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# Feeding areas of Atlantic Puffins *Fratercula arctica* assessed by GPS technology

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Large areas of sea around Britain have been identified as potential sites for renewable energy development heightening the need for information about important areas for seabirds. The Atlantic Puffin *Fratercula arctica* is one of the commonest seabirds in north-east Britain yet little is known about where individuals feed. We used back-mounted GPS loggers to track Atlantic Puffins breeding at a colony close to where wind farms are proposed. During chick rearing, birds made two types of feeding trip: long absences that included an overnight stay at distant (38 – 66 km) feeding areas and short daytime excursions to areas much nearer the colony (9 – 17 km). There was considerable overlap of the distant feeding area with the proposed wind farms. However, Atlantic Puffins are known to be sensitive to disturbance and comparison of the GPS birds and individuals without loggers showed that the birds' behaviour had been disrupted by some aspect of the procedure. While the areas used by the GPS birds accorded with expectations based on other methods, it is possible that results from GPS birds represent a worst case scenario and overestimate the degree of overlap with the proposed wind farms.

Running head: *Feeding areas of Puffins*

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Large areas of coastal and offshore waters around Britain have been identified as potential sites for renewable energy development (The Crown Estate 2006). Many of these sites are in the vicinity of major breeding colonies of seabirds and have the potential to impact on these birds, for example where they overlap with foraging hotspots (Grecian *et al* 2010, Witt *et al* 2012). Thus information on where seabirds feed is essential for assessing the environmental risk of such developments. During the breeding season the foraging range of most species is constrained by the need to return to the colony at frequent intervals to relieve the mate and/or feed the brood. Switching to alternative feeding areas may not, therefore, be a viable option. Knowledge of where individuals from particular colonies feed is largely lacking because many seabirds fly fast (typical flight speeds of 30 – 70 km/h; Pennycuick 1987) and use areas well out of sight of a land-based observer. Until recently, Global Positioning System (GPS) loggers that provide detailed data on location have been too large to deploy on many of the seabird species breeding in the UK, but devices now available are potentially small enough to be used on birds weighing as little as 300-400 g. However, despite it having long been recognised that bird-borne devices can affect the flight and foraging behaviour of seabirds, particularly auks and other diving species (Wilson *et al* 1986, Barron *et al* 2010, Vandenabeele *et al* 2012), the urgency with which information is required risks results being used uncritically.

The Atlantic Puffin *Fratercula arctica* (hereafter referred to as Puffin) is a small, burrow-nesting, pursuit-diving seabird. It is one of the most abundant seabirds breeding in north-east Britain (Harris & Wanless 2004) yet a recent review of data relevant to the foraging ranges of British seabirds revealed that less is known of the feeding areas used by Puffins than most other species and more information is urgently needed (Thaxter *et al* 2012). One reason for this knowledge gap is that Puffins are sensitive to disturbance, particularly handling (Wernham 1993, Rodway *et al* 1996, Harris & Wanless 2011) and, like the Tufted Puffin *F. cirrhata* (Whidden *et al.* 2007), seem intolerant of back-mounted devices (personal observations). However, extensive areas within the likely foraging range of Puffins at many of the major colonies in Scotland have recently been designated as potential sites for the generation of wave, tidal or wind energy (The Crown Estate 2006). Given the heightened imperative for information on populations in these areas, we carried out a small study to assess the feasibility of using some of the smallest available GPS loggers to obtain information on the foraging areas used. The original intention was to scale up the study in subsequent years but the results of these first deployments were sufficiently worrying to be worth putting on record.

## METHODS

The study was carried out, under the relevant licences, at the colony of c.40,000 pairs of Puffins on the Isle of May (56$^{o}$ 11'N, 2$^{o}$ 34'W) in the Firth of Forth, south-east Scotland (Figure 1) during the chick rearing period in 2010.

On 3 June, three Puffins with chicks were removed from their burrows and each fitted with a dummy package of the same dimensions (40 x 22 x 11 mm) and weight (15 g) as the larger type of GPS logger intended to be used for data collection. Each dummy was attached to a few central back feathers using three strips of waterproof tape (Tesa Ltd; total mass 1.5 g). To minimise handling time the birds were not weighed. However, the mean mass of a sample of Puffins feeding chicks caught concurrently in the same area was 386 g ± SE 3.3 (n = 75), which indicated that, on average, a dummy plus attachment tape was 4.3% of the body mass. Birds were ringed and then returned to their burrow. The whole procedure took 3-5 min. To check how long dummies stayed attached and if there was any evidence that birds deserted their burrows and/or stopped feeding their chicks, opportunistic observations were made from a hide c. 20 m away from the burrows over the following two weeks.

Results from the dummy packages were encouraging (see Results). Six GPS loggers (i-gotU GT-120, Mobile Action Technology) that had been repackaged to make them more streamlined and which were of the same dimensions and weight as the dummies, were therefore attached using the same method to Puffins with chicks on 19 June. Another of these loggers plus three smaller ones (GiPSy-2, TechnoSmart; 48 x 20 x 9 mm, 11.5 g with tape attachment; 3.0% of adult mass) were attached on 23 June. The larger loggers recorded one position (accurate to c. 20 m) every 1 min, whereas the smaller ones recorded continuously every second for 1 min (same accuracy) but were then off for 5 min. The larger loggers recorded data for 2-3 days and the smaller ones for 1-2 days.

One to two days after deployment, any instrumented bird seen entering its burrow was re-caught, the device removed and the bird put back in the burrow. This procedure took 1-2 min. Deployments and retrieval details are given in Table 1.

Data from both types of logger were used to identify when birds were in the vicinity of the colony (assumed to correspond to periods when signals were constant and positions were within 500 m of the release location) or on foraging trips (all other periods). Neither logger type recorded a bird's diving activity directly. However, the signal to the satellite is lost when the device is underwater and Puffins typically spend c.78% time underwater when diving (Wanless *et al* 1988; Harris & Wanless 2011), so locations where the bird remained approximately stationary (distance between subsequent locations < 500 m) and fixes were obtained intermittently instead of every minute were assumed to correspond to diving. The approach was not feasible for the smaller loggers due to the lower recording frequency.

Population distributions for all fixes and diving fixes were derived from fixed kernel analysis performed in ArcGIS (Hawth's Analysis Tools 3.27; Beyer 2004) using a smoothing parameter (*h*) of 6000 m (identified using the Least-squares cross-validation method; Worton 1989) and a cell size of 1000 m. Maps with 50% (representing the core area of use), 70% and 90% (active area of use) kernel density contours were produced in a Lambert equal-area azimuthal (North Pole) projection. To assess the extent of overlap between population range and proposed offshore wind farms, the proportion of 50% and 90% kernels within the proposed sites was calculated. To assess the extent of overlap between population range and proposed offshore wind farms, the proportion of 50% and 90% kernels within the proposed sites was calculated using ArcGIS.

To check for effects of dummies and loggers on colony attendance and chick provisioning, the burrows of these birds were watched for a total of 38.7 h (mean 3.5 ± 0.9 h per day; n = 11 days, mainly during the daily peak of feeding (0500 – 0900 h; Harris & Wanless 2011)). During watches we recorded visits to burrows by these birds and their mates, and whether or not they had fish. Observations ceased on 1 July and the contents of burrows of dummy and logger birds were checked the next day to establish whether a chick was still present. Some burrows were too long for chicks to be caught but where possible chicks were weighed (to nearest g) and their wing length measured (to nearest mm) as a proxy for age. These measurements were compared with those of 24 chicks in an adjacent part of the colony so as not to increase disturbance of the focal birds, obtained on 30 June and 3 July. Thirty-four chicks whose parents were not handled that were known to be alive at the start of the logger work were checked on 1 - 3 July to see how many had survived.

To quantify chick provisioning rates of undisturbed Puffins, all-day watches of 60 and 68 burrows elsewhere in the colony were carried out on 24 and 28 June, respectively.

## RESULTS

All three Puffins with dummy loggers continued to feed their chicks. One bird lost its dummy device after c. 5 days but the other two dummies were still attached 13 and 20 days later when the birds were re-caught and the dummies removed (Table 1). On the basis of these observations we concluded that the behaviour of these Puffins had not been severely disrupted and there was a good chance of obtaining data from loggers.

Of the ten GPS loggers that were subsequently deployed, seven (70%) were retrieved. These provided information on 15 trips away from the colony over 14 bird-days (Table 2, Figure 1). It was apparent that Puffins made two types of trips: long absences where individuals were away overnight (12 cases lasting 15.0 – 41.0 h; maximum distance from the colony 37.8 – 65.5 km) and shorter excursions (3 cases lasting 0.7 - 3.8 h; 9.3 – 17.5 km from the colony). Although some diving occurred within 5 km of the Isle of May, most took place during the long trips when the birds were in areas 30-60 km to the east and north-east of the island. Consequently, there was considerable overlap between the Puffin kernel distributions and proposed offshore wind farms (Figure 2). For all fixes, there was 84% overlap for the 50% kernel and 52% overlap for the 90% kernel. For diving fixes, the overlaps were 73% and 50%, respectively.

However, observations indicated that the behaviour of the Puffins carrying loggers differed in several important respects from those without loggers. Instrumented birds made an average of 1.07 trips per day (range 0.67 – 2.0; Table 1). Chicks in undisturbed burrows elsewhere in the colony at this time received 4.1 ± 0.3 (n = 68 burrows) and 4.9 ± 0.3 (n = 60 burrows) feeds per day, respectively. Both members of a Puffin pair feed their chick so to attain equivalent feeding rates as undisturbed pairs, uninstrumented adults in logger pairs would have to deliver food at a rate 3-4 times greater than their instrumented mates. The limited data on feeding rates of members of a pair suggest that such a marked disparity is unlikely (personal observations). In addition, two of the seven logger birds (29%) had returned without fish when they were re-caught (Table 2). In contrast, at the same time Puffins without devices returned without fish significantly less frequently (2 (2%) of 81 returns; Fisher Exact test *P* = 0.03).

Although the overall retrieval rate of dummy and logger devices was high (69%), observations of the birds' burrows indicated that attendance patterns had been disrupted both after initial capture and retrieval of the logger. Thus, three birds deserted after deployment while another was not seen for two days despite frequent checks of the study area (Table 1). A further two birds deserted following logger retrieval while another was never seen going down its burrow again even though its chick was alive. On a more encouraging note, three logger birds and two dummy birds did then behave more normally. For example, Bird 7 brought in three loads of fish within 3 h, and three loads within 5 h, three and four days respectively after the removal of its logger. Overall, it returned with more food loads than its mate (13 cf. 8 loads; n = 34.5 h of observation). Similarly, Bird 13 brought in three loads in 5.5 h four days of observations after its logger was taken off, twice as many as its partner (8 cf. 4 loads; n = 22.7 h).

The check of burrow contents on 2 July indicated that 3 (23%) no longer contained chicks. This loss rate was markedly higher than that recorded over the same period at control burrows (3/34 i.e. 9%), although the difference was not statistically significant (Fisher Exact test, *P* = 0.3). Of the four chicks that were weighed, only that of Bird 1 was of normal mass compared to the 24 control chicks (Figure 3).

## DISCUSSION

A standard criterion for assessing the impact of loggers is retrieval rate, with high rates assumed to reflect low impact.  On this basis, our overall retrieval rate of 69% of dummies and devices did not cause undue concern. However, because the Puffin is well-documented as being less tolerant of disturbance than many other seabirds, we were alert to additional effects. It became obvious that some aspect of the deployments affected attendance behaviour sufficiently to impact on chick weights and breeding success although small sample sizes made statistical evaluation difficult. These effects need to be kept in mind when considering locational data for which there is no direct method to compare behaviour of birds with and without devices.

Data from the GPS loggers indicated that Puffins were using areas many tens of kilometres away from the Isle of May and these overlapped with the proposed wind farm sites. The only previous direct information on where Puffins from this colony forage when they have chicks was a single bird tracked using VHF radio-telemetry in 1987 (Wanless *et al* 1990). Eleven (73%) of 15 trips made by this bird were to feeding sites within the c.10 km detection range of the receiving station on the Isle of May but on four trips it flew out of range. Flight directions of both the close and more distant trips were predominantly to the south-east of the island and thus there was little overlap with areas used in 2010 that were mainly to the east and north-east. The only other GPS data for Puffins that we are aware of are unpublished results of Richard Bevan from the Farne Islands, 100 km south of the Isle of May, that suggest that the majority of foraging there occurs within 20 km of the colony (BBC 2010). Other information on foraging ranges of Puffins comes from ship-based surveys of Puffins in the vicinity of breeding colonies. These suggest that on Skomer, south-west Wales, 85% of Puffins carrying fish were within 15 km, 99% were within 25 km and the maximum recorded distance from the colony was 35 km (Stone *et al*1992). Similarly, Puffins seen feeding near St Kilda, north-west Scotland were mostly within 40 km of the nearest colony (Leaper *et al*1988). Around Newfoundland, Puffins generally forage 3-5 km from the colony but sometimes up to 70 km away (Bradstreet & Brown 1985, Schneider et al. 1990). However, when feeding conditions are poor, Puffins appear to use more distant areas since they have been recorded carrying fish up to 137 km and 250 km from the nearest colonies in Norway and the Faeroe Islands, respectively (Anker-Nilssen & Lorentsen 1990, M. L. Tasker, pers. comm.).

Whilst foraging range of individuals in our study accorded with previous work, the question remains as to whether the positional information we obtained is likely to be representative of the foraging distribution of the population as a whole. Work in 2008 using small leg-mounted time-depth recorders (weight 2.7 g) deployed overwinter, showed that Puffins feeding young on the Isle of May did not dive during the night, had peaks of diving late in the evening and early in the morning and the mean start of diving by 10 individuals on 58 mornings in early July was 27 ± 4 min before sunrise (Harris & Wanless 2011, unpublished data). These observations agree with the daily peak of Puffins returning with fish that occurs a few hours after dawn, and support the hypothesis that the parents fly to feeding grounds for self-feeding, perhaps on prey that are easily caught but too low food value to carry back to a chick, late in the evening. They then stay on the feeding grounds overnight, feed again soon after dawn and return to the colony with fish for the chick an hour or two later.

It is more problematic to use the dive data to evaluate what happens during the remainder of the day. Chick provisioning rates were lower in GPS birds suggesting that shorter, and therefore quite possibly closer, trips were under-represented in the daytime data. Such a bias would mean that the true kernel distribution would be concentrated closer inshore (most likely between the current kernel distribution and the colony) and the overlap with the proposed wind farm developments would be reduced. Thus, our recorded distributions can be viewed as a worst case scenario in terms of interactions of Puffins from the Isle of May with the proposed wind farm sites. However, it is likely that even if Puffins make more use of closer areas than we recorded, most, if not all, will spend time in the distant areas. Further insights could potentially be gained by combining kernel density distributions with those from at-sea surveys although the latter would include nonbreeding Puffins and those from other colonies. Concentrations of Puffins that coincide with those indicated by the kernel analysis would provide reassurance that the distant locations for GPS birds are robust. By a similar argument, hotspots of birds close to the colonies would provide support for the suggestion that shorter trips are under-reported by the GPS deployments.

Device effects are species specific, and the Puffin is well documented as being intolerant of disturbance and thus likely to be towards the upper end of the device effect scale. More generally, even in species where effects are less pronounced, responses will probably vary according to environmental conditions. In the case of Puffins on the Isle of May, 2010 appeared to be an average season in terms of breeding success and provisioning activity so it is possible that disruption might have been even more severe if conditions had been less favourable. To date, impact assessments for proposed wind farms in UK waters have relied heavily on data from aerial and ship-based surveys. These methods have several serious limitations notably that the provenance and breeding status of the birds recorded is unknown. Bio-logging, in particular GPS telemetry provides a complementary approach that overcomes these problems. However, recognizing that the behaviour of tagged individuals will probably be affected to some extent needs to be taken into account and attempts made to quantify the impact, particularly any implications this might have for interactions between birds and marine renewables.


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**Table 1.** Details of deployment of dummy devices and GPS loggers on Atlantic Puffins on the Isle of May and their effect on burrow attendance and breeding success.

| Bird No. | Logger type | Date attached | Hours deployed | Trips made | Subsequent sightings | Contents of burrow on 2 July |
|---|---|---|---|---|---|---|
| 1 | Dummy | 3 June | 488.0 | - | Regular throughout | Chick healthy |
| 2 | Dummy | 3 June | 306.0 | - | Regular throughout | Chick alive |
| 3 | Dummy | 3 June | 150-170* | - | Reluctant to go down burrow | Burrow empty |
| 4 | i-gotU | 19 June | - | - | Not seen after deployment | Chick very thin |
| 5 | i-gotU | 19 June | - | - | Not seen after deployment | Chick alive |
| 6 | i-gotU | 19 June | 48.1 | 3 | Not seen after removal | Chick alive |
| 7 | i-gotU | 19 June | 47.1 | 2 | Regular after removal | Chick healthy |
| 8 | i-gotU | 19 June | 70.7 | 3 | Not seen after removal | Burrow empty |
| 9 | i-gotU | 19 June | 47.7 | 2 | Delayed return, burrow dug-out | Burrow empty |
| 10 | GiPSy-2 | 23 June | - | - | Not seen after deployment | Chick thin |
| 11 | GiPSy-2 | 23 June | 74.1 | 2 | Never entered burrow after removal | Chick alive |
| 12 | i-gotU | 23 June | 24.9 | 1 | Regular after removal | Chick alive |
| 13 | GiPSy-2 | 23 June | 26.4 | 2 | Regular after removal | Chick alive |

Note: * Lost during this period

**Table 2.** Duration and maximum distance of trips made by Atlantic Puffins fitted with GPS loggers on the Isle of May. Where known, whether or not a bird was carrying a fish when it was recaught is also shown.

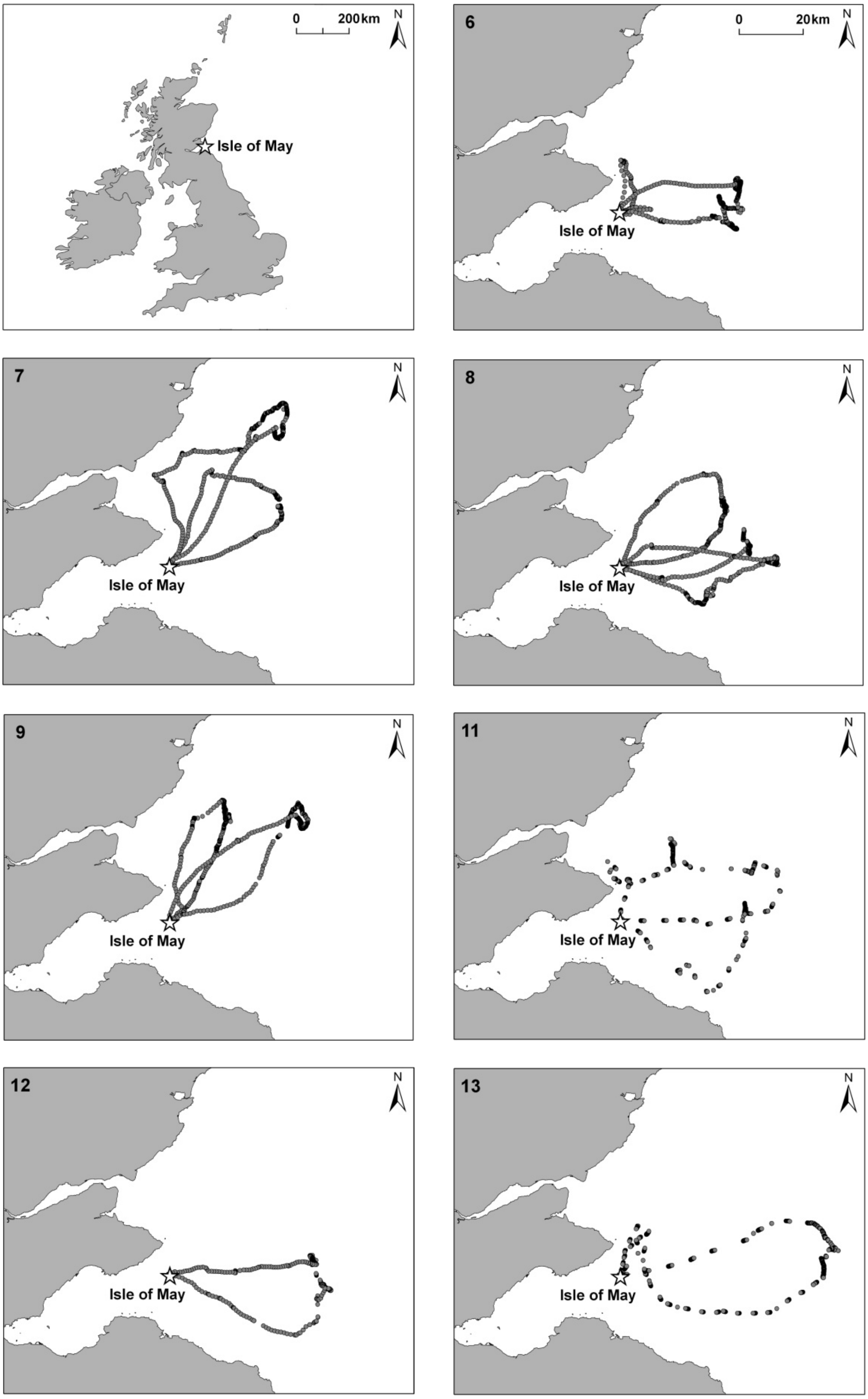
| Bird | Trip | Trip duration (hours) | Maximum distance from colony (km) | Carrying fish at recapture |
|---|---|---|---|---|
| 6 | 1 | 3.8 | 17.2 | |
| 6 | 2 | 0.7 | 9.3 | |
| 6 | 3 | 41.0 | 37.6 | yes |
| 7 | 1 | 15.0 | 39.6 | |
| 7 | 2 | 24.7 | 63.3 | yes |
| 8 | 1 | 22.6 | 42.0 | |
| 8 | 2 | 23.1 | 47.4 | |
| 8 | 3 | >12.5* | >39.7 | no |
| 9 | 1 | 23.3 | 43.1 | |
| 9 | 2 | 23.1 | 54.8 | yes |
| 11 | 1 | 24.4 | 49.7 | |
| 11 | 2 | >17.5* | >37.7 | no |
| 12 | 1 | 24.5 | 48.2 | yes |
| 13 | 1 | 23.9 | 65.5 | |
| 13 | 2 | 1.2 | 17.5 | yes |

*Logger out of storage space

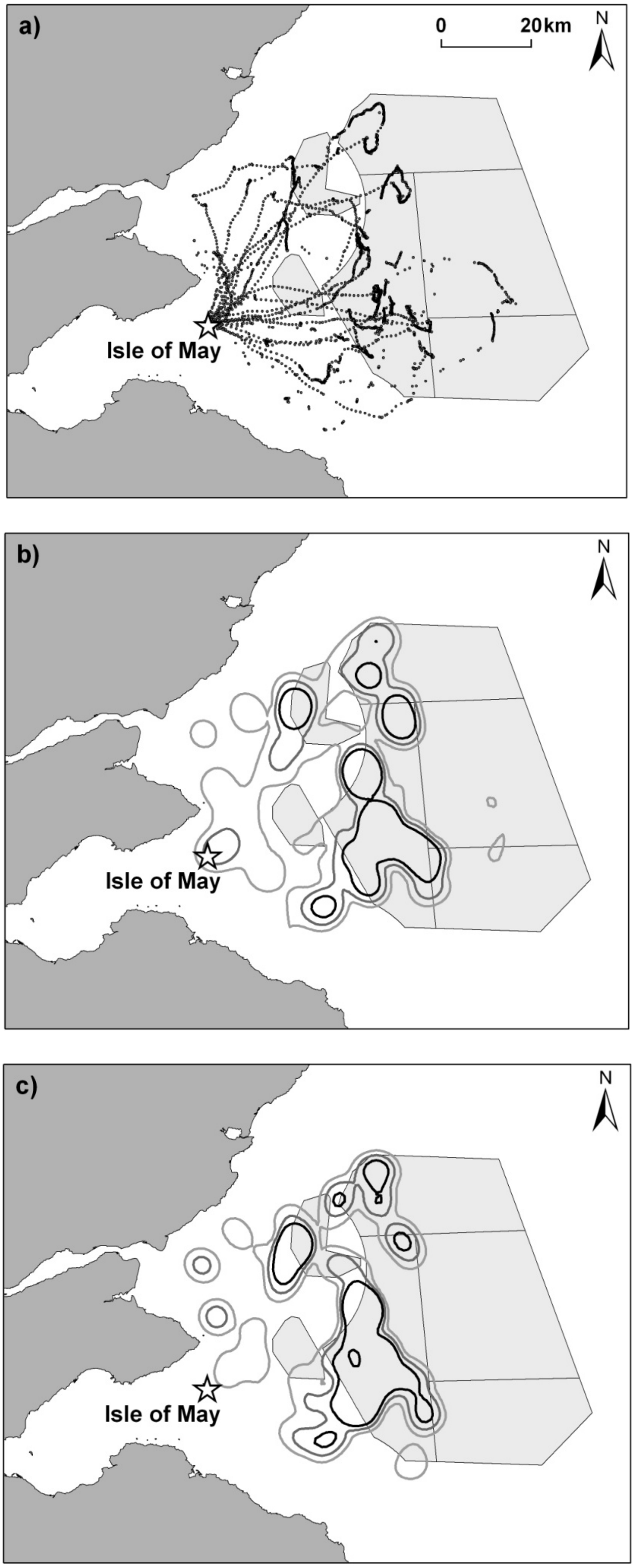
**Figure 1**. Foraging trips of Atlantic Puffins breeding on the Isle of May in 2010. The top left panel shows the location of the Isle of May in a British Isles context, the other panels show the GPS tracks of individual birds (bird number given in top left corner).

**Figure 2**. a) All fixes of Atlantic Puffins from the Isle of May obtained from i-gotU GT-120 GPS loggers overlaid on the areas (light shading) of sea of the Firth of Forth being considered for the location of wind turbines (The Crown Estate 2006); b) 50, 70 and 90% kernel density contours based on all locations obtained from i-gotU GT-120 loggers; c) 50, 70 and 90% kernel density contours based on diving locations obtained from i-gotU GT-120 loggers.

**Figure 3**. Mass in relation to wing length of Atlantic Puffin chicks where one adult had had a dummy or a GPS logger attached compared to chicks where neither adult had been handled.




Harris et al. Figure 1.




Harris et al. Figure 2.

Figure 3. Mass in relation to wing length of Puffin chicks where one adult had had a dummy or a GPS logger attached compared to chicks where the adult had not been handled.