

The following supplement accompanies the article

Simultaneous multi-colony tracking of a pelagic seabird reveals cross-colony utilization of a shared foraging area

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Marine Ecology Progress Series 538: 239–248 (2015)

Supplement.

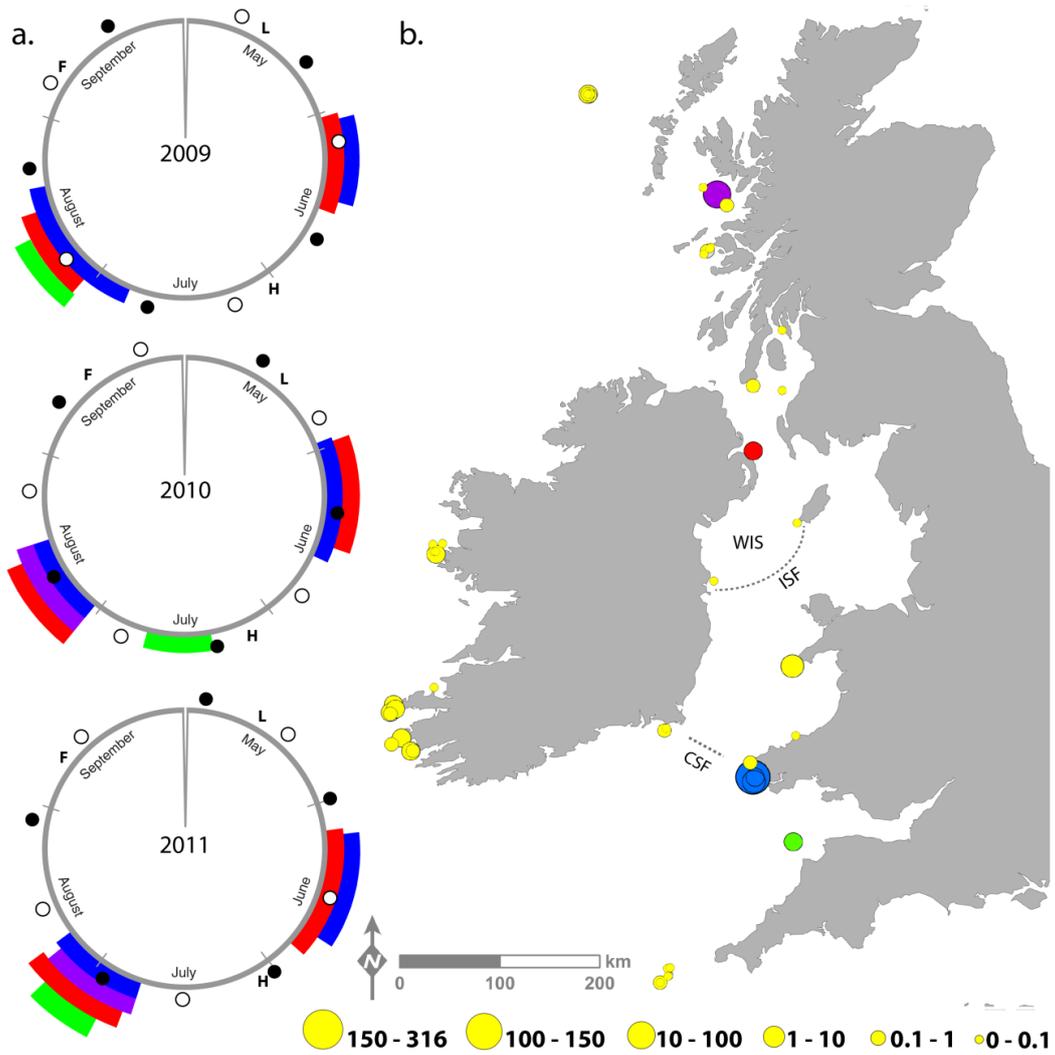


Figure S1. (a) Timing of deployments at each colony in each year with respect to the timing of breeding. Deployments are shown as coloured bands (from first to last recorded GPS fix): Rum (Purple), Copeland (Red), Skomer (Blue), Lundy (Green). The median lay (L), hatch (H) and fledge (F) dates are shown for nests monitored on Skomer. Moon phase is indicated as black circles (new moon) and white circles (full moon). (b) The locations of study colonies are shown, scaled by colony size (in thousands of pairs), and colour coded as in the deployment plots. The locations of all other significant colonies are also shown, scaled by colony size and coloured yellow (data from Mitchell et al. (2004), Booker & Price (2010) and Perrins et al. (2012)). The approximate positions of the Irish Sea Front (ISF, curved broken line), Celtic Sea Front (CSF, broken straight line) and Western Irish Sea (WIS) are shown (Simpson & Hunter 1974).

Location-filtering

Because we were interested in the extent of overlap between foraging ranges of birds from different colonies, we aimed to identify the parts of the birds' tracks most likely associated with foraging behaviour by filtering out those GPS track locations most likely to be associated with commuting flight and resting. The filtering process was based time of day, ground speed, and track sinuosity. It aimed to filter out non-diving locations associated with commuting flight and resting while maximising retention of known diving locations. We developed a three-stage filtering process using data from the 25 birds tracked with GPS and TDRs from Skomer.

Diving behaviour was highly constrained to daylight hours (Figure S2a). To exclude nocturnal activity, we excluded all nocturnal track locations within the window 21:00–04:00 h. Nocturnal locations excluded at this stage appeared to be primarily roosting away from the colony, or activity close to the colony (Figure S3a). Twenty-nine per cent of locations were excluded and 99.7% of time submerged was retained at this stage.

To remove commuting flight, we looked at ground speed, calculated as the distance/time between two sequential locations. The daytime locations retained in stage 1 showed a skewed distribution of ground speed (Figure S2b). Comparison with the distribution of ground speeds for locations where diving occurred revealed that little diving activity was associated with higher-speed movements. Exclusion of locations with speeds $>7 \text{ m s}^{-1}$ retained 95% of time submerged, while excluding the fastest 19% of locations in which no diving occurred. Rapid movement locations excluded at this stage appeared to be direct movements between the colony and patches of area-restricted search (Figure S3b).

To remove daytime resting on the sea surface, we looked at track turning angle, since periods spent drifting on the sea surface are likely to produce relatively linear or curvilinear segments of track. Turning angle was calculated between sequential track locations. The standard deviation (SD) of turning angle was calculated over six sequential locations to capture periods of low variability in turning angle (linear movement on a maintained course). The low-speed daytime locations retained in stage 2 showed a skewed distribution of turning angle SD (Fig. S2c). Comparison with the distribution of turning angle SD for remaining locations where diving occurred revealed that little diving activity was associated with periods of movement involving low variability in turning angle. Exclusion of locations with turning angle SD $< 18^\circ$ retained 95% of time submerged, while excluding 14% of locations (associated with low variability in turning angle) in which no diving occurred. Locations associated with variability in turning angle excluded at this stage appeared to be short-distance, slow-speed movements along linear or curvilinear routes (Fig. S3c).

Overall, the filter process excluded 50% of recorded locations (those likely to be associated with nocturnal roosting, high-speed commuting flight, or periods spent resting on the sea surface). The retained locations were likely to be associated with searching and foraging behaviour and accounted for 89% of all time spent submerged. Calculated for the 25 GPS-TDR birds individually, the retained locations accounted for a mean (\pm SD) $89.6 \pm 7.1\%$ of time submerged. As a result, the distribution of retained locations and locations in which diving occurred showed a high level of spatial matching (Fig. S3d).

The above filtering process was then applied to identify likely foraging locations in the whole tracking dataset (including all birds from all colonies). Applied to the entire GPS tracking dataset, the filtering process excluded a similar percentage (51%) of locations likely to be associated with nocturnal roosting, high-speed commuting flight, or periods spent resting on the sea surface. Thus, the retention of diving locations was assumed to be similar to that in the diving dataset.

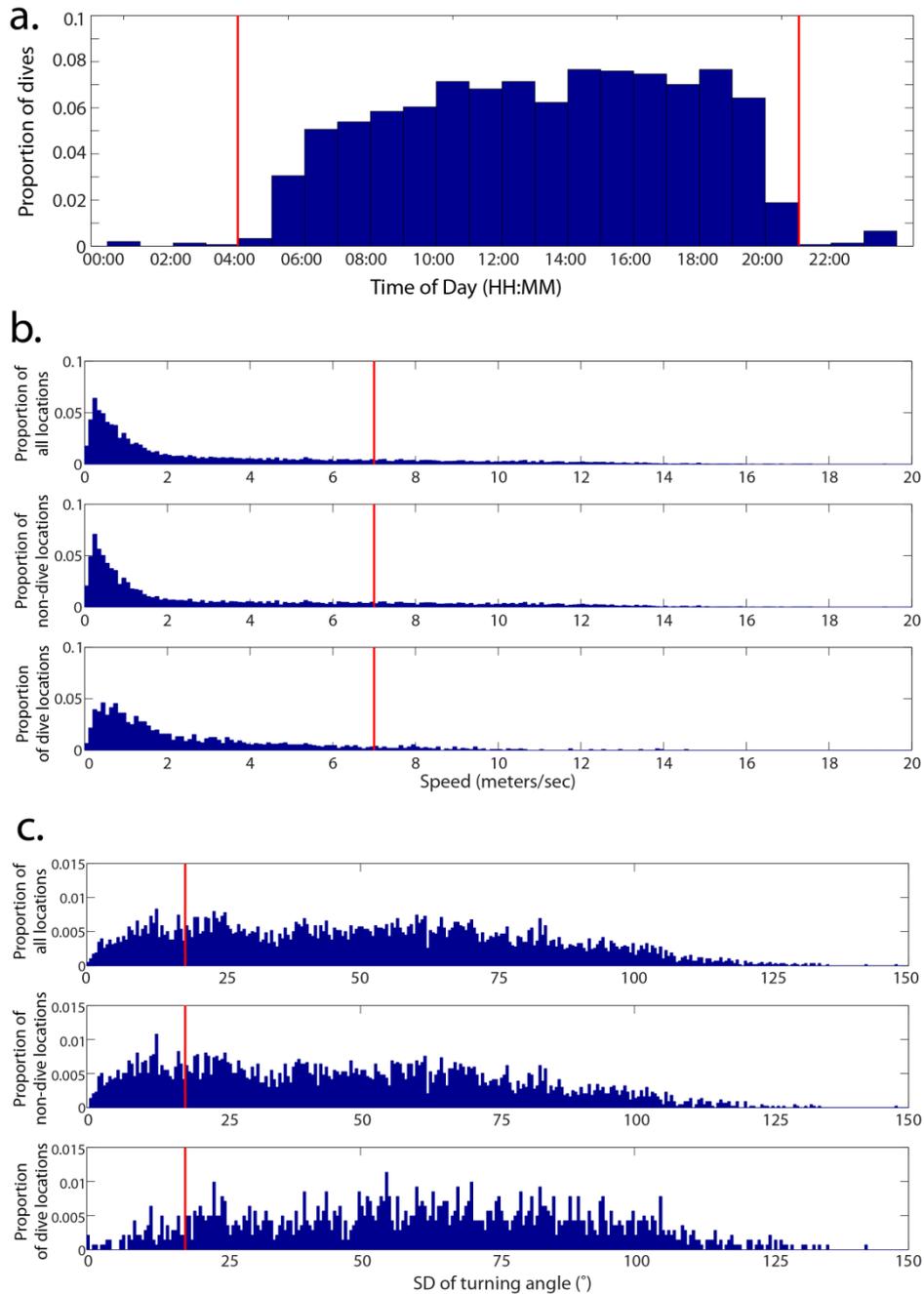


Figure S2. (a) Distribution of diving behaviour over 24 hours; bars represent hourly proportion of total time submerged. Locations recorded between 21:00 and 04:00 GMT (indicated by the red lines) were excluded in the first stage of the filtering process. (b) Distribution of ground speeds for all daytime locations retained in the first stage of the filtering process. Exclusion of locations with speeds $>7 \text{ m s}^{-1}$ (indicated by red lines) retained 95% of time submerged, while excluding the fastest 19% of locations in which no diving occurred. (c) Distribution of standard deviations (SD) of turning angle (over a moving window of 6 locations) for all low-speed daytime locations retained in the second stage of the filtering process. Exclusion of locations with $\text{SD} > 18^\circ$ retained 95% of time submerged, while excluding 14% of locations – those associated with low variability in turning angle and in which no diving occurred.

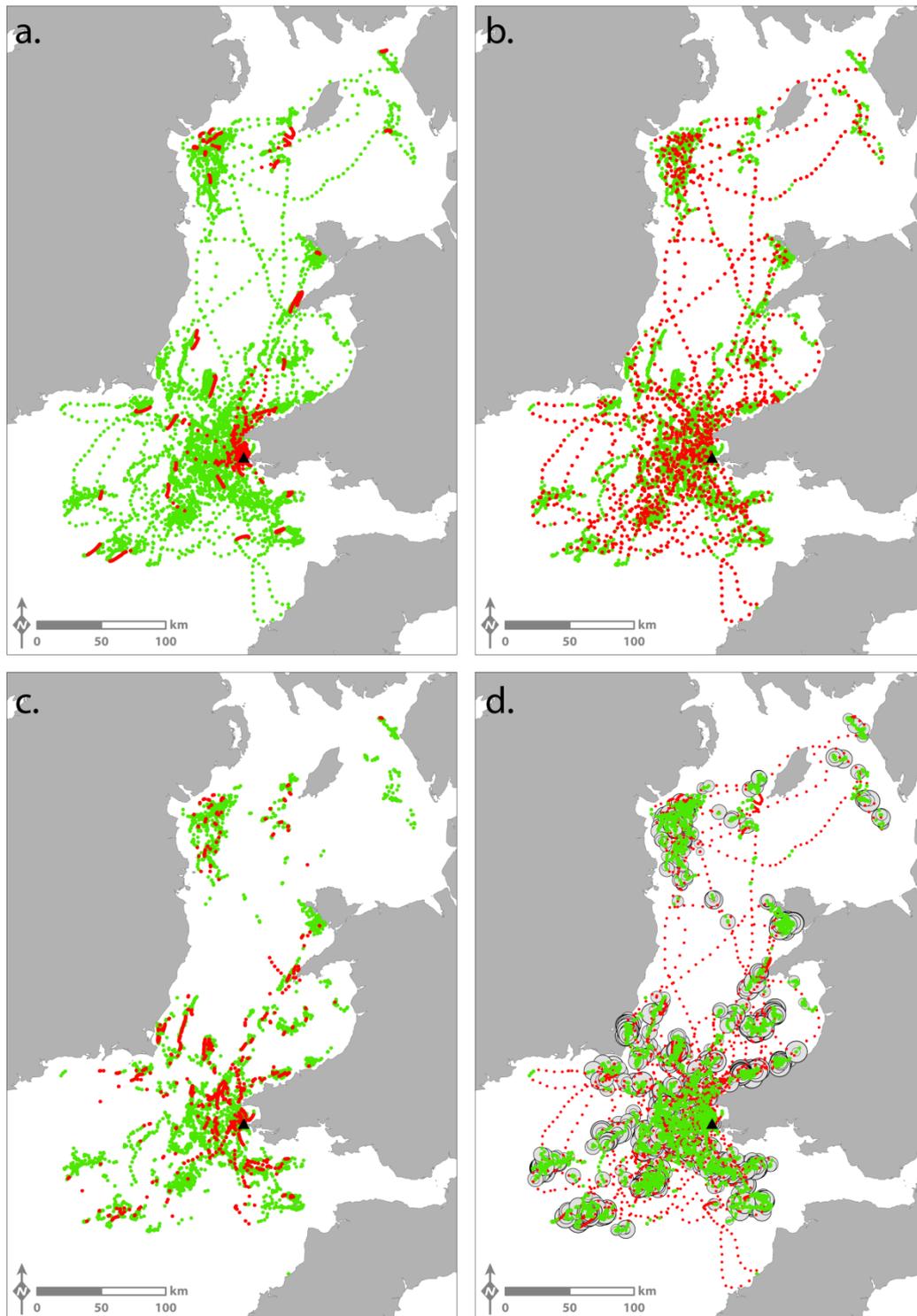


Figure S3. (a) All track location data from the 25 birds tracked with GPS and TDRs from Skomer with nocturnal locations (21:00–04:00) excluded in the first stage of the filtering process coloured red. (b) All daytime locations with high speed locations (speed $> 7 \text{ m s}^{-1}$) excluded in the second stage of the filtering process coloured red. (c) All low-speed daytime locations with variable turning angle locations ($\text{SD} > 18^\circ$) excluded during the third stage of the filtering process coloured red. (d) All retained locations (green), excluded locations (red), and locations where diving occurred (grey - sized in proportion to total time submerged).

Selection of smoothing parameter (h)

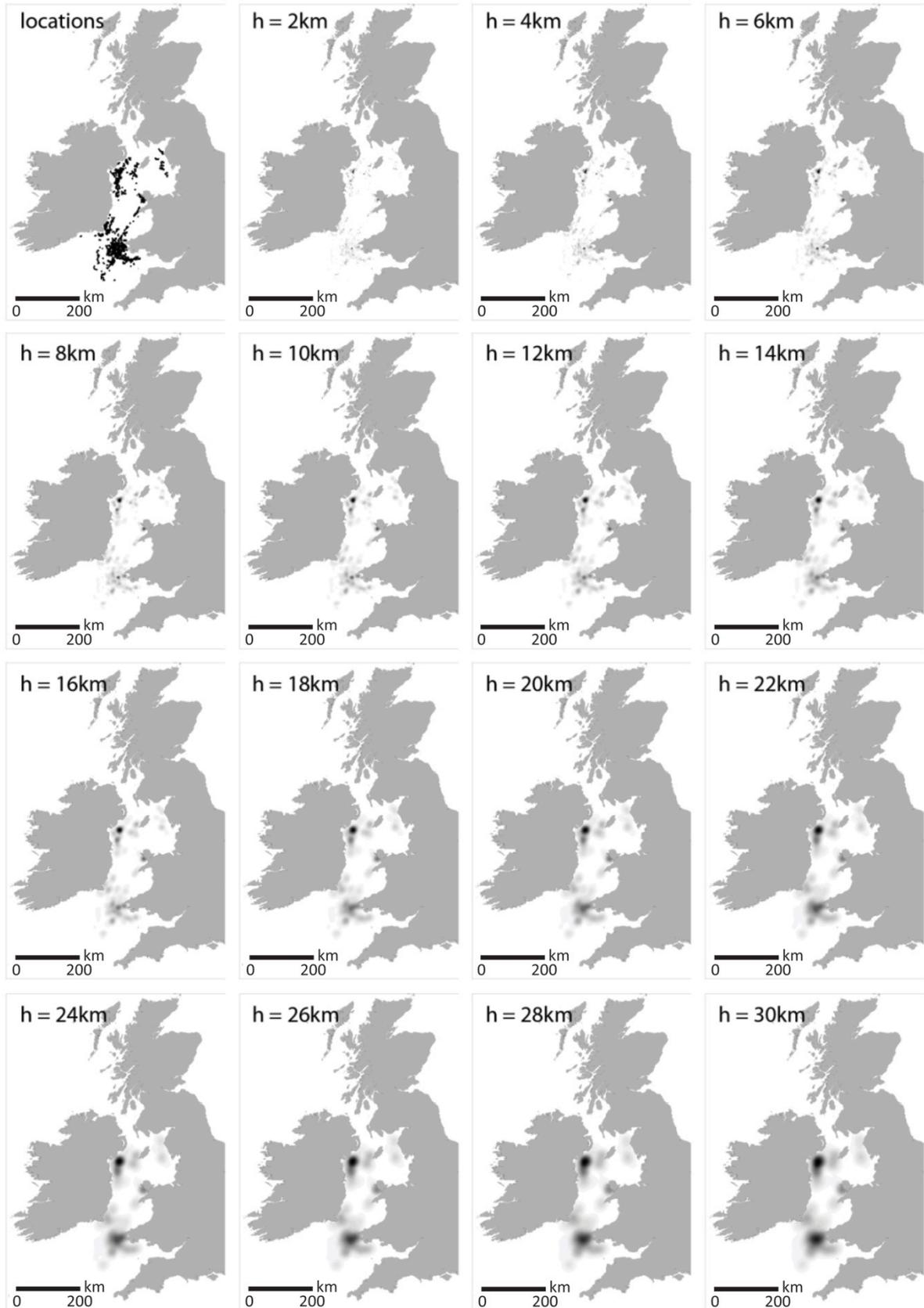


Figure S4. The top-left panel shows all foraging locations for birds tracked from Skomer during chick-rearing 2009. The subsequent panels show kernel density foraging-range estimates for the same data using progressively increasing values for h (2–30 km). Areas of low densities are light grey, areas of high density are black. This figure illustrates the effect of the choice of h on the resulting estimates. Low values do not result in contiguous range estimates, while large values result in over-smoothed estimates with relatively high densities in areas where no birds were recorded. A smoothing factor value of 16 km was chosen in this study to give contiguous range estimates without oversmoothing (Kie 2013), and was very similar to that selected using cross-validation by Dean et al. (2012).

Excluded trips

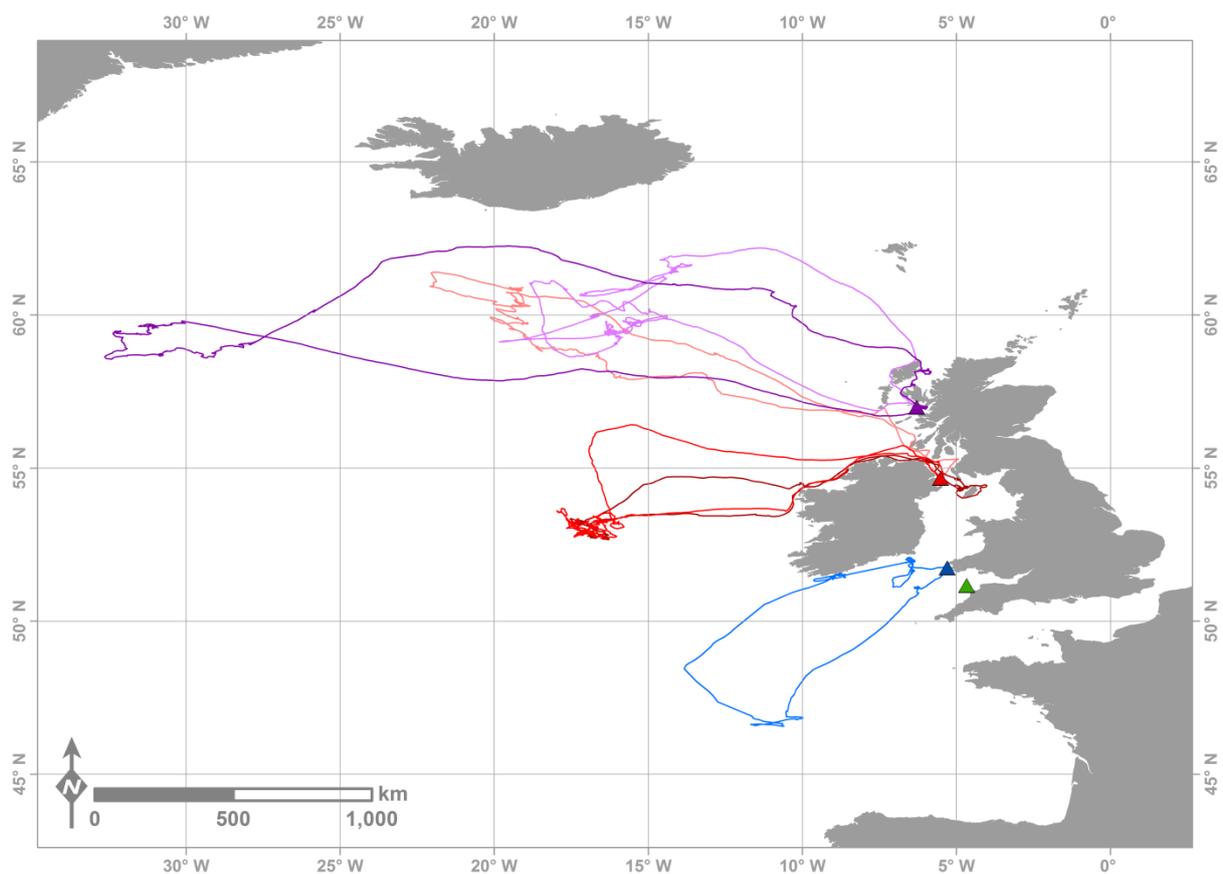


Figure S5. Six very long-distance offshore trips into the Atlantic: two from Rum, three from Copeland and one from Skomer. These were excluded from the analysis as outliers because they (i) probably represent a different kind of rare foraging event, and (ii) for practical reasons they would distort the analyses.

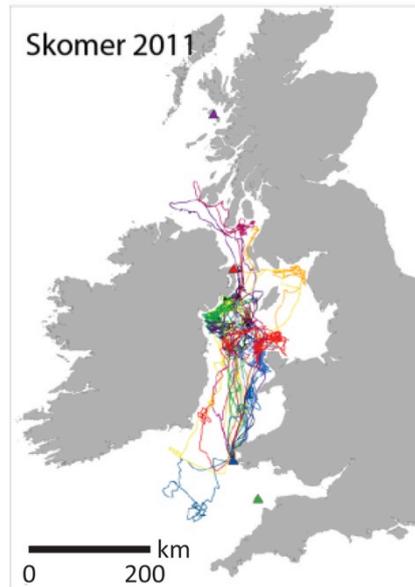
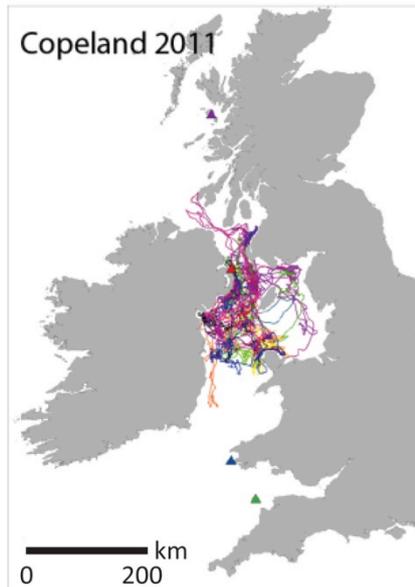
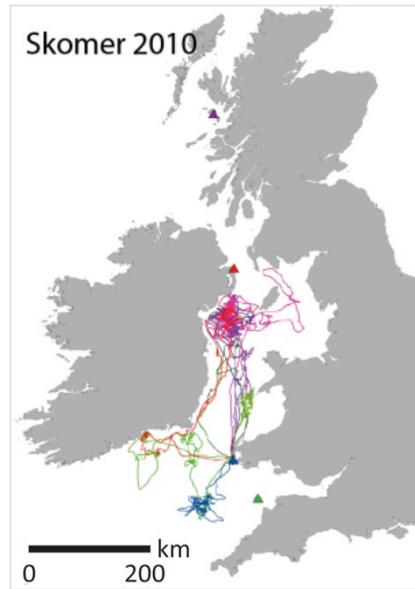
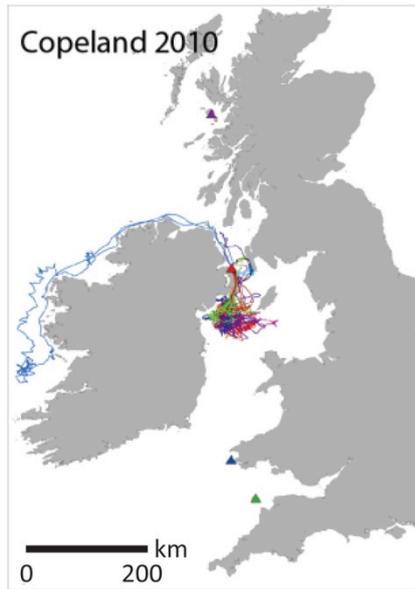
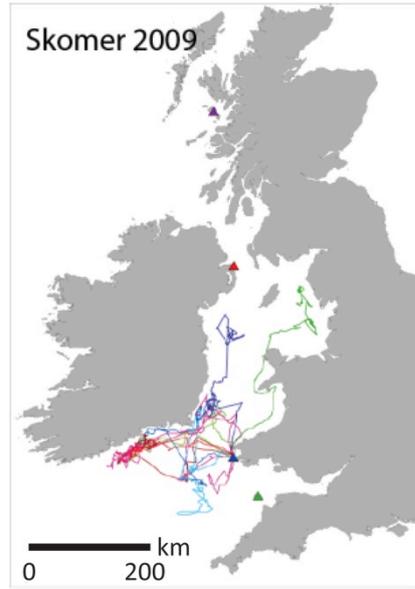
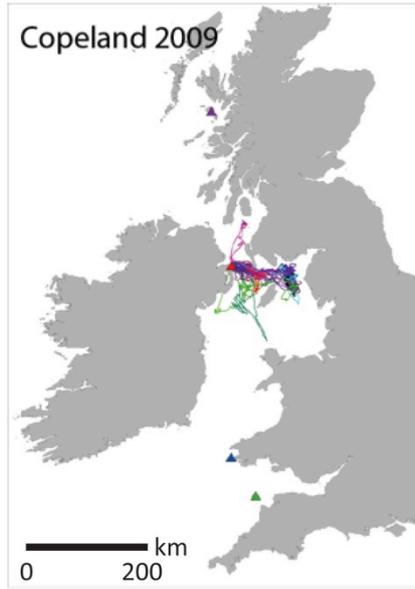


Figure S6. All foraging trips recorded during incubation from each of the two colonies in each year: Copeland (red triangle), Skomer (blue triangle). Trips coloured by individual (some colours re-used).

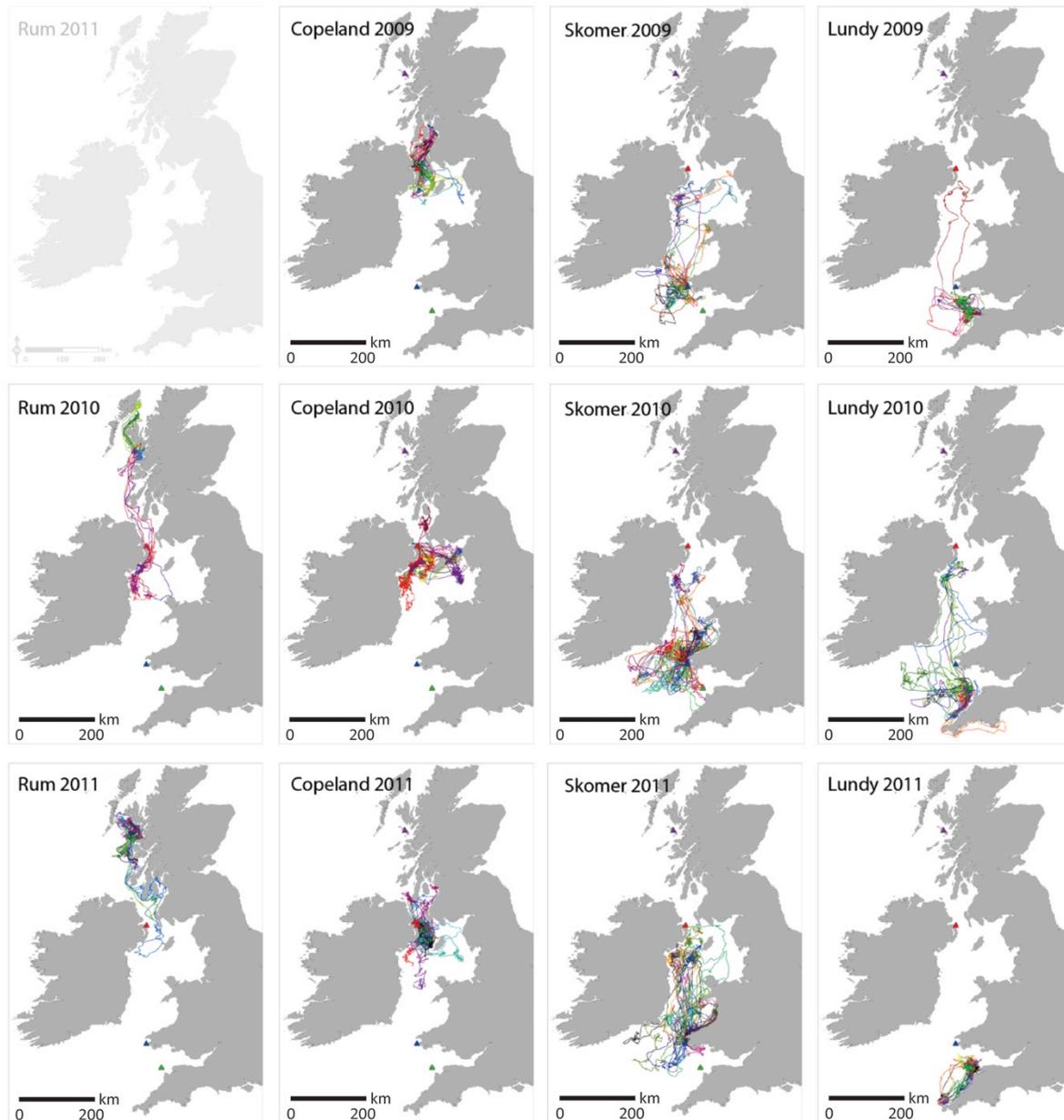


Figure S7. All foraging trips recorded during chick-rearing from each of the four colonies in each year: Rum (purple triangle), Copeland (red triangle), Skomer (blue triangle) and Lundy (green triangle). Trips coloured by individual (some colours re-used).

Literature Cited

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