect to the Z1 proposed wind farm development, guillemots, razorbills and kittiwakes tended not to use this area during the tracking period; instead all three species showed quite similar tactics foraging around mainly inshore waters and none were found foraging in development area. Small numbers of guillemots and kittiwakes commuted through the proposed site between foraging locations and the breeding colony. Despite the evidence that the proposed site is not important a foraging or commuting grounds for these three seabird species, we cannot exclude the possibility that these areas are used at other times of the reproductive cycle. Because of recapture constraints, tracking was confined to late incubation and early chick rearing. Intra-seasonal variation in seabird foraging behaviour arises because of the conflicting needs of the parent and offshore and foraging trips send to be shortest during the early brooding in some seabirds (Williams & Rothery 1990). Alternatively, variation in foraging tactics may arise as a function of short-term variation in the availability of prey resources (Erwin et al. 2007).

Fulmars foraged far more widely than the other three largely inshore species and also overlapped extensively with the proposed development site. 32% of the 28 tracks passed through the proposed site at some point and a further 10.7% of tracks showed intensive use of the proposed site consistent with foraging behaviour

(Fig. 19). Fulmars tend to forage offshore and also have a more generalist foraging behaviour compared with the highly piscivorous behaviour of guillemots, razorbills and kittiwakes and this may in part explain the differences in the way in which they foraged within the Moray Firth. It is not clear why some fulmars were foraging within the proposed site, but as a species attracted to vessels (Camphuysen & Garthe 1997), boat activity could act as an attractant.

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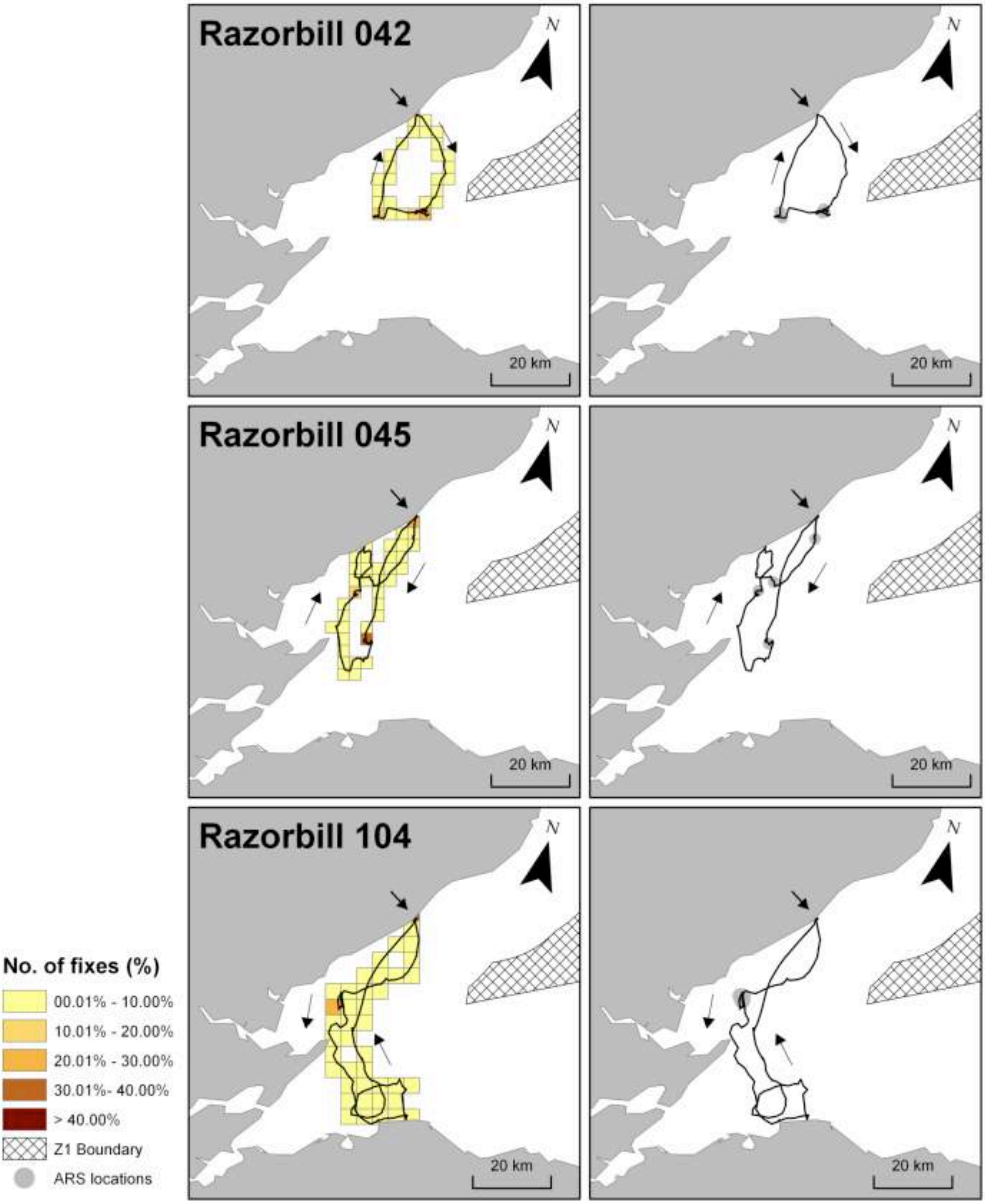
Appendix 1. GPS position binned into 3 x 3 km grid cells (left maps) and Area-restricted search (ARS) areas identified using first passage time analysis (right maps) for three Razorbill tracks. These data reveal that using gridded GPS data provides qualitatively similar results as using FPR to indentify ARS behaviours – brown and orange grids coincide with ARS.



SEABIRD MODELLING TECHNICAL REPORT (DRAFT)
10th October 2011

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APPENDIX 4.5 C

1. INTRODUCTION

Understanding how seabirds interact with the natural environment is vital to our understanding of how they may be impacted by anthropogenic changes, such as the installation of marine renewable energy developments.

Recent developments in bio-logging technology have seen an exponential increase in the use of miniaturised logging devices to study the fine scale movements and behaviour of free-living animals. In the context of the proposed Round 3 Zone 1 Offshore Wind Farm development in the Moray Firth, bio-logging has provided detail of the fine-scale movements of seabirds breeding at the colonies of the East Caithness cliffs (see previous report).

Nevertheless, these data only provide information from one season, and without understanding the mechanisms behind these movement patterns it is difficult to make informed decisions about seabird distributions in the future. Furthermore, these data stem from a limited number of colonies within the Moray Firth and it is important to consider seabird distributions at a wide scale.

In this report we investigate the distribution of seabirds within the whole of the Moray Firth seabird community by combining tracking data and modelling analyses to project potentially important areas for foraging and movement of 4 different species. We use information on the distribution and size of seabird colonies with species-specific foraging ranges, to project at-sea distribution. We also examine the relationship between the movement patterns of tracked birds and candidate environmental variables that may influence foraging behaviour. Based upon the findings of this analysis, we model habitat used based on these covariates.

2. METHODS

To understand the movement of seabirds we take a three stage approach. The first step is to track breeding individuals of known provenance and examine foraging behaviour. The second step uses information on the location and size of colonies in combination with information on the foraging range of each species to project colony-centred foraging radii. The final step combines these two approaches to predict the behaviour of seabirds breeding within the Moray Firth.

Seabird tracking

Deployment of GPS loggers

In May to July of 2011 we deployed miniaturised GPS loggers (iGotU, Mobile Action Technologies, Taiwan) on adult black-legged kittiwake *Rissa tridactyla*, common guillemot *Uria aalge*, razorbill *Alca torda*, and northern fulmar *Fulmarus glacialis* breeding at colonies on the cliffs of East Caithness between Helmsdale (58.115, -3.650) and Dunbeath (58.246, -3.425).

GPS loggers were removed from the manufacturers housing and waterproofed by sealing them in lightweight heat-shrink tubing prior to deployment, this reduced the total package size to circa 75 mm x 25 mm 12 mm (L x B x H) and weight to 17 g. Loggers were set to record a GPS fix every two minutes, providing an estimated battery life of 100 hours. For fulmars, devices were elongated to reduce the profile and aid dorsal attachment (110 mm x 25 mm x 8 mm). Birds were caught using an adjustable carbon fibre pole (maximum length 11 m) equipped with a noose made from fishing line (tensile strength of 60 – 100 lb). Loggers were attached to common guillemot, razorbill and northern fulmar dorsally, between the wings using 3 to 4 strips of Tesa ® cloth tape.

Attachment methods varied for kittiwakes, the initial tape attachment proved unsuccessful, as did wing harnesses. Tape attachment failed after 24 hours due to the fine structure of kittiwake mantle feathers. The most successful attachment method for kittiwakes was to reduce the package weight and tail-mount the devices. The standard 3.7 V 230 mAh battery was replaced with a lighter 2.5 g 3.7 V 90 mAh battery (http://www.micronradiocontrol.co.uk/) reducing the total package weight to 11 g. However, the reduced capacity limited battery life to approximately 30 hours. These lighter-weight devices were then attached under the tail to the base of the feathers using two translucent cable ties.

Track analysis

Following device retrieval, data was downloaded using the manufacturer's software (@trip PC). Individual movements were then reconstructed from GPS fixes and checked for location errors. To examine the movements of individuals away from the colony we split the data into trips, defined as the occurrence of more than one GPS fix at least one kilometre from the colony. Each "trip" from the colony therefore began and finished as the individual passed a 1 km buffer around the colony of capture.

Modelling seabird foraging habitats

Foraging metrics

To examine individual behaviour we used speed along each track as a proxy for foraging activity, with slow speeds indicating high searching or foraging behaviour and high speeds representing transiting behaviour (Votier et al. 2010). We calculated

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speed as the straight line distance travelled between the entry and exit points of a circle of set radius, divided by the time taken to travel between those two points. We determined speed at a spatial scale of 4 km to match the scale of our environmental covariates. The additional metric of track tortuosity was also calculated (total distance travelled between entry and exit points of the circle, divided by the straight line distance between the points) and was highly correlated with speed but was problematic to model due to its binomial distribution so was removed from further analysis.

Explanatory variables

We extracted monthly 4 km^2 resolution sea surface temperature (SST, °C) and chlorophyll *a* (CHL, mg m^{-3}) composites for the Moray Firth and North Sea (Figure 1) from the MODIS instrument on board the Aqua (EOS PM) satellite (http://oceancolor.gsfc.nasa.gov/). Information on depth, slope and sediment type within the Moray Firth were provided (under licence 2010/091I) by The British Geological Survey, using Seazone data from Edina Digimap (Figure 2). Environmental data were gridded at 4 km^2 resolution to match the spatial scale of the SST and CHL data. For fulmars, individuals spend large amounts of time outside the Moray Firth and are pelagic foragers; we do not use slope and sediment type as covariates in these models, and at this scale depth data was available at 1 km^2 resolution. Before running any analysis, all records with incomplete environmental information, e.g. where remote sensed data were not available owing to positions very close to shore, where removed from the datasets. This resulted in the elimination of 18% (mean) of all records across species.

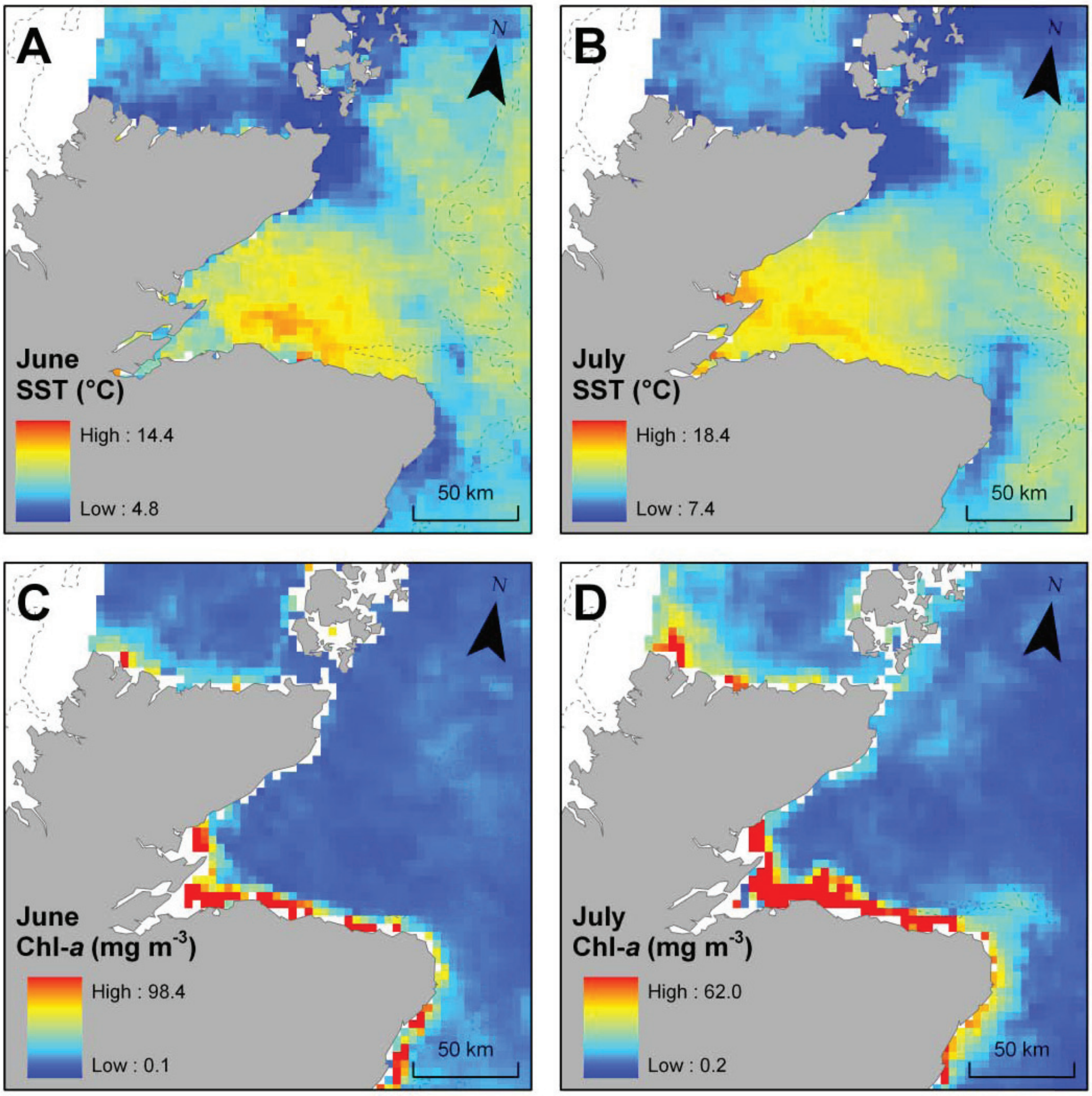

Figure 1 Monthly mean composite 4 km^2 sea surface temperature (A-B) and Chlorophyll-a (C-D) distribution in the Moray Firth during June (A & C) and July (B & D) 2011.

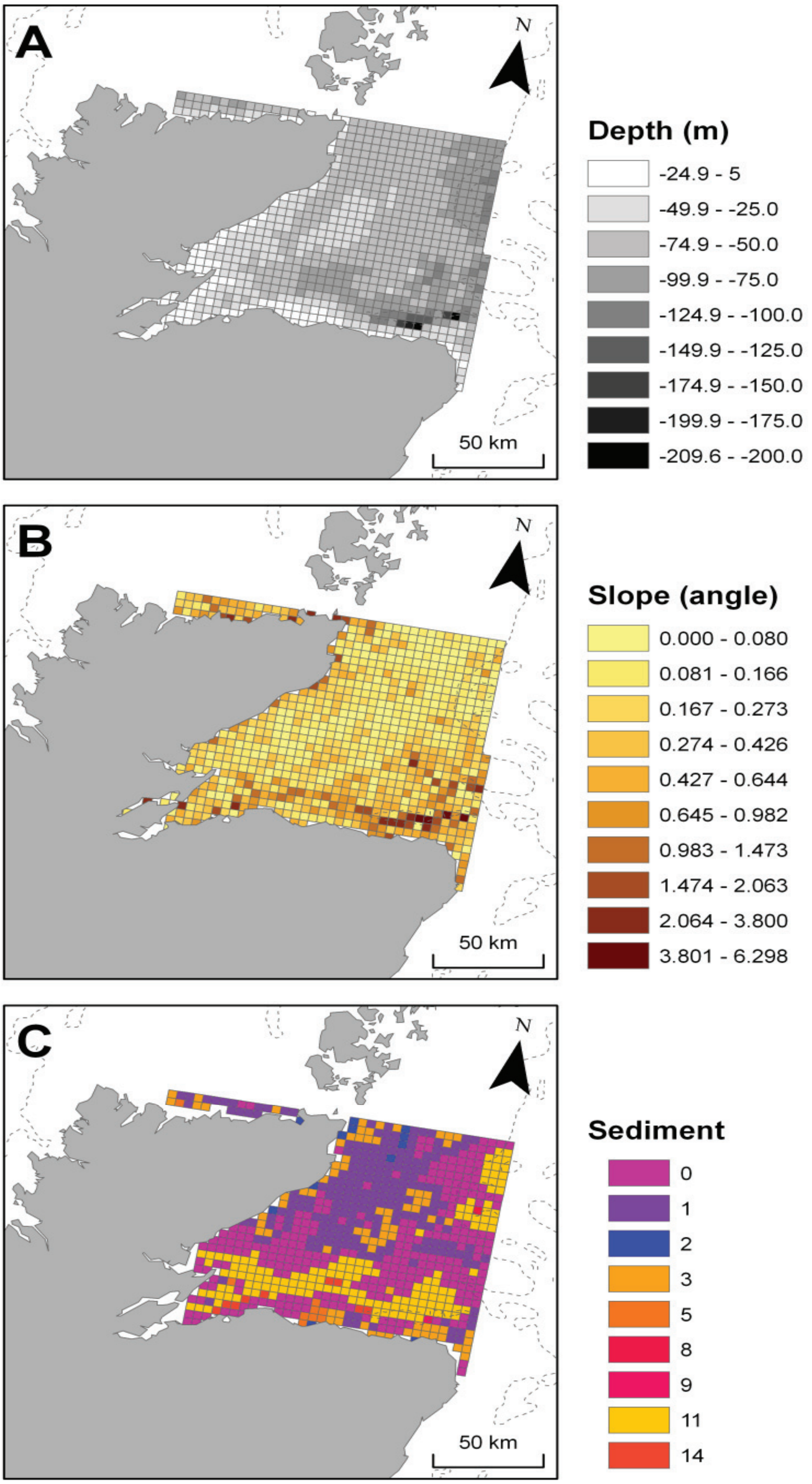

Figure 2 Describing the marine environment in the Moray Firth: sea depth (A), sea floor slope (B) and sea floor sediment type (C) at 4 km^2 resolution.

Modelling analysis

We determined factors influencing path speed using Generalised Linear Mixed Models (GLMMs) and the lme4 package in R 2.12.0 (R Development Core Team, Austria). We normalised speed by using log(speed) before using it as a response variable with Gaussian distribution, and nested track within individual bird as a random effect to account for repeated observations. We modelled SST, CHL, depth and slope as continuous fixed factors, and included sediment type as a 14 level factor. We took an information-theoretic approach to model selection, fitting all covariate combinations and ranking the candidate models by Akaike's Information Criteria (AIC). This was performed using the package 'MuMIn' and function 'dredge' in R 2.12.0. A manual model simplification process using ANOVA to assess the significance of each covariate once removed from the maximum model was also conducted to confirm the best-fitting model. To assess the variance explained by the best-fitting models, Nagerkerke values (Nagelkerke 1991) were calculated as an equivalent linear model r^2 values. Models with low Nagelkerke values were assumed to have little explanatory power and not used in any model predictions which included covariate estimates (see Table 2).

Model Projections

Projecting foraging radii from the colony

Information on the location of the East Caithness seabird colonies was taken from the Seabird 2000 dataset (Mitchell et al. 2004), and combined with maximum mean and maximum foraging radii estimated from the tracking data to construct colony-centred foraging radii for each colony and species. This was then overlaid upon a high resolution digital elevation model (TerrainBase, National Geophysical Data Centre) to derive the total available area of marine habitat, and exclude any areas of land within range of the colony. The density of breeding adults was calculated from the colony size and area of available marine habitat, to give an estimate of colony-specific foraging effort (birds km^{-2}). This process was repeated for each colony and summed to give a total population distribution estimate. Near-colony areas are important for maintenance behaviours (Wilson et al. 2009), and central-place foragers also spend large proportions of time transiting between the colony and diffuse foraging sites; therefore bird density decreases with increasing distance from the colony, and studies of gannets have suggested this decline takes a log or exponential form (Garthe et al. 2011; McSorley et al. 2003). To incorporate this behaviour, we multiplied the number of pairs within a given cell by the inverse scaled log distance from the focal colony. This weighted the waters in close proximity to the colony to be of relatively higher importance due to transiting and maintenance behaviours, thus creating hotspots around a colony. However, it is unlikely in all cases that these are also important foraging locations (Grémillet et al. 2006).

Predicting foraging habitats using GLMM covariates

To predict the distribution of seabirds within the Moray Firth, we also extracted the covariate slopes from the best models of speed for razorbills, guillemots and kittiwakes. These were used to predict the speed response (km/h) of each species to the environmental covariates across the Moray Firth. All analyses were carried out in ArcGIS 9.3 and 10 (ESRI, USA), MATLAB R2009b (The Mathworks, USA), and R 2.11.1 (R Development Core Team, Austria).

3. RESULTS

Tracking

There was a low rate of device recovery for the kittiwakes, guillemots and fulmars (Table 1). For kittiwakes, this was attributed to a combination of a low re-sighting rate of the tagged birds and a high level of device loss. Those devices mounted dorsally on kittiwakes were preened vigorously. However, when the package weight was reduced by using a lighter battery and the logger was mounted on the tail, far fewer birds preened the area of device attachment. This preening action may have accounted for the high level of device loss. Nevertheless, the re-sighting rate for tagged kittiwakes was only 50%, and so it is likely that device deployment may have overly impacted the birds and lead to nest abandonment. The low device retrieval rate for fulmars was due to a low re-sighting rate of tagged birds rather than from loss of devices. We attribute this to a combination of the low breeding success rate of fulmars in the 2011 season, potentially exacerbated by tagging effects or disturbance. The low device retrieval rate for guillemots can be attributed the difficulties involved in resighting individuals within busy colonies, and the disturbance involved in retrieving birds. Nevertheless, tag effects cannot be excluded.

The foraging statistics from the tracking data are summarised in Table 2 and detail the maximum mean and maximum foraging ranges (including partial trips) incorporated in the second stage model projections using foraging radii from colonies.

Modelling

The best-fitting models identified by ranked AIC for razorbills, guillemots and kittiwakes all included CHL, SST and sediment type, and had Nagelkerke values that suggest an important proportion of the variation is explained by the models (Table 3, Appendix 1). However, the best-fitting model for Fulmars, including all covariates, had a low Nagelkerke value suggesting low explanatory power and, therefore, was not used in projections using model covariates. Model simplification using ANOVA identified the same best-fitting models for all species.

Table 1 Number of GPS devices deployed, retrieved, trip data available and approximate re-sighting and device loss rates for four species of seabird tracked from the East Caithness Cliffs.

Species	Tags deployed	Tags retrieved	Tags containing trip data	Total trips	Approx. target bird re-sighting rate (%)	Tags seen lost from target birds (%)
Kittiwake	77	25	19*	34	~50%	>60%**(mantle) <1% (tail-mount)
Guillemot	92	26	20	63	~50%	<5%
Razorbill	31	20	18	60	>80%	<1%
Fulmar	48	17	15	32	~40%	<1%
Totals	**248**	**87**	**72**	**189**	**-**	**-**

*The smaller batteries (3.7 volt 90 mAh) have reduced battery life and so only provide partial trips (90mAh ~ 30 hrs vs. 230 mAh ~ 100 hrs). **The majority of mantle mounted devices retrieved from kittiwakes did not contain long foraging trips, indicating these birds either stayed on their nest or performed short bathing trips.

Table 2 Summary statistics for devices retrieved from fulmars, guillemots, kittiwakes and razorbills with foraging trip data. Some devices recorded only partial track information and the results from these are included for completeness. This information was also used to inform the projection model.

Species:	No. indiv:	Description:	No. trips:	Mean (km):	Std. (km):	Min (km):	Max (km):
Fulmar	15	Complete trips	28	47.360	59.512	1.202	218.453
Fulmar	15	Trips (incl. partial)	32	59.828	73.867	1.202	402.195
Guillemot	21	Complete trips	61	40.183	32.095	1.110	155.970
Guillemot	21	Trips (incl. partial)	63	39.826	31.826	1.110	155.970
Kittiwake	19	Complete trips	28	41.940	36.913	1.060	119.638
Kittiwake	19	Trips (incl. partial)	34	44.621	32.647	1.060	119.638
Razorbill	18	Complete trips	59	30.065	11.585	1.327	63.877
Razorbill	18	Trips (incl. partial)	61	33.234	17.131	1.327	137.253

Table 3 Best-fitting models (GLMM) for each seabird species and the associated Nagelkerke values. All models had track number nested in bird ID as a random effect. Full models included 5 covariates, except fulmars which had 3 covariates.

Species	**Best-fitting model**	**Nagelkerke (pseudo r^2)**	**Projected with covariate estimates**
Razorbill	CHL + SST + slope + sediment	0.39	Yes
Guillemot	CHL + SST + depth + slope + sediment	0.83	Yes
Kittiwake	CHL + SST + depth + sediment	0.61	Yes
Fulmar	CHL + SST + depth	0.14	No
Random terms : 1|birdID/track			

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Model Projections

Projecting foraging radii from the colony

The maximum mean foraging radii model projections for species in the Moray Firth (Figure 3) show separate high-density foraging/transiting areas off the East Caithness and Aberdeenshire coast for razorbills, guillemots and kittiwakes. High mean maximum range and few fulmar colonies on the south coast result in a larger predicted high-density zone off the Caithness coast for this species. When maximum range is included in these models the high-density areas cover the Moray Firth for all species and spans a large part of the North Sea for fulmars.

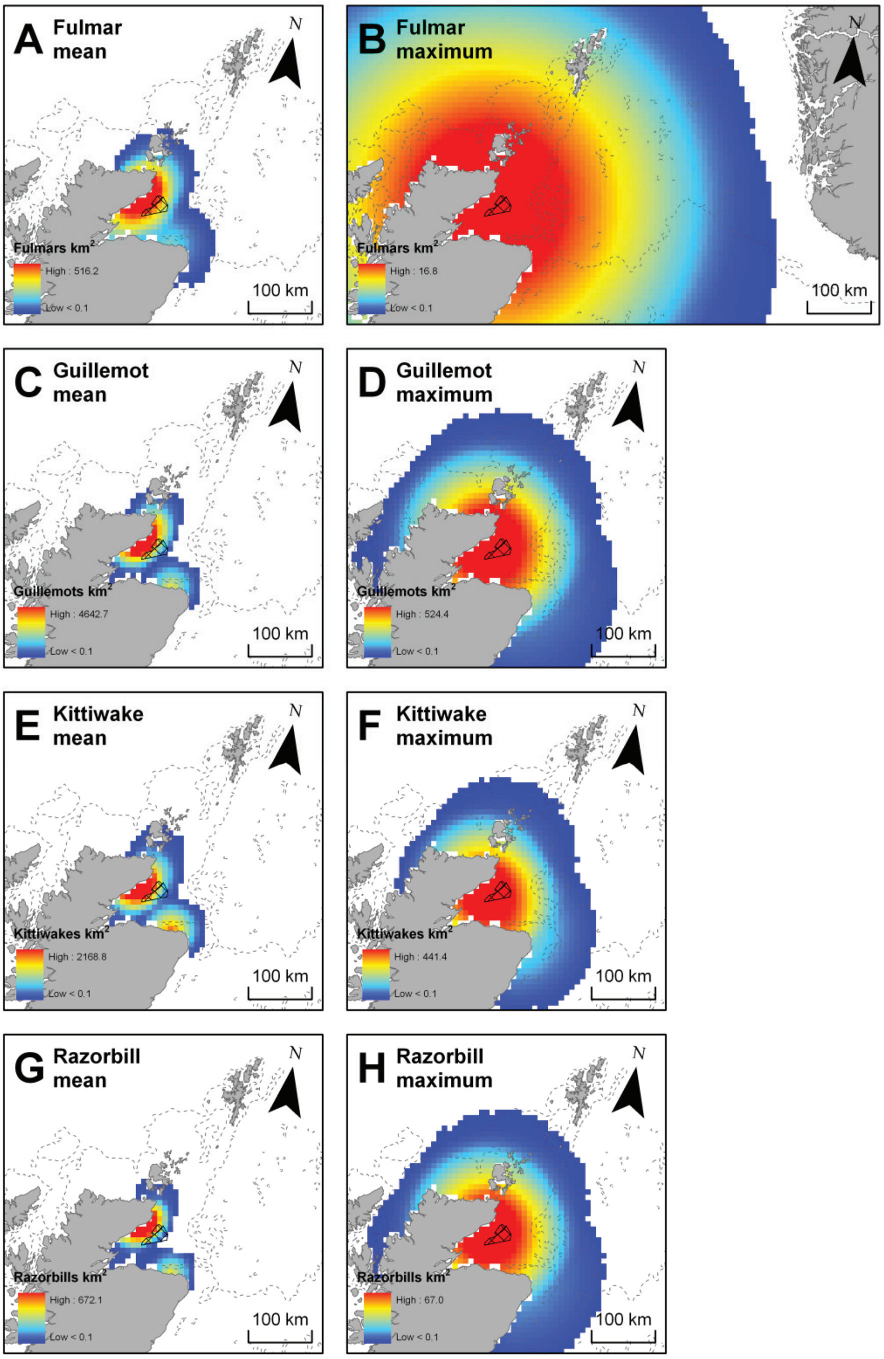

Figure 3 The distribution of four species of breeding seabird (individuals per km^2) in the Moray Firth predicted using a colony projection model (see Methods). Projections are shown using both the mean population maximum foraging distance (A, C, E, G), and the absolute maximum distance logged by an individual (B, D, F, H). The location of the BOWL and MORL sites is indicated by the hatched area.

Predicting foraging habitats using GLMM covariates

The projections that incorporate environmental covariate slopes from the best-fitting models produce maps (Figure 4) that predict similar areas of slow speed (high foraging), in the south and south-west of the Moray Firth, for both razorbills and kittiwakes (Figures 4A and 4E). The east also looks to have suitable foraging habitat for razorbills, but not in the central or northern areas. The central area is predicted to have some suitable foraging habitat for kittiwakes. The guillemot map shows suitable foraging habitat across a large part of the Moray Firth but particularly in the south-west, towards the estuary mouth, and in the north, near Wick (Figure 4C).

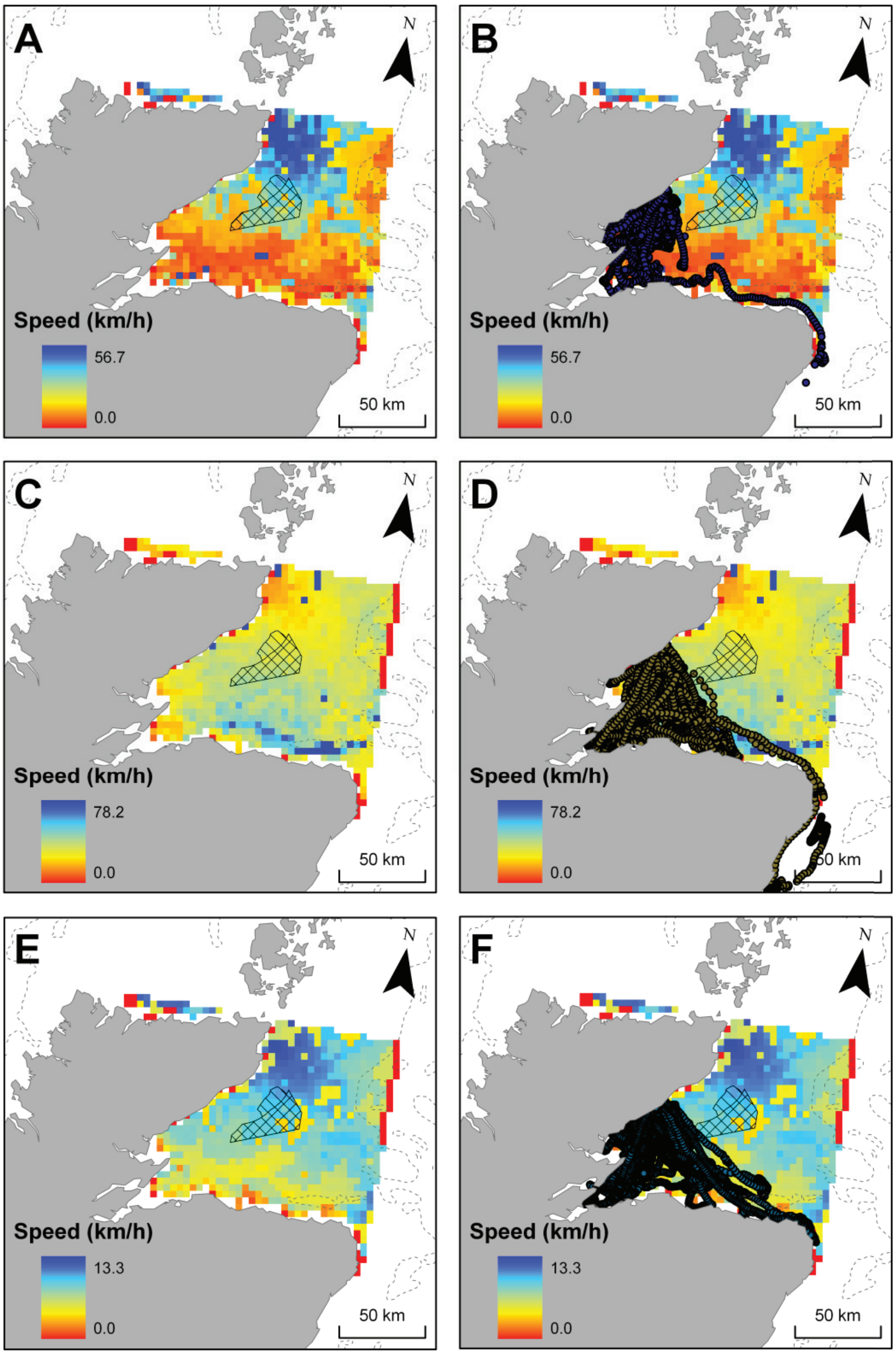

Figure 4 The estimated speed (km/h) of Razorbills (A-B), Guillemots (C-D) and Kittiwakes (E-F) across the Moray Firth, predicted by modelling the response of tracked birds to the marine environment (see Methods). Low speeds (indicated in warm colours) reveal areas of most intensive usage. The tracking data used to inform the model are shown (B, D, F) for comparison with the outputs (A, C, E). The location of the MORL site is indicated by the cross-hatched area, and the BOWL site by the hatched area.

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Discussion

Incorporating fine-scale movement and behavioural information into analytical models can help predict potentially important seabird foraging or transiting areas (Louzao et al. 2006). This information is essential to assess any potential impact of human activities in the marine environment, such as renewable energy devices. The two different modelling approaches we used in this study both benefit from the incorporation of information derived from empirical tracking data but produce different projections of the potential use of the Moray Firth by 4 seabird species.

In the next stage of the analysis, we investigated a range of environmental covariates that could influence flight speed of the four study species. Decreasing speed is associated with intensive searching and foraging behaviour (Hamer et al. 2009); therefore covariates negatively correlated with speed are assumed to be suitable for foraging. The responses were complex, but in short we found a range of covraiates that appeared to be good proxies of suitable foraging locations in the Moray Firth (Table 3).

The projections based on colony foraging radii and distance from colony suggest important foraging and transiting areas close to the main colonies, as would be expected. However they also show that all 4 species could potentially (Figures 4 B,D,F,H) use the entire Moray Firth and beyond. These projections are based on models that have the advantage of few inputs and have been found useful for long range foragers such as northern gannets *Morus bassanus* (Grecian et al. In Review) but they may have more limited application for the short range foragers that form the bulk of the seabird community in the Moray Firth.

The model projections that use the environmental variables from the best-fitting models (Table 3) show a more detailed picture of the potential use of the Moray Firth by the razorbills, guillemots and kittiwakes (Figure 4) – but due to model uncertainty were not conducted for fulmars. These models predict areas of variable flight speed, with low speeds suggestive of increased foraging. The south-west of the Moray Firth consistently shows as an area suitable for foraging (as indicated by consistently low predicted flight speeds) in all three species and the southern coast is also important for both razorbills and kittiwakes (Figure 4). These are mostly influenced by high levels of chlorophyll-a (Figures 1 C & D) in the south and south-west over that period, which has a positive relationship with foraging activity in all 3 species (Appendix 1). The high activity predicted in the north of the Moray Firth for guillemots is due to the colder waters found there in June and July (Figure 1 A & B) – guillemots tended to show slower flight speeds in association with colder waters (Appendix 1b). Based on these species specific projections it would suggest that the proposed Z1 development and existing BORL wind farm (Figures 4 A, C, & E) are situated in potential foraging areas for guillemots and, to a lesser extent, kittiwakes, but not important areas for razorbills. However, transiting behaviour between foraging areas and colonies is not specifically shown in these projections and would also need to be considered as a potential interaction. The lack of a fulmar projection also highlights the limitation to these type of models, and the importance of the covariates within them to produce meaningful outputs to use in such projections.

We urge caution in the application of these projections however. There are potentially other environmental variables that could help explain and model the distribution of seabirds in the Moray Firth. For instance we have only used indirect proxies for prey availability rather than actual forage fish – further studies would benefit from these direct estimates of resource abundance. Moreover by studying flight speed we believe that this does explain much about the use of the marine environment, but it is not a direct measure of actual foraging so may also be sensitive to errors.

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APPENDIX 1. GLMM model outputs investigating the impacts of candidate environmental covariates on flight speed in four species of tracked seabird.

a. Razorbills R GLMM Output –Models

DREDGE MODEL SELECTION OUTPUT (TOP MODELS <DELTA 4)

Global model: lmer(formula = log(MATspeed) ~ GISdepth + GISsst_june + GISchl_june + sediment + GISslope + (1 | birdID/track), REML = FALSE)

Model selection table

(Int)	GIS	GIS.1	GIS.2	GIS.3	sdm	k	Dev.	AICc	delta	weight
30	7.436	-0.03276		-0.5546	-0.4671	+	13	22790 22820	0.00	0.681
32	7.411	-0.03156	-0.001244	-0.5490	-0.4692	+	14	22790 22820	1.52	0.319

Random terms: 1 | birdID/track

BEST MODEL LMER OUTPUT

Linear mixed model fit by maximum likelihood

Formula: log(MATspeed) ~ GISchl_june + GISslope + GISsst_june + sediment + (1 | birdID/track)

AIC	BIC	logLik	deviance	REMLdev
22817	22908	-11395	22791	22828

Random effects:

Groups	Name	Variance	Std.Dev.
track:birdID	(Intercept)	0.950395	0.97488
birdID	(Intercept)	0.060323	0.24561
Residual		0.923413	0.96094

Number of obs: 8173, groups: track:birdID, 54; birdID, 18

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	7.435758	0.897656	8.284
GISchl_june	-0.032762	0.006028	-5.435
GISslope	-0.554640	0.056144	-9.879
GISsst_june	-0.467085	0.076358	-6.117
sediment1	0.971684	0.051720	18.787
sediment2	-1.230593	0.267741	-4.596

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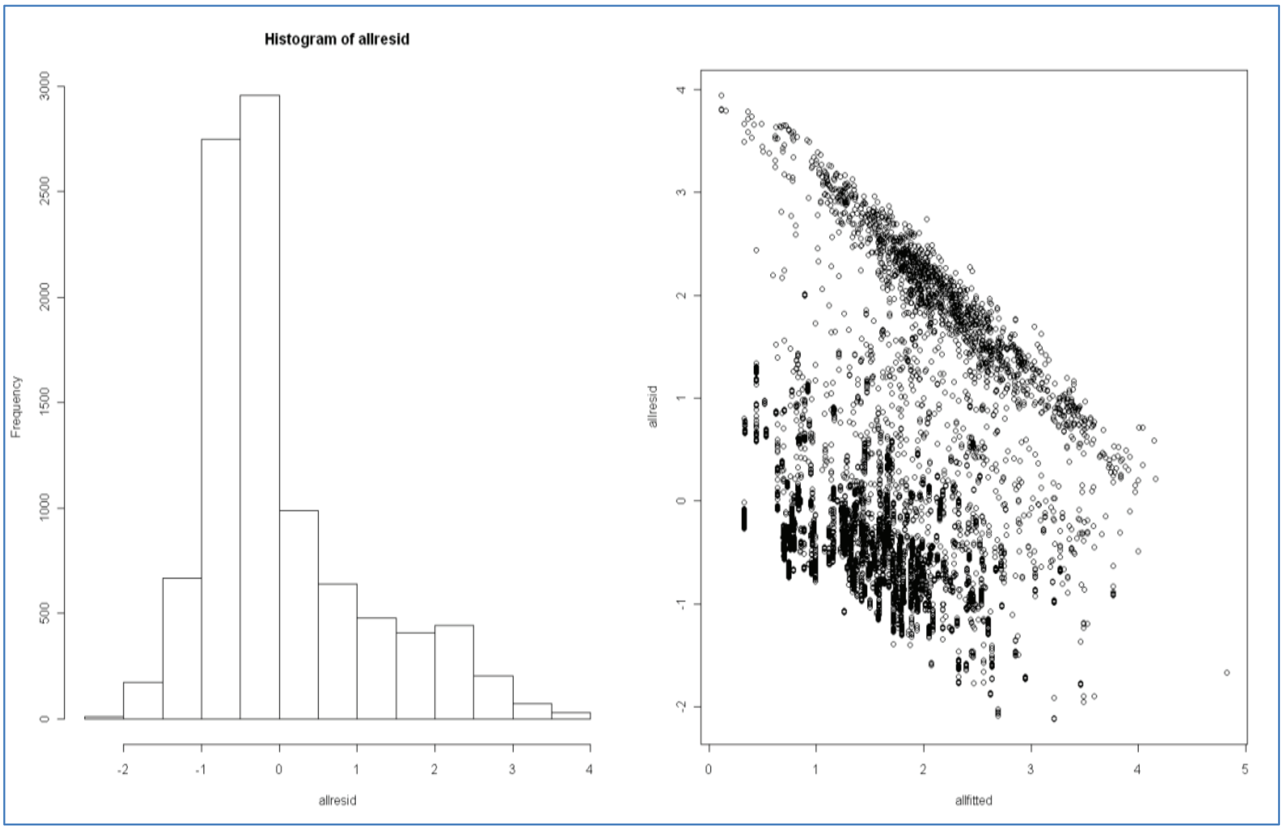
sediment3	0.795501	0.049629	16.029
sediment5	-0.959187	0.070162	-13.671
sediment11	-0.679745	0.030839	-22.042
sediment14	2.109885	0.211740	9.964

Correlation of Fixed Effects:

	(Intr)	GISch_	GISslp	GISss_	sdmnt1	sdmnt2	sdmnt3	sdmnt5	sdmn11
GISchl_june	-0.198								
GISslope	0.059	-0.032							
GISsst_june	-0.985	0.190	-0.073						
sediment1	0.093	-0.007	-0.068	-0.103					
sediment2	-0.042	0.035	-0.025	0.036	0.022				
sediment3	0.119	0.041	-0.061	-0.135	0.216	0.037			
sediment5	0.219	-0.077	0.179	-0.230	0.131	0.005	0.107		
sediment11	0.134	-0.195	-0.082	-0.145	0.236	0.053	0.214	0.274	
sediment14	-0.035	-0.145	-0.267	0.039	0.037	0.007	0.028	-0.029	0.095

Nagelkerke= 0.3876550

Residuals of best model:



b. Guillemot R GLMM Output –Model Outputs

DREDGE MODEL SELECTION OUTPUT (TOP MODELS <DELTA 4)

Global model: lmer(formula = log(MATspeed) ~ GISdepth + GISsst_june + GISchl_june + sediment + GISslope + (1 | birdID/track), REML = FALSE)

Model selection table

	(Int)	GIS	GIS.1	GIS.2	GIS.3	sdm	k	Dev.	AICc	delta	weight
32	-5.256	-0.01868	-0.005338	0.2928	0.6071	+	14	28890	28920	0	1

Random terms: 1 | birdID/track

BEST MODEL LMER OUTPUT

Linear mixed model fit by maximum likelihood

Formula: log(MATspeed) ~ GISdepth + GISsst_june + GISchl_june + sediment + GISslope + (1 | birdID/track)

AIC	BIC	logLik	deviance	REMLdev
28919	29020	-14446	28891	28946

Random effects:

Groups	Name	Variance	Std.Dev.
track:birdID	(Intercept)	0.31795	0.56387
birdID	(Intercept)	0.36819	0.60678
Residual		1.08350	1.04091

Number of obs: 9827, groups: track:birdID, 57; birdID, 20

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-5.256417	0.707644	-7.428
GISdepth	-0.005338	0.001018	-5.245
GISsst_june	0.607091	0.060056	10.109
GISchl_june	-0.018676	0.001879	-9.938
sediment1	0.079355	0.038743	2.048
sediment2	1.662425	0.371590	4.474
sediment3	0.021099	0.047191	0.447
sediment5	0.131593	0.082687	1.591
sediment11	-0.231812	0.032537	-7.125
sediment14	-0.162303	0.066079	-2.456
GISslope	0.292796	0.035943	8.146

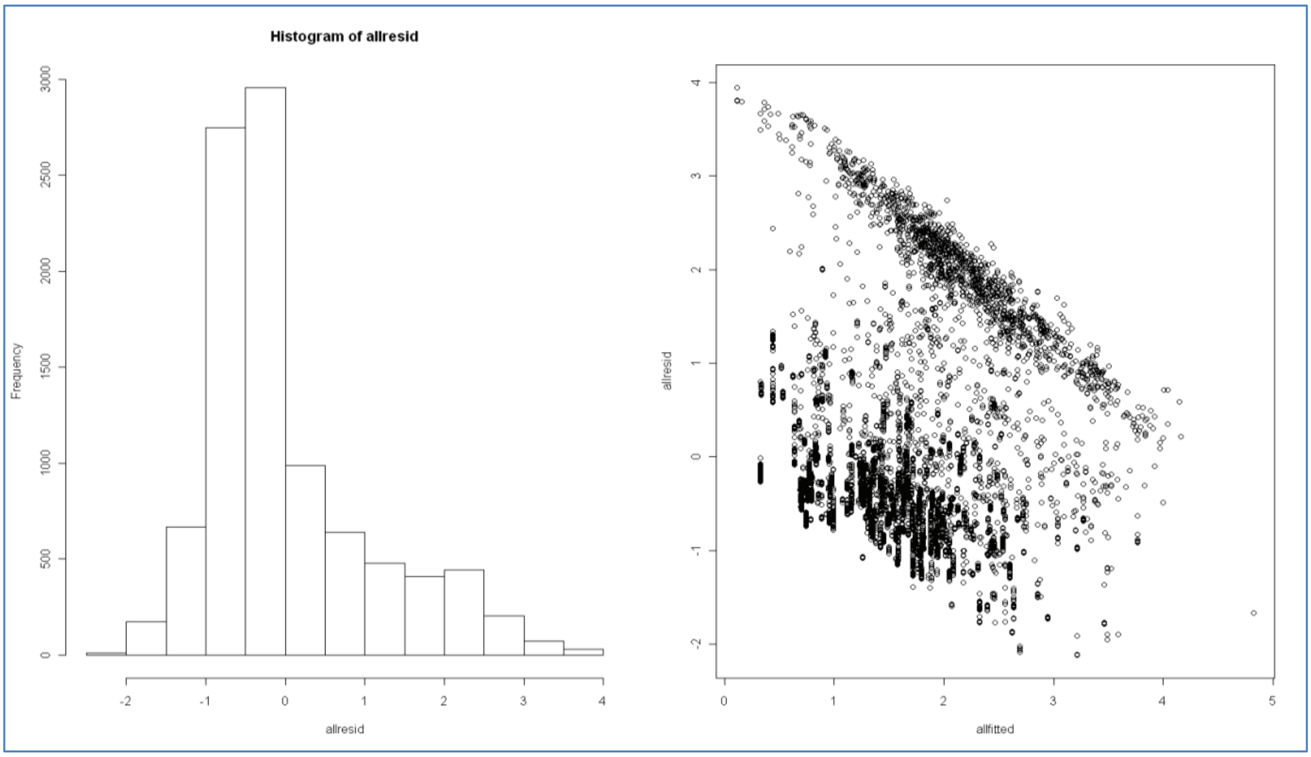
Correlation of Fixed Effects:

(Intr) GISdpt GISss_ GISch_ sdmnt1 sdmnt2 sdmnt3 sdmnt5 sdmn11 sdmn14

GISdepth	-0.254									
GISsst_june	-0.972	0.312								
GISchl_june	-0.283	-0.231	0.265							
sediment1	0.012	-0.056	-0.028	0.091						
sediment2	-0.041	-0.004	0.040	0.028	0.020					
sediment3	-0.031	-0.191	-0.001	0.097	0.183	0.020				
sediment5	-0.003	-0.231	-0.018	0.047	0.091	0.011	0.193			
sediment11	-0.142	0.370	0.151	-0.037	0.223	0.021	0.123	0.067		
sediment14	-0.288	0.330	0.307	-0.056	0.116	0.023	0.027	-0.026	0.438	
GISslope	0.103	0.012	-0.115	-0.064	-0.028	-0.001	0.004	0.076	-0.112	-0.315

Nagelkerke= 0.8268776

Residuals of best model:



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c. Kittiwake R GLMM Output –Model outputs

DREDGE MODEL SELECTION OUTPUT (TOP MODELS <DELTA 4)

Global model: lmer(formula = log(MATspeed) ~ GISdepth + GISsst_june + GISchl_june + sediment + GISslope + (1 | birdID/track), REML = FALSE)

Model selection table

	(Int)	GIS	GIS.1	GIS.2	GIS.3	sdm	k	Dev.	AICc	delta	weight
28	4.502	-0.03058	0.0009593		-0.1912	+	13	22330	22360	0.0000	0.484
30	4.655	0.02953		-0.01346	-0.2071	+	13	22330	22360	0.8503	0.316
32	4.507	-0.03056	0.0009952	-0.01614	-0.1912	+	14	22330	22360	1.7700	0.200

Random terms: 1 | birdID/track

BEST MODEL LMER OUTPUT

Linear mixed model fit by maximum likelihood

Formula: log(MATspeed) ~ GISchl_june + GISdepth + GISsst_june + sediment + (1 | birdID/track)

AIC	BIC	logLik	deviance	REMLdev
22355	22447	-11165	22329	22384

Random effects:

Groups	Name	Variance	Std.Dev.
track:birdID	(Intercept)	0.14216	0.37704
birdID	(Intercept)	0.12009	0.34653
Residual		0.72284	0.85020

Number of obs: 8836, groups: track:birdID, 29; birdID, 19

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	4.5017243	0.5250450	8.574
GISchl_june	-0.0305813	0.0034074	-8.975
GISdepth	0.0009593	0.0009504	1.009
GISsst_june	-0.1912196	0.0442506	-4.321
sediment1	0.0915763	0.0361826	2.531
sediment2	-0.4051328	0.0966129	-4.193
sediment3	-0.4435198	0.0492483	-9.006
sediment5	-0.6346596	0.0575913	-11.020

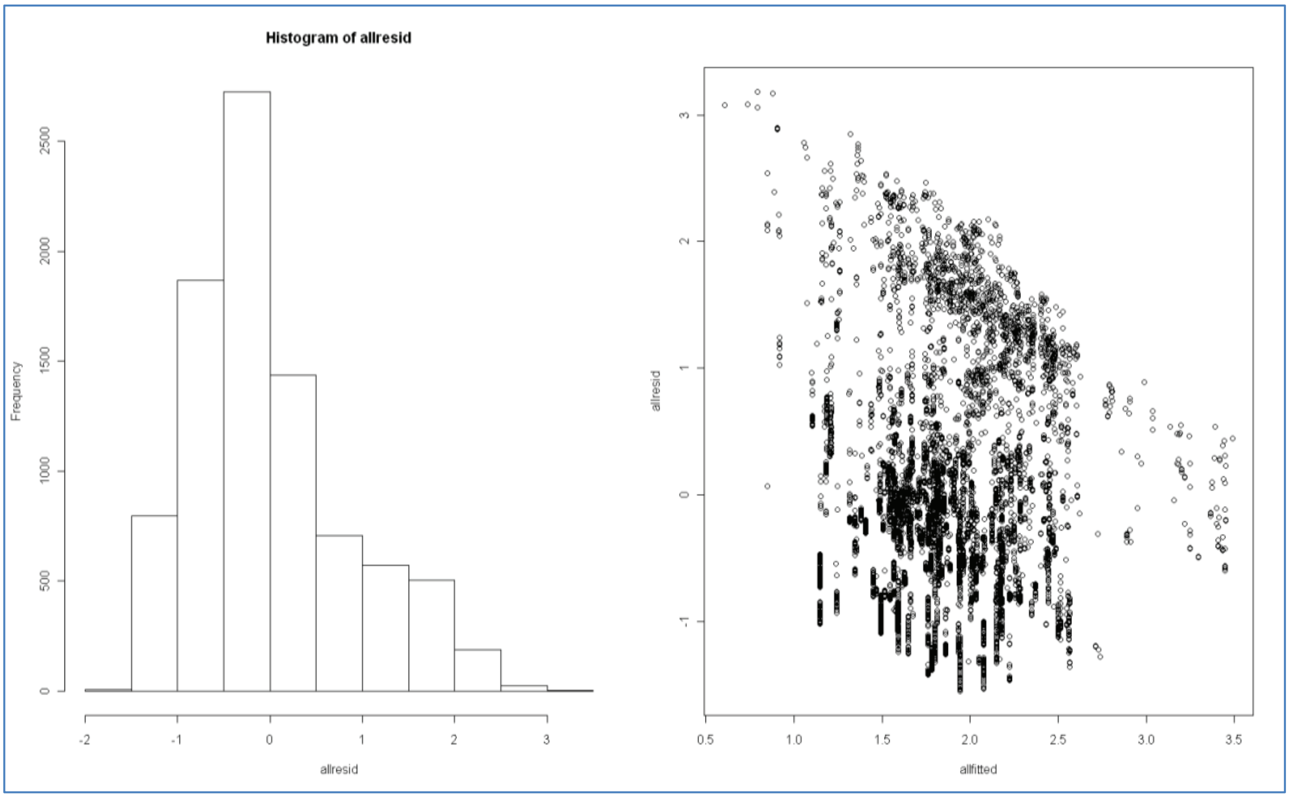
```
sediment11    -0.1786860     0.0272659      -6.553
sediment14    -0.3156266     0.0631506      -4.998
```

Correlation of Fixed Effects:

```
            (Intr) GISch_ GISdpt GISss_ sdmnt1 sdmnt2 sdmnt3 sdmnt5 sdmn11
GISchl_june -0.134
GISdepth    -0.263 -0.294
GISsst_june -0.974  0.101  0.337
sediment1    0.131  0.059 -0.281 -0.166
sediment2   -0.120  0.078 -0.085  0.106  0.078
sediment3    0.249 -0.156 -0.305 -0.281  0.231  0.049
sediment5    0.204  0.098 -0.200 -0.227  0.169  0.026  0.140
sediment11   0.044 -0.222  0.480 -0.023  0.105  0.023  0.064  0.097
sediment14  -0.079 -0.215  0.339  0.098  0.022  0.048  0.039  0.004  0.337
```

Nagelkerke= 0.6119111

Residuals of best model:



d. Fulmar R GLMM Output – Model outputs

DREDGE MODEL SELECTION OUTPUT (TOP MODELS <DELTA 4)

Global model: lmer(formula = log(MATspeed) ~ GISdepth + GISsst_june + GISchl_june +
(1 | birdID/track), REML = FALSE)

Model selection table

	(Int)	GIS	GIS.1	GIS.2	k	Dev.	AICc	delta	weight
8	7.811	-0.07111	0.01332	-0.3494	7	24050	24060	0	1

Random terms: 1 | birdID/track

BEST MODEL LMER OUTPUT

Linear mixed model fit by maximum likelihood

Formula: log(MATspeed) ~ GISchl_june + GISdepth + GISsst_june + (1 | birdID/track)

AIC	BIC	logLik	deviance	REMLdev
24059	24109	-12023	24045	24073

Random effects:

Groups	Name	Variance	Std.Dev.
track:birdID	(Intercept)	0.28472	0.53359
birdID	(Intercept)	0.17792	0.42180
Residual		0.79487	0.89156

Number of obs: 9178, groups: track:birdID, 24; birdID, 15

Fixed effects:

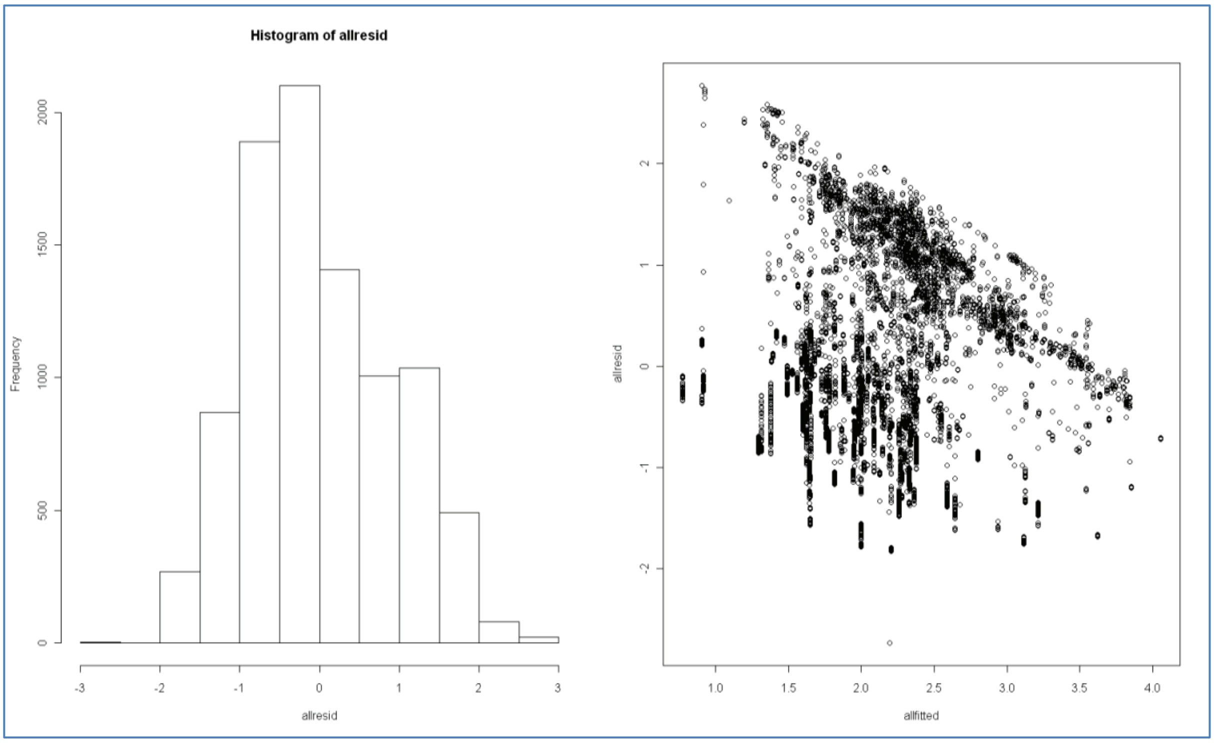
	Estimate	Std. Error	t value
(Intercept)	7.8109234	0.4775081	16.358
GISchl_june	-0.0711060	0.0088248	-8.058
GISdepth	0.0133211	0.0005108	26.079
GISsst_june	-0.3494339	0.0317057	-11.021

Correlation of Fixed Effects:

	(Intr)	GISch_	GISdpt
GISchl_june	0.067		
GISdepth	0.058	-0.219	
GISsst_june	-0.939	-0.101	0.003

Nagelkerke= 0.1383704

Residuals of best model:



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