Desk-based revision of seabird foraging ranges used for HRA screening

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Summary

The recently announced Offshore Wind Leasing Round 4 will play a key role in meeting government targets to generate 30% of energy from offshore wind by 2030. However, offshore wind farms may have a negative impact on seabird populations and, a plan-level Habitats Regulations Assessment may be required in order to ensure there is no risk of adverse effects on designated SPAs that form part of the Natura 2000 network. A key first step in the screening process for any HRA is understanding the potential interactions between seabird breeding colonies and the proposed development areas. This is typically assessed based on generic foraging ranges from the review of Thaxter *et al.* (2012) as well as other evidence such as from additional tracking studies, in particular where these relate to specific colonies of interest. These foraging ranges can be used to highlight potential connectivity between breeding colonies and offshore wind farms and, therefore, the potential for any negative population-level effects.

Thaxter *et al.* (2012) reviewed foraging ranges for 25 seabird species as a preliminary tool for identifying potential Marine Protected Areas. However, since their review was published, there has been a significant growth in seabird tracking studies with technological improvements making it possible to track a wider range of species. This resulting increase in the volume of data available – both in terms of the number of individual birds and the number of colonies from which tracking data originate – has the potential to enable more robust and representative assessments of species' foraging ranges, thereby reducing uncertainty in assessments and consenting risks. In addition to published foraging ranges sourced from the literature reviews, data from the RSPB FAME, RSPB STAR and BTO tracking datasets have also been considered as part of this study, in order to ensure that the foraging range datasets for each species are as complete as possible. The focus of this project is on breeding season interactions with offshore wind farms. Incorporating these new data has meant that we are able to update estimates of foraging range and improve confidence in those assessments for a number of species.

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BACKGROUND

Globally, offshore wind farms are likely to play a key role in strategies to reduce our reliance on energy generated using fossil fuels (Toke 2011). The rapid growth in this sector is driven by falling costs, with the recently announced outcome from the Contracts for Difference Scheme providing support for six offshore wind farms for as little as £39.65 per MWh[1]. As costs fall, under the recently announced industrial strategy, the UK Government has set a target to generate 30% of the country's energy from offshore wind farms by 2030[2]. The next step in achieving these targets will be the recently announced Offshore Wind Leasing Round 4 which aims to deliver at least 7 GW of energy through projects in English and Welsh waters in coming years[3].

However, there are also concerns about the potential for offshore wind farms to negatively impact the environment, with the risk to seabirds receiving particular attention (Furness *et al.* 2013). The UK hosts internationally important populations of seabirds (Mitchell *et al.* 2004), many of which are designated features of sites protected under the European Union Birds[4] and Habitats Directives[5]. There are concerns about the potential consequences for these populations of collisions with turbines, the loss of habitat as a result of displacement and barrier effects resulting in elevated energy expenditure costs. There is an obligation under the EU Birds and Habitats Directives to ensure that these effects do not result in an adverse effect on the integrity of protected sites. Consequently, as part of a Habitats Regulations Assessment (HRA), it will be necessary to determine whether the developments proposed as part of Offshore Wind Leasing Round 4 may have a likely significant effect on populations within protected sites i.e. Special Protection Areas (SPA).

Understanding the potential overlap between seabird breeding colonies and the development areas identified as part of the Offshore Wind Leasing Round 4 is a key first step in the screening process for the plan-level HRA. In the past, such assessments have been based on the representative foraging ranges identified in the review of Thaxter *et al.* (2012), and data from other relevant sources. These foraging ranges are applied as a buffer to the breeding colony of interest in order to assess whether they overlap with proposed offshore wind farms. This process can be used to highlight potential connectivity between breeding colonies and offshore wind farms and, therefore, the potential for any negative population-level effects.

In Thaxter *et al.* (2012) estimates of species foraging range based on tracking data were assessed as providing the strongest evidence about the extent of habitat use around a breeding colony. This is because they provided a direct link between the colony concerned and the areas used at sea, as opposed to data from surveys from which it was only possible to draw inferences about links to nearby breeding colonies. The review highlighted a number of species, such as red-throated diver, razorbill and great skua, which have been highlighted as being sensitive to offshore wind farms (Furness *et al.* 2013; Garthe & Huppop 2004), for which extremely limited data were available. Such limited data to assess overlaps between offshore wind farms and seabird breeding colonies

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[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/832924/Contracts_for_Difference_CfD_Allocation_Round_3_Results.pdf

[2] https://www.gov.uk/government/news/offshore-wind-energy-revolution-to-provide-a-third-of-all-uk-electricity-by-2030

[3] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2019-the-crown-estate-launches-the-uk-s-first-major-offshore-wind-leasing-round-in-a-decade-opening-up-the-opportunity-for-at-least-7gw-of-new-clean-energy/

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0147

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043

can add to uncertainty in the consenting process which, in turn, can add delays and costs to the industry and, may lead to over-precaution in assessments (Masden *et al.* 2015). It is important to note that this approach is applicable during the breeding season when birds are constrained by their need to provision for chicks, but is not applicable at other times of year.

Since the review was published, seabird tracking technology has advanced considerably (e.g. Bouten *et al.* 2013) meaning that we are able to track a wider range of species whilst remote download capabilities mean that we no longer have to recapture birds in order to recover data. The resulting increase in the volume of data available – both in terms of the number of individual birds and the number of colonies from which tracking data originate – has the potential to enable more robust and representative assessments of species' foraging ranges, thereby reducing uncertainty in assessments and consenting risks.

In order to address this, this project seeks to review the published literature in order to identify studies that may enable us to update published foraging range estimates for UK breeding seabirds considered to be vulnerable to the impacts associated with offshore wind farms. We also consider data from the RSPB FAME and STAR[6] and BTO tracking datasets and identify other potential sources of data in consultation with stakeholders.

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[6] https://www.rspb.org.uk/our-work/conservation/projects/tracking-seabirds-to-inform-conservation-of-the-marine-environment/

METHODS/APPROACH

Literature review

Thaxter *et al.* (2012) reviewed foraging ranges for 25 seabird species as a preliminary tool for identifying potential Marine Protected Areas, covering all studies published up to, and including 2010. This review incorporated studies, data and information from across the globe, and was not restricted to the UK. A full literature review was therefore undertaken to search for studies undertaken since 2010 for these 25 species. A search covering all years was undertaken for great black-backed gull and black guillemot, which were not included in Thaxter *et al.* (2012), making a total of 27 species covered (Table 1). These species have been selected due to their potential vulnerability to offshore renewable developments (Garthe & Hűppop 2004; Furness *et al.* 2012; Furness *et al.* 2013 Table 1), their status as Special Protection Area (SPA) designated features, or both.

Table 1: List of species covered by this review, and vulnerability scores from previous assessments relating to marine renewables. The vulnerability scores for wind farms are from Garthe & Hűppop (2004), and those for tidal turbines and wave engine devices from Furness *et al.* (2012). Note that the scores are based on different scales: the highest value in each column is shown in bold. The verbal description from "High" to "Very Low" given in parentheses is as reported by Furness *et al.* (2012). Garthe & Hűppop (2004) did not make a similar assessment. Note that for some species (e.g. divers and seaducks) vulnerability may reflect wintering rather than breeding season distributions.

Species Name	**Scientific Name**	**Wind Farm vulnerability** (Garthe & Hűppop)	**Wind Farm vulnerability – Displacement** (Furness *et al.* 2013)	**Wind Farm vulnerability – Collision** (Furness *et al.* 2013)	**Wind Farm vulnerability – Disturbance/ Displacement** (Wade *et al.* 2016)	**Wind Farm vulnerability – Collision** (Wade *et al.* 2016)	**Tidal turbine vulnerability** (Furness *et al.* 2012)	**Wave engine device vulnerability** (Furness *et al.* 2012)
Common eider	*Somateria mollissima*	20.4	16	117	20	39	1.5 (Low)	130 (Low)
Red-throated diver	*Gavia stellata*	**43.3**	**32**	213	**40**	60	3.8 (Moderate)	**288** (Moderate)
European storm petrel	*Hydrobates pelagicus*	NA	2	91	3	45	0.5 (Very Low)	68 (Very Low)
Leach's storm petrel	*Oceanodroma leucorhoa*	NA	2	85	3	43	0.5 (Very Low)	64 (Very Low)
Northern fulmar	*Fulmarus glacialis*	5.8	2	48	3	0	0.5 (Very Low)	80 (Very Low)
Manx shearwater	*Puffinus puffinus*	NA	2	0	3	0	1.5 (Low)	102 (Low)
Northern gannet	*Morus bassanus*	16.5	3	725	9	159	1.4 (Low)	136 (Low)
European shag	*Phalacrocorax aristotelis*	NA	14	150	11	60	9.6 (High)	165 (Low)
Great cormorant	*Phalacrocorax carbo*	23.3	13	103	8	231	7.0 (High)	110 (Low)
Black-legged kittiwake	*Rissa tridactyla*	7.5	6	523	8	229	0.9 (Very Low)	98 (Very Low)
Black-headed gull	*Chroicocephalus ridibundus*	7.5	5	288	7	144	0.6 (Very Low)	60 (Very Low)

Species Name	**Scientific Name**	**Wind Farm vulnerability** (Garthe & Hűppop)	**Wind Farm vulnerability – Displacement** (Furness *et al.* 2013)	**Wind Farm vulnerability – Collision** (Furness *et al.* 2013)	**Wind Farm vulnerability – Disturbance/ Displacement** (Wade *et al.* 2016)	**Wind Farm vulnerability – Collision** (Wade *et al.* 2016)	**Tidal turbine vulnerability** (Furness *et al.* 2012)	**Wave engine device vulnerability** (Furness *et al.* 2012)
Mediterranean gull	*Ichthyaetus melanocephalus*	NA	NA	NA	NA	NA	NA	NA
Common gull	*Larus canus*	12	5	598	8	390	0.7 (Very Low)	65 (Very Low)
Great black-backed gull	*Larus marinus*	18.3	6	1225	8	578	1.0 (Very Low)	75 (Very Low)
Herring gull	*Larus argentatus*	11	3	**1306**	5	579	0.8 (Very Low)	48 (Very Low)
Lesser Black-backed Gull	*Larus fuscus*	13.8	3	960	5	**608**	0.7 (Very Low)	64 (Very Low)
Sandwich tern	*Thalasseus sandvicensis*	25	9	245	12	263	1.1 (Low)	125 (Low)
Little tern	*Sternula albifrons*	NA	10	212	13	61	0.7 (Very Low)	156 (Low)
Roseate tern	*Sterna dougallii*	NA	9	175	12	105	1.0 (Very Low)	135 (Low)
Common tern	*Sterna hirundo*	15	8	229	11	65	0.6 (Very Low)	126 (Low)
Arctic Tern	*Sterna paradisaea*	13.3	10	198	14	79	1.9 (Low)	153 (Low)
Great skua	*Stercorarius skua*	12.4	3	320	5	224	0.7 (Very Low)	96 (Very Low)
Arctic skua	*Stercorarius parasiticus*	10	3	327	4	163	0.6 (Very Low)	84 (Very Low)
Common guillemot	*Uria aalge*	12	14	37	24	0	9.0 (High)	176 (Low)
Razorbill	*Alca torda*	15.8	14	32	24	0	9.6 (High)	192 (Low)
Black guillemot	*Cepphus grylle*	NA	16	30	20	0	**9.9** (High)	169 (Low)
Atlantic puffin	*Fratercula arctica*	15	10	27	19	0	3.8 (Moderate)	160 (Low)

The literature review was undertaken using two search engines, *Web of Science*[7] and *Google Scholar*[8]. In each search engine, a search was undertaken for each species using the following search term:

("Species name" OR "Scientific name" OR "Alternative species name(s)") AND (foraging OR distance OR range OR GPS OR telemetry OR "boat survey" OR "aerial survey").

Studies or web pages identified by this search were reviewed manually during an initial review, and saved for further more detailed review where it was considered possible or likely that they may include foraging range data based on the abstract or an initial scan of the paper. In the case of *Web of Science*, which searches peer-reviewed journals, all studies identified during the search for each species were assessed during this initial review, ranging from six studies (for Mediterranean gull) to 198 studies (for northern gannet). However, *Google Scholar* searches have a much wider scope, including 'grey literature', blogs and other non peer-reviewed websites; hence resulted in a much larger number of 'hits', up to a maximum of 18,200 (for common guillemot). Therefore *Google Scholar* searches were sorted by "Relevance" in order to identify the hits most likely to contain foraging range data. For all species, at least the first 100 *Google Scholar* hits (five results pages) were then reviewed during an initial review and saved where appropriate for further more detailed review. Additional results pages were reviewed for some species, with the decision on whether to review additional pages based on the results of the first 100.

On completion of the initial literature search the Steering Group was provided with a complete list of the publications which were identified as being of potential relevance to this review. A small number of additional studies which had not been found by the initial literature search were identified through the working group or through contacting seabird researchers directly, e.g. 'grey' literature or papers in press but not yet published.

Initial data extraction from literature

Prior to data extraction, the list of potentially relevant publications was reviewed and any studies using data available to this review from the RSPB FAME and STAR datasets or from BTO datasets were excluded (see below). All remaining studies were reviewed closely to ascertain whether or not they contained foraging range data and, where appropriate, to extract any relevant data.

Following Thaxter *et al.* (2012), data were extracted from published studies and assigned to one of four categories (Table 2). In addition to advances in tagging technology, there have also been significant advances in analytical approaches since Thaxter *et al.* (2012). These include the use of Habitat Association Models and Hidden Markov Models which can be used to better quantify birds' locations and behaviour from tracking data (e.g. Dean *et al.* 2013). Consequently, the 'Direct' category was initially further split into studies where data have been modelled ('Direct Modelled') in order to produce more refined estimates of foraging areas, and those studies in which raw (i.e. observed) tracking data have been presented ('Direct'). However, it became apparent that where modelling has been used within recent tracking studies it has normally been used to refine the identification of key foraging areas within reach of the colony, rather than to refine the foraging ranges themselves, often using observed foraging ranges to define the limits of the area to be

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[7] https://wok.mimas.ac.uk/
[8] https://scholar.google.com/intl/en/scholar/about.html

modelled. For the purposes of this study, therefore, the 'Direct Modelled' category has not been retained. Although these modelled data have not been considered relevant here for the identification of representative foraging ranges to be used in the initial stages of HRA screening, these modelling approaches are likely to become increasingly important tools for latter stages of the process to enable identification of key protected areas within range of colonies.

Table 2: Categories to which data from published studies were assigned. For a more detailed description of these categories, see Thaxter *et al.* (2012).

Category	**Description**
Direct	Foraging ranges were obtained through direct attachment of devices such as VHF tags or GPS tags to individual seabirds, enabling precise measurement of seabird movements. This category also includes visual tracking of terns in boats equipped with a GPS device (Perrow *et al.* 2011).
Indirect	Foraging ranges were estimated indirectly using specific information from breeding colonies such as average trip duration. This category also includes foraging range estimates based on the attachment of geolocators to individual seabirds, as these devices have a much larger error than GPS tags and hence are not suitable for measuring precise geographical positions.
Survey	Foraging ranges were estimated using visual surveys of birds at sea, based on the assumption that the concentrations of birds observed are breeding birds which are associated with the nearest colony.
Speculative	Foraging range estimates were more speculative, e.g. based on habitat associations, ring recoveries or anecdotal speculation by the author.

From each study, we extracted information including the sample size for each species, the breeding stage at which foraging data were collected, if known (e.g. incubation, chick-rearing), and the maximum and mean foraging ranges recorded. In order to understand the uncertainty associated with the foraging ranges, where possible we also extracted information on the variance associated with the mean data (standard deviation or standard error).

In some studies, foraging range data were presented separately for certain subsets of data (e.g. annual foraging ranges, male/female foraging ranges, foraging ranges at different breeding stages). Where this was the case, we extracted the data for each subset, in addition to the combined foraging range (if aggregated data had also been presented in the paper).

In other studies, foraging ranges were not published, but the study included figures showing either foraging tracks or foraging areas presented as kernel density maps. In such cases, maximum foraging ranges have been estimated using these maps, with mean maximum foraging ranges also being estimated in a small number of studies which presented separate tracks for different individuals. These foraging range estimates were calculated using the scalebar shown on the map, where such a scale was shown. If no scalebar was shown on the map, geographical features on the map were used in order to estimate the scale. In order to ensure this estimate did not introduce substantial inaccuracies in foraging ranges estimates resulting from potential errors on the source maps (e.g. from an inaccurate scalebar or from the map projection), these estimates were also cross-checked against an estimate made using Google Maps Distance Calculator. Where these disagreed, the estimate based on Google Distance Calculator was used.

RSPB FAME & STAR and BTO datasets

Two of the most significant datasets collected since the completion of Thaxter *et al.* (2012) are the RSPB FAME and STAR datasets. Many of these data have been previously analysed in order to understand the foraging ranges of UK seabird species (e.g. Wakefield *et al.* 2017). The BTO also hold a substantial volume of data from their own tracking studies, in particular on lesser black-backed gulls and herring gulls (e.g. Thaxter *et al.* 2015; Thaxter *et al* 2018). BTO data included tracking data from lesser black-backed gulls for six UK breeding colonies (compared with just one UK colony included in direct estimates of Thaxter *et al.* 2012). These data spanned between three and five years per colony between 2010 and 2018. For herring gulls, data were available from two UK colonies from BTO and the RSPB FAME datasets combined. Data from these three sources have therefore been incorporated into the foraging range dataset. By extracting these data directly from the datasets rather than from published studies enables the data to be extracted in a consistent format specific to this study and allows annual data to be used where relevant in our analyses.

Whilst many of the data from these datasets have been published in peer-reviewed literature, these datasets include some unpublished foraging range data and, for some species, data from additional colonies, hence increasing the sample size available to this study both in terms of number of individuals tracked and also the number of colonies. This will help us to understand the variability in foraging range between individuals and how representative estimates of foraging ranges from one colony is of other colonies.

Data review and identification of duplicate data

If papers focus on different aspects of foraging behaviour, there is a risk that the same data may be presented in multiple papers. Consequently, the studies identified by the literature review were cross-checked against each other and against the studies previously identified by Thaxter *et al.* (2012) in order to ensure that each dataset is only included once. This included checking the study dates, locations, the number of individuals involved and, the type of devices used. Similarly, where studies have reported foraging ranges separately for different subsets of data, the data have been reviewed to exclude duplicate data.

As a result of the variation in the information reported by different studies, it has been necessary to follow a pragmatic approach to identify and remove duplication. As a general rule, published mean foraging ranges have been retained wherever possible in order to update representative foraging ranges, rather than recalculating mean values for a site, but calculation of new mean values has been necessary where studies do not publish aggregate figures, or where two or more studies published figures for the same site covering different years. Where two studies cover the same site and the same year(s) or where one study uses data which are clearly a subset of the data used in another study, data from the study with the larger sample size have usually been retained for our analysis. In such instances, the data from both studies have been included in the final foraging ranges dataset (Appendix 2) even though one set of data have been excluded from the analysis. However, where two datasets overlap slightly but the overlap only makes up a small proportion of both datasets, both studies have been retained, as the duplication cannot be removed without excluding a larger subset of data.

Data Analysis - Methodology

All data management and foraging range calculations were carried out in R version 3.5.1 (R Development Core Team 2019). Foraging range maps were produced using R package rgeos v0.5.1 (Bivand 2019) and graphs were produced using R package ggplot2 v3.0.0 (Wickham 2016).

Following data extraction and review, the data were analysed in order to update the recommended foraging ranges for each species. Following Thaxter *et al.* (2012), the highest quality data were prioritised for each species; hence, wherever possible, estimates are based on data from 'direct' studies only. Despite the advances in tracking technology, there are still no direct measurements of foraging ranges for some of the target species, and indirect or survey estimates are used for these species, as was the case in Thaxter *et al.* (2012).

For those species which were measured using the same data category as Thaxter *et al.* (2012), whether 'Direct', 'Indirect' or 'Aerial/Boat/Land Survey', most of the studies that contributed to the Thaxter *et al.* (2012) estimates have been re-used in the calculation of the updated estimates, along with more recent studies identified during the literature review. However, a small number of the earlier studies have been excluded from our calculations. Most notably, Thaxter *et al.* (2012) included observations of distances from the coastline in the foraging range calculation for some species, but we have chosen to exclude all such observations from the updated calculations, and only include foraging range estimates which are linked to a known colony during the breeding season and hence are more likely to relate to actively breeding birds.

The representative foraging ranges presented in this report were calculated as follows:

- Potential duplicate data were reviewed to ensure that, wherever possible, data from each individual were only included once in the analyses. As a rule, the highest aggregation level reported is retained, i.e. the combined foraging range data published for all individuals are used from each study if they were available. Where a combined figure for all individuals was not published, the published data from two or more unique subsets are retained.
- Mean and Maximum foraging ranges were initially calculated for each site/year combination. Where data from two or more different studies, or from two or more unique subsets from the same study, related to the same site/year, a weighted mean foraging range value was calculated for that site/year, with the sample size (number of birds) used as the weighting variable.
- The Mean and Maximum foraging ranges for each site/year combination were then combined to calculate single Mean and Maximum foraging ranges for each site. Again, for sites with data covering more than one year, a weighted mean foraging range value was calculated, again using the sample size as the weighting. Finally, the Mean and Maximum foraging ranges for each site were used to calculate three foraging range metrics described in Table 3.

Table 3: Foraging range measures presented in this paper:

Measure	**Description**
Max Max	The maximum foraging range from all studies reviewed.
Mean Max	The maximum range reported for each colony, averaged across all colonies.
Mean	The mean foraging range reported for each colony, averaged across all colonies.

The relevant data were extracted from the additional RSPB and BTO tracking datasets to match those metrics derived from the wider literature. Further information on number of birds tracked in given years was also obtained.

For lesser black-backed gull and herring gull, additional complications arose through inclusion of inland data that could potentially bias foraging range estimates for contextualising the offshore environment – we therefore excluded inland data estimates where possible by only taking maximum foraging range information from trips of birds at each colony per year when they entered the marine environment. The RSPB FAME and STAR tracking data came from individuals of known breeding status. However, for the BTO datasets of lesser black-backed gull and herring gull, these did not include precise periods of breeding (incubation or chick-rearing) as in nearly all colonies, monitoring of nests is hampered by difficulty in observing nesting status reliably without disturbance, with further obstacles of visibility to nests often being obstructed through vegetation, or the inability to relocate the precise nests of tagged birds in subsequent years. As a result, the tracking data for large gulls also included many pre-breeding and post-breeding movements. The focus for this report is the breeding season; consequently, incorporating these data may bias estimates of species foraging range. Therefore, we adopted a bespoke methodology for these data to remove foraging trips from individual birds that may not have been representative of breeding season central-place foraging behaviour.

We first estimated the mean lay date, and minimum and maximum egg hatching and 'fledging' date for each colony, based on known hatching dates of the colony, and known incubation and chick-rearing periods for the species (see Thaxter *et al.* 2015 for more details on this method). This enabled potential breeding periods to be defined, within which we then considered the duration of foraging trips as indicative of likely breeding/non-breeding delineation – we considered trips longer than 1.5 days in duration were unlikely to be representative of an adult attending a nest, but also leaving leeway in the approach for birds making excessively long trips, e.g. due to potential food shortage. We then assumed that a consecutive period of trips less than 1.5 days within the breeding period represented central-place foraging for active nests. Should a trip then suddenly exceed 1.5 days, this was considered a likely breeding failure, even if there were trips after this point below 1.5 days – the same was true for trips leading up to the start of breeding within the defined breeding periods based on dates above. The combination of filters reduced the dataset to more realistic approximation of breeding season foraging range for large gulls.

Uncertainty and presentation of foraging range information

It is desirable to present estimates of foraging ranges with some uncertainty around them. In order to estimate the uncertainty around the final estimate, the standard deviation has therefore also been calculated for the Mean Max and Mean foraging ranges estimates for each species. In both cases, this calculation is based on the final point estimates for each site.

In order to present the uncertainty graphically, three different graphs have been produced for all species for which there are data from more than five colonies, as follows:

(1) Boxplots have been produced to show the variability in the site mean foraging range estimates.

(2) Scatterplots have been produced to compare the maximum and mean foraging range estimates from different colonies. To aid interpretation, lines have been added to the plots to represent how close the mean estimate is to the maximum value (25%, 50% and 75%), and

the size of the points have been weighted by sample size.

(3) Graphs have been produced to show how the mean and maximum foraging range estimates have changed over time. For each estimate, cumulative foraging ranges are shown, i.e. the estimates for each year are based on the available data from studies which ended in that year or earlier. The cumulative mean foraging range estimates are weighted by sample size.

Confidence estimates

An assessment about our confidence in the foraging range estimate has been made for each species (Table 4). This assessment is subjective, as was the case in Thaxter *et al.* (2012), where the confidence level is mostly based on the measurement category (Table 2) and sample sizes of studies available, but with further adjustments to these levels in special cases using numbers of individuals contributing data. Although the measurement category and sample size both remain important in the updated confidence assessments, a much larger number of studies are now available for many species, and we therefore have a better understanding of the variability in foraging ranges as presented in the boxplots and scatterplots. In the current study, the confidence assessments are therefore updated from Thaxter *et al.* (2012) to take this variability into account, with an additional category of "Good" also inserted between "Highest" and "Moderate" to add increased resolution to the scale of confidence based on this variability (Table 4). As a consequence, a higher sample size does not necessarily lead to a higher confidence assessment for directly measured estimates.

Table 4 Description of the confidence categories normally used in this report. *Note however that for some species the confidence level has been upgraded or downgraded as a result of additional information available about the foraging ranges. In such instances, reasons for the change are given in the footnotes to Table 5 and in the Further Information section in Appendix 1 (the Species Accounts).*

Confidence Category	Description
Highest	> 5 direct studies; graphs and standard deviation suggest relatively low variability between sites and hence higher confidence that estimates are likely to be representative for unsampled sites.
Good	> 5 direct studies; graphs and standard deviation show wider variability between sites, hence lower confidence that estimates will be representative for all sites.
Moderate	2-5 direct studies
Low	Indirect measures or only 1 direct study
Uncertain	Survey-based estimates
Poor	Few survey estimates or speculative only

RESULTS

Although less than ten years have passed since the publication of representative foraging ranges by Thaxter *et al.* (2012), a large number of direct tracking studies have subsequently been undertaken following advances in technology. We present summarised estimates of species foraging ranges and a comparison with the estimates from Thaxter *et al.* (2012) in table 5 and, individual accounts for each species in Appendix 1. As a consequence of the growth in tracking studies, the foraging ranges dataset (Appendix 2) holds more than double the number of records than the dataset that was available to Thaxter *et al.* (2012). These advances have enabled higher, hence more robust, categories of study data to be used for five species (European storm petrel, Leach’s storm petrel, little tern, roseate tern, black guillemot and puffin), and also increased the sample size for many other species' estimates. As a result, our confidence in the representativeness of the updated foraging range estimate has improved for 12 of the 25 species assessed by Thaxter *et al.* (2012) (Table 5).

Table 5: Comparison of the updated foraging ranges with those of Thaxter *et al.* (2012). The foraging range measures and categories are as described in Tables 3 and 2 above respectively. For Mean Max and Mean values the error is presented as ± SD and the sample sizes are shown in parentheses (i.e. the number of sites from which maximum or mean foraging ranges were available). Shading indicates a change from Thaxter *et al.* (2012). Green indicates an increase in value or category and blue indicates a decrease in value or category.

Species	Thaxter *et al.* (2012)					Updated foraging ranges (Current study)				
	Max (km)	Mean Max (km)	Mean (km)	Category	Confidence	Max (km)	Mean Max (km)	Mean (km)	Category	Confidence
Common eider	80	80 (1)	2.4 (1)	All data	Poor	22.5[J]	21.5 (1)[J]	3.2±4.2 (3)[J]	Indirect	Poor
Red-throated diver	9	9 (1)	4.5 (1)	Direct	Low	9	9 (1)	4.5 (1)	Direct	Low
European storm petrel	>65	-	-	Survey	Poor	336	336 (1)	NA	Direct	Poor
Leach's storm petrel	<120	91.7±27.5 (3)	-	All data	Poor	NA[J]	NA[J]	657 (1)[J]	Direct	Moderate[E]
Northern Fulmar	580	400±245.8 (3)	47.5 (2)	Direct	Moderate	2736	542.3±657.9 (16)	134.6±90.1 (11)	Direct	Good
Manx shearwater	>330[B]	>330 (1)[B]	2.3 (3)[A]	Direct	Moderate	2890	1346.8±1018.7 (6)	136.1±88.7 (4)	Direct	Moderate
Northern Gannet	590	229.4±124.3 (7)	92.5±59.9 (8)	Direct	Highest	709	315.2±194.2 (21)	120.4±50 (19)	Direct	Highest
European shag	17	14.5±3.5 (2)	5.9±4.7 (3)	Direct	Moderate	46	13.2±10.5 (17)	9.2±4.9 (17)	Direct	Highest
Cormorant	35	25±10 (3)	5.2± 1.5 (3)	Direct	Moderate	35	25.6±8.3 (4)	7.1±3.8 (4)	Direct	Moderate
Black-legged Kittiwake	120	60±23.3 (6)	24.8±12.1 (8)	Direct	Highest	770	156.1±144.5 (37)	54.7±50.4 (37)	Direct	Good[I]
Black-headed gull	40	25.5±20.5 (2)	11.4±6.7 (4)	Survey	Uncertain	18.5	18.5 (1)	7 (1)	Direct	Uncertain
Mediterranean gull	20	20 (1)	11.5 (1)	Survey	Uncertain	20	20 (1)	11.5 (1)	Survey	Uncertain
Common gull	50	50 (1)	25 (1)	Survey	Poor	50	50 (1)	NA[C]	Survey	Poor
Great black-	NA	NA	NA	NA	NA	73	73 (1)	16.7 (1)	Direct	Low

Species	Thaxter *et al.* (2012)					Updated foraging ranges (Current study)				
	Max (km)	Mean Max (km)	Mean (km)	Category	Confidence	Max (km)	Mean Max (km)	Mean (km)	Category	Confidence
backed gull										
Herring gull	92	61.1±44 (2)	10.5 (1)	Direct	Moderate	92	58.8±26.8 (10)	14.9±7.5 (7)	Direct	Good
Lesser black-backed gull	181	141±50.8 (3)	71.9±10.2 (2)	Direct	Moderate	533	127±109 (18)	43.3±18.4 (16)	Direct	Highest
Sandwich tern	54	49±7.1 (2)	11.5±4.7 (3)	Direct	Moderate	80	34.3±23.2 (9)	9±9.2 (9)	Direct	Moderate[F]
Little tern	11	6.3±2.4 (6)	2.1 (3)	Survey	Low	5	5 (1)	3.5 (1)	Direct	Moderate[G]
Roseate tern	30	16.6±11.6 (6)	12.2±12.1 (6)	Survey	Low	24	12.6±10.6 (3)	4.1±2.6 (2)	Direct	Moderate
Common tern	30	15.2±11.2 (6)	4.5±3.2 (5)	Direct	Moderate	30	18.0±8.9 (16)	6.4±4.5 (10)	Direct	Good
Arctic tern	30	24.2±6.3 (4)	7.1±2.2 (3)	Direct	Moderate	46	25.7±14.8 (9)	6.1±4.4 (6)	Direct	Good
Great skua	219[B]	86.4 (1)[B]	-	Direct	Low	1003	443.3±487.9 (3)	67±31.5 (2)	Direct	Uncertain[H]
Arctic skua	75	62.5±17.7 (2)	6.4±5.9 (5)	Survey	Uncertain	NA[D]	NA[D]	2±0.7 (2)[D]	Survey	Poor[D]
Common guillemot	135	84.2±50.1 (5)	37.8±32.3 (5)	Direct	Highest	338	73.2±80.5 (16)	33.1±36.5 (16)	Direct	Highest
Razorbill	95	48.5±35.0 (4)	23.7±7.5 (2)	Direct + indirect	Moderate	313	88.7±75.9 (16)	61.3±33.4 (18)	Direct	Good
Black guillemot	NA	NA	NA	NA	NA	8	4.8±4.3 (2)	4.9 (1)	Direct	Moderate[G]
Atlantic puffin	200	105.4±46.0 (8)	4 (1)	Indirect	Low	383	137.1±128.3 (7)	62.4±34.4 (7)	Direct	Good

[A] For Manx shearwater, the mean estimate Thaxter *et al.* (2012) is from a study focusing on near-colony rafting birds, and hence is likely to be a substantial under-estimate

[B] Two estimates were presented by Thaxter *et al.* (2012), and the larger total foraging range estimates are shown here.

[C] The mean foraging range for common gull from Thaxter *et al.* (2012) has not been repeated here following a slightly different interpretation of the data.

[D] The estimates for Arctic skua presented in Thaxter *et al.* (2012) used data from three studies which have been dropped from our estimation as they measured distance from coast/shore/land rather than from a known breeding colony.

[E] Foraging ranges from seven sites using geolocators suggest that this direct foraging range for Leach's Petrel is likely to be reasonably robust even though it is based on data from only one site.

[F] Maximum and mean foraging distances from two GPS studies for Sandwich tern were substantially higher than previous estimates using visual tracking. These two studies are in close proximity to each other so this may be a site-effect, but it would be prudent to carry out further research to confirm this and hence the confidence level has been downgraded to "Moderate".

[G] Foraging ranges from observational surveys suggest that the foraging range estimates for little tern and black guillemot are likely to be robust even though based on only one direct study.

[H] Great Skua confidence has been assessed as "Uncertain" due to the substantial differences between the distances measured in the three direct studies.

[I] Black-legged Kittiwake confidence has been downgraded from "Highest" to "Good" due to evidence to strong variability in foraging range between sites.

[J] Data from Thaxter *et al.* (2012) excluded as these were drawn from shore-based counts

DISCUSSION

Comparison of foraging ranges with Thaxter *et al.* (2012)

For many species, including northern gannet, herring gull, common guillemot and four of the five tern species, the updated mean and mean max foraging range based on higher sample size were similar to the estimates previously reported in Thaxter *et al.* (2012), increasing our confidence that these estimates are reasonably robust. However for six species (northern fulmar, Manx shearwater, black-legged kittiwake, razorbill, Atlantic puffin and great skua) the increase in the number of birds tracked by GPS has resulted in updated foraging range estimates which are more than double the previous estimates presented. For Manx shearwater and northern fulmar, in particular, recent GPS tracking has identified that actively breeding individuals can make journeys out into the mid north-Atlantic during incubation, travelling over 2,500 km away from their nest and leaving their partner for many days (Dean *et al.* 2015; Edwards *et al.* 2016). Distances travelled during the chick-rearing stage are often much shorter, and as a result the mean foraging distances are 136 km and 135 km respectively for the two species – which still represent substantial increases on the previous mean values. It is important to take these longer trips into account as they establish connectivity between an area and an SPA population.

A breeding lesser black-backed gull has also been tracked making an extremely long foraging trip, of 533 km (Camphuysen 2013). However in contrast to the studies of Manx shearwater and northern fulmar, which confirm that such long trips are common for these two species, the data suggest that such extreme trips are very unusual for lesser black-backed gull, and the estimate of the mean foraging distance has fallen from 72 km to 38 km for this species which has been the subject of many additional tracking studies since Thaxter *et al.* (2012). The only other species for which a substantial reduction in the mean foraging range estimate has occurred is roseate tern, for which the previous estimate of 12.2 km was based on survey data and included two studies with mean foraging distances of 25 km and 30 km (Heinmann 1992; Parkin 2004). The new estimate of 4.1 km, although calculated from a lower sample size, is based on the more robust method of directly tracking terns by boat and is closer to those for the related Common and Arctic terns (5.6 km and 6.1 km respectively) which are calculated from larger sample sizes. However further direct studies will be needed to confirm whether there are sites where foraging ranges for Roseate Tern are substantially higher. It should be noted that many of the studies relating to terns were carried out during the incubation and early chick-rearing periods, and that further data may be required from other parts of the breeding season in order to fully assess the species foraging ranges.

Representativeness of foraging ranges

The comparison between the current estimates and those from Thaxter *et al.* (2012) also highlights the problems inherent in using data from a relatively small number of studies or sites to produce representative foraging ranges. Three species were rated with the "Highest" confidence level in Thaxter *et al* (2012). While the updated mean foraging ranges for both northern gannet and common guillemot remain close to the previous estimates, the mean foraging range estimate for black-legged kittiwake has more than doubled from 24.8 km to 54.7 km. Data for black-legged kittiwake are available from more sites than any other species (37) and the boxplots show four outlying points (Figure 1) suggesting intra-specific foraging ranges can be highly variable between sites. Although the mean estimate for Common Guillemot has barely changed (from 37.8 km to 33.1 km), the boxplot suggests that, like black-legged kittiwake, mean foraging range estimates from individual sites can sometimes be much higher.

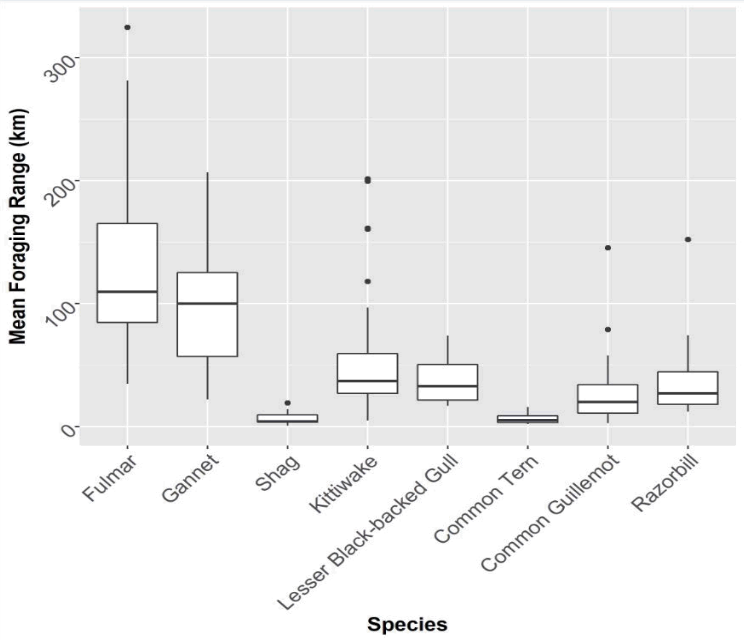
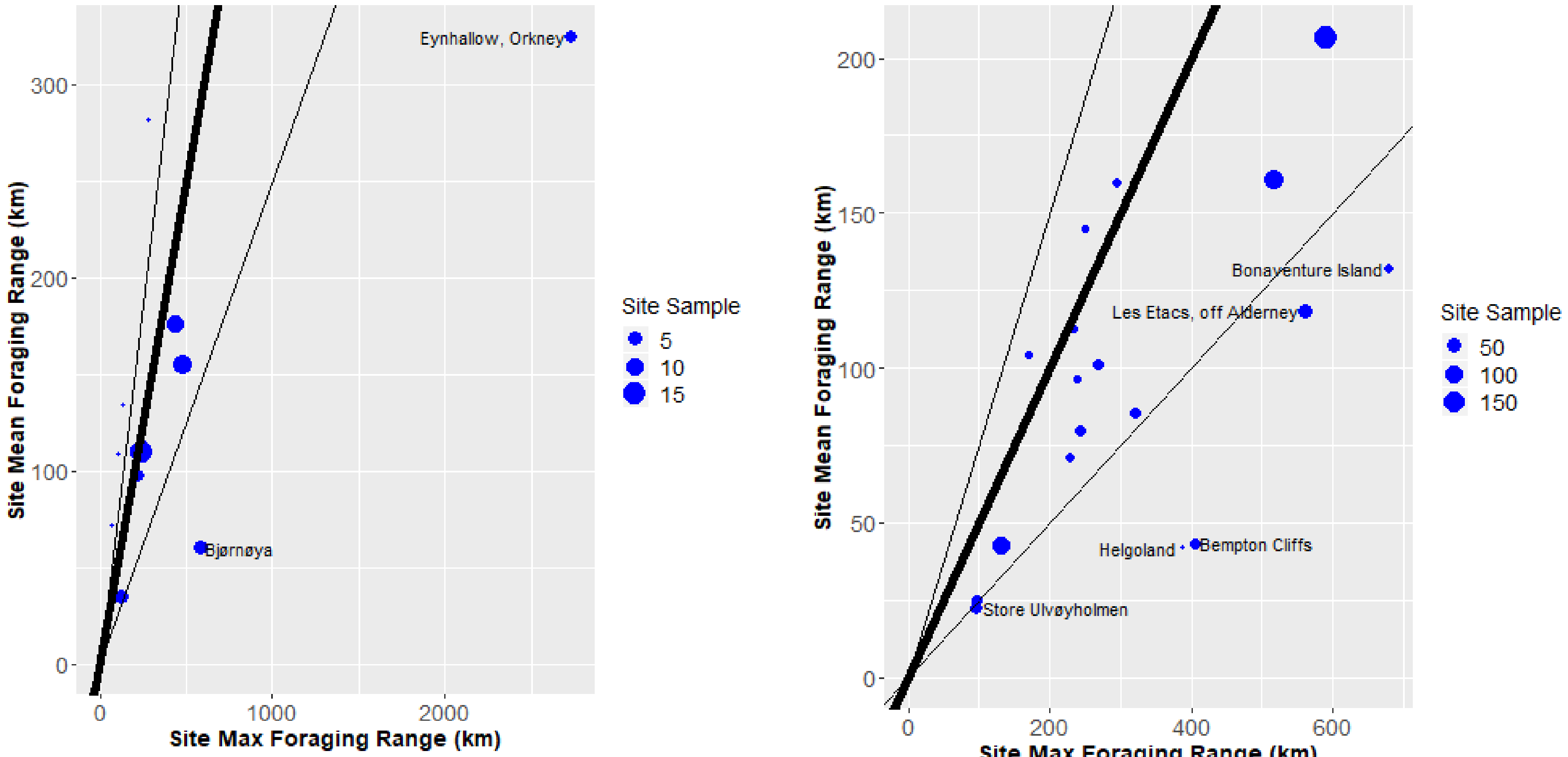


Figure 1: Boxplot showing the variation in the site mean foraging ranges. Species for which mean foraging ranges are available from ten or more colonies are shown.

For the other species for which we now have data from more than ten sites, the foraging range estimates for northern fulmar were more variable, with one outlier. This may be in part related to the fact that sample sizes from some of the sites are small, and also in part to the difficulty in measuring foraging ranges for a species which, like Manx shearwater, can travel nearly 3,000 km from the colony during the pre-laying period (Edwards *et al.* 2013, 2016; Dean *et al* 2015; Fayet *et al.* 2015; Wischnewski *et al.* 2019) and highlights the need for extra work on this species.

In contrast, the variation in foraging range estimates for lesser black-backed gull and European shag was relatively small, increasing our confidence that the updated estimates are robust. Whilst further studies would be valuable to confirm this assessment, ideally such studies should also collect data that can be used to assess the use of particular foraging areas within the range of the colony.

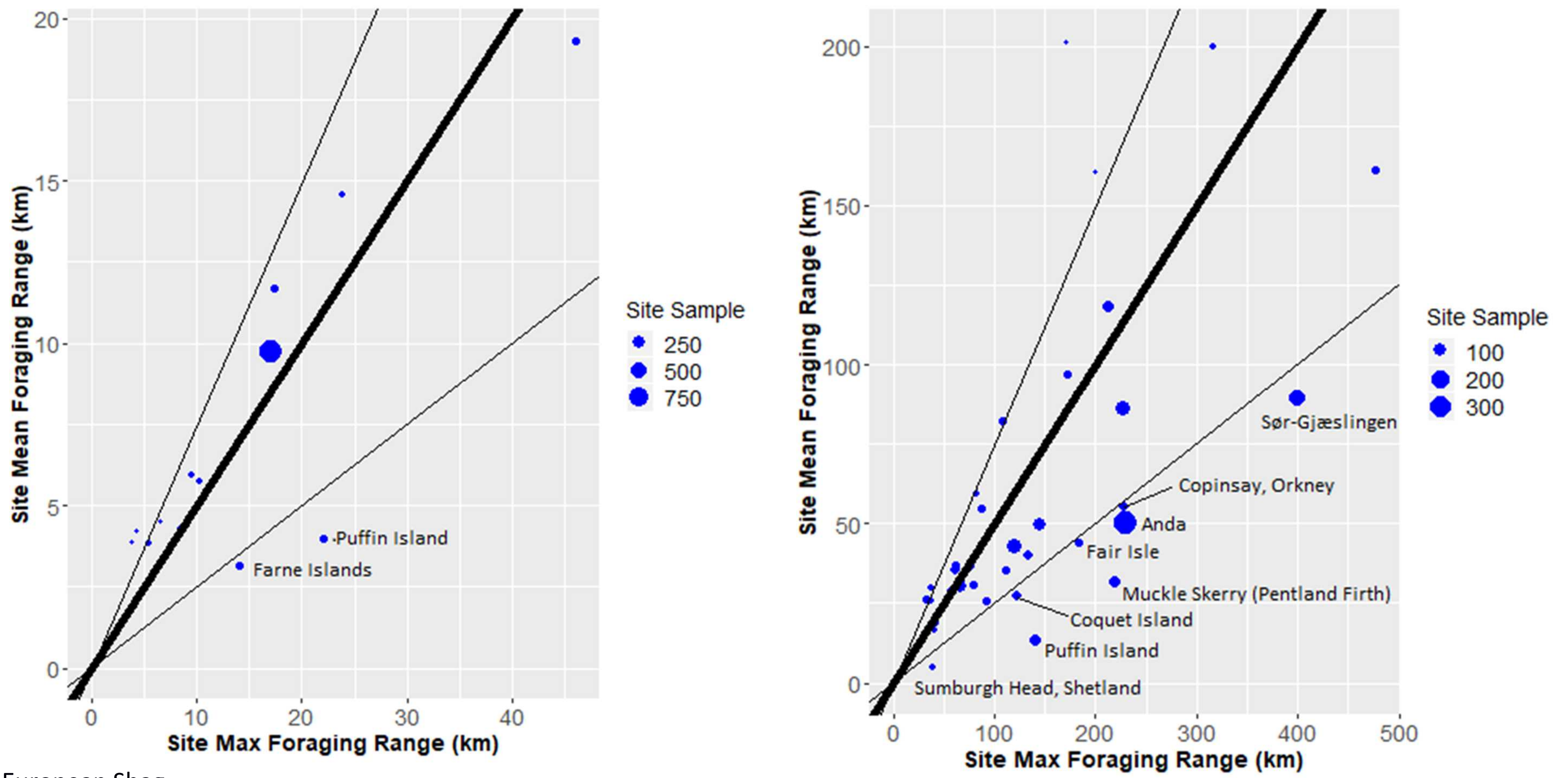
The regressions of mean versus maximum foraging ranges below (Figure 2) showed that the relationship between mean foraging ranges and maximum foraging ranges was consistent for most species and sites. As might be expected, the relationship appeared to be linear for most species, with sites with larger mean foraging distances often also having larger maximum foraging ranges, and in most cases the mean foraging range was between 25% and 75% of the maximum distance (Figure 2). Two species showed outlying points which are much further away from the lower (25%) reference line. The case of lesser black-backed gull has already been discussed above, and relates to what appears to be an exceptional foraging trip made by one individual at one site which therefore could justifiably excluded as abnormal. In contrast, further tracking should confirm whether or not the outlying point for northern fulmar is abnormal; the research to date is based on a relatively low sample size compared to other species, but suggests that very long trips may not be unusual as they have been recorded for several different individuals (Edwards *et al.* 2013, 2016). Although the points for most species were mostly concentrated within the reference lines, those for black-legged kittiwake were slightly more scattered, showing the greater variability that was evident in the boxplots (Figure 1). Further, as a note of caution, it should be acknowledged that occasionally in some studies, it was not always possible to be certain of breeding status when interpreting foraging range values from some colonies (although note in this study the efforts made for lesser black-backed gull to circumvent this risk). There is nonetheless potential for outliers of foraging range values that may be partly driven by non-breeding movements while birds are still associated with their breeding colony.



Northern Fulmar

Northern Gannet

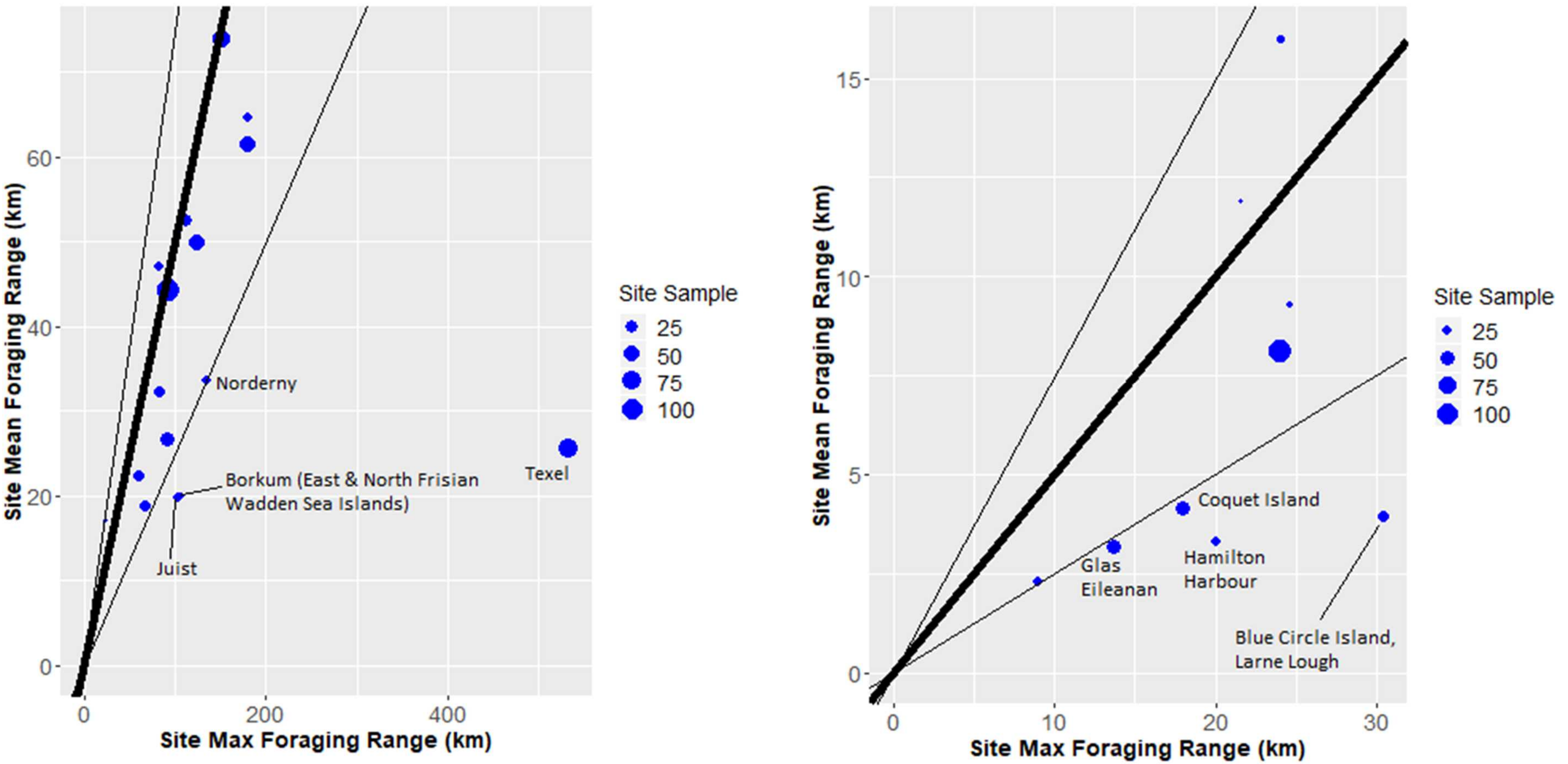
Figure 2: Scatterplots comparing the maximum and mean foraging range estimates from different colonies for species with data available from ten or more sites. Lines have been added to the plots to represent how close the mean estimate is to the maximum value (25%, 50% and 75%, with the 50% line shown in bold). The size of the points has been weighted by sample size. The site name is shown for points falling below the 25% line (i.e. sites where the maximum foraging range is more than four times higher than the mean foraging range).



European Shag

Black-legged Kittiwake

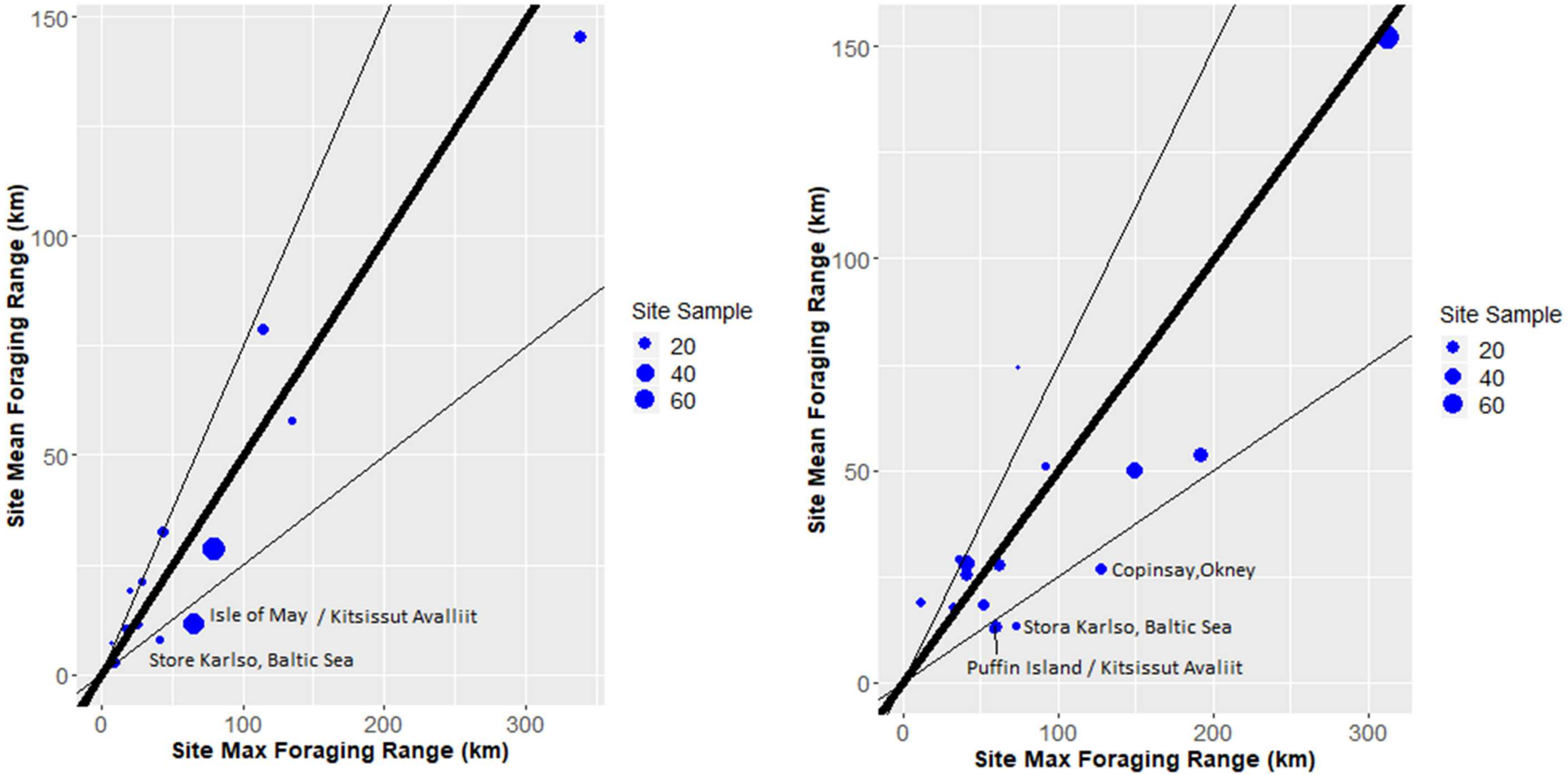
Figure 2 continued: Scatterplots comparing the maximum and mean foraging range estimates from different colonies for species with data available from ten or more sites. Lines have been added to the plots to represent how close the mean estimate is to the maximum value (25%, 50% and 75%, with the 50% line shown in bold). The size of the points has been weighted by sample size. The site name is shown for points falling below the 25% line (i.e. sites where the maximum foraging range is more than four times higher than the mean foraging range).



Lesser Black-backed Gull

Common Tern

Figure 2 continued: Scatterplots comparing the maximum and mean foraging range estimates from different colonies for species with data available from ten or more sites. Lines have been added to the plots to represent how close the mean estimate is to the maximum value (25%, 50% and 75%, with the 50% line shown in bold). The size of the points has been weighted by sample size. The site name is shown for points falling below the 25% line (i.e. sites where the maximum foraging range is more than four times higher than the mean foraging range).



Common Guillemot

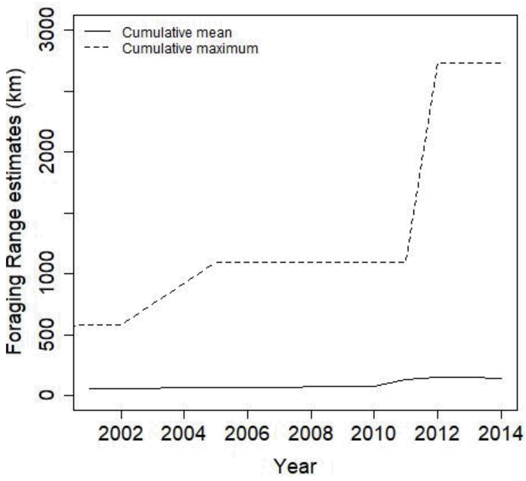
Note: the data point for Kitsissut Avalliit (sample 5) is hidden behind the point for Isle of May (sample 61)

Razorbill

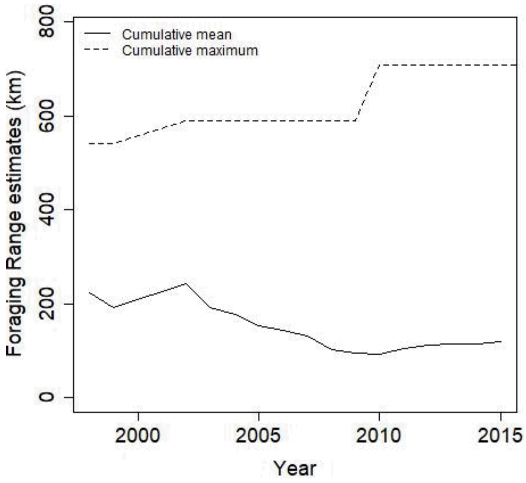
Note: the data point for Kitsissut Avalliit (sample 5) is hidden behind the point for Puffin Island (sample 22)

Figure 2 continued: Scatterplots comparing the maximum and mean foraging range estimates from different colonies for species with data available from ten or more sites. Lines have been added to the plots to represent how close the mean estimate is to the maximum value (25%, 50% and 75%, with the 50% line shown in bold). The size of the points has been weighted by sample size. The site name is shown for points falling below the 25% line (i.e. sites where the maximum foraging range is more than four times higher than the mean foraging range).

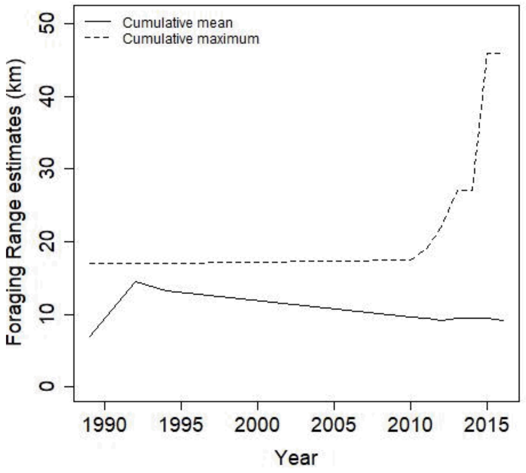
Another alternative method for assessing the robustness of foraging range estimates is how they have changed over time as more tracking data have become available. For both northern gannet and lesser black-backed gull, the maximum foraging ranges have not changed substantially since 2010 and the mean values have also remained relatively constant since that time. The decrease in the cumulative mean value for northern gannet can be attributed to the fact that much of the early tracking work took place at the largest colony at Bass Rock. Subsequent research has identified that foraging ranges for this species may be density-dependent; hence birds at larger colonies travel further on average than those at small colonies (Davies *et al.* 2013). The mean values have also remained relatively constant as data from additional sites have become available for the other five species, for which data are available from ten or more sites, but there have been step changes in the maximum values for these species (Figure 3).



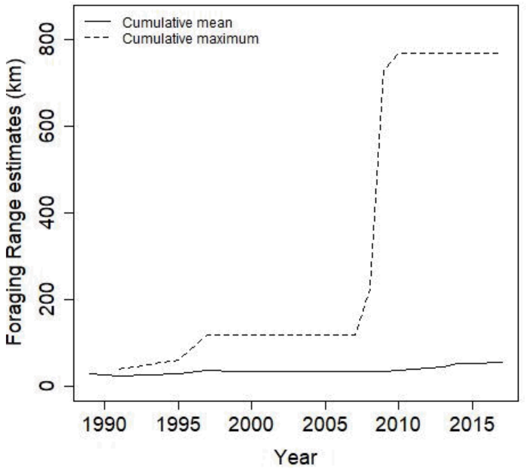
Northern Fulmar



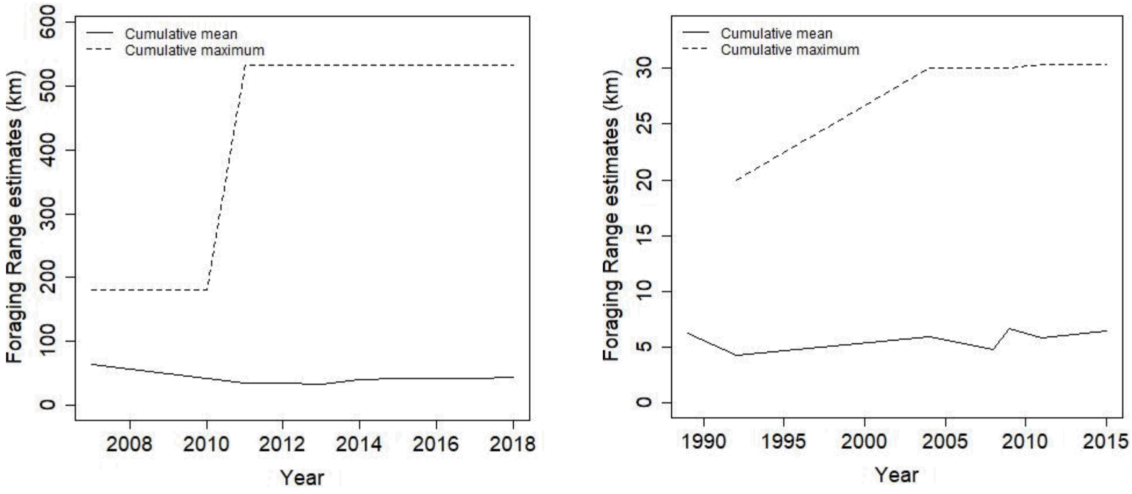
Northern Gannet



European Shag

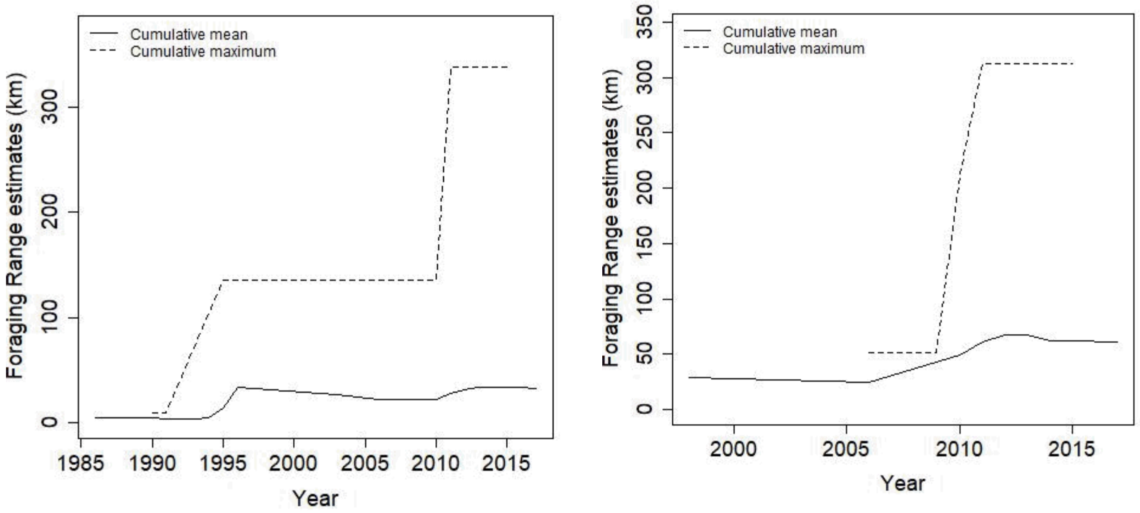


Black-legged Kittiwake



L.B.B. Gull

Common Tern



Common Guillemot

Razorbill

Figure 3 cont.: Cumulative mean (solid line) and maximum (dashed line) foraging range estimates over time. The estimates for each year are based on the available data from studies which ended in that year or earlier, and are shown for species for which data are available from ten or more colonies.

Additional boxplots and cumulative graphs are shown in the Species Accounts (Appendix 1) for species with foraging range estimates from more than five but less than ten sites. The graphs for European herring gull, common tern, Arctic tern and Atlantic puffin, along with the standard deviations around the mean foraging range estimates, suggest that there is moderate to good confidence in these estimates, although it would be advisable to obtain further data if possible as sample sizes are still low.

Potential for tag effects

The use of GPS tags has enabled a vast improvement in our understanding of the movements of seabirds at sea. However, questions remain about the potential for the tags to negatively affect birds (Bodey *et al.*, 2018; Geen *et al.*, 2019) and, therefore mean that data may not be representative of the wider population. The use of tags has been shown to affect the survival (Thaxter *et al.*, 2016), reproduction (Adams *et al.*, 2009) and activity budgets (Bodey *et al.*, 2018; Chivers *et al.*, 2016) of seabirds.

Due to the potential for tag effects, the deployment of bird borne devices in the UK is licensed by the independent Special Methods Technical Panel (SMTP). As part of the licensing process, researchers are required to demonstrate that they have considered the potential for tag effects, and have put in place a protocol to assess any potential impacts. Following the completion of the study, researchers are required to submit a report to the SMTP, which includes the results of any analysis of potential tag effects. In other countries, ethical considerations about the deployment of bird borne devices may be considered at a local or national level.

Historically, a weight limit of a maximum of 5% of body weight for any tag was imposed within the UK, and this value is still used in other countries. However, this has subsequently been revised to a maximum of 3% of body weight in the UK, and it has been noted that lighter tags are generally desirable (Bodey *et al.*, 2018). Following recent analyses, the importance of attachment methodology, tag positioning and, ensuring the tag is stream-lined are being recognised (Geen *et al.*, 2019; S. P. Vandenabeele *et al.*, 2014, 2012; S. Vandenabeele *et al.*, 2015).

Assessing tag effects can be challenging given sample sizes are typically small and the number of potentially confounding variables including; individual or sex-linked differences, colony differences, annual effects and changes in foraging behaviour through the breeding season. Where appropriate guidelines are followed, evidence suggests that tag effects on survival and productivity are likely to be very small (Bodey *et al.*, 2018; Geen *et al.*, 2019). However, there is a suggestion that the overall duration of a trip may increase in response to a bird being fitted with a tag (Bodey *et al.*, 2018). However, there is significant uncertainty surrounding this assessment.

Overall, the evidence for a tag effect on foraging duration in the species considered as part of this review is mixed. For example, some studies in auks have suggested that the overall duration of foraging trips may be greater for tagged birds (Hamel *et al.*, 2004; Kidawa *et al.*, 2012; Wanless *et al.*, 1988). However, recent studies in gannets have found that the trip durations of tagged and untagged birds are similar (Cleasby *et al.*, 2015a; Hamer *et al.*, 2007). Chivers *et al.* (2016) compared foraging behaviour in kittiwakes which were equipped with a combined GPS tag and accelerometer weighing 5% of body weight with foraging behaviour when the same birds were equipped with an accelerometer weighing 1% of body weight only. When wearing the heavier tags, birds spent slightly less time in flight. However, they made a similar number of foraging trips, had similar wingbeat patterns and, similar overall acceleration. It should be noted that an increase in trip duration may not necessarily correspond to an increase in foraging range for example, if birds spend that additional time sitting on the sea surface, as may be the case in Chivers *et al.* (2016). Indeed, analyses of the RSPB FAME and STAR data incorporated in this review suggests that while the duration of foraging trips for birds equipped with heavier tags may be greater, there was no clear difference in the overall foraging range of these species (A. McCluskie *pers. comm).*

Assessing whether tag effects can influence a species foraging range is challenging because, by definition, you do not know how far an untagged bird has travelled. One approach is to compare the distributions inferred from tagging data to those collected using traditional boat or aerial surveys. In one such study, Sansom *et al.* (2018) compared distributions obtained from tracking data for kittiwake, shag, razorbill and common guillemot to data obtained from boat based surveys. This study showed that whilst there was some similarity in the distributions, this declined with distance from the colony. Such differences may be related to the presence of non-breeding birds or, birds from other breeding colonies within survey transects, temporal differences in the distribution of birds (the boat-based survey data were collected some years before the tracking data) or, the choice of modelling approach. However, a second analysis comparing the distributions from GPS tracking data and simultaneous boat-based surveys found that, when populations were geographically isolated there was a high degree of overlap between distributions derived for each type of data (Carroll *et al.*, 2019). This finding suggests that foraging ranges estimated from GPS tagging data may be broadly representative of the wider population. Whilst it is important to acknowledge the potential for tag effects, at present data from GPS tracking studies reflect the best available evidence with which to assess seabird foraging ranges.

Other factors influencing foraging ranges

Foraging range may also be affected by other factors that were not possible to fully investigate as part of this study. Often the data required for such analyses were not reported in sufficient detail (e.g. stage of breeding season) or, were unavailable as a result of methodological difficulties (e.g. difficulties in differentiating between the sexes of some species). However, key factors may include the stage of the breeding season (incubation, chick-rearing) (e.g. Edwards 2015; Dean *et al.* 2015), changes in the availability of food resources between years (e.g. Chivers *et al.* 2012; Robertson *et al.* 2014; Bogdonova *et al.* 2014; Warwick-Evans *et al.* 2016) or time of day/night (e.g. Kuepfer 2012) and can also vary between different subsets of individuals of a species, such as between males and females (e.g. Stauss *et al.* 2012; Cleasby *et al.* 2015a; Camphuysen *et al.* 2015). A particular concern is the potential inclusion of data from failed breeders within published studies. Following an unsuccessful breeding attempt, birds may no longer be tied to a breeding colony and may therefore embark on longer foraging trips. As part of our review, we did not identify any studies which examined this. However, analyses of GPS tracking data from Bempton Cliffs suggest that kittiwakes which are known to be failed breeders travelled similar distances to those which are known to have bred successfully (S. Wischnewski *pers. comm.*).

As noted above, methods can be applied where sample sizes permit to investigate finer-scale movements of birds and interactions with wind farms with consideration for some of these additional sources of variation. Some brief information about such differences is provided in the Species Accounts (Appendix 1) where appropriate, although this may not be comprehensive for all species as a full species review of factors affecting foraging ranges was beyond the scope of this project.

Analytical developments in the use of tracking data

Although the use of representative and SPA specific foraging ranges is likely to remain an important part of the wind farm planning and application process, advances in tracking technology and analytical techniques, have enabled an improved understanding of different aspects of behaviour of tracked birds (Thaxter & Perrow 2019). As noted in Thaxter & Perrow (2019), at the very outset, simple characterisation of area use from GPS fixes can be highly informative, yielding information on connectivity and spatio-temporal overlaps between specific SPAs and developments at stages of their construction (proposed, consented, operational). Modelling the specific home range areas used by breeding seabirds, has therefore enabled seabird distribution maps to be defined more precisely rather than simply using maximum foraging distances (e.g., Wade *et al.* 2014, Soanes *et al.* 2013a; Thaxter *et al.* 2015, Wakefield *et al.* 2017; Sansom *et al.* 2018). Through techniques such as kernel density estimation (KDE), these studies have shed light on how some species may travel considerable distances from the colony to forage, but may be restricted to relatively small areas within reach of this range, that may in turn overlap with wind farm development. Assessments of sample sizes required to robustly define home ranges can also be carried out (e.g. Soanes *et al.* 2013b; Thaxter *et al.* 2017). Existing studies can therefore already be used during the impact assessment process, provided a reasonable sample size exists, to highlight the areas within the foraging range where birds are most likely to be at risk. Determining what constitutes a reasonable sample size is likely to require some assessment of the power of the available data following the examples of the analyses described above.

However, there are now a myriad of different movement modelling and resource-selection approaches that can be applied to assess behaviour and habitat use of species in more detail, to further understand potential and realised interactions between species and wind farm developments. Such refinements may include identification of general behaviours such as commuting (Cleasby *et al.* 2015b), foraging and diving behaviour (e.g. Cox *et al.* 2016; Shoji *et al.* 2016; Browning *et al.* 2017) and resting or rafting behaviour (e.g. Carter *et al.* 2016); further, movements of birds in three dimensions including flight heights (e.g. Cleasby *et al.* 2015b; Ross-Smith *et al.* 2016), are also being applied and translated into 3D space to consider aspects such as avoidance (Thaxter *et al.* 2018). Individual based models have also been developed to predict impacts of developments and how these may vary under different scenarios (e.g. Langton *et al.* 2011; Warwick-Evans *et al.* 2018). For further discussion on these topics see Thaxter & Perrow (2019). Work is therefore ongoing for many species to understand the importance environmental drivers of area use, behaviour and resource-selection, and how these factors may govern susceptibility to specific effects such as collision, displacement and barrier effects. These techniques are still being developed and can be expected to lead to even better knowledge in the future which will form an important part of the assessment process. Future advancements in analysis approaches for some species may also enable the identification of likely important foraging areas around SPAs where tracking data are not available.

Foraging range metrics

We consider the foraging range estimates for each species extracted from the literature in four different ways – the maximum foraging range, the mean maximum foraging range, the mean foraging range, and site-specific foraging ranges. These metrics may be applied throughout the impact assessment process for offshore wind from the initial screening stage to the apportioning of impacts to protected sites. However, each metric has its strengths and weaknesses and, it may be appropriate to make use of different metrics at different points throughout the process. The use of these values in relation to the assessment of the impacts associated with offshore wind farms should be discussed and agreed with the Statutory Nature Conservation Bodies. Below, we highlight some of the issues that should be considered when selecting which foraging range metric to use.

Maximum foraging range

The maximum foraging range is the maximum recorded foraging range for a species across all studies. Logically, as more data are collected, this value can only increase. There are concerns that such values may not reflect the conditions typically faced by birds at a given breeding colony. For example, during periods of food shortages, birds may embark on longer foraging trips (e.g. Kitayasky *et al.* 2000; Wanless *et al.* 2005; Burke & Montevecchi 2009). As part of our review, we identified some instances where birds embarked on longer than typical foraging trips (e.g. Razorbills and Common Guillemots on Fair Isle which travelled in excess of 300 km on occasion), which may be the result of local food conditions. When determining whether to incorporate such data into assessments, it is important to consider how regularly species at an SPA may experience depleted local food conditions, and whether other SPAs may be experiencing similar conditions.

An additional factor influencing the maximum recorded foraging range for a species may be the inclusion of failed breeders in the dataset. Whilst we are confident that failed breeders were not included in either the BTO or RSPB datasets used in this review, studies rarely report whether tagged birds have successfully bred and, in many cases, it may not be practical to collect such data. Such data need careful consideration, and it may not necessarily be appropriate to exclude them, as whilst birds may no longer be breeding that year, they may still be associated with the colony and expected to return to breed in subsequent years. Such decisions are likely to require careful discussion amongst stakeholders.

Mean maximum foraging range

The mean maximum foraging range is the mean of the maximum foraging ranges recorded at each site. As such, it is subject to many of the issues described above for the maximum foraging range. In deciding whether to use the maximum foraging range or the mean maximum foraging range in impact assessments, attention should be paid to the confidence level and level of uncertainty associated with the estimated mean maximum foraging range. Where the estimated mean maximum foraging range is considered robust, and there is limited variation around the value, it may be appropriate to apply this to multiple sites. However, where there is greater uncertainty, or estimates are felt to be less robust, it may be more appropriate to use the maximum foraging range.

Mean foraging range

Whilst the maximum and mean maximum foraging ranges may reflect the maximum distance a bird may be expected to travel from its colony when foraging, the mean foraging range may better reflect the location of the core foraging habitat. This may be of particular value in identifying core areas around a colony likely to be used for foraging. Such information may be particularly useful when apportioning impacts back to individual colonies as it indicates areas most likely to be used by birds from a given colony as opposed to establishing connectivity between a colony and a given area, as is the case for the maximum or mean maximum foraging range. Some initial analyses of these data suggest that the mean foraging range for a colony is typically within 25-75% of the maximum foraging range (Figure 2).

Site-specific foraging range

Since the original Thaxter *et al.* (2012) review, the number of studies investigating seabird movements using tracking data has increased dramatically. As a result, there are now a number of sites where foraging ranges can be estimated using data collected from a large number of individual birds, often across multiple breeding seasons (Table 6). This offers the potential to generate site-specific estimates of species foraging ranges, reducing the uncertainty associated with relying on more generic data. However, for this to be possible, there must be a high level of confidence about the data underlying the estimates.

Wade *et al.* (2016) set out a process whereby information about the sample size and number of years over which data are collected could be used to determine uncertainty scores for the site-specific data. These could then be used as part of a process to assess where site-specific data could, or should, be used.

A key question that needs addressing is when SPA specific sample sizes should be considered as robust, insufficient or 'intermediate'. In the case of Lesser Black-backed Gull, Thaxter *et al.* (2017) concluded that "a minimum of 13 birds and a precautionary upper maximum of 41 birds were needed to describe 95% of the estimated area use of the population (defined by 100% occupancy)". These figures are likely to be influenced by colony specific differences. However, such analyses can help to identify thresholds that can be considered a starting point for assessing the confidence levels in SPA specific foraging ranges. However, it cannot be assumed that these thresholds will apply to other species; indeed it is likely that they will vary from species to species. In order to ensure more objective decisions can be made about whether SPA specific foraging ranges should be used, it is recommended that similar analyses to Thaxter *et al* (2017) are carried out for other species, where sufficient data are available. In the absence of such analyses, it would be prudent to set a higher upper maximum for defining sample sizes as 'intermediate'.

For these intermediate sample sizes, factors such as the number of years over which data were collected and the variability in the SPA foraging range values should be considered, alongside knowledge about the variability of foraging range values at other sites and between years and sexes for each species. The graphs and further information sections for each species in Appendix 1 include some information about these factors, where they are known. For example, research on European shag on the Isle of May has found that foraging ranges can increase in exceptional circumstances (Bogdanova *et al.* 2014) and exceptional foraging ranges have been measured for the auk species breeding on Fair Isle (RSPB dataset). For these species a higher sample size may be necessary before SPA specific foraging ranges are used.

A final consideration over whether site-specific values should be used is how they compare to the generic values. Where site-specific tracking data suggests that birds may travel further than the generic mean, or mean maximum, foraging range, the precautionary approach would be to use the site-specific values, regardless of whether these meet the criteria outlined above relating to sample size and the number of years data available. In such circumstances, tracking data from the colony concerned showing potential overlap with a wind farm would reflect a realistic worst case scenario.

Table 6: **SPA specific maximum foraging ranges (km)**. SPA specific maximum foraging ranges are only shown for sites where the measurement category is the same as that used to produce representative foraging range statistics (usually 'Direct'; see Table 5). The dataset (Appendix 2) may include SPA specific data from other measurement categories. Note that in a small number of cases, specific foraging range data are available at the highest measurement category from more than one location within the same SPA and the highest value is shown in this table. Further details are included in the species section in Appendix 1, which also shows the sample sizes and mean foraging ranges for SPA specific data, and should be considered when making a decision about whether to use these SPA specific foraging ranges rather than representative ranges in impact assessments.

SPA Name (listed by country)	**Red-throated Diver**	**Fulmar**	**Manx Shearwater**	**Gannet**	**Shag**	**Kittiwake**	**Herring Gull**	**Lesser Black-backed Gull**	**Sandwich Tern**	**Little Tern**	**Roseate Tern**	**Common Tern**	**Arctic Tern**	**Great Skua**	**Arctic Skua**	**Guillemot**	**Razorbill**	**Puffin**
SCOTLAND																		
Ailsa Craig				296														
Buchan Ness to Collieston Coast		224				88												
Cape Wrath						38												
Copinsay		480				228										27		
East Caithness Cliffs		240																
Fair Isle		247			7.6	183										338	312	242
Flannan Islands																	92	
Forth Islands				590	17	$25^{\#}$										65	52	66
Foula		120												219	2.5			95
Fowlsheugh						172										44		
Glas Eileanan												14						
Hermaness, Saxa Vord and Valla Field																		383
Hoy														108				
Imperial Lock Dock, Leith												15						
North Colonsay and Western Cliffs						145												
Orkney Mainland Moors	9																	
Rousay		2736																

SPA Name (listed by country)	**Red-throated Diver**	**Fulmar**	**Manx Shearwater**	**Gannet**	**Shag**	**Kittiwake**	**Herring Gull**	**Lesser Black-backed Gull**	**Sandwich Tern**	**Little Tern**	**Roseate Tern**	**Common Tern**	**Arctic Tern**	**Great Skua**	**Arctic Skua**	**Guillemot**	**Razorbill**	**Puffin**
Rum			2890															
St Abb's Head to Fast Castle						109												
St Kilda, Outer Hebrides		1020		709														
Sule Skerry and Sule Stack				107														
Sumburgh Head						40										9		
The Shiant Isles																7	36	46
Ythan Estuary, Sands of Forvie and Meikle Loch									23									
ENGLAND																		
Alde-Ore Estuary								124										
Coquet Island									28		11	18	36					
Farne Islands					14.1	111												
Flamborough and Filey Coast				404		317												
Great Yarmouth North Denes										5								
Isles of Scilly					9.6													
Morecambe Bay and Duddon Estuary							84	93										
North Norfolk Coast									54			9						
Ribble and Alt Estuaries								112										
WALES																		
Anglesey Terns									25			12	29					
Glannau Aberdaron Ac Ynys Enlli /			162															
Grassholm				517														
Skomer, Skokholm and the Seas off Pembrokeshire			1250					151									62	

SPA Name (listed by country)	**Red-throated Diver**	**Fulmar**	**Manx Shearwater**	**Gannet**	**Shag**	**Kittiwake**	**Herring Gull**	**Lesser Black-backed Gull**	**Sandwich Tern**	**Little Tern**	**Roseate Tern**	**Common Tern**	**Arctic Tern**	**Great Skua**	**Arctic Skua**	**Guillemot**	**Razorbill**	**Puffin**
NORTHERN IRELAND																		
Copeland Islands			1970										40					
Larne Lough									17		3	30						
Outer Ards													46					
Rathlin Island						76											74	

Recommendations for further study

Knowledge of seabird foraging ranges has improved substantially in recent years and has enabled estimates based on direct measurements to be presented in this paper for five species for which the estimates were based on a lower category in Thaxter *et al.* (2012). For most other species, the updated estimates are based on a much larger sample size. However, despite these advances, further improvements could be made and the following actions are recommended:

- More focused research will be particularly important for those species with the largest foraging ranges in order to determine whether these foraging ranges can be refined, or whether it is necessary to screen all SPAs for these species into the assessment process.
- Foraging range information remains sparse for many of the species considered by this review; although foraging ranges are believed to be small for some of these species, further research is recommended to confirm this in order to ensure that any decisions based on foraging ranges are using a robust evidence base. Priority should be given to those species which are considered to be most vulnerable to, or there is some uncertainty surrounding their vulnerability to, wind farms, such as red-throated diver, Sandwich tern, cormorant and great black-backed gull (Garthe & Huppop 2004; Furness *et al.* 2013; Wade *et al.* 2016).
- For species which are already well-studied, tracking data from additional sites would be helpful to improve our understanding of the spatial and temporal variability in foraging ranges. However, such studies should also seek to improve our understanding of behavioural and environmental factors that influence the specific areas used within the representative foraging distance from the colony, and the outbound and inbound routes followed to reach these areas. For many species, recent research is already becoming more focused in this way.
- The constraints of tag application, longevity and retrieval mean that much of the available foraging range information is focused on the incubation and early chick rearing periods. As technology develops (e.g. through the use of remote download tags) it would be valuable to extend this to other parts of the breeding season when adults may be less constrained by the need to provision for chicks and may therefore be able to travel further.
- For well tracked species, recent research often focuses on other aspects of foraging, such as behaviour or modelling foraging areas against environmental variables. These papers do not always publish simple summary metrics such as mean and maximum foraging ranges for the study as a whole and/or different subsets of birds. Therefore, we were often unable to use many of these data to help improve our understanding of foraging ranges. It would help to increase the sample size and hence robustness of our knowledge about foraging ranges if simple foraging metrics were routinely published either within the paper itself or as supplementary material. Alternatively, it would be useful if simple foraging tracks could be made available via data repositories such as Movebank (https://www.movebank.org/) or the Seabird Tracking Database (http://www.seabirdtracking.org/).
- There is a need to develop a standardised format with which to report tracking data contributing to future studies. As a minimum, the following should be reported: the site(s) from which data were collected; the number of birds tracked; the number of individual foraging tracks collected; the dates during which data were collected; an estimate of the mean or median foraging range across all tracks; an estimate of the variance in foraging range across all tracks; and, the maximum foraging range recorded.

CONCLUSIONS

This study has made use of the great increases in information collected in the last decade on the movements of marine birds from their breeding colonies during the breeding season to provide updated foraging range estimates of species presented originally in Thaxter *et al.* (2012). This update will be of considerable value to the offshore wind farm industry using the most up-to-date information in the scoping and assessing of impacts from wind farm developments, apportioning of effects, and addressing specific risk posed by developments for particular SPAs using tracking data available for those locations. The resource, however, should be used following the recommendations outlined above and in consultation with the relevant SNCBs, with the recognition that this is a continuously moving research field. At present, these data reflect the best available evidence with which to assess species foraging ranges from their breeding colonies.

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APPENDIX 1: SPECIES ACCOUNTS

KEY TO USING INFORMATION FROM THE SPECIES ACCOUNTS

MEASUREMENT CATEGORY: The type(s) of survey methodology that were included in the foraging ranges estimation. See description in Table 2 on page 10.

CONFIDENCE LEVEL: An assessment of our level of confidence about how representative the foraging range estimates are likely to be. For further details see the description of confidence categories in Table 4 on page 14 of the main report.

REPRESENTATIVE FORAGING RANGE STATISTICS: A summary table showing the foraging range estimates for this species. The methodology used to calculate these estimates is described in pages 11-14. The numbers for references given here and in the SPA specific foraging range statistics table are listed in the foraging range spreadsheet (Appendix 2).

MAP OF REPRESENTATIVE FORAGING RANGES AROUND SPAs: The map shows the area that falls within the mean (blue area) and maximum representative foraging ranges, around all SPAs for which the species is a designated feature or part of the seabird assemblage[9]. SPAs are shown in red; the representative foraging area based on the mean is shown in blue; and the Maximum foraging boundary is represented by a black line, with separate maximum lines shown for NI and GB SPAs. A European scale map is also shown if the species forages well beyond the area covered by the map of the British Isles.

SPECIFIC SPA FORAGING RANGE STATISTICS: This summary table shows foraging range estimates for specific SPAs for which this species is a designated feature or part of the seabird assemblage[9]. or in some cases for sites within SPAs where studies collected data from different sites. The methodology used to calculate these estimates is the same as for the representative estimates (see pages 11-15). Data are only shown for studies based on the highest measurement category available (i.e. the same category used for the representative foraging ranges). It is important to be aware that these estimates are usually based on a much smaller sample than the representative foraging range statistics for the species, and may be based on sampling from a single year only. Further discussion about the merits of using SPA specific rather than representative ranges can be found on pages 32-38.

GRAPHS: Graphs incorporate data from all sites for which data are available at the highest measurement category for the species, and are presented for species for which data are available for six or more sites. Up to three graphs are presented:

(1) Boxplots have been produced for all species for which mean foraging ranges are available from ten or more sites, to show the variability in the foraging range estimates between sites. Data points, weighted by sample size, have been added to the boxplots to show the individual site means.

(2) Scatterplots have been produced for all species for which data are available from more than five sites, to compare the maximum and mean foraging range and estimates from different colonies. To aid interpretation, lines have been added to the plots to represent how closely the mean estimate approaches to the maximum value: the lines represent 25%,

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[9] A species is considered a designated feature or part of a seabird assemblage if it is named specifically in the SPA site citations (http://archive.jncc.gov.uk/page-1400), or if the site is listed in the SPA species accounts (http://archive.jncc.gov.uk/page-1419) (both accessed on 02/12/2019).

50% and 75% of the maximum foraging estimate. The size of the points have also been weighted by sample size.

(3) The third graph shows how the mean foraging range (solid line) and maximum foraging range (dashed line) estimates have changed over time. For each estimate, cumulative foraging ranges are shown, i.e. the estimates for each year are based on the available data from studies which ended in that year or earlier.

FURTHER INFORMATION: Some brief information is provided in this section where appropriate about the foraging range information presented in the species accounts, and about further information that may be available in the foraging range dataset (appendix 2). Where different foraging range information has been published for different 'subsets', e.g. for males and females or for 'long trips' and 'short trips', these have been included in the foraging range dataset and may be discussed briefly here. However a full literature review to investigate published research into foraging approaches and behaviour was beyond the scope of this project, and papers that did not include foraging range estimates may have not been considered here. Therefore, it is important to be aware that the information provided in this section is not necessarily comprehensive.

Eider *Somateria mollissima*

Measurement Category: INDIRECT
Confidence Level: Poor

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	22	21.5	3.2±4.2
Number of studies	1		3
Number of colonies	1		3
Sample (number of birds)	92		199
References	49		49,240,250

Specific SPA foraging range statistics

This species is not a designated breeding feature at any SPAs.

Map of foraging ranges around SPAs

The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Graphs

Not produced due to low sample size

Further information

- Incubation is carried out exclusively by females and the birds do not normally forage during the incubation period and only leave the nest for very short periods, usually heading to the nearest water source to drink (Criscuolo *et al.* 2000; Bolduc & Guillemette 2003; Waltho & Coulson 2015).
- The young leave the nest soon after hatching: the breeding season foraging ranges given here therefore refer to distances travelled by the female and young to preferred feeding areas. The young are flightless during this time; hence these journeys are made on the water's surface.

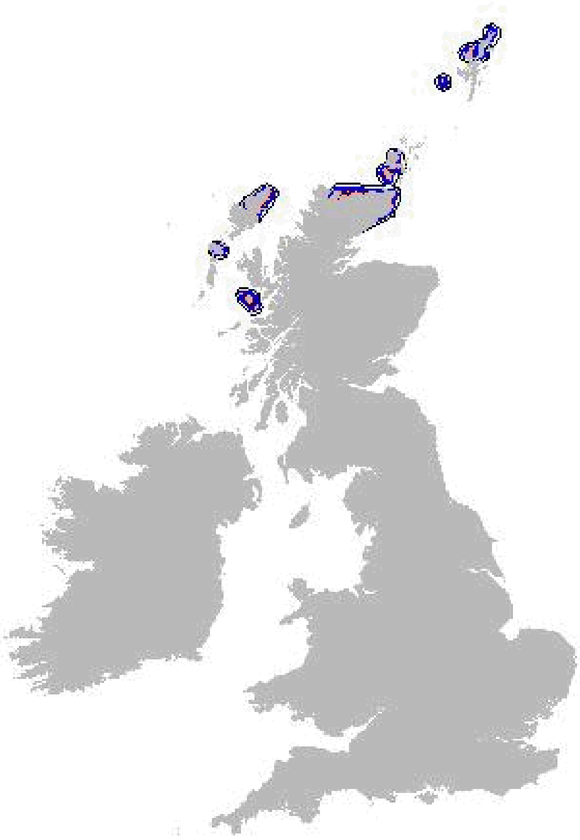
Red-throated Diver *Gavia stellata*

Measurement Category: DIRECT
Confidence Level: Low

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	9	9	4.5
Number of studies	1		1
Number of colonies	1		1
Sample (number of birds)	Unknown		Unknown
References	327		327

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Orkney Mainland Moors	Orkneys	9	4.5	1	327

Graphs

Not produced due to low sample size

Further information

- Red-throated divers usually nest on inland waterbodies (lochs and larger lakes) but the parents may make foraging flights to coastal waters during the incubation and pre-fledging period to feed themselves and provision the young (e.g. Reimchen 1984). However, information about offshore foraging distances made by adults during the breeding period is extremely sparse. Tracking studies of red-throated divers have focused on migration and wintering areas (e.g. McCloskey *et al.* 2018) and hence have used geolocators and do not provide sufficient resolution to assess breeding season foraging ranges.
- The estimates presented here are based on the only directly measured breeding season foraging ranges, and come from a study in the Orkneys which used VHF to measure flight distance to the ocean (JNCC unpublished data).

European Storm Petrel *Hydrobates pelagicus*

Measurement Category: DIRECT
Confidence Level: Poor

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	336.0	336	NA
Number of studies	1		NA
Number of colonies	1		NA
Sample (number of birds)	Unknown		NA
References	81		NA

Map of representative foraging ranges around SPAs

The black line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Note: Mean foraging range areas are not shown as no representative estimate is available

Specific SPA foraging range statistics

None available.

Graphs

Not produced due to low sample size

Further information

- As a small species, Storm Petrel is difficult to track due to the weight of GPS attachments, and the only direct foraging range data available for this species comes from unpublished GPS data from a study in Co Galway, Ireland. (A. Kane*, pers. comm*. in Critchley *et al.* 2018).
- Elsewhere, a study in the Mediterranean Sea used bleaching to identify birds caught at four colonies (Aguado-Giménez.*et al.* 2016). Although the authors could not be certain that the marked birds were actively nesting, some birds were re-sighted at fish farms along with large numbers of unmarked birds and it was considered likely that some birds were foraging at least 90 km from their home colony.

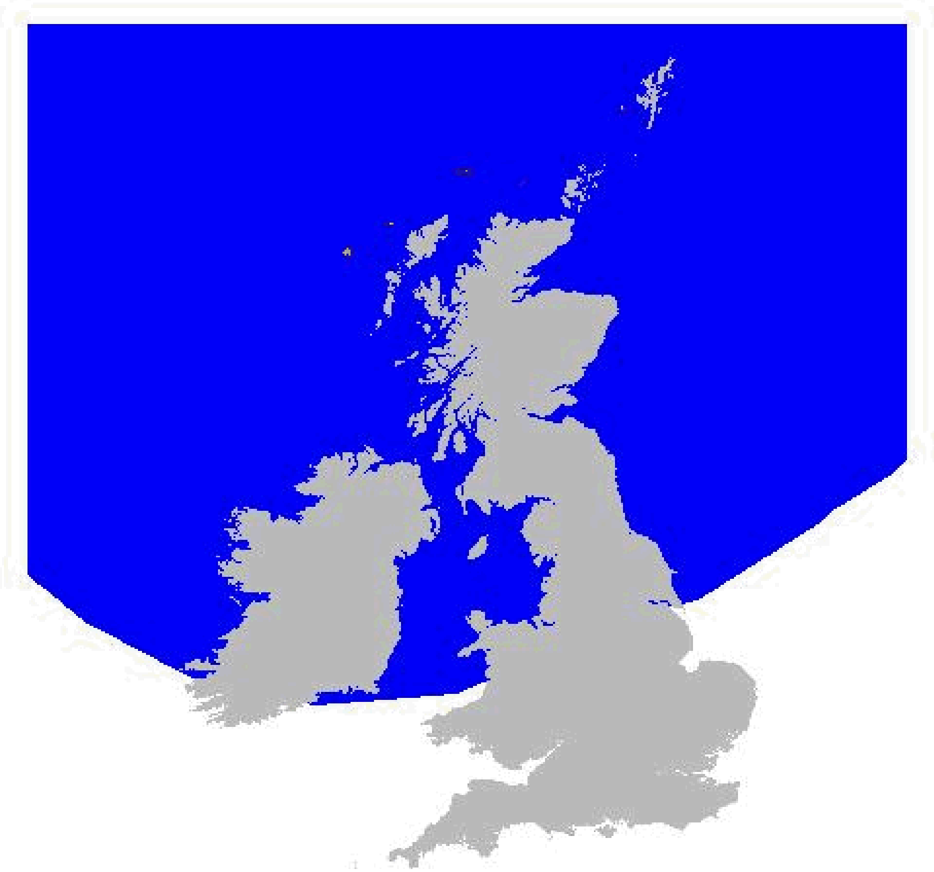
Leach’s Petrel *Oceanodroma leucorhoa*

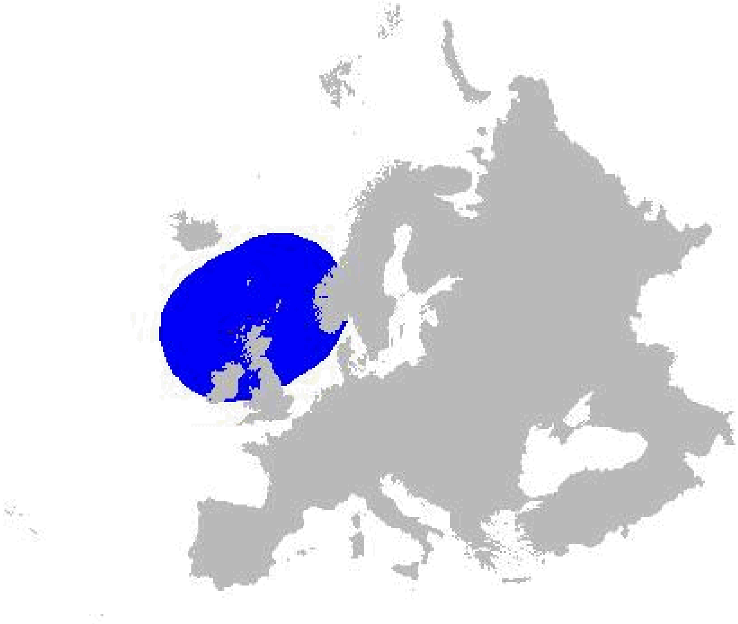
Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	NA	NA	657
Number of studies	NA		1
Number of colonies	NA		1
Sample (number of birds)	NA		11
References	NA		169

Maps of representative foraging ranges around SPAs





The mean representative foraging range is shown in blue around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Note: Maximum foraging range areas are not shown as no representative estimate is available

Specific SPA foraging range statistics

None available.

Graphs

Not produced due to low sample size

Further information

- As a small species, Leach's Petrel is difficult to track using GPS due to the weight of attachments: the only direct study using GPS tags was carried out from Gull Island in Canada (Hedd *et al.* 2018).
- However, measurements have also been carried out in Canada, using geolocators, meaning that a much bigger sample of indirect foraging range measurements is available, covering seven sites (Pollet *et al* .2014; Hedd *et al.* 2018), and giving a mean foraging range estimate of 634±186 km and a maximum range of 1,580 km. Foraging ranges based on geolocators are much less precise than GPS measurements, but these indirect measurements confirm that Leach's Petrel regularly forages several hundred kilometres from the colony (at least in eastern Canada) and hence gives increased confidence that the direct foraging range is likely to be reasonably robust even though it is only based on one site.

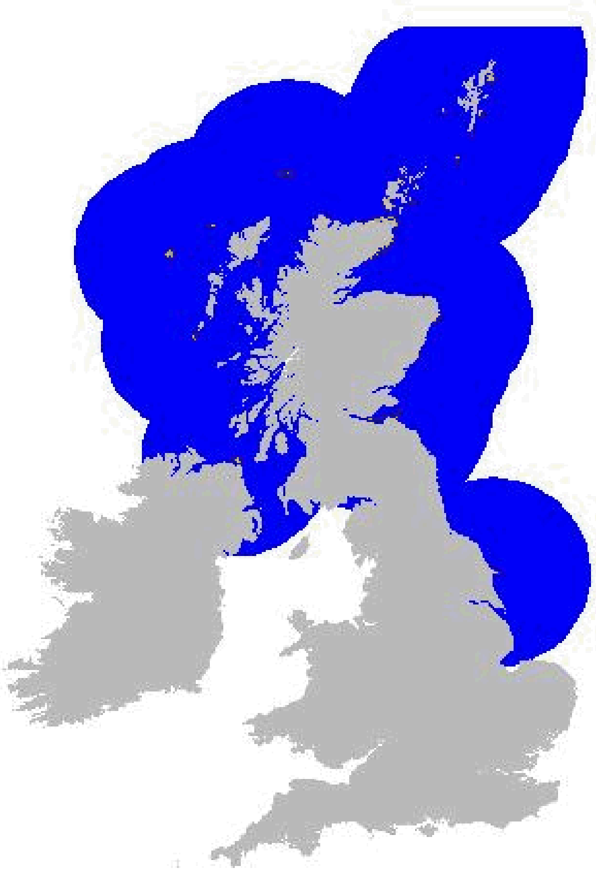
Northern Fulmar *Fulmarus glacialis*

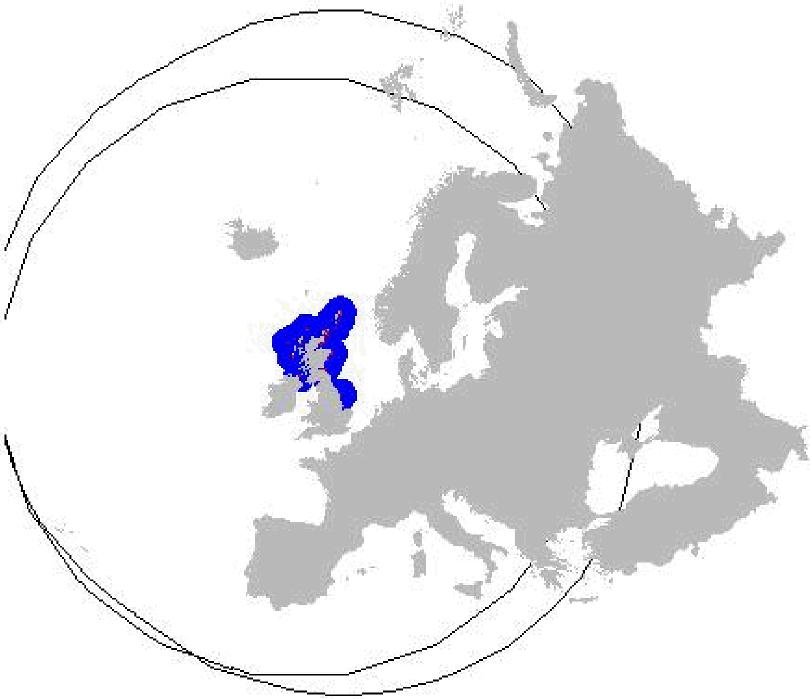
Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	2736	542.3±657.9	134.6±90.1
Number of studies	8		4
Number of colonies	16		11
Sample (number of birds)	86		60
References	102,103,104,114,123,168,360,374		102,123,360,374

Maps of representative foraging ranges around SPAs



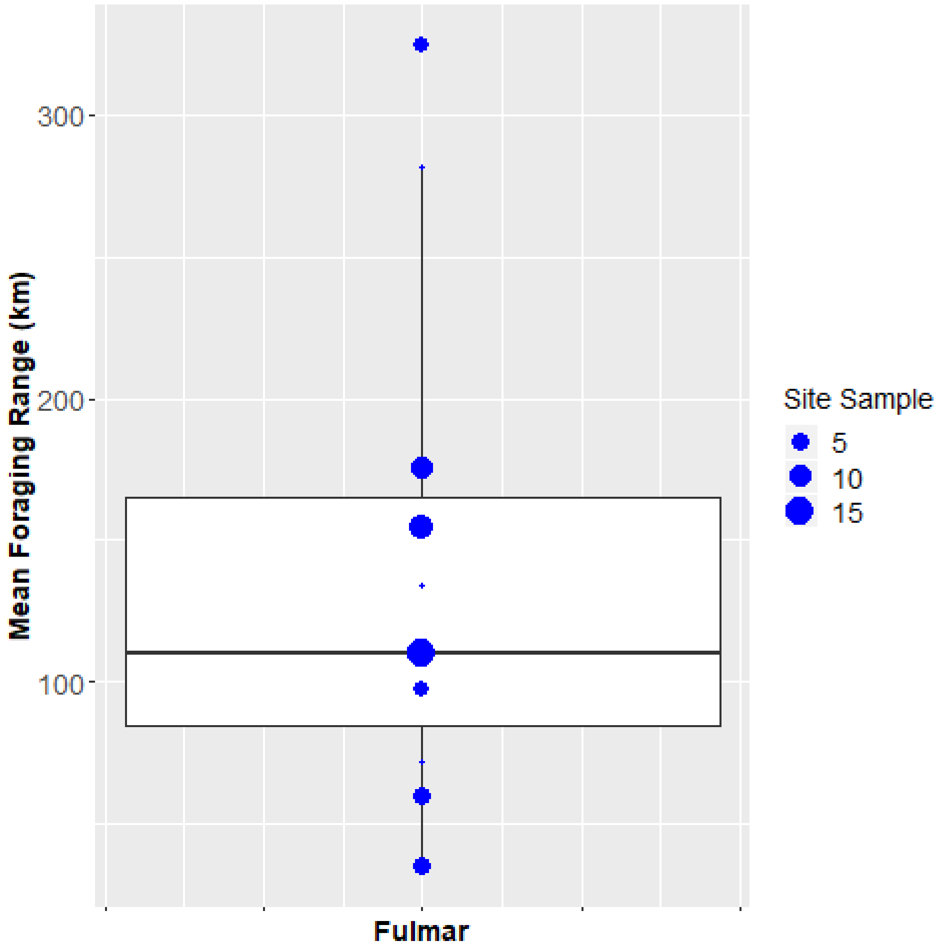


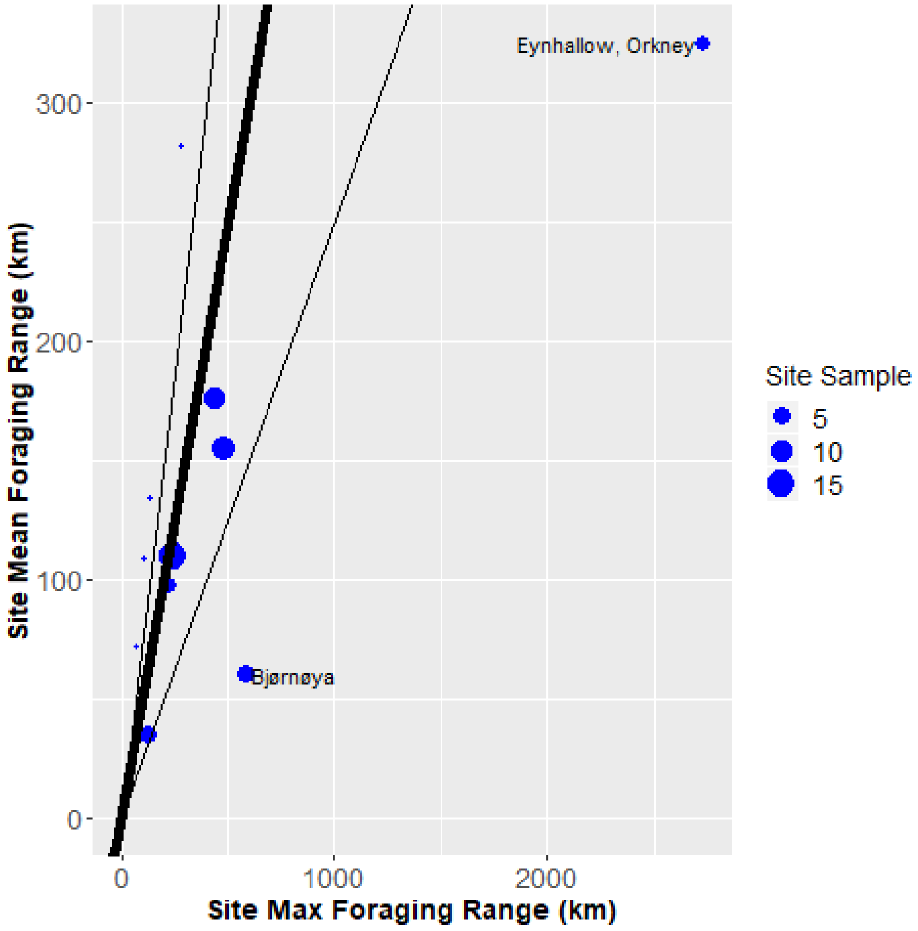
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

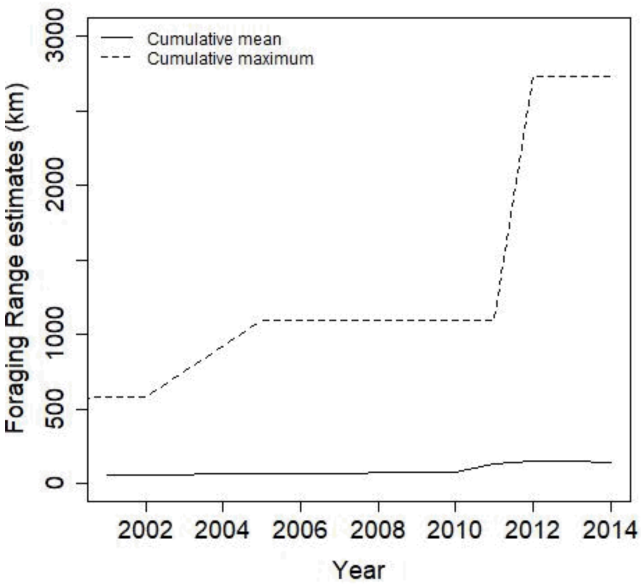
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Buchan Ness to Collieston Coast	Bullers of Buchan	223.6	97.4	4	374
Buchan Ness to Collieston Coast	Whinnyfold	108.4	108.4	1	374
Copinsay	Copinsay, Orkney	479.5	154.3	12	374
East Caithness Cliffs	Caithness (near Berriedale)	240	NA	NA	102
Fair Isle	Fair Isle	246.8	109.7	15	374
Foula	Foula	120	35	5	123
Rousay	Eynhallow, Orkney	2736	324.4	4	102,103, 104
St Kilda	St. Kilda, Outer Hebrides	1020	NA	NA	102

Graphs


300
200
100
Mean Foraging Range (km)
Fulmar
Site Sample
5
10
15


300
200
100
0
0
1000
2000
Site Mean Foraging Range (km)
Site Max Foraging Range (km)
Eynhallow, Orkney
Bjørnøya
Site Sample
5
10
15



Further information

- Sample sizes are still relatively small for this species compared to most other species of similar size, although data are available from a relatively large number of colonies, e.g. the RSPB tracking dataset holds data from eight sites.
- Recent GPS data shows that both males and females can travel extensive distances from breeding colonies during pre-laying and incubation, including trips lasting 2-3 weeks out into the (northern) mid-Atlantic (Edwards *et al.* 2013, 2016).
- One study found that females tended to make longer trips that males during the pre-laying period, with most males remaining within the North Sea region (Edwards *et al.* 2016).
- The limited data available to date suggests that foraging distances travelled during the chick-rearing period are often (comparatively) much shorter, but one maximum distance of over 1,000 km was also recorded during chick-rearing (Edwards 2015).
- The graphs suggest that the site mean foraging ranges are reasonably consistent across different sites and do not vary substantially but, given the small sample sizes, it would be prudent to confirm this with additional data from further tracking studies.

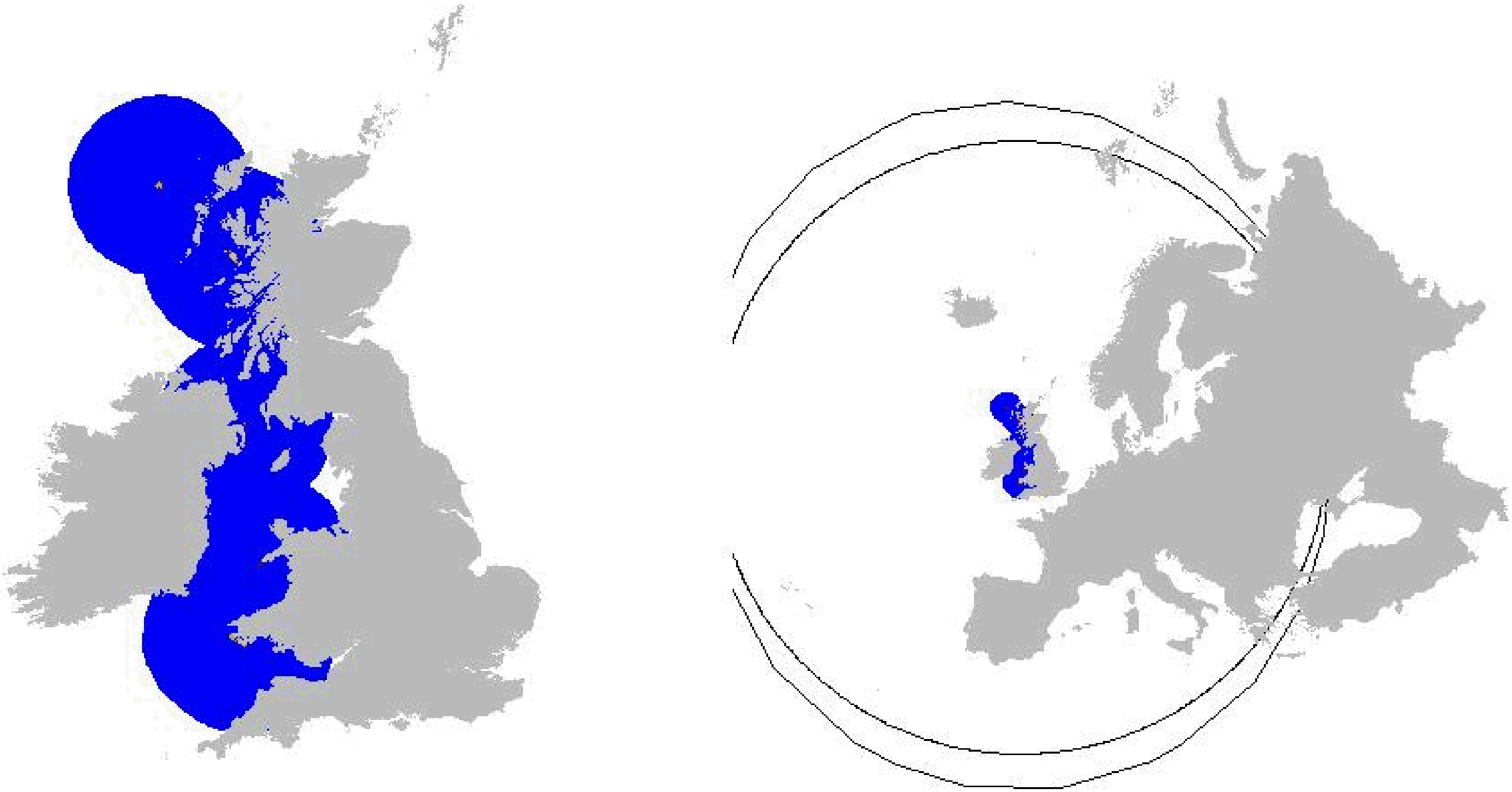
Manx Shearwater *Puffinus puffinus*

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	2890	1346.8±1018.7	136.1±88.7
Number of studies	10		5
Number of colonies	6		4
Sample (number of birds)	484		267
References	91,92,93,116,121,137,151,310,365,366		91,116,310,365, 366

Maps of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Copeland Islands	Copeland	1970	NA	NA	92,93,121
Glannau Aberdaron ac Ynys Enlli/ Aberdaron Coast and Bardsey Island	Bardsey Island	162.1	18.5	36	310,365
Rum	Rum	2890	2#	25	92,365
Skomer, Skokholm and the Seas off Pembrokeshire	Skomer	1250	190.9	155	91,92,93, 116,151, 296,365

#The mean value from Rum comes from a study using VHF focusing on near-colony rafting birds, and hence is likely to be a substantial under-estimate (Wilson *et al.* 2009). More recent tracking confirmed foraging distances are much longer but did not state mean values (Dean *et al.* 2015).

Graphs

Not produced due to low sample size

Further information

- Like northern fulmar, breeding Manx Shearwaters can travel extensive distances including trips far out into the northern Atlantic Ocean, particularly during the pre-laying and incubation periods (Dean *et al.* 2015; Fayet *et al.* 2015; Wischnewski *et al.* 2019). The data suggest that foraging distances during chick-rearing are generally much shorter but can still be considerable.
- There is evidence suggesting that Manx shearwaters may carry out a dual foraging strategy with both members of a pair making both long and short trips (Shoji *et al.* 2015; Fayet *et al.* 2015; Tyson *et al.* 2017).
- There can be high annual variation in foraging ranges (Dean *et al.* 2015)
- The existing research for this species includes several studies which use tracking data to look at behaviour and map core foraging areas used by birds from Skomer (Shoji *et al.* 2015) and from Skomer, Rum, Copeland and Lundy (Dean *et al.* 2015).

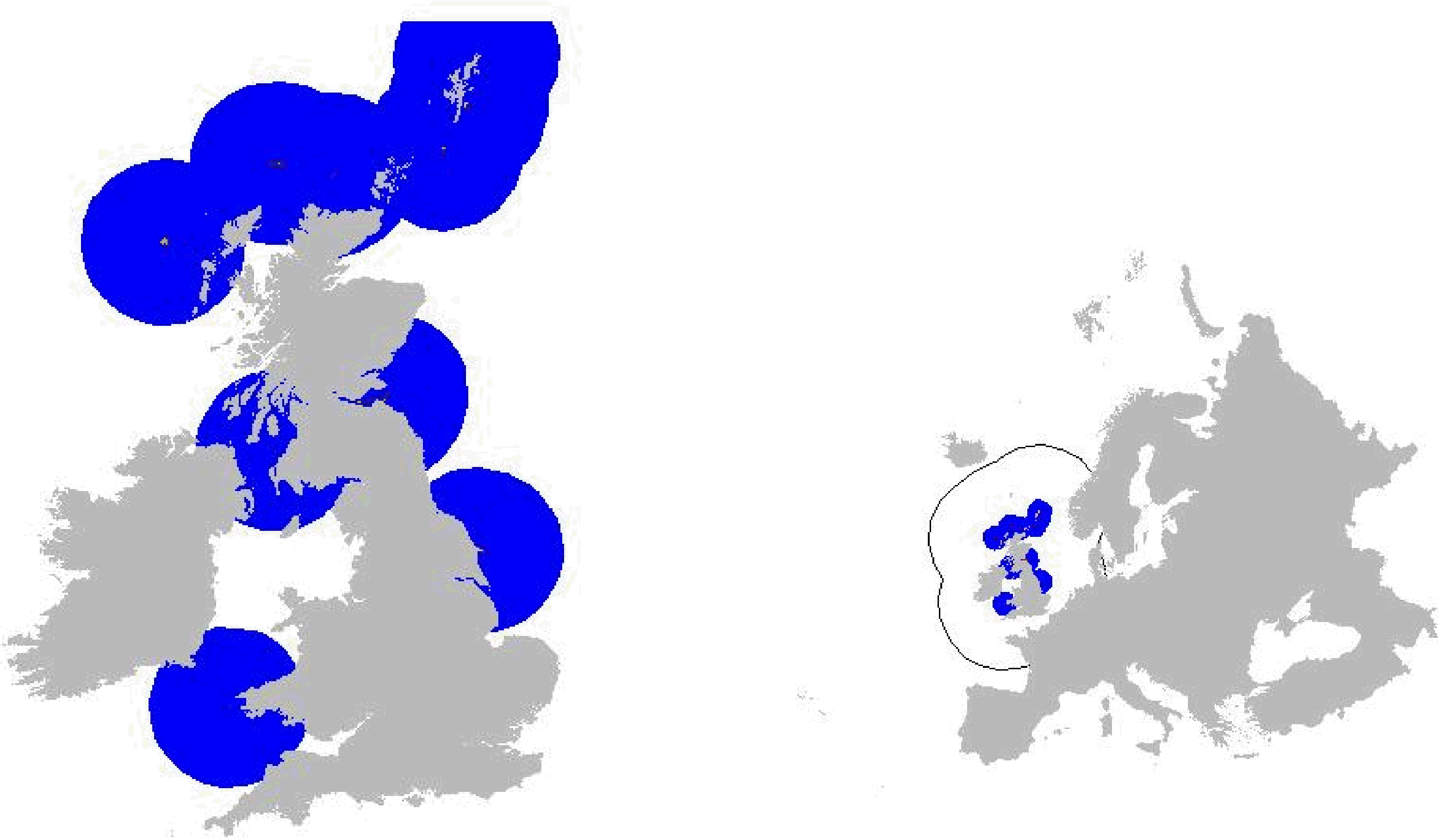
Northern Gannet *Morus bassanus*

Measurement Category: DIRECT
Confidence Level: Highest

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	709	315.2±194.2	120.4±50
Number of studies	31		22
Number of colonies	21		19
Sample (number of birds)	1322		678
References	8,23,32,62,69,77,130,131,133,134,146,152,155,156,158,159,200,222,248,255,256,257,258,284,312,343,345,346,347,354,355		32,69,77,130,131,133,146,150,155,156,158,159,200,222,255,256,257,258,284,346,354,355

Maps of representative foraging ranges around SPAs

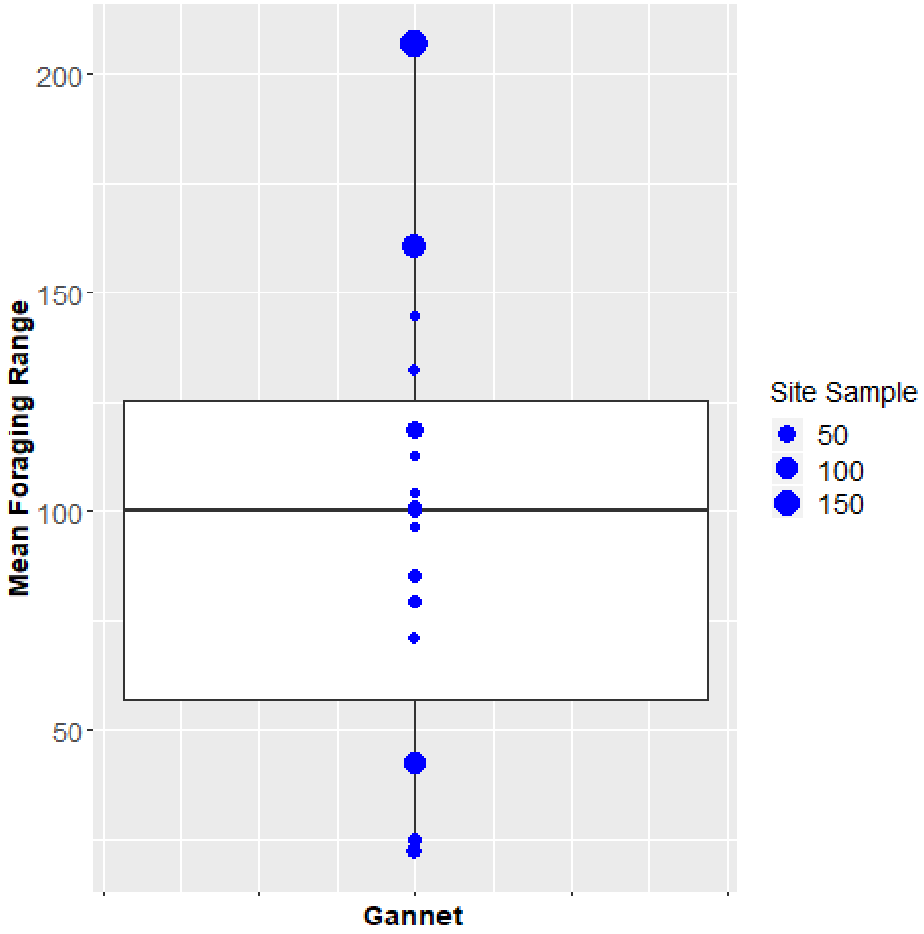


The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

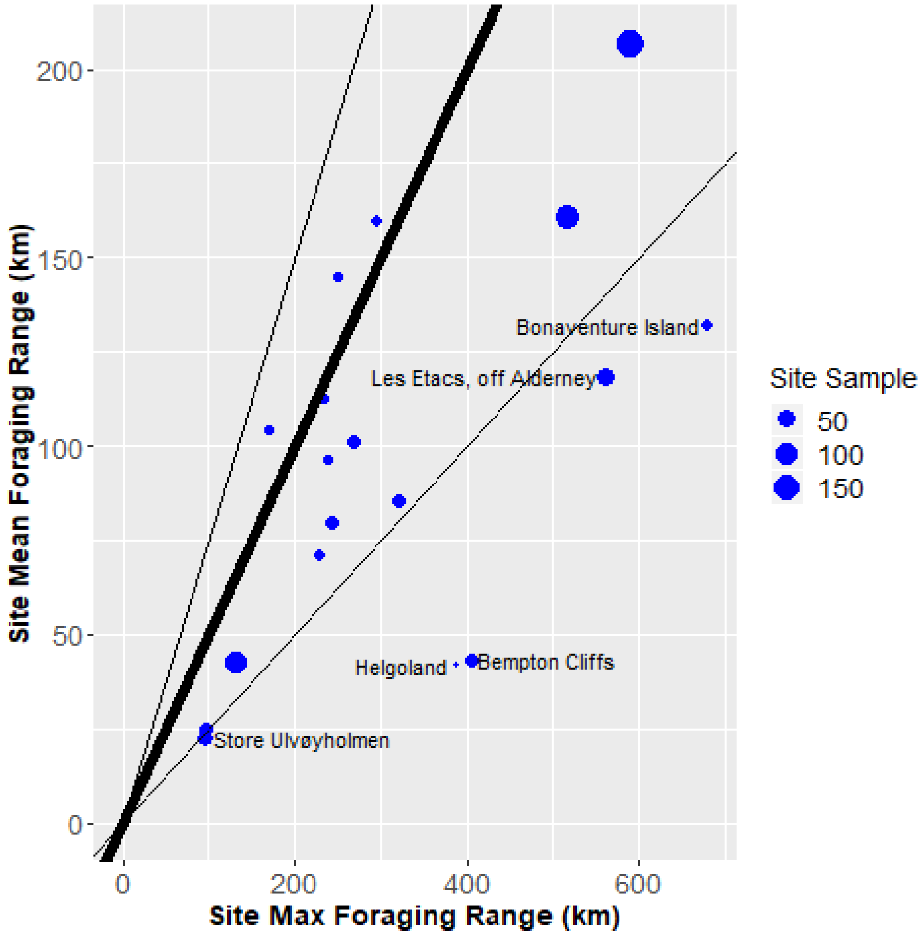
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Ailsa Craig	Ailsa Craig	296	159.5	16	32,347
Flamborough and Filey Coast	Bempton Cliffs	404.4	43.3	25	200
Forth Islands	Bass Rock	590	206.7	152	23,69,146, 155,156, 159,347
Grassholm	Grassholm	516.7	160.6	119	62,77,248, 284,312, 343,345,346 347
St Kilda	St. Kilda, Outer Hebrides	709	NA	NA	347
Sule Skerry and Sule Stack	Sule Skerry, Outer Hebrides	107	NA	NA	347

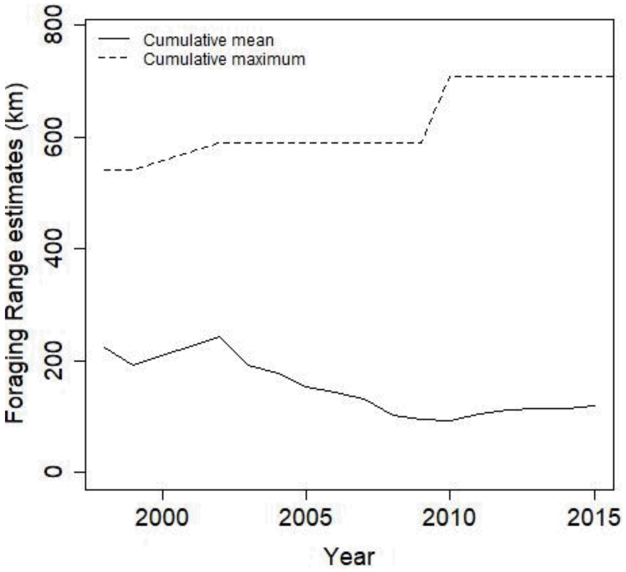
Graphs



Mean Foraging Range
200
150
100
50
Gannet
Site Sample
● 50
● 100
● 150



Site Mean Foraging Range (km)
200
150
100
50
0
0
200
400
600
Site Max Foraging Range (km)
Bonaventure Island
Les Etacs, off Alderney
Helgoland
Bempton Cliffs
Store Ulvøyholmen
Site Sample
● 50
● 100
● 150



Further information

- Northern gannet is one of the best studied seabird species, particularly at Bass Rock (Forth Islands SPA) and at Grassholm, hence the high level of confidence in the representative foraging ranges.
- This research includes studies including those looking at diving behaviour (Cox *et al.* 2016), rafting behaviour (Carter *et al.* 2016) and studies modelling interactions with wind farms (Langston & Boggio 2011; Soanes *et al.* 2013a; Warwick-Evans *et al.* 2018).
- There is some evidence that the foraging ranges of northern gannet may be density-dependent, with greater foraging ranges being associated with larger colonies (Davies *et al.* 2013). Hence the highest mean foraging range shown on the boxplot and scatterplot above is associated with the largest colony at Bass Rock.
- There is also variation in foraging ranges between years (e.g. Garthe *et al.* 2011; Warwick-Evans *et al.* 2016) and also between the sexes with females making longer trips than males (Stauss *et al.* 2012; Cleasby *et al.* 2015).

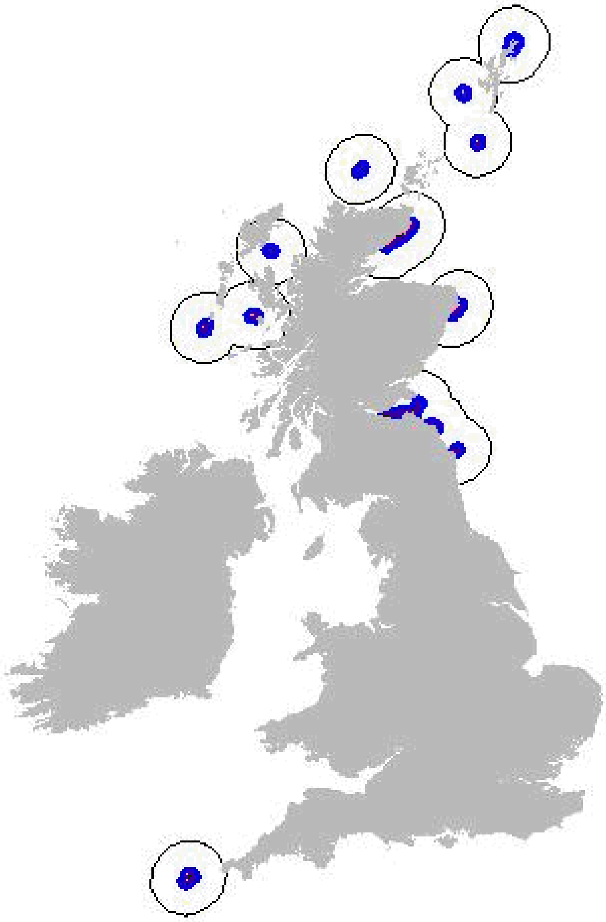
European Shag *Phalacrocorax aristotelis*

Measurement Category: DIRECT
Confidence Level: Highest

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	46.0	13.2±10.5	9.2±4.9
Number of studies	10		11
Number of colonies	17		17
Sample (number of birds)	303		1261
References	66,90,119,224,305,306,307,349,352,374		34,66,90,109,224,305,306,307,349, 352,374

Map of representative foraging ranges around SPAs

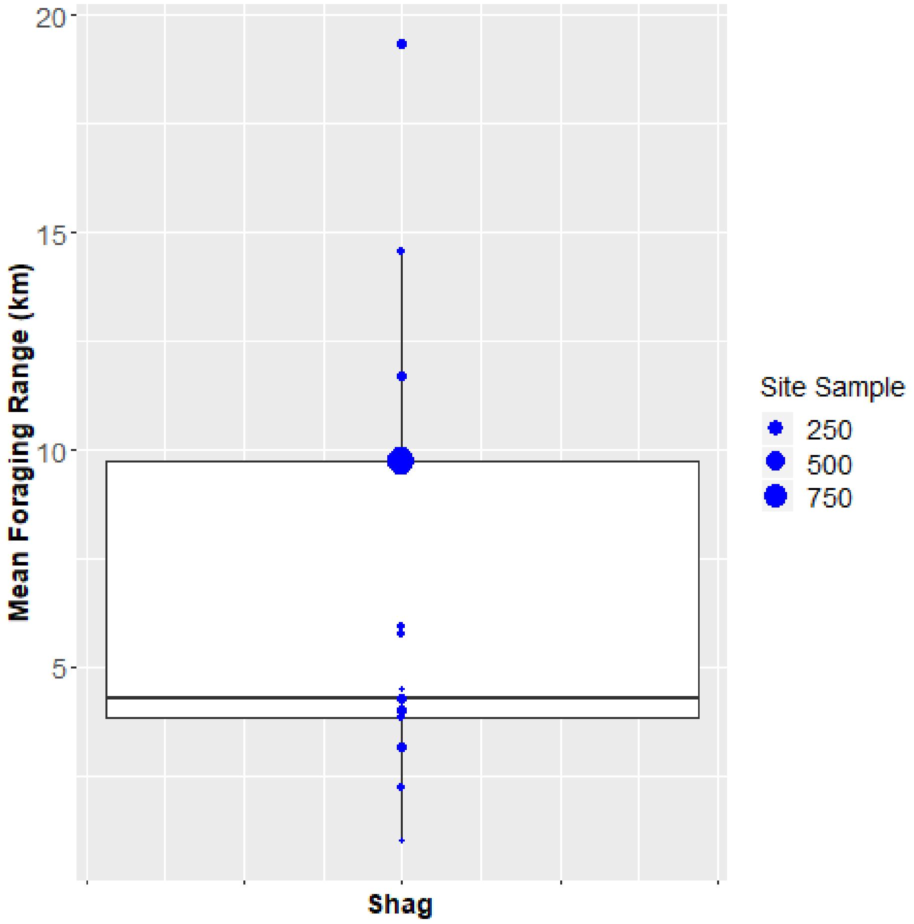


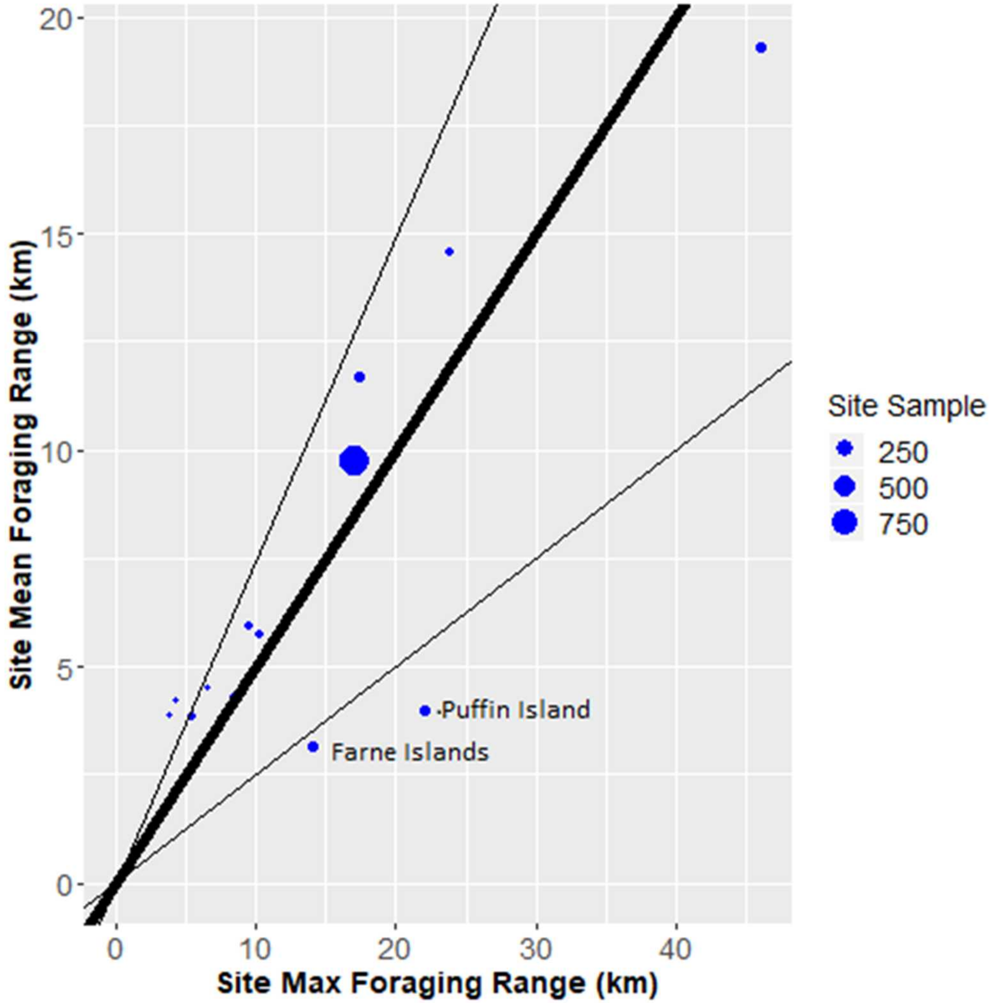
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

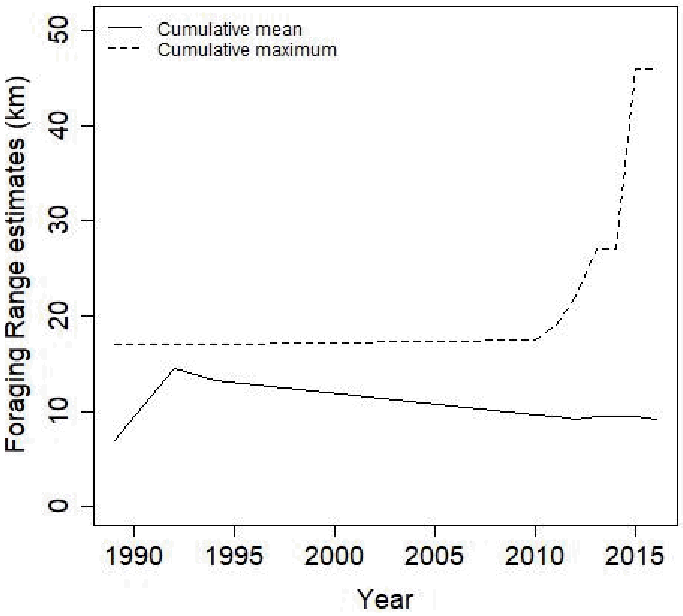
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Fair Isle	Fair Isle	7.6	3.8	13	374
Farne Islands	Farne Islands	14.1	3.2	52	224
Forth Islands	Isle of May	17	9.7	989	34,349,352
Isles of Scilly	Annet	9.6	5.9	6	110,374
Isles of Scilly	Little Ganninick	3.9	1.0	1	109,374
Isles of Scilly	Sansom	5.5	3.9	6	110,374

Graphs


20
15
10
5
Mean Foraging Range (km)
Shag
Site Sample
250
500
750


20
15
10
5
0
Site Mean Foraging Range (km)
0
10
20
30
40
Site Max Foraging Range (km)
Puffin Island
Farne Islands
Site Sample
250
500
750



Further information

- The long-term study on the Isle of May has contributed the vast majority of the sample on which the representative foraging ranges are based; hence the representative mean estimate is close to the Isle of May estimate.
- The data suggest that the foraging ranges at the Isle of May may be higher than those at the many other sites, as shown by the graphs. However, higher mean foraging distances have been recorded elsewhere, with a mean distance of 16 km and a maximum of 46 km recorded at Sklinna in Norway. The foraging range distribution at Sklinna was bimodal, with birds either foraging within 4 km of the colony or greater than 15 km from the colony (Christensen-Dalsgaard *et al.* 2017).
- Distribution modelling has also been undertaken using RSPB tracking data to map and model foraging areas used by European shag around the UK (Wakefield *et al.* 2017; Sansom *et al.* 2018).
- Whilst foraging range is generally consistent between years, the study on the Isle of May showed that foraging ranges may increase substantially in exceptional circumstances. The mean foraging range over 19 years between 1986 and 2010 was 8.4 km, but in 1992 the mean foraging range was 17.7 km (Bogdanova *et al.* 2014).
- Some of the research suggests that foraging ranges do not differ between males and females (De Rijcke 2015; Christensen-Dalsgaard *et al.* 2017), although analysis of the largest data set from the Isle of May showed that the mean foraging range for females (11.4 km) was significantly greater than that of males at this site (11.4 km v. 8.4 km; Bogdanova *et al.* 2014)
- In conclusion, although foraging ranges are generally relatively short, there can be variability between individuals at a site and across years. Therefore extra caution should be applied when using site specific foraging ranges for European shag, particularly if these are based on a small sample size or on data from a small number of years.

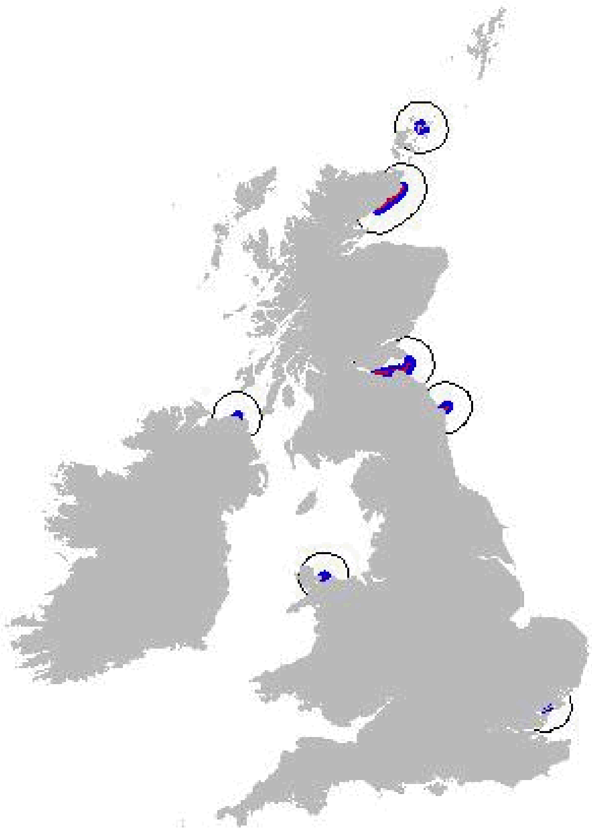
Cormorant *Phalacrocorax carbo*

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	35	25.6±8.3	7.1±3.8
Number of studies	4		4
Number of colonies	4		4
Sample (number of birds)	35		38
References	118,148,149,242		118,148,149,203

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

None available.

Graphs

Not produced due to low sample size

Further information

- The limited number of direct studies suggests that the foraging range of Cormorant is relatively small like its relative the European shag for which a much larger sample size exists; this is in line with the (also limited) information from aerial/boat/land surveys and speculative estimates.

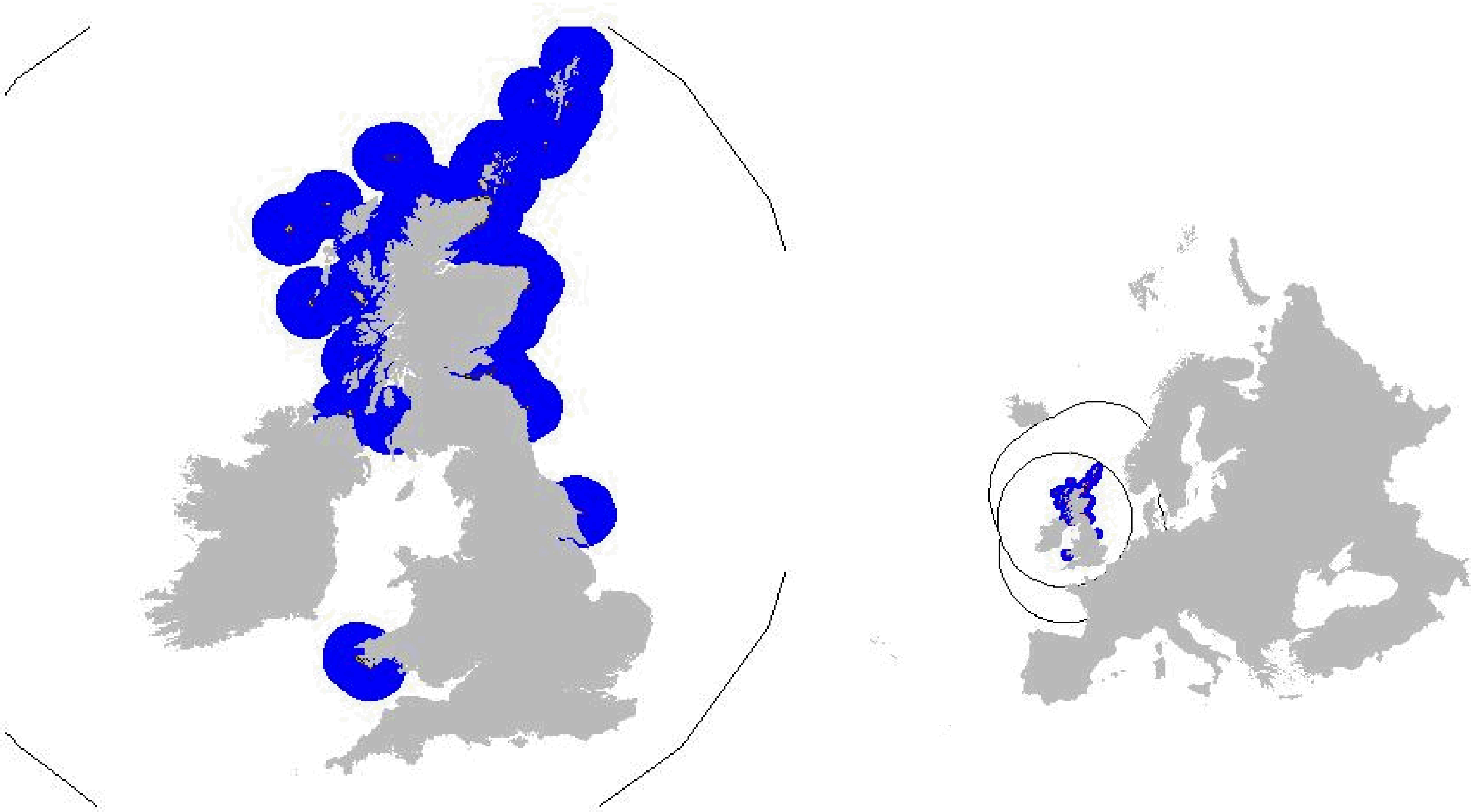
Black-legged Kittiwake *Rissa tridactyla*

Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	770	156.1±144.5	54.7±50.4
Number of studies	19		18
Number of colonies	37		37
Sample (number of birds)	1452		1435
References	1,4,64,65,67,70,145,157,196,241,244, 265,271,277,303,304,307,316,374		1,4,64,67,126,157,180,182,196, 241, 245,265,271,277, 303,307,316,374

Maps of representative foraging ranges around SPAs

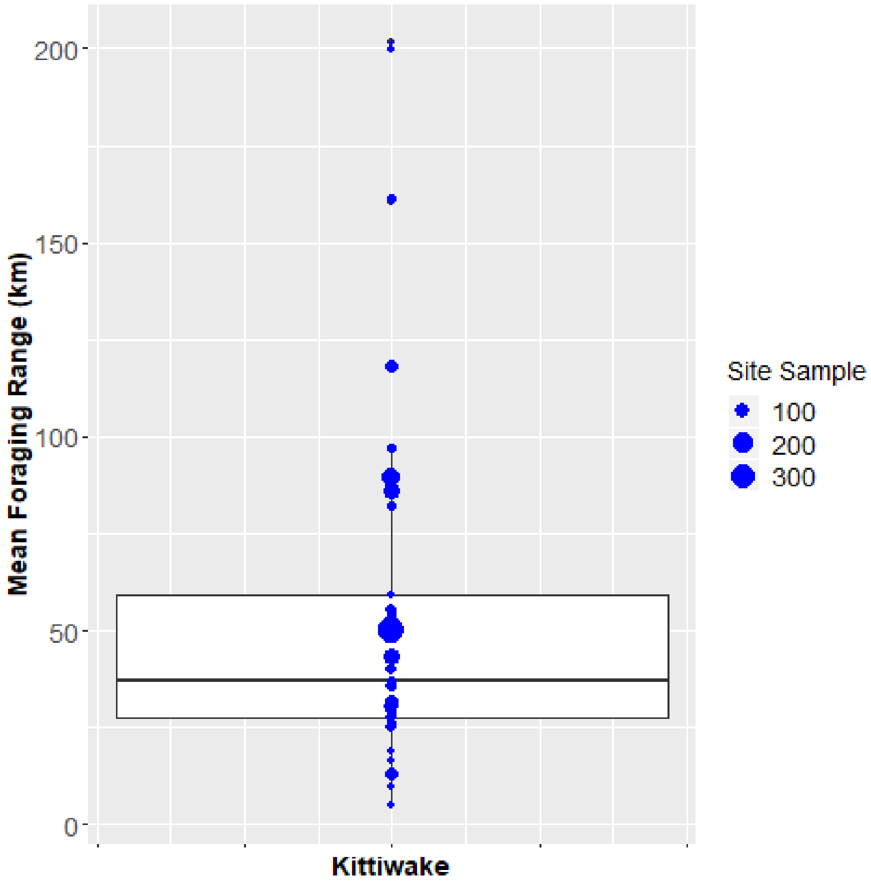


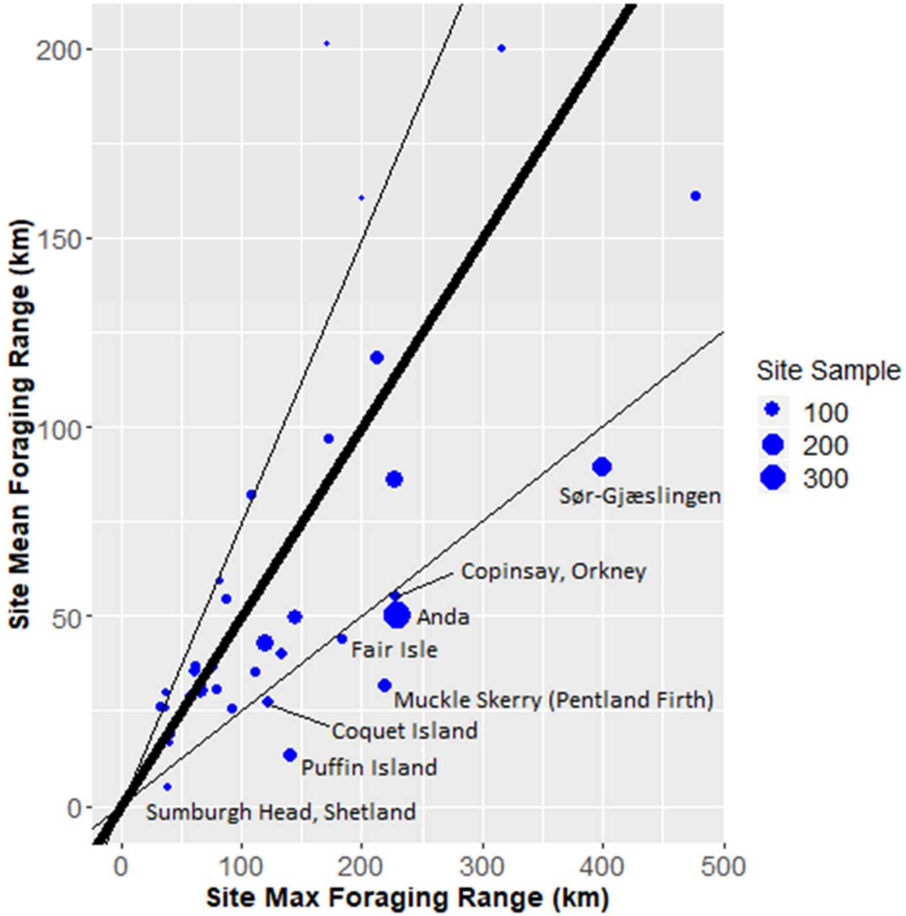
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

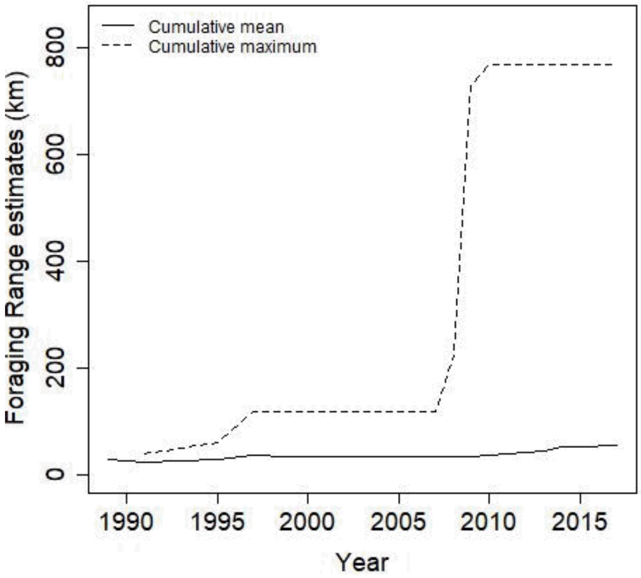
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Buchan Ness to Collieston Coast	Bullers of Buchan	81.9	59.4	5	374
Buchan Ness to Collieston Coast	Whinnyfold	88.1	54.5	20	374
Cape Wrath	Cape Wrath	38	25.7	5	374
Copinsay	Copinsay, Orkney	227.8	55.2	32	374
Fair Isle	Fair Isle	183.4	44	13	374
Farne Islands	Farne Islands	111.2	35.6	19	271
Flamborough and Filey Coast	Bempton Cliffs	226.9	86.2	102	374
Flamborough and Filey Coast	Flamborough Head	316.9	199.6	9	374
Flamborough and Filey Coast	Filey	212.4	118.1	52	374
Forth Islands	Isle of May	NA	25	31	180
Fowlsheugh	Fowlsheugh	172.3	97	14	374
North Colonsay and Western Cliffs	Colonsay	144.5	49.8	82	374
Rathlin Island	Rathlin Island	76	37.1	18	64,374
St Abb`s Head to Fast Castle	St Abbs Head	108.7	82.4	15	374
Sumburgh Head	Sumburgh Head, Shetland	40	5	9	157

Graphs


Mean Foraging Range (km)
0
50
100
150
200
Kittiwake
Site Sample
100
200
300


Site Mean Foraging Range (km)
0
50
100
150
200
Site Max Foraging Range (km)
0
100
200
300
400
500
Sør-Gjæslingen
Copinsay, Orkney
Anda
Fair Isle
Muckle Skerry (Pentland Firth)
Coquet Island
Puffin Island
Sumburgh Head, Shetland
Site Sample
100
200
300



Further information

- Black-legged kittiwake is one of the most frequently tracked UK seabird species, and a number of modelling studies have hence been carried out investigating behaviour and modelling and mapping UK foraging distribution (e.g. Wakefield *et al.* 2017; Sansom *et al.* 2018; Collins *et al.* 2018), including modelling against environmental variables (Ponchon *et al.* 2014).
- Whilst most studies around the UK and elsewhere have found that black-legged kittiwake usually have relatively short foraging ranges, site foraging distances are variable and birds can travel much longer distances from some colonies.
- Birds at some colonies may sometimes undertake a dual foraging strategy making occasional long distance oceanic trips and regular shorter trips (Ponchon *et al.* 2014; Christensen-Dalsgaard *et al.* 2018).
- Foraging ranges may vary at different stages of the breeding cycle but this may not be consistent: Robertson *et al.* (2014) recorded longer foraging distances during incubation, whereas Ponchon *et al.* (2014) recorded longer distances during chick-rearing.
- Foraging distance may also be dependent on prey availability and so may vary from year to year, potentially, with shorter foraging ranges in years with more abundant prey (Chivers *et al.* 2012; Paredes *et al.* 2014; Robertson *et al.* 2014).
- Foraging distances in Svalbard differed between the sexes, with males travelling further than females (Goutte *et al.* 2014), although it should be noted that this study was carried out during the pre-laying period rather than during incubation or chick-rearing.
- Therefore caution should be applied when assessing potential foraging ranges at colonies where no tracking or where foraging ranges are based on a small sample size.
- In conclusion, there can be variability between individuals at a site and across years. Therefore extra caution should be applied when using site specific foraging ranges for black-legged kittiwake, particularly if these are based on a small sample size or on data from a small number of years.

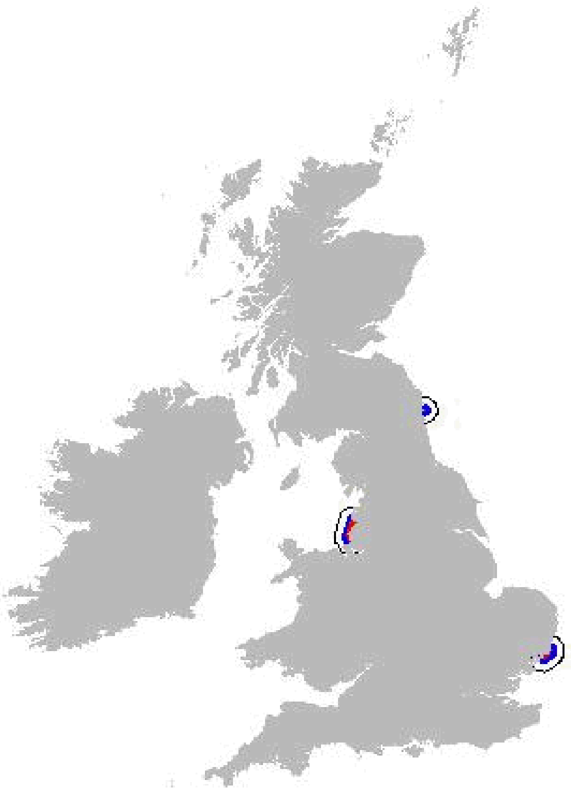
Black-headed Gull *Chroicocephalus ridibundus*

Measurement Category: DIRECT
Confidence Level: Poor

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	19	18.5	7
Number of studies	1		1
Number of colonies	1		1
Sample (number of birds)	5		5
References	140		140

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics
None available.

Graphs
Not produced due to low sample size

Further information

- Very limited data are available for this species and no new studies have occurred since Thaxter *et al.* (2012). The foraging ranges stated above are based on the only 'direct' study which was based on VHF tracking (Brandl & Gorke 1988). The maximum range reported from the small number of aerial/boat/land surveys (eight studies) was 40 km.

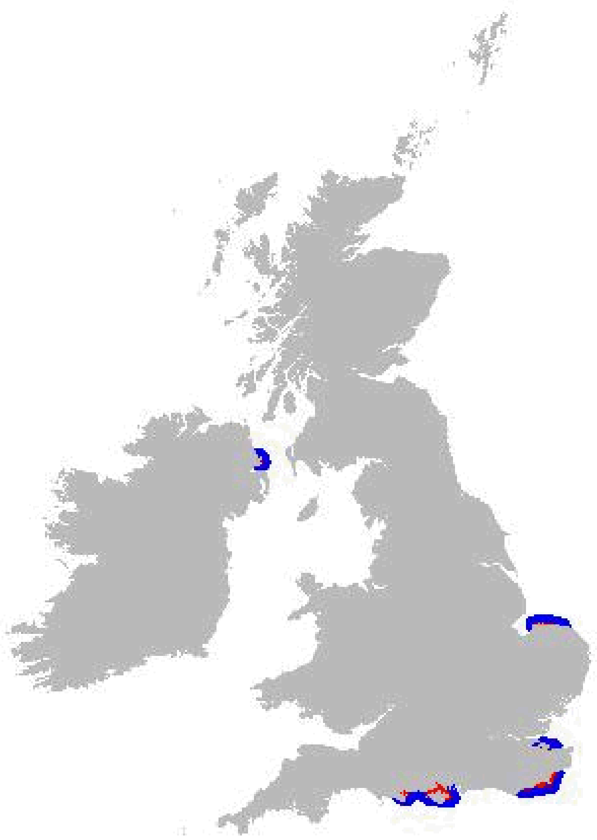
Mediterranean Gull *Ichthyaetus melanocephalus*

Measurement Category: AERIAL/BOAT/LAND SURVEY
Confidence Level: Uncertain

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	20	20	11.5
Number of studies	1		1
Number of colonies	1		1
Sample (number of birds)	Unknown		Unknown
References	115		115

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

None available.

Graphs

Not produced due to low sample size

Further information

- No new studies are available, and the foraging range reported here is repeated from Thaxter *et al.* (2012), and is based on a single boat survey carried out in the 1980s on the River Po delta in Italy (Fasola & Bogliani 1990).

Common Gull *Larus canus*

Measurement Category: AERIAL/BOAT/LAND SURVEY
Confidence Level: Poor

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	50	50	NA
Number of studies	1		NA
Number of colonies	1		NA
Sample (number of birds)	Unknown		NA
References	127		NA

Map of representative foraging ranges around SPAs

The black line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.
Note: Mean foraging range areas are not shown as no representative estimate is available

Specific SPA foraging range statistics
None available.

Graphs
Not produced due to low sample size

Further information

- No new studies are available, hence the foraging range reported here is repeated from Thaxter *et al.* (2012), and is based on a single boat survey in the German Bight (south-eastern North Sea) (Garthe 1997).

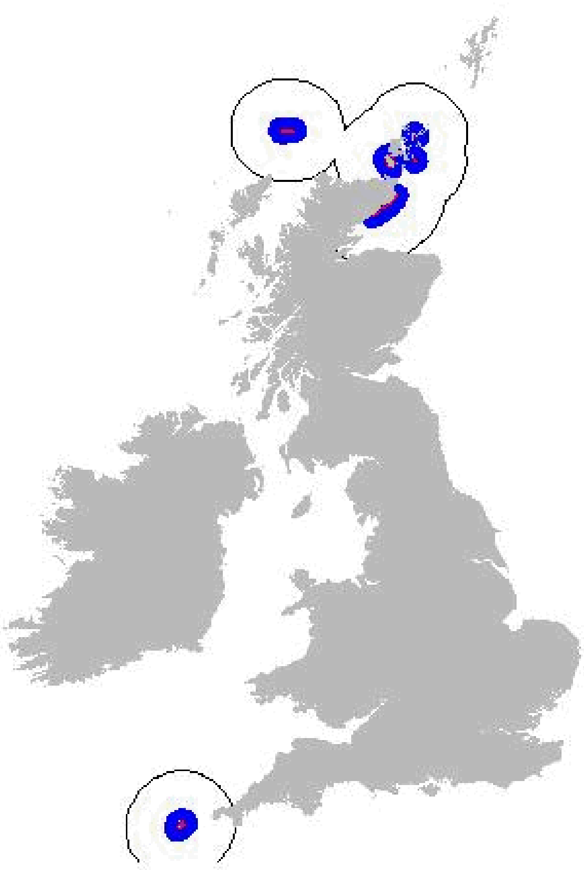
Great Black-backed Gull *Larus marinus*

Measurement Category: DIRECT
Confidence Level: Low

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	73	73	16.7
Number of studies	1		2
Number of colonies	1		1
Sample (number of birds)	3		6
References	214		213,214

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

None available.

Graphs

Not produced due to low sample size

Further information

- Direct information about the foraging ranges of this species is sparse.
- The only information to date comes from six individuals which were tagged in Nova Scotia, Canada (Maynard 2018; Maynard & Ronconi 2018).
- As for herring gull and lesser black-backed gull, distances may include both inland and offshore foraging trips, though note that in the UK this species tends to be more maritime than the other two large gull species.
- Breeding outcomes are unknown for the tagged individuals; therefore the foraging distances stated here may include foraging after breeding failure. One bird was known to have lost its clutch during handling but continued to attend the nest site – it is not known for certain whether or not this pair relaid.

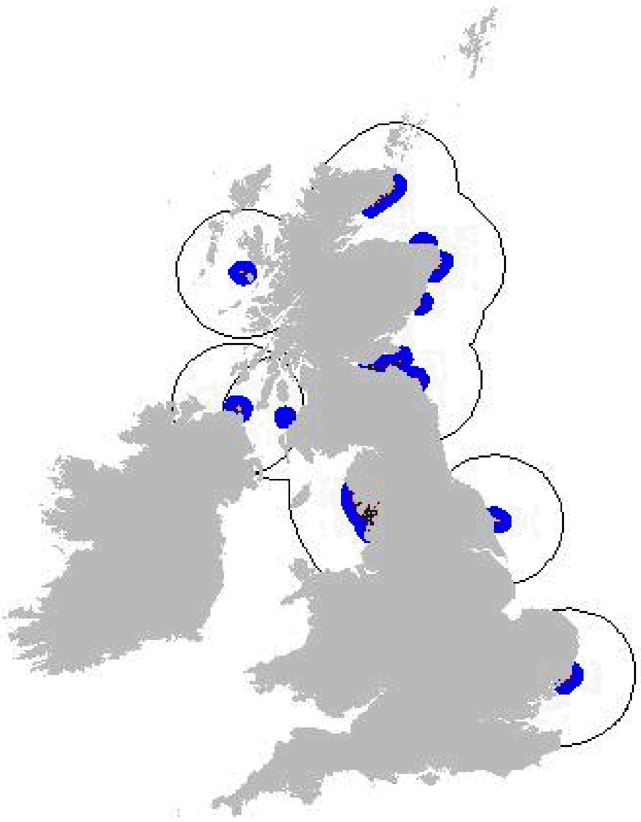
European Herring Gull *Larus argentatus*

Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	92	58.8±26.8	14.9±7.5
Number of studies	7		4
Number of colonies	10		7
Sample (number of birds)	170		97
References	106,107,281,334,335,373,374		106,107,373,374

Map of representative foraging ranges around SPAs

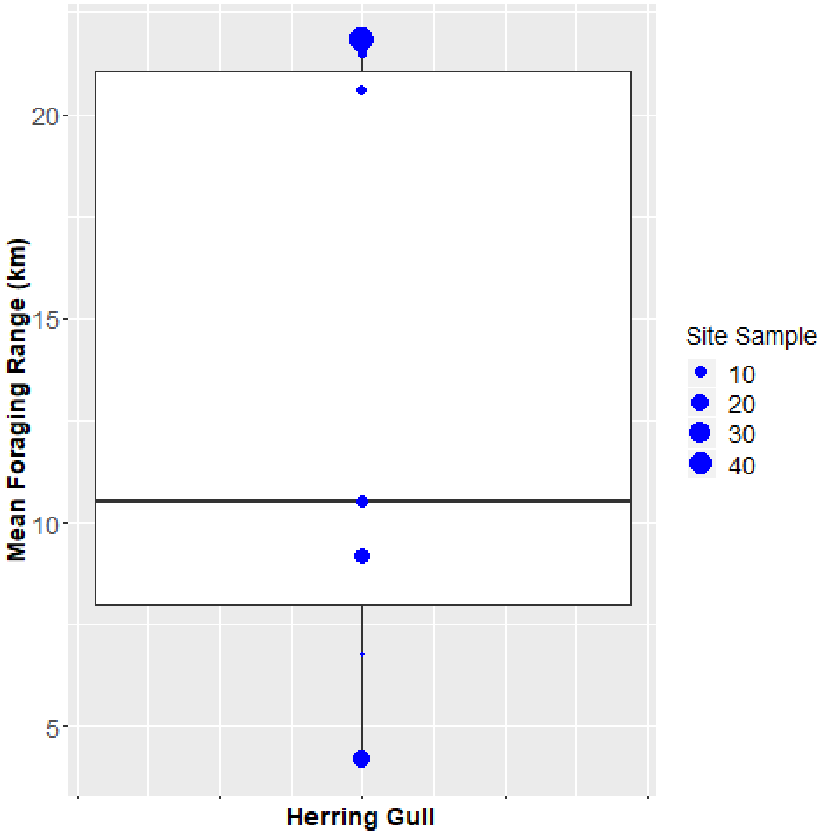


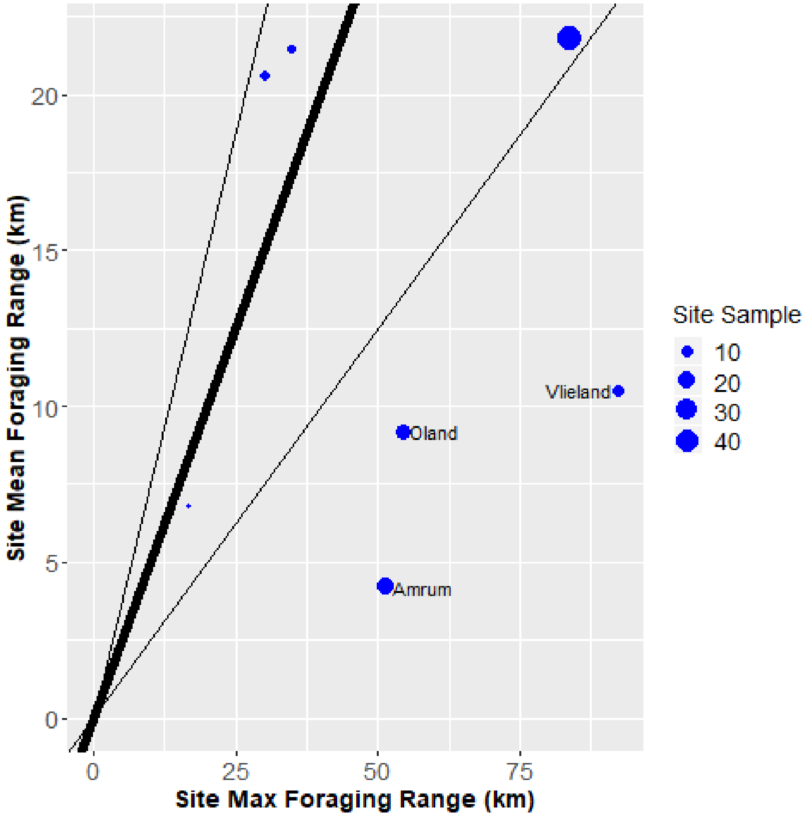
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

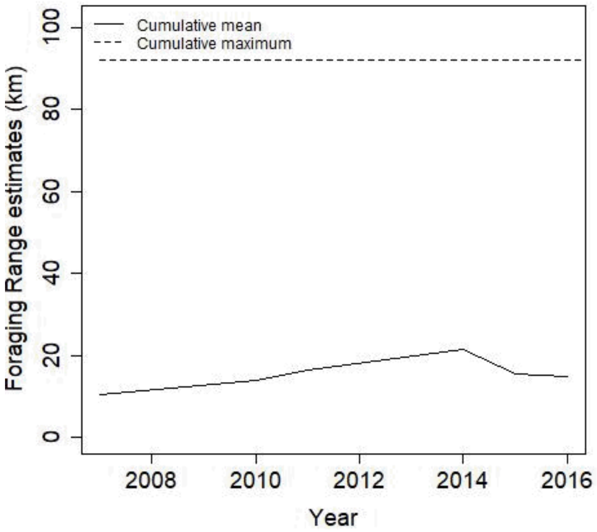
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Morecambe Bay and Duddon Estuary	Walney Island	83.7	21.8	42	373

Graphs


Mean Foraging Range (km)
20
15
10
5
Herring Gull
Site Sample
10
20
30
40


Site Mean Foraging Range (km)
20
15
10
5
0
Vlieland
Oland
Amrum
0
25
50
75
Site Max Foraging Range (km)
Site Sample
10
20
30
40



Further information

- Results from only one GPS tracking study had been reported at the time of Thaxter *et al.* (2012); and the number of direct studies has since increased considerably as a result of research in Germany, Belgium, the Netherlands and the UK.
- Nesting herring gulls may forage both in terrestrial and offshore habitats, with individual adults sometimes specialising in their foraging approach. For the purposes of this report, inland nesting colonies have been excluded, but foraging range estimates from coastal colonies may include terrestrial as well as offshore foraging trips.

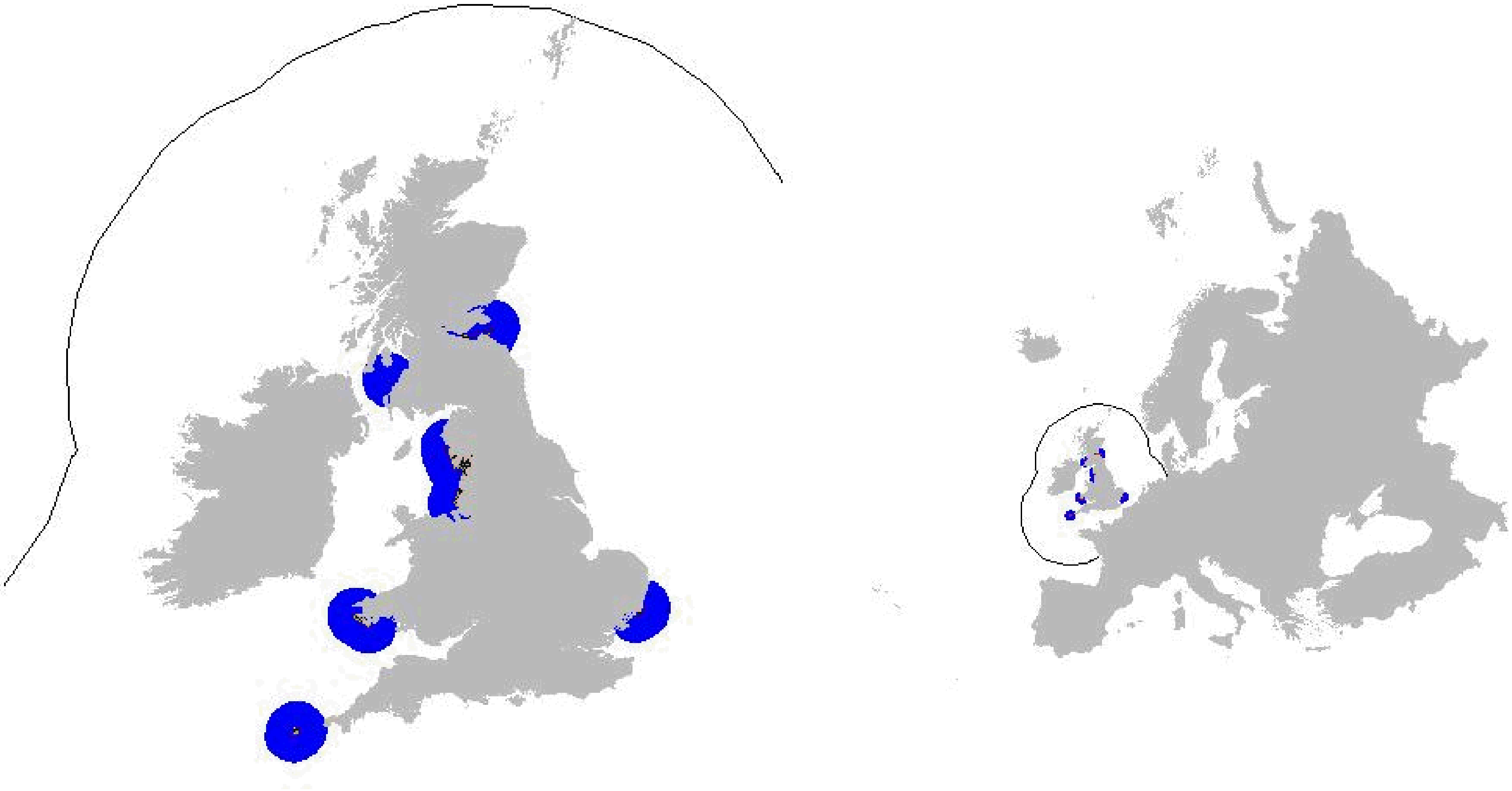
Lesser Black-backed Gull *Larus fuscus*

Measurement Category: DIRECT
Confidence Level: Highest

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	533	127±109	43.3±18.4
Number of studies	9		8
Number of colonies	18		16
Sample (number of birds)	535		542
References	55,60,73,74,107,184,193,373,374		58,60,73,74,107, 184,373,374

Maps of representative foraging ranges around SPAs



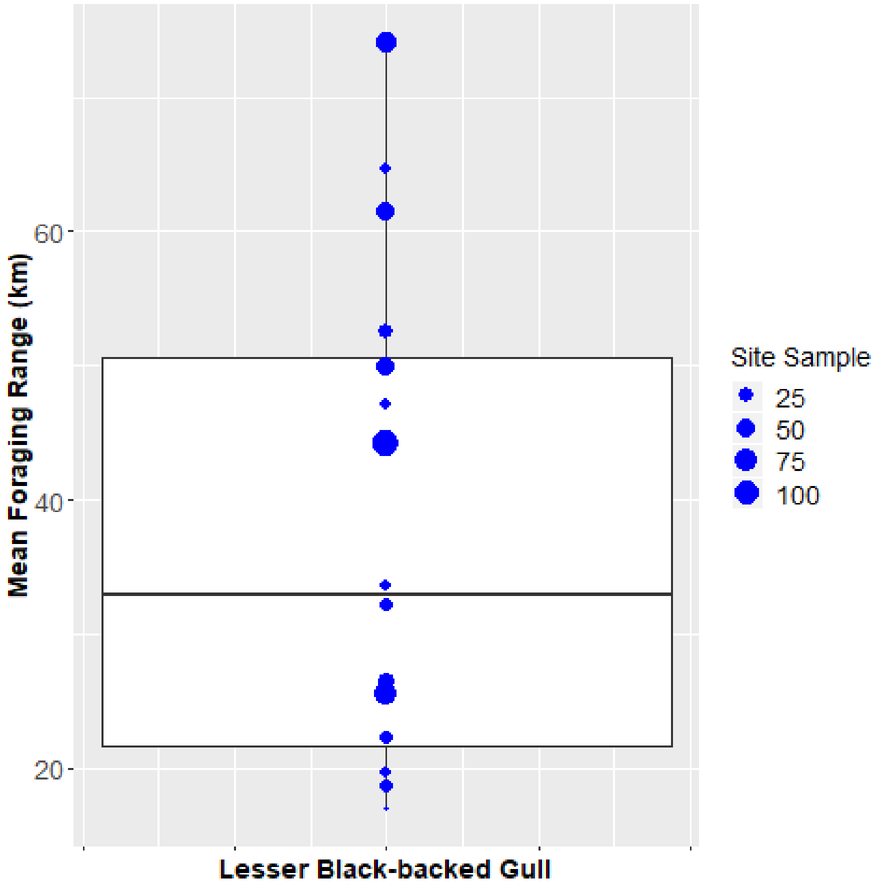
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

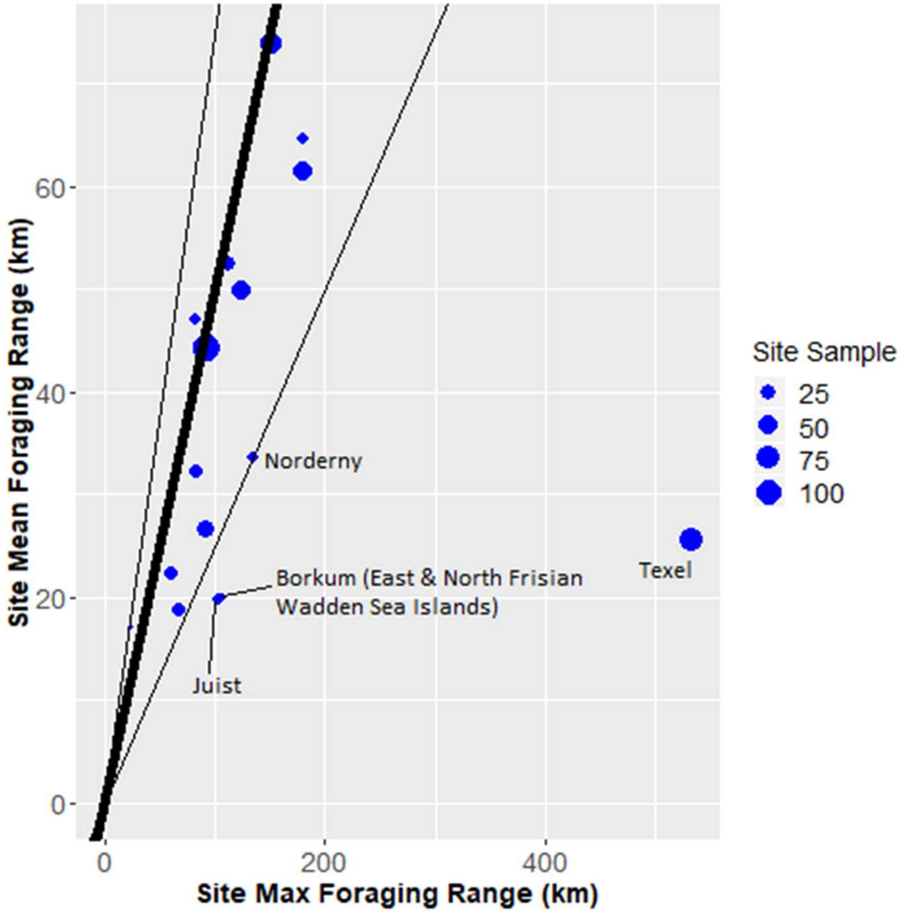
Specific SPA foraging range statistics

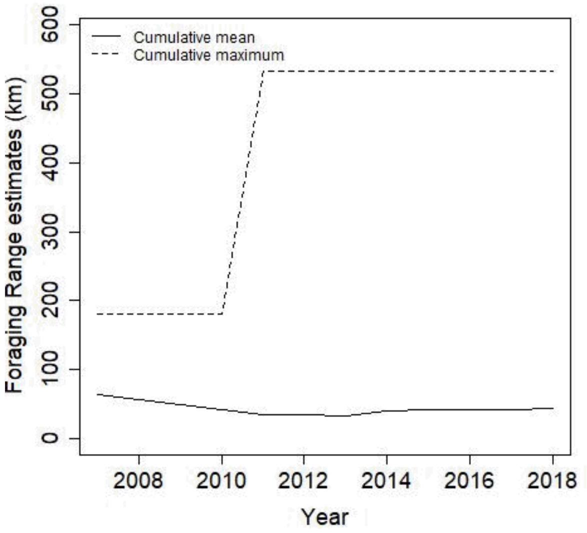
SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Alde-Ore Estuary	Havergate	22.5#	17.1#	4	374
Alde-Ore Estuary	Orford Ness	124	49.9	55	373,374
Morecambe Bay and Duddon Estuary	Walney Island	92.7	44.2	109	373
Ribble and Alt Estuaries	Ribble	111.9	52.5	32	373
Skomer, Skokholm and the Seas off Pembrokeshire	Skokholm	150.5	74	59	373

Tracking was during Incubation; foraging distances may be higher during chick-rearing.

Graphs


Mean Foraging Range (km)
60
40
20
Lesser Black-backed Gull
Site Sample
25
50
75
100


Site Mean Foraging Range (km)
60
40
20
0
Norderny
Borkum (East & North Frisian Wadden Sea Islands)
Juist
Texel
0
200
400
Site Max Foraging Range (km)
Site Sample
25
50
75
100



Further information

- Nesting lesser black-backed gulls may forage both in terrestrial and offshore habitats, with individual adults sometimes specialising in their foraging approach. For the purposes of this report, inland nesting colonies have been excluded, but foraging range estimates from coastal colonies may include terrestrial as well as offshore foraging trips.
- Most trips made by breeding birds are close to the colony, as indicated by the mean foraging range of 43 km. The foraging distance covered by birds tends to increase after breeding failure or at the end of the breeding season prior to migration (BTO dataset - see also the filters applied to the BTO dataset in methods). It cannot necessarily be assumed that exceptionally long foraging trips are by failed breeders: Camphuysen (2013) recorded five trips of greater than 250 km from Texel, The Netherlands, two of which were by birds which were still actively breeding including one which travelled 533 km from the colony. However the scatterplot above suggests that this trip was extremely unusual and the maximum foraging range reported from the other 17 colonies was 181 km.
- Camphuysen (2015) suggests sexually distinct foraging strategies occur – see also Corman (2015). Thaxter *et al.* (2015) found that although males did go further offshore than females, they spent more time than females offshore later in the breeding season and thus interacted more with proposed offshore wind farm areas. Similarly, at Texel, Netherlands, Camphuysen (2011) found that males spent twice as much time around offshore wind farms as females, which used a greater mosaic of different habitats.

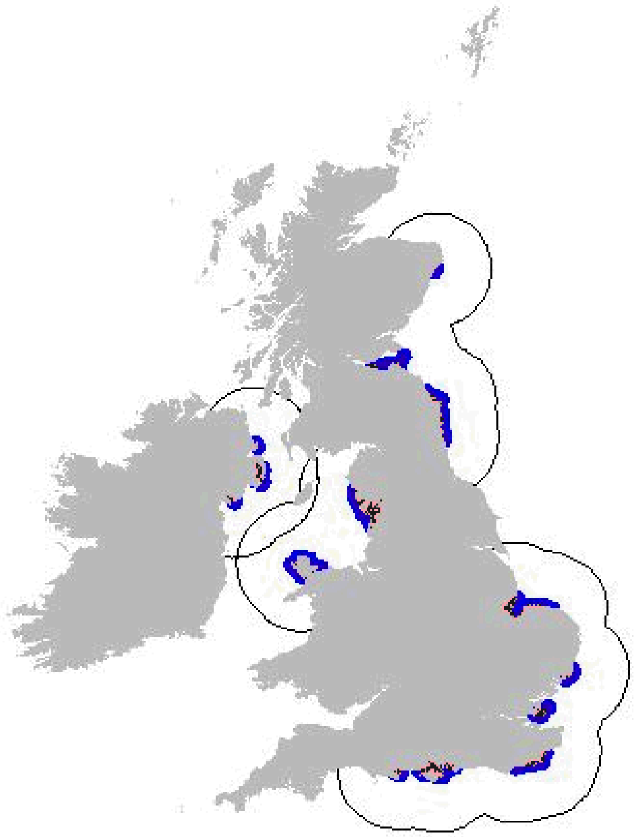
Sandwich Tern *Thalasseus sandvicensis*

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	80.0	34.3±23.2	9±9.2
Number of studies	5		4
Number of colonies	9		9
Sample (number of birds)	369		278
References	117,251,270,363,364		40,117,251,364

Map of representative foraging ranges around SPAs

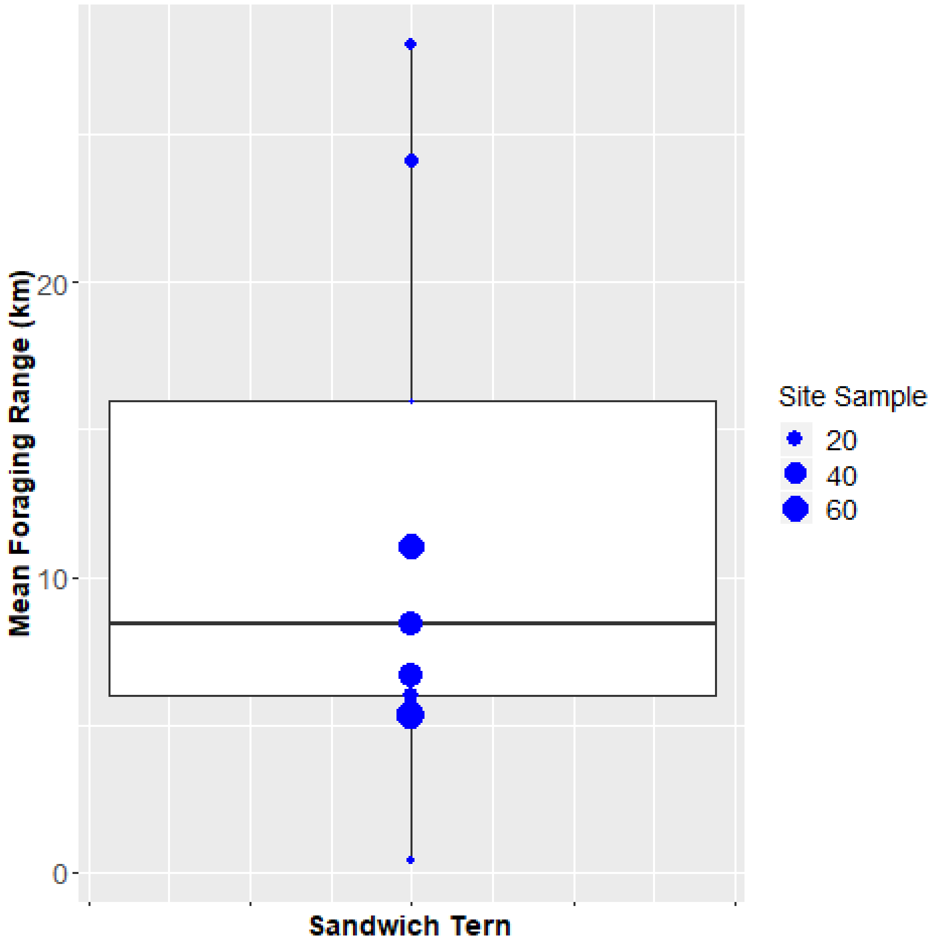


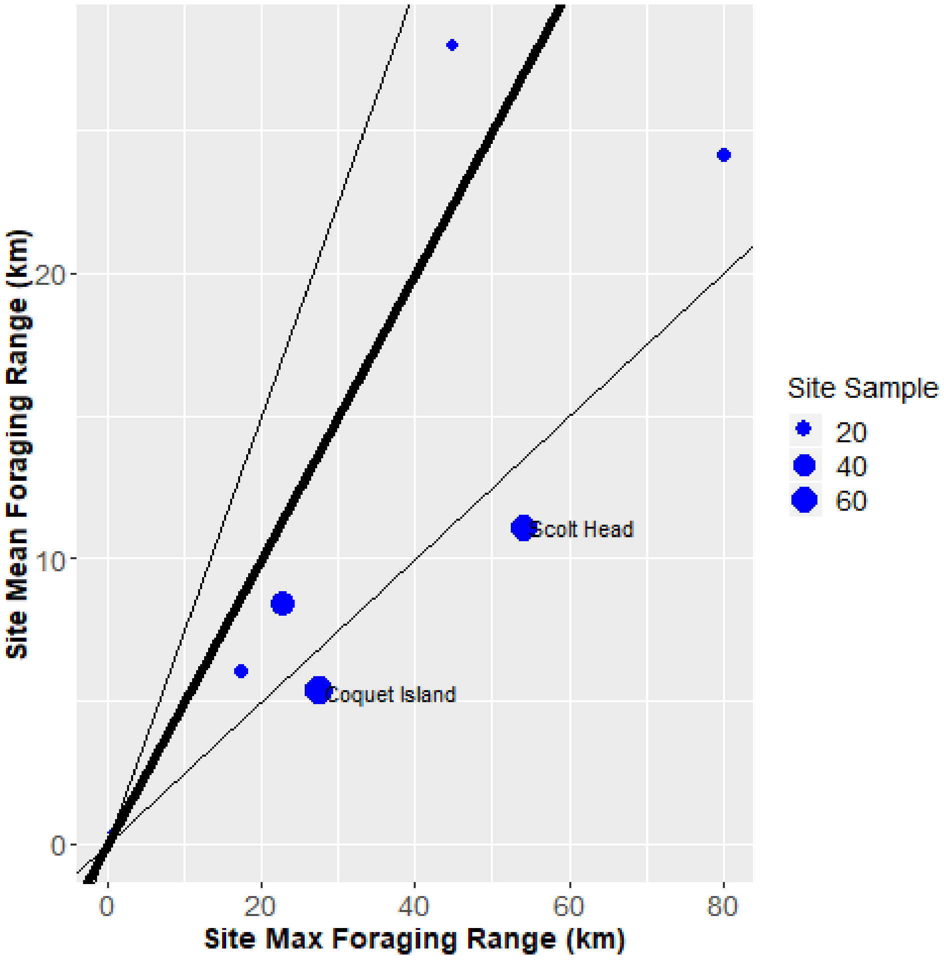
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

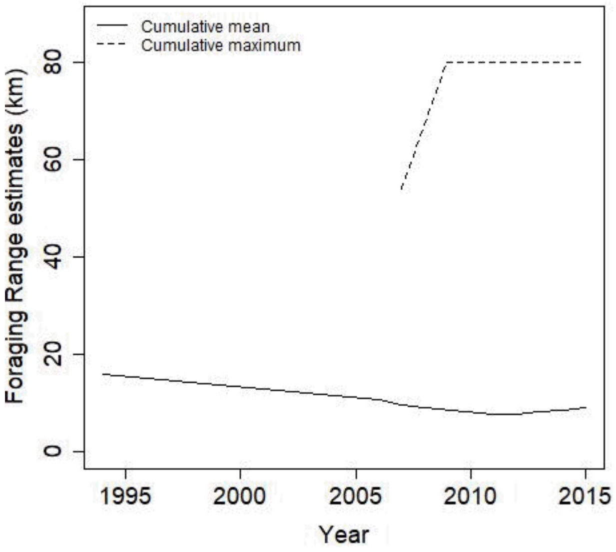
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Anglesey Terns / Morwenoliaid Ynys Mon	Cemlyn	24.8	NA	NA	363
Coquet Island	Coquet Island	27.6	5.3	71	363,364
Larne Lough	Blue Circle Island, Larne Lough	17.2	6	15	364
North Norfolk Coast	Blakeney Point	NA	6.7	55	251
North Norfolk Coast	Scolt Head	54	11.1	62	251
Ythan Estuary, Sands of Forvie and Meikle Loch	Sands of Forvie (Ythan Estuary)	22.9	8.4	51	364

Graphs


Mean Foraging Range (km)
20
10
0
Sandwich Tern
Site Sample
20
40
60


Site Mean Foraging Range (km)
20
10
0
0
20
40
60
80
Site Max Foraging Range (km)
Scolt Head
Coquet Island
Site Sample
20
40
60



Further information

- The majority of foraging distance estimates, including all those reported in the UK to date, come from visual tracking studies carried out by following foraging terns in high speed boats using a method described by Perrow *et al.* (2011)
- However, in recent studies in the Netherlands (two sites), GPS tracking has been used on Sandwich terns for the first time (Fijn *et al.* 2017). Maximum and mean foraging distances from these two study were higher than those previously recorded in the UK (comparison stats). The two Dutch sites are in close proximity to each other so this may be a site-effect and is not necessarily a result of the different measurement technique, but it would be prudent to carry out further research to confirm this.
- Tracking from Cemlyn, North Wales, indicates there may be a strong directionality in foraging behaviour with birds travelling east, but not west to forage. In such circumstances a combination of tracking and modelling may provide a more refined estimate of foraging ranges than relying on the tracking data alone (M. Murphy *pers. comm.*)

Little Tern *Sternula albifrons*

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	5	5	3.5
Number of studies	2		1
Number of colonies	1		1
Sample (number of birds)	40		21
References	252,253		252

Map of representative foraging ranges around SPAs

The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Great Yarmouth North Denes	Scroby Sands	5	3.5	21	252,253

Graphs

Not produced due to low sample size

Further information

- This species is too small to be tracked by GPS tags and the only direct data to date come from VHF tracking at a single site, Scroby Sands in Norfolk (Perrow *et al.* 2006, 2015).
- However, land and boat based observational surveys have been carried out at five sites around the UK (including Scroby Sands), and these support the findings of the VHF tracking and suggest that this species does not normally travel further than 5 km from the colony.

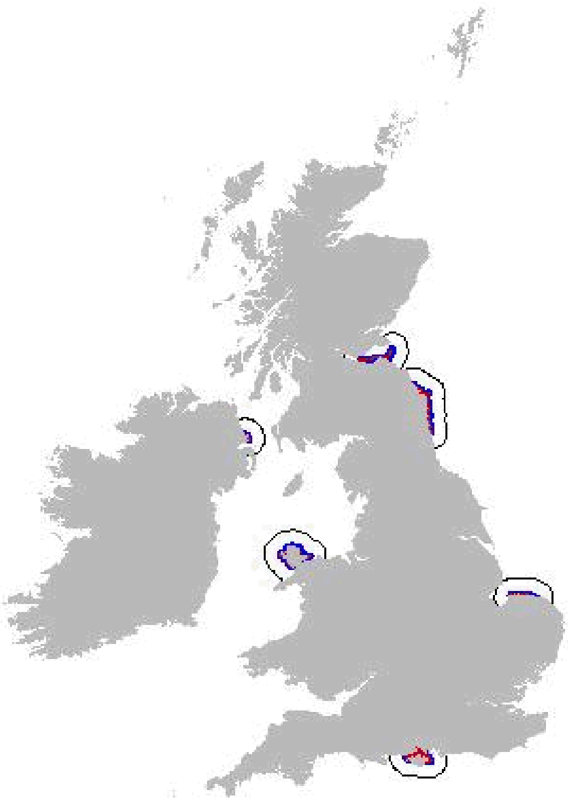
Roseate Tern *Sterna dougallii*

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	23.9	12.6±10.6	4.1±2.6
Number of studies	3		2
Number of colonies	3		2
Sample (number of birds)	63		41
References	279,363,364		279,364

Map of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Coquet Island	Coquet Island	10.8	3.2	31	363,364
Larne Lough	Blue Circle Island, Larne Lough	3	NA	NA	364

Graphs

Not produced due to low sample size

Further information

- All studies in the UK have used visual tracking of foraging birds by following them in a high speed boat. A Canadian study using VHF tracking is also included in the direct category (Rock *et al.* 2007b). Although the maximum distance observed in the UK was 11 km, both the maximum foraging distance (24 km) and the mean foraging distance (7 km) were considerably higher in the Canadian study, suggesting that foraging distances may be variable and may depend on local conditions.
- The previous foraging range estimates presented in Thaxter *et al.* (2012) were based on less robust data from observations and boat surveys, with four of the six studies reporting mean foraging ranges of 6.5 km or less. However, mean foraging distances of 25 km at Falkner Island, United States (Heinmann 1992) and 30 km at Rockabill, Ireland (Parkin 2004) were reported.
- Further research work is therefore recommended to confirm whether longer foraging distances may occur more frequently at some colonies.

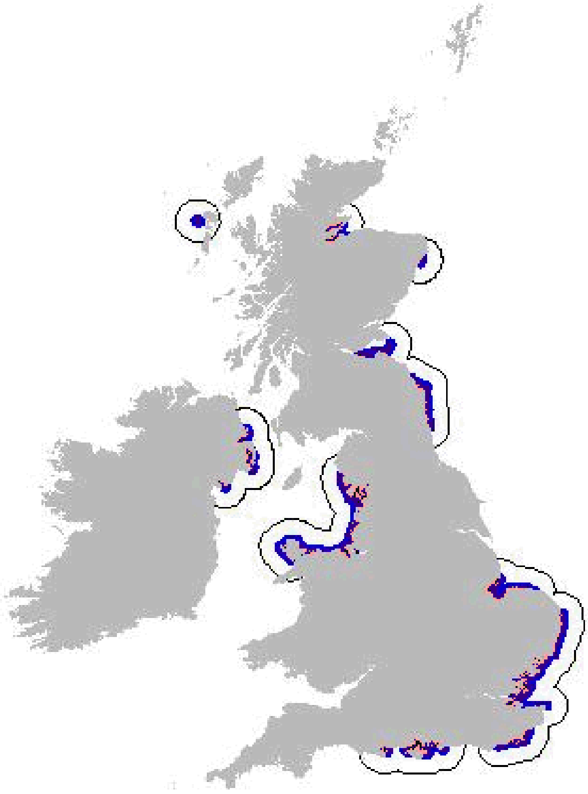
Common Tern *Sterna hirundo*

Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	**Max Max (km)**	**Mean Max (km)**	**Mean (km)**
Foraging range	30	18.0±8.9	6.4±4.5
Number of studies	9		7
Number of colonies	16		10
Sample (number of birds)	577		336
References	30,61,223,251,270,280,363,364,377		20,61,223,251, 280,364,377

Map of representative foraging ranges around SPAs

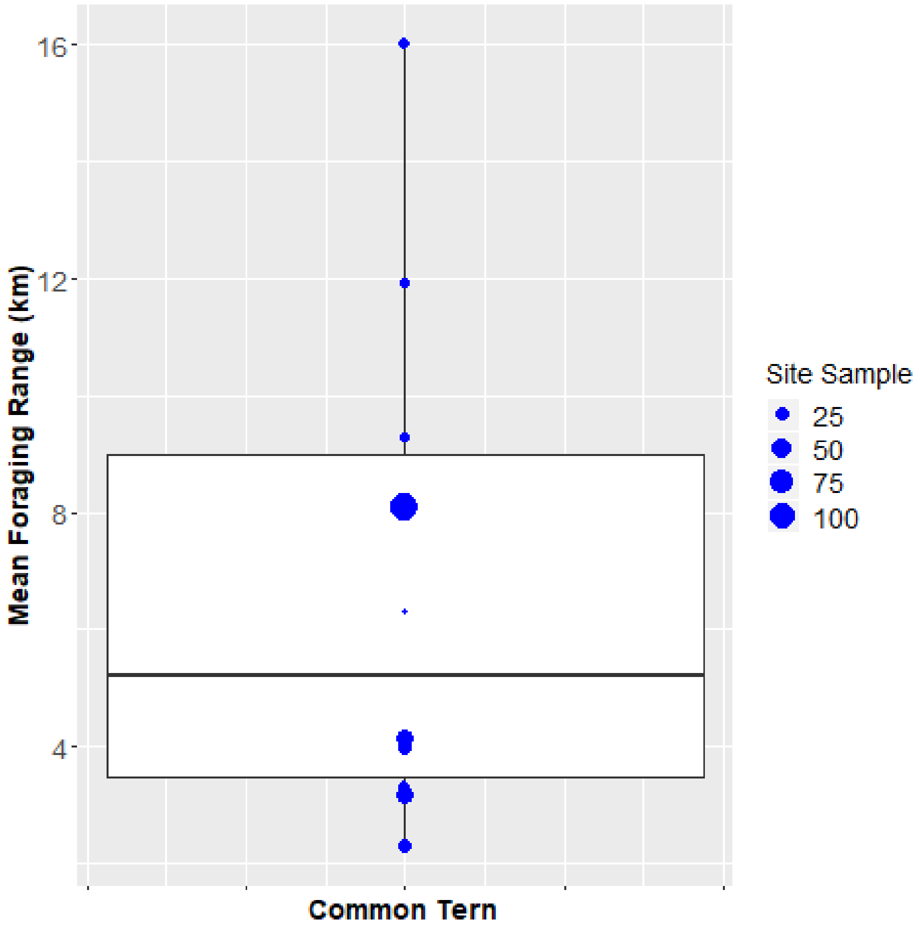


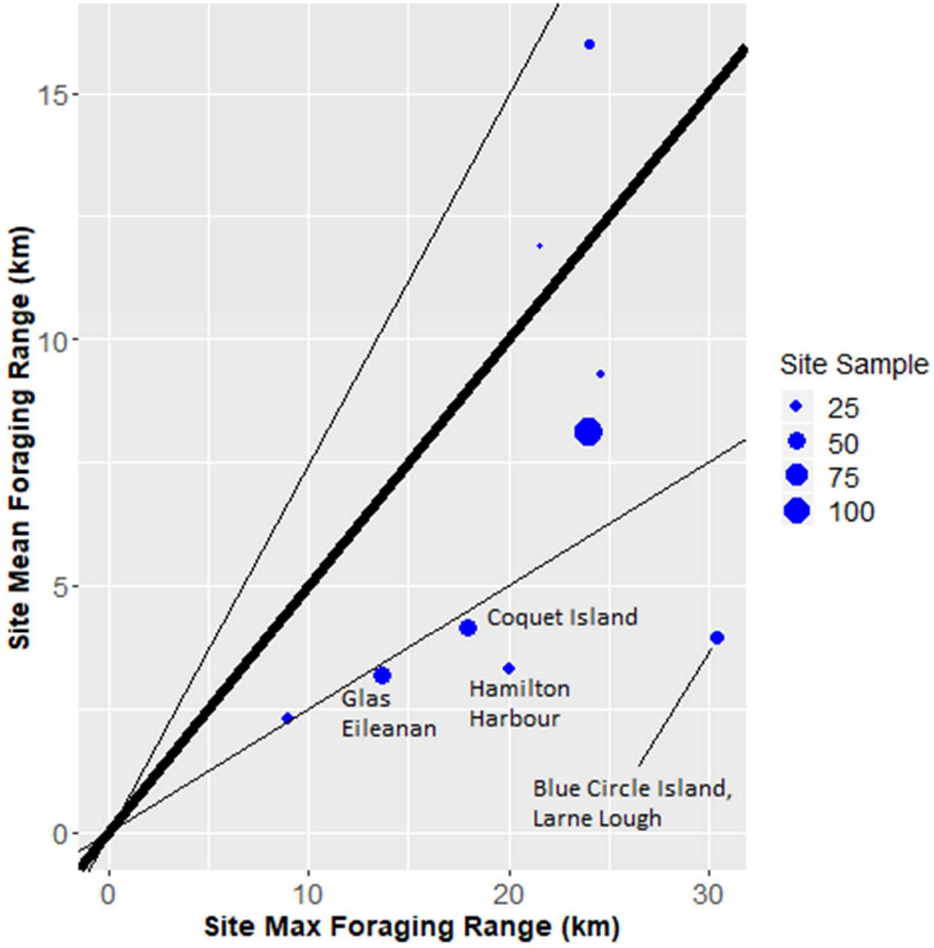
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

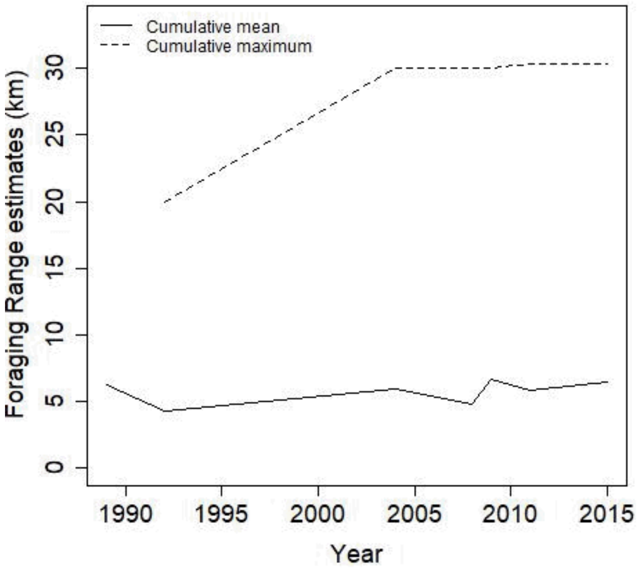
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Anglesey Terns / Morwenoliaid Ynys Mon	Cemlyn	12.2	NA	NA	363
Coquet Island	Coquet Island	17.9	4.1	42	363,364
Glas Eileanan	Glas Eileanan	13.7	3.2	48	364
Imperial Dock Lock, Leith	Leith Docks	15.2	NA	NA	363
Larne Lough	Blue Circle Island, Larne Lough	30.4	4	28	364
Larne Lough	Swan Island, Larne Lough	1.4	NA	NA	364
North Norfolk Coast	Blakeney Point	9	2.3	25	251

Graphs


16
12
8
4
Mean Foraging Range (km)
Common Tern
Site Sample
25
50
75
100


15
10
5
0
0
10
20
30
Site Mean Foraging Range (km)
Site Max Foraging Range (km)
Coquet Island
Glas Eileanan
Hamilton Harbour
Blue Circle Island, Larne Lough
Site Sample
25
50
75
100



Further information

- All direct studies in the UK have used either VHF tracking or visual tracking of foraging birds by following them in a high speed boat. However one study in the United States used GPS tracking (Carloni 2018).
- Most studies suggest foraging distances are usually small, with mean foraging estimates of 6 km or less at six of the nine sites for which data are available. However, mean distances of 16 km and 12 km were reported respectively from New Hampshire (Carloni 2018) and from South Shain, Scotland (Wilson *et al.* 2012), suggesting foraging ranges may sometimes be higher, perhaps as a result of site-specific effects.

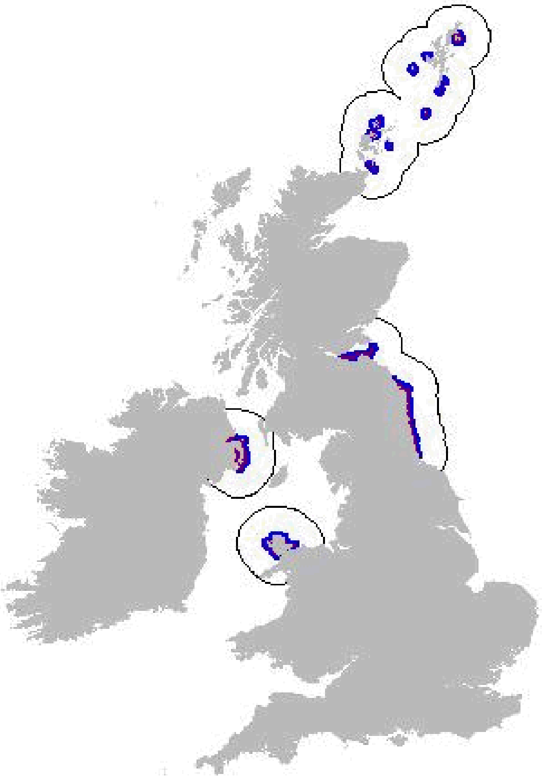
Arctic Tern *Sterna paradisaea*

Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	46	25.7±14.8	6.1±4.4
Number of studies	5		3
Number of colonies	9		6
Sample (number of birds)	160		90
References	30,251,280,363,364		251,280,364

Map of representative foraging ranges around SPAs

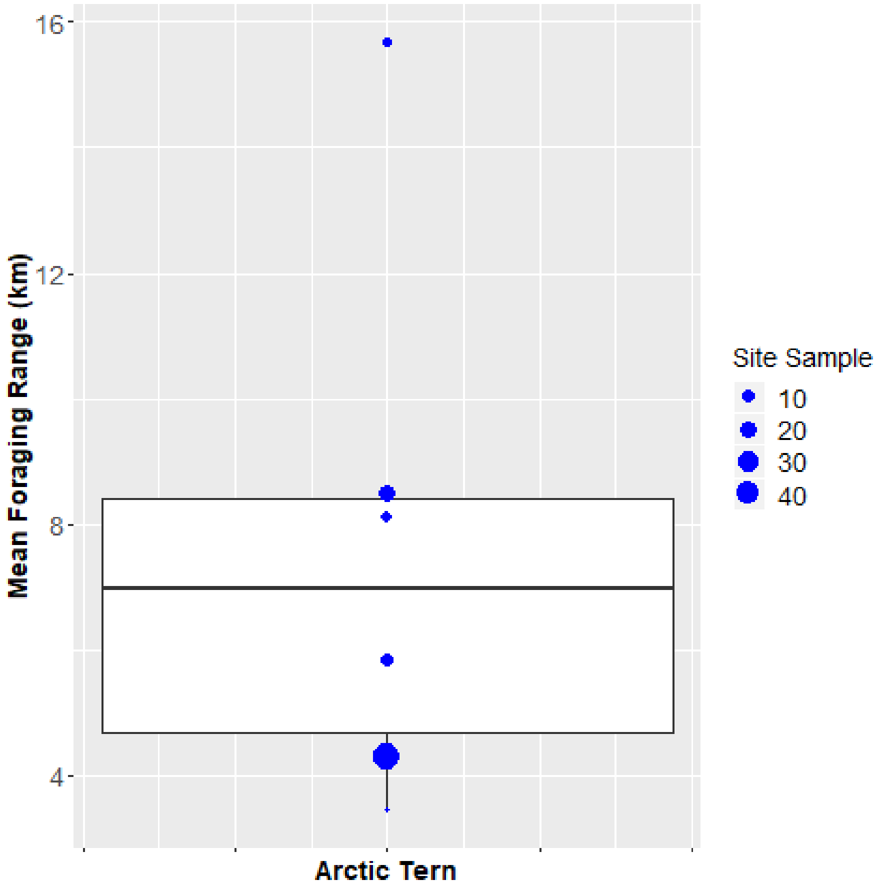


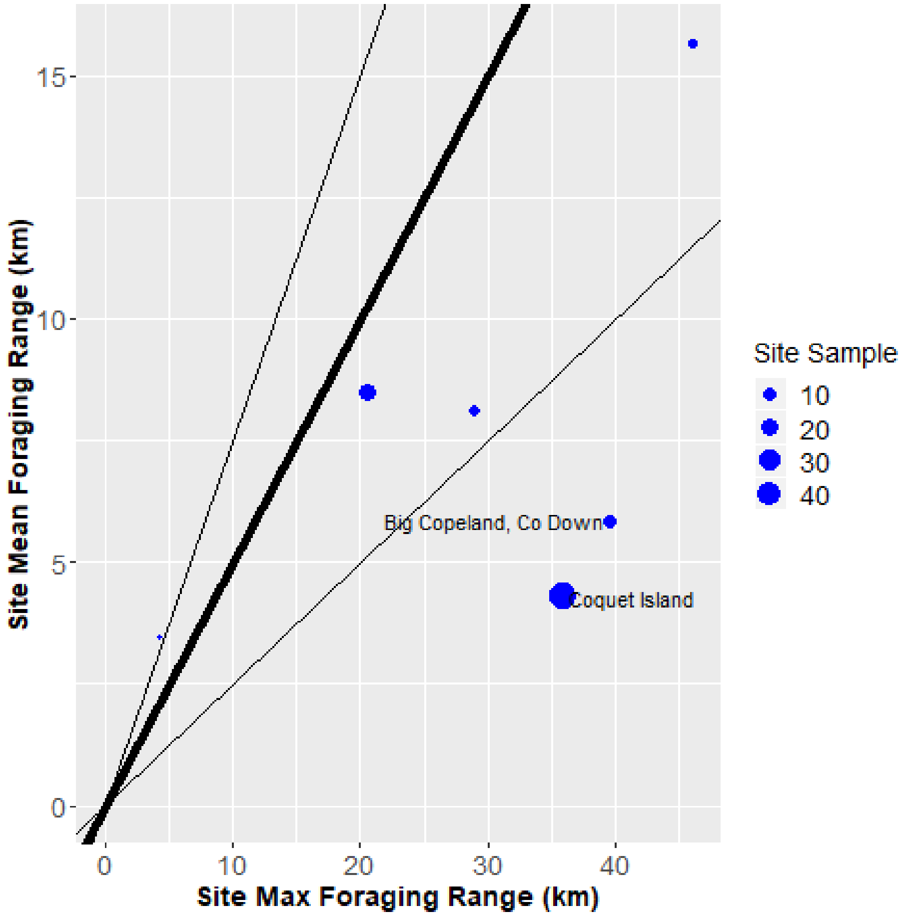
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

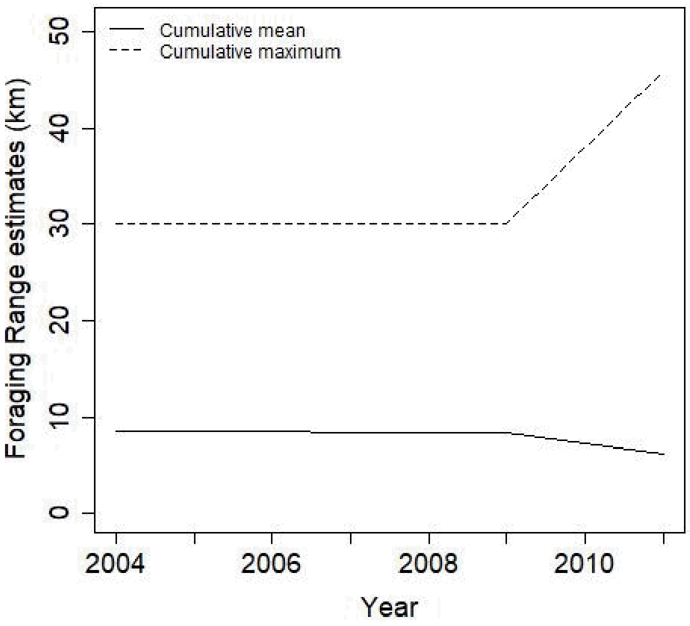
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Anglesey Terns / Morwenoliaid Ynys Mon	Cemlyn	2.6	NA	NA	363
Anglesey Terns / Morwenoliaid Ynys MonMon	Skerries - Anglesey	29	8.1	7	251
Copeland Islands	Big Copeland, Co Down	39.6	5.8	10	364
Coquet Island	Coquet Island	36	4.3	49	363,364
Outer Ards	Cockle Island, Groomsport, Co Down	46	15.7	4	364

Graphs


16
12
8
4
Mean Foraging Range (km)
Arctic Tern
Site Sample
10
20
30
40


15
10
5
0
Site Mean Foraging Range (km)
0
10
20
30
40
Site Max Foraging Range (km)
Big Copeland, Co Down
Coquet Island
Site Sample
10
20
30
40



Further information

- All studies in the UK have used visual tracking of foraging birds by following them in a high speed boat. A Canadian study using VHF tracking is also included in the direct category (Rock *et al.* 2007a).
- The mean foraging range was 8.5 km or less at five of the six sites for which data are available. The mean foraging range at Cockle Island was 15.7 km, suggesting foraging ranges can be higher at some sites, although it should be noted that this estimate is based on a sample of only four tracked birds with one of the four birds travelling 46 km from the colony.

Great Skua *Stercorarius skua*

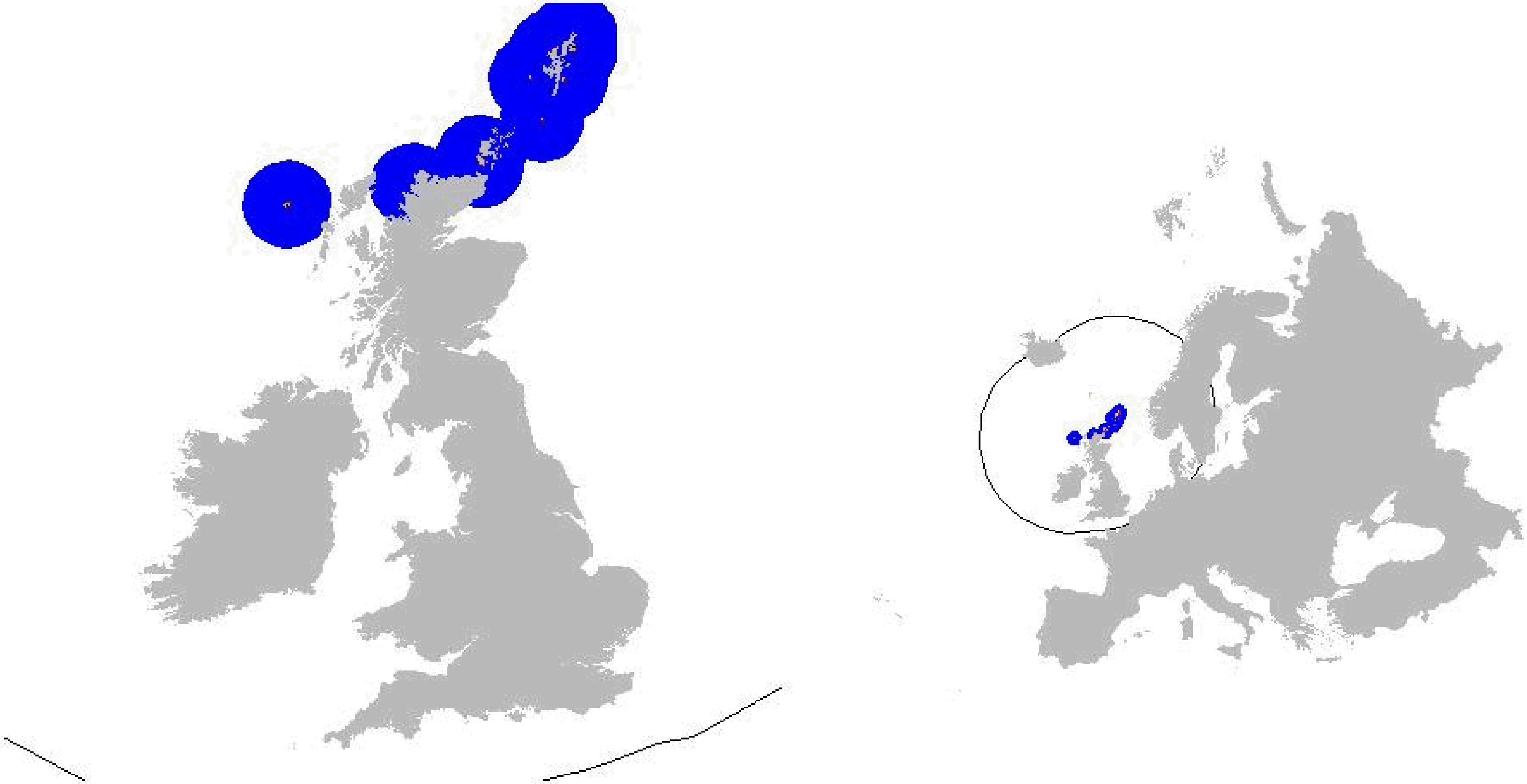
Measurement Category: DIRECT
Confidence Level: Low

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	1003	443.3±487.9	67±31.5
Number of studies	2#		1#
Number of colonies	3		2
Sample (number of birds)	41		24
References	188,323		323

Note that data from three studies which were used in the Thaxter *et al.* (2012) foraging range estimates have been excluded from the calculation of the updated statistics. These are considered unrepresentative as they were made using VHF restricted to the area close to the colony and hence could not pick up longer foraging trips.

Maps of representative foraging ranges around SPAs



The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References	Notes
Foula	Foula	219	85.6	14	323	
Hoy	Hoy	108	41	10	323	

Graphs

Not produced due to low sample size

Further information

- Whilst the maximum foraging distance reported from a British colony is 219 km, the maximum distance recorded at Bjørnøya, Svalbard was 1,003 km (Jakubas *et al.* 2018), indicating that birds can forage much further.
- The Svalbard study by Jakubas *et al.* (2018) showed variation in foraging strategies between individuals, with one female flying exclusively to seabird colonies at the south end of the island and remaining within 1 km of the colony for six of her seven flights.
- Published data are only available to date on a relatively low number of tagged birds (40 in the UK and 17 on Svalbard) but further tagging work may confirm whether the longer maximum distance recorded from Svalbard is exceptional or may be typical at some colonies.

Arctic Skua *Stercorarius parasiticus*

Measurement Category: AERIAL/BOAT/LAND SURVEY
Confidence Level: Poor

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	NA	NA	2±0.7
Number of studies	NA		2
Number of colonies	NA		2
Sample (number of birds)	NA		2
References	NA		259,264

Map of representative foraging ranges around SPAs

The mean representative foraging range is shown in blue around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.
Note: Maximum foraging range areas are not shown as no representative estimate is available

Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Foula	Foula	NA	2.5	1	259

Graphs

Not produced due to low sample size

Further information

- Published information on Arctic skua foraging ranges is sparse, with the only information available coming from boat surveys which may under-estimate the distances travelled.
- Given the strong decline of Arctic skua in the UK (Perkins *et al.* 2018), conservation action may be particularly important for this species and robust measurement of foraging ranges may be an important component of this action. Recent tracking work has been undertaken in Scotland which may enable more robust directly measured foraging ranges to be published in the near future.

Common Guillemot *Uria aalge*

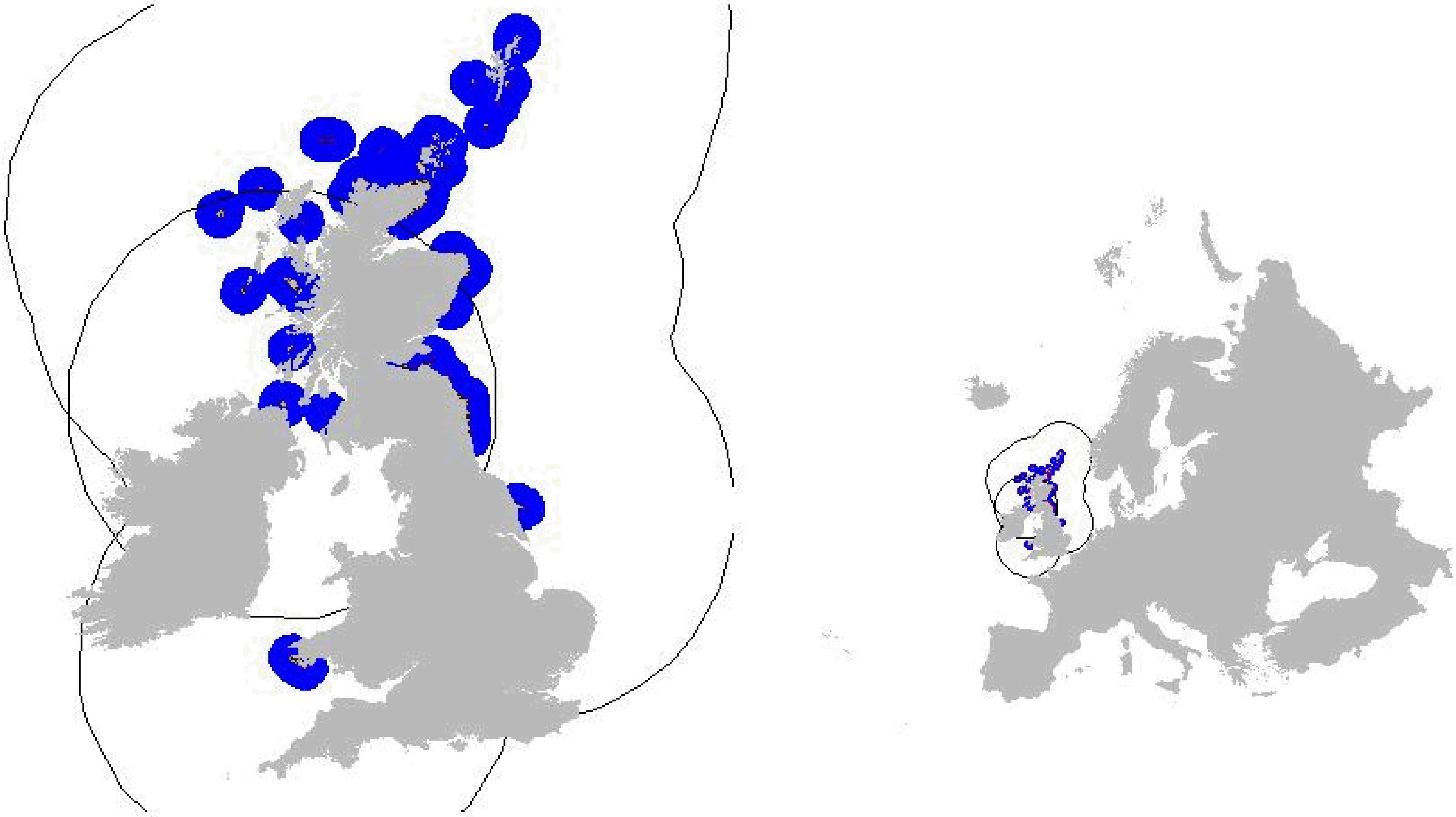
Measurement Category: DIRECT
Confidence Level: Highest

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	338 (135)*	73.2±80.5 (55.5±39.7)*	33.1±36.5 (23.9±21.1)*
Number of studies	7		9
Number of colonies	16		16
Sample (number of birds)	201		232
References	111,167,207,221,273,322,374		111,154,167,207, 221,322,351,368, 374

*Excluding data from Fair Isle where foraging range may have been unusually high as a result of reduced prey availability during the study year.

Maps of representative foraging ranges around SPAs

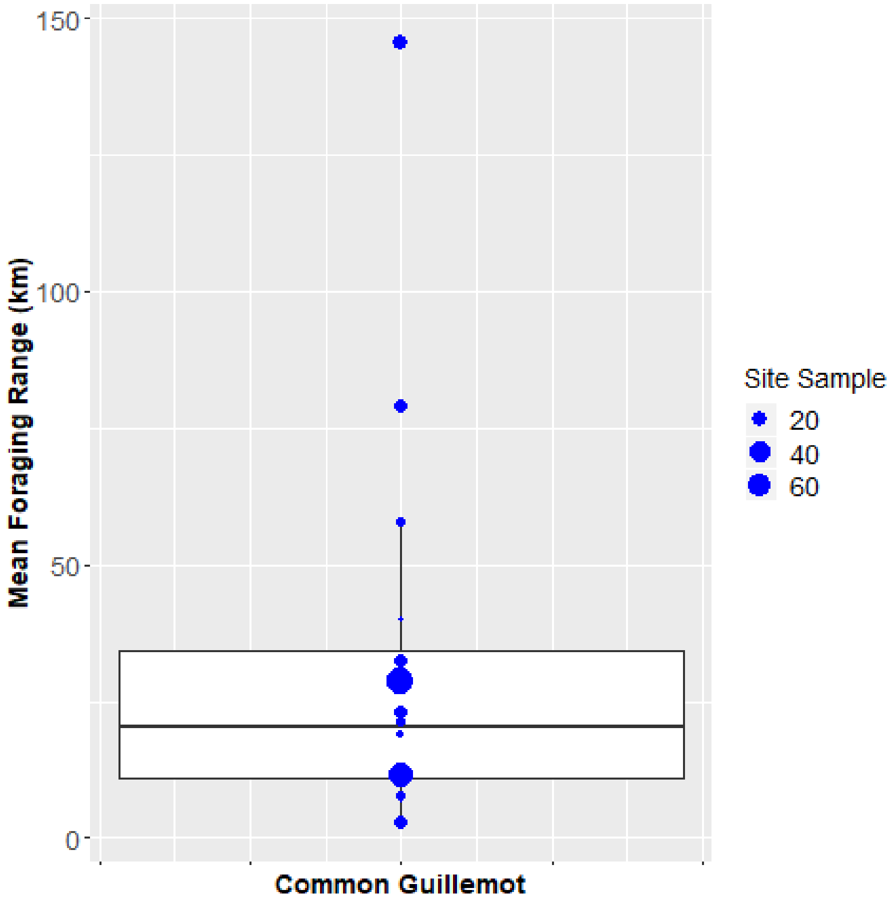


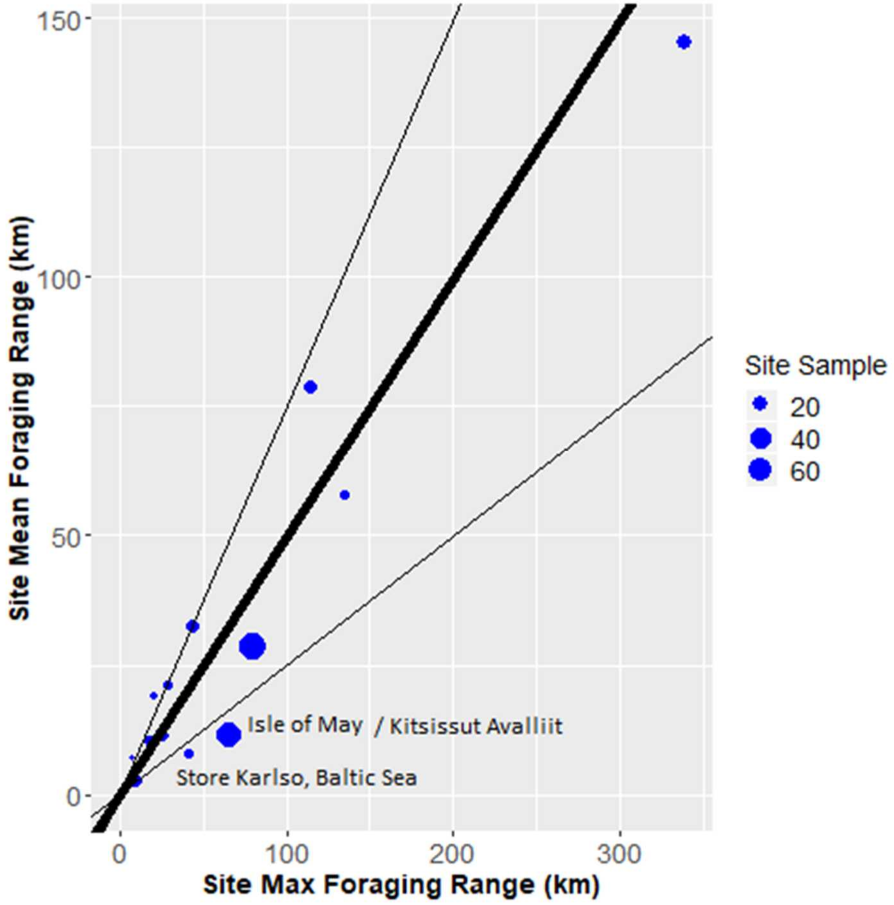
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

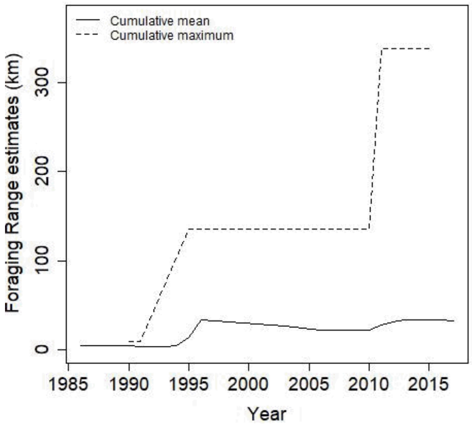
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Copinsay	Copinsay, Orkney	26.6	11.1	9	374
Fair Isle	Fair Isle	338.4	145.4	18	374
Forth Islands	Isle of May	65.1	11.5	61	322,351
Fowlsheugh	Fowlsheugh	44.2	32.4	10	374
Sumburgh Head	Sumburgh Head, Shetland	9.4	2.9	11	221,368
The Shiant Isles	The Shiant Isles	7	7	1	374

Graphs


Mean Foraging Range (km)
150
100
50
0
Common Guillemot
Site Sample
20
40
60


Site Mean Foraging Range (km)
150
100
50
0
Isle of May / Kitsissut Avalliit
Store Karlso, Baltic Sea
0
100
200
300
Site Max Foraging Range (km)
Site Sample
20
40
60



Further information

- The direct studies have been carried out using several different methods, including PTT tags, VHF and more recently GPS tags.
- The available data suggest that this species often forages reasonably close to the colony, with 12 of the 16 site means being lower than the overall mean of 33.1 km. However, occasionally, foraging distances can be considerably further, with the tracked birds from Fair Isle having a mean foraging distance of 145 km and a maximum distance of 338 km (RSPB dataset). This may relate to poor prey availability during the period in which data were collected on Fair Isle[10]. Excluding these data from the analysis the maximum foraging range is reduced to 135 km, the mean maximum to 55.5 km and the mean to 23.9 km.
- Distribution modelling has also been undertaken using RSPB tracking data to map and model foraging areas used by Guillemot around the UK (Wakefield *et al.* 2017; Sansom *et al.* 2018).
- In Newfoundland, maximum foraging distances increased from 60 km to 81 km in years when food resources were low (Burke *et al.* 2009).

  Information on whether foraging ranges vary between the sexes and between the different stages of breeding remains sparse.

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[10] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010051/EN010051-001301-Forewind%20-%20Apportioning%20of%20Flamborough%20and%20Filey%20Coast%20pSPA%20and%20Farne%20Islands%20guillemot%20and%20razorbill%20population.pdf

Razorbill *Alca torda*

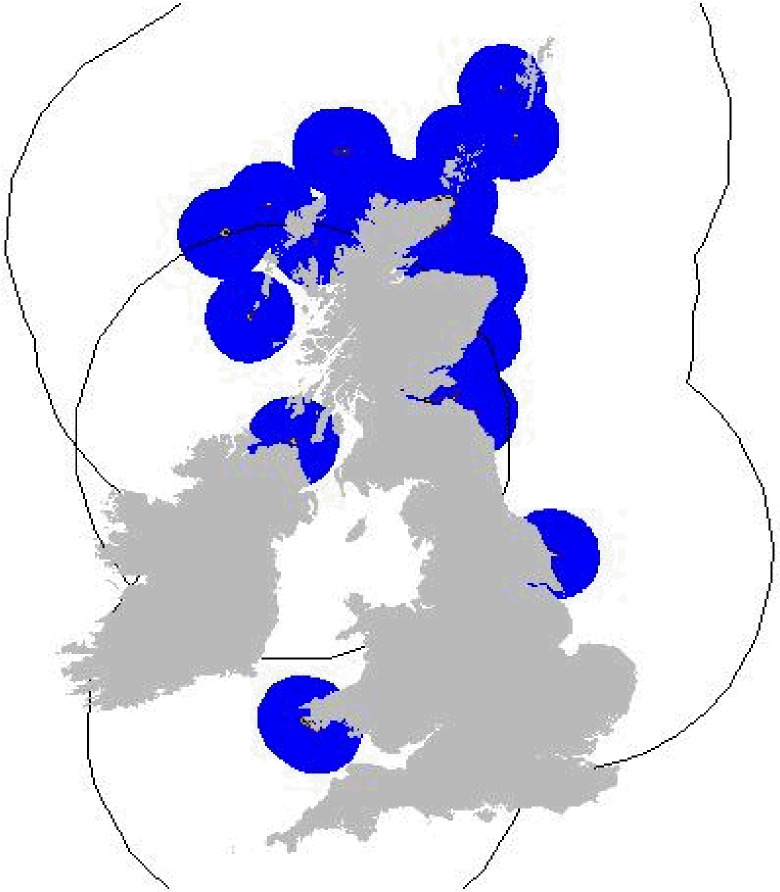
Measurement Category: DIRECT
Confidence Level: Good

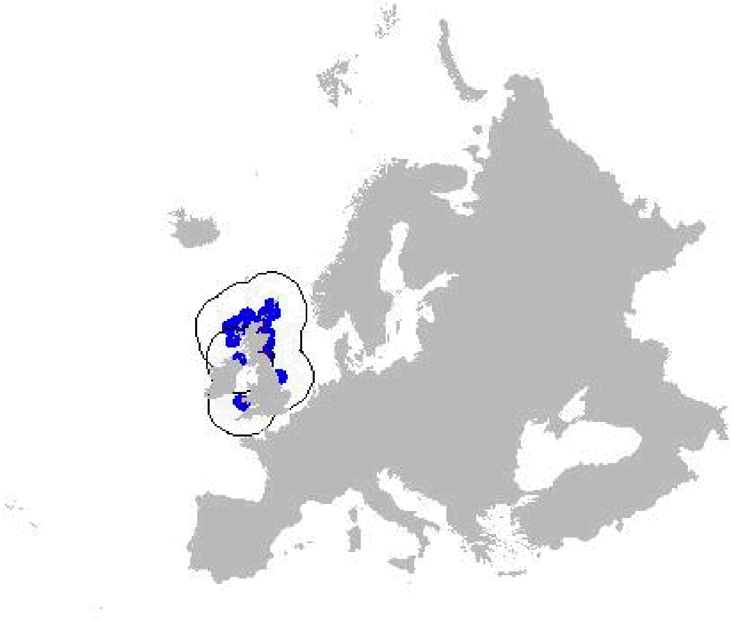
Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	313 (191)*	88.7±75.9 (73.8±48.4)*	61.3±33.4 (31.2±17.3)*
Number of studies	8		9
Number of colonies	16		18
Sample (number of birds)	297		317
References	68,183,199,207,297,300,324,374		83,154,183,199, 207,297,317,324, 374

*Excluding data from Fair Isle where foraging range may have been unusually high as a result of reduced prey availability during the study year.

Maps of representative foraging ranges around SPAs



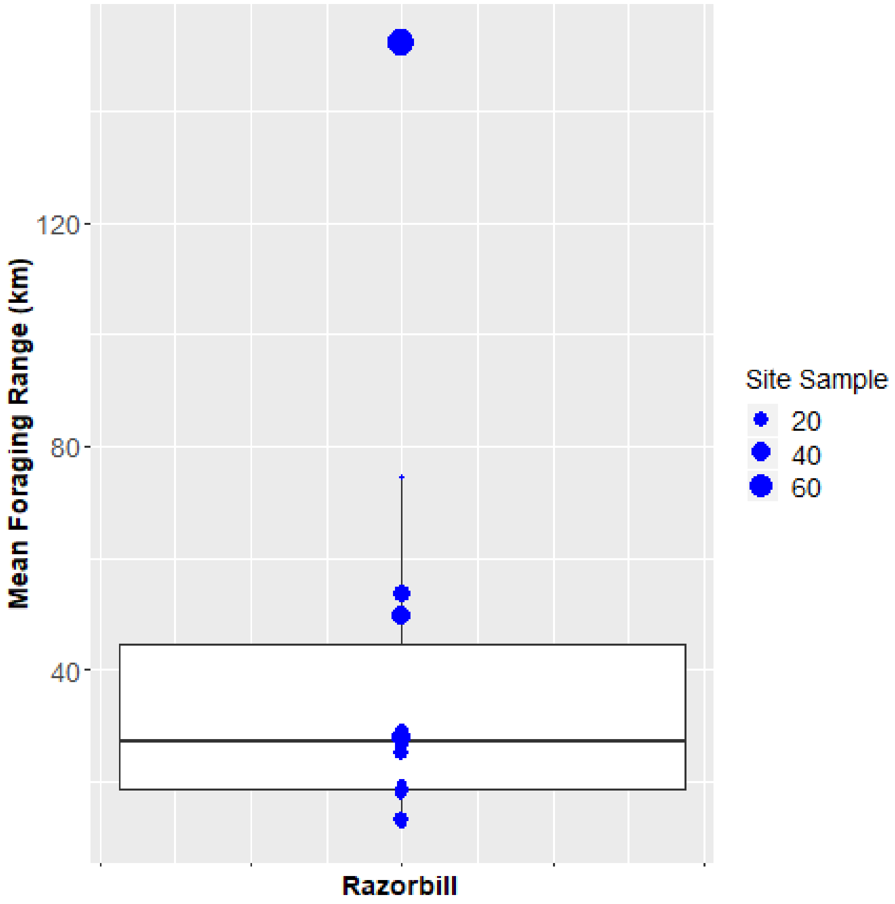


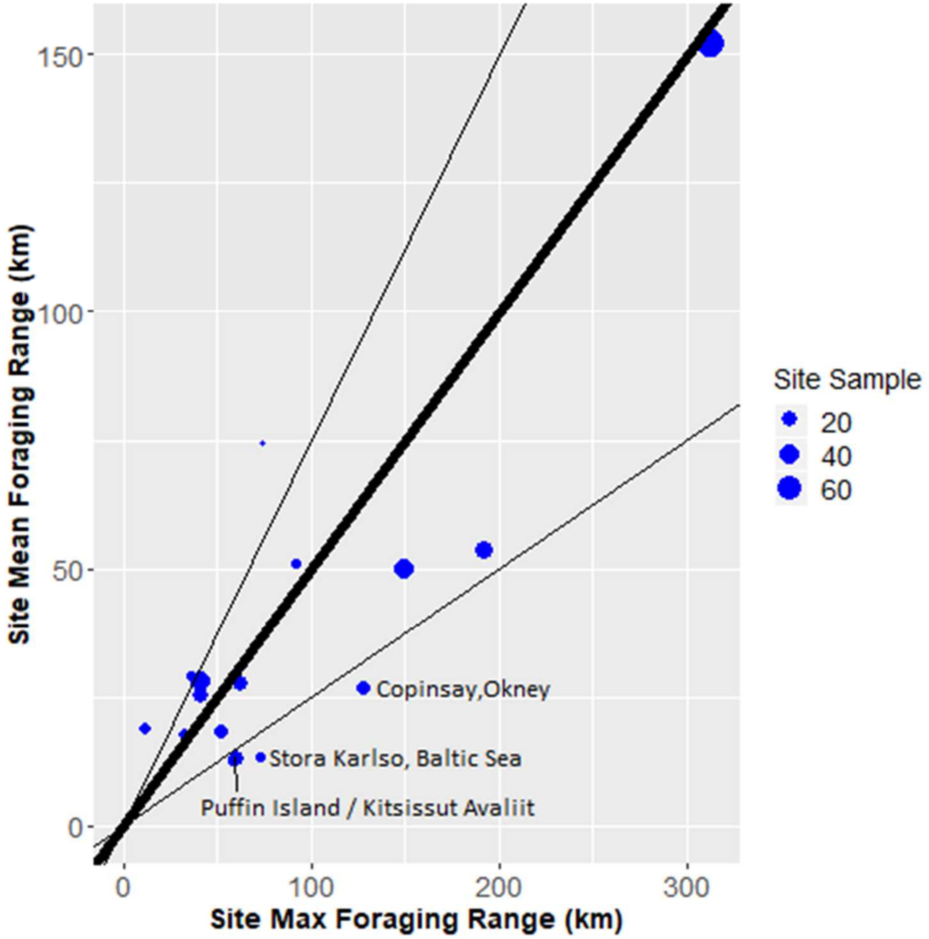
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

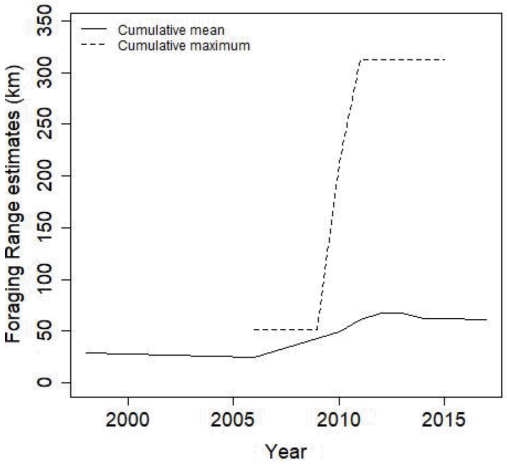
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Fair Isle	Fair Isle	312.9	152.2	79	374
Flannan Isles	Flannans	92.2	50.8	4	374
Forth Islands	Isle of May	52	18.4	11	324,351
Rathlin Island	Rathlin Island	74.4	74.4	1	374
Skomer, Skokholm and the seas off Pembrokeshire	Skomer	62.0	27.4	18	297,300
The Shiant Isles	The Shiant Isles	36	29.1	4	374

Graphs


Mean Foraging Range (km)
120
80
40
Razorbill
Site Sample
20
40
60


Site Mean Foraging Range (km)
150
100
50
0
0
100
200
300
Site Max Foraging Range (km)
Copinsay,Okney
Stora Karlso, Baltic Sea
Puffin Island / Kitsissut Avaliit
Site Sample
20
40
60



Further information

- A large number of new studies have published direct measurements of foraging ranges (using GPS tags) since Thaxter *et al.* (2012), hence the foraging range estimates published here are based on data from 18 sites, compared to the four sites available to Thaxter *et al* (2012).
- As for Guillemot, foraging distances undertaken by razorbill from Fair Isle appear to be particularly high with a mean of 152 km and a maximum of 313 km (RSPB dataset). The high sample size (79 birds) suggests this estimate is likely to be robust for the site but the data from elsewhere suggest this site may be unusual. For 16 of the other 17 colonies for which data were available, the site mean foraging ranges were less than the overall mean of 61.3 km, and at 13 of these colonies they were less than 30 km. If Fair Isle is removed from the calculation, the mean maximum foraging range would fall to 73.8 km and, the representative mean foraging range would be 31.2±17.3 km. Sampling at further sites would be prudent to ascertain whether other colonies are similar to Fair Isle.
- Distribution modelling has also been undertaken using RSPB tracking data to map and model foraging areas used by razorbill around the UK (Wakefield *et al.* 2017; Sansom *et al.* 2018).
- Kuepfer (2012) found that individuals at Atlantic puffin and Bardsey Islands undertook longer nocturnal foraging trips and shorter diurnal trips.
- Shoji *et al.* (2014) found that foraging distance increased with sea surface area which they suggested could possibly be related to prey availability or quality.

Measurement Category: DIRECT
Confidence Level: Moderate

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	8	4.8±4.3	4.9
Number of studies	2		1
Number of colonies	2		1
Sample (number of birds)	15		14
References	299,374		374

Map of representative foraging ranges around SPAs

Not produced as there are no SPAs for which this species is a designated breeding feature

Specific SPA foraging range statistics

This species is not a designated breeding feature at any SPAs.

Graphs

Not produced due to low sample size

Further information

- Although the short foraging estimate given here is based on only two GPS studies, it is further supported by observations from land based observers. As early as the 1980s, Cairns (1987) followed 71 foraging flights made by black guillemots actively feeding chicks at two colonies in Canada and observed that every bird landed and began feeding whilst still in sight of land, at an estimated maximum distance of 2 km. However, Cairns (1985) also observed black guillemots during boat surveys at distances of up to 15 km from the colony, suggesting that breeding birds may sometimes travel further from the colony.

Atlantic Puffin *Fratercula arctica*

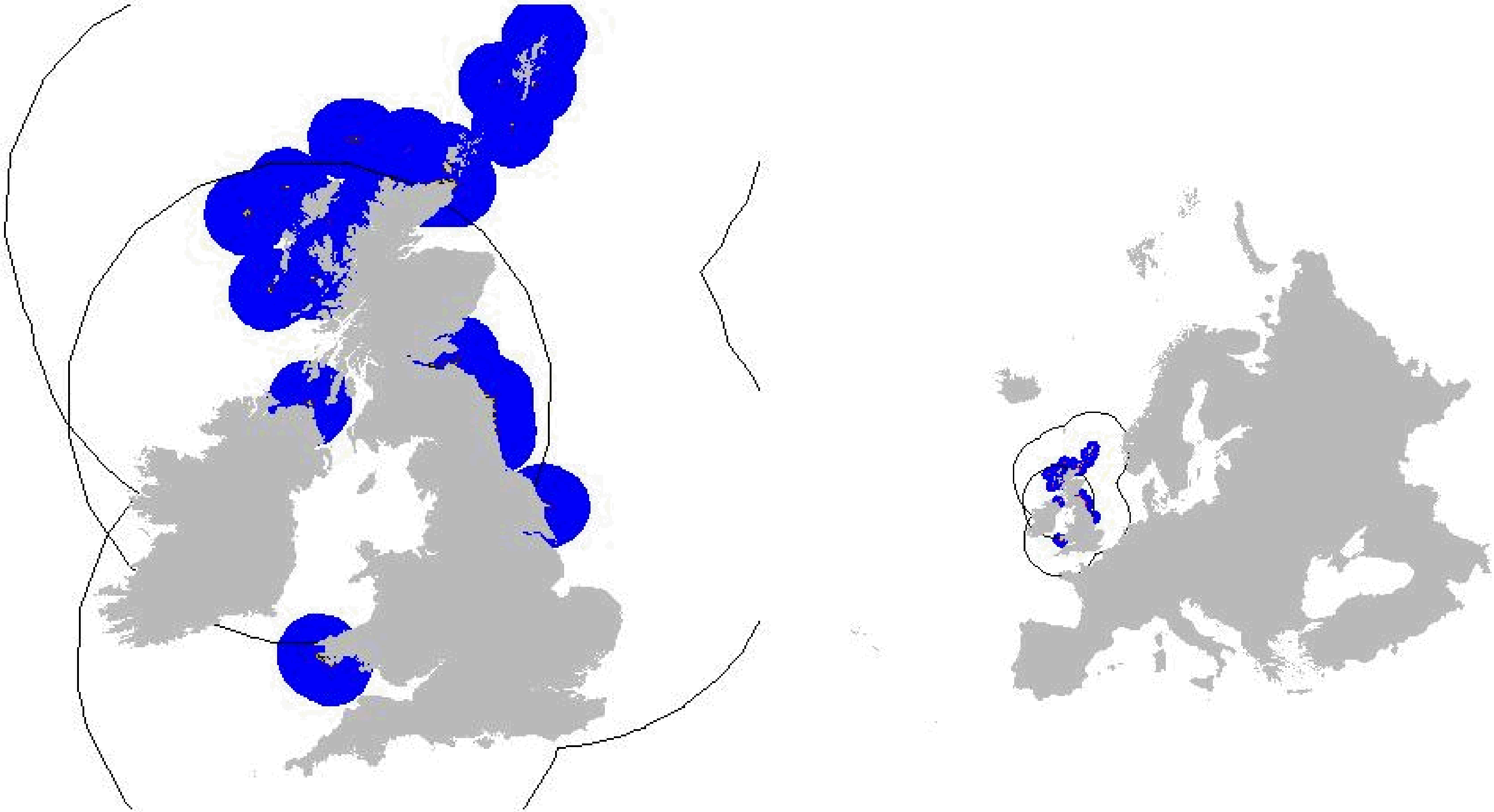
Measurement Category: DIRECT
Confidence Level: Good

Representative foraging range statistics

Measure	Max Max (km)	Mean Max (km)	Mean (km)
Foraging range	383	137.1±128.3 (119.6±131.2)*	62.4±34.4 (48.1±28.3)*
Number of studies	5		4
Number of colonies	7		7
Sample (number of birds)	119		118
References	24,163,317,351,374		24,163,317,374

*Excluding data from Fair Isle where foraging range may have been unusually high as a result of reduced prey availability during the study year.

Maps of representative foraging ranges around SPAs

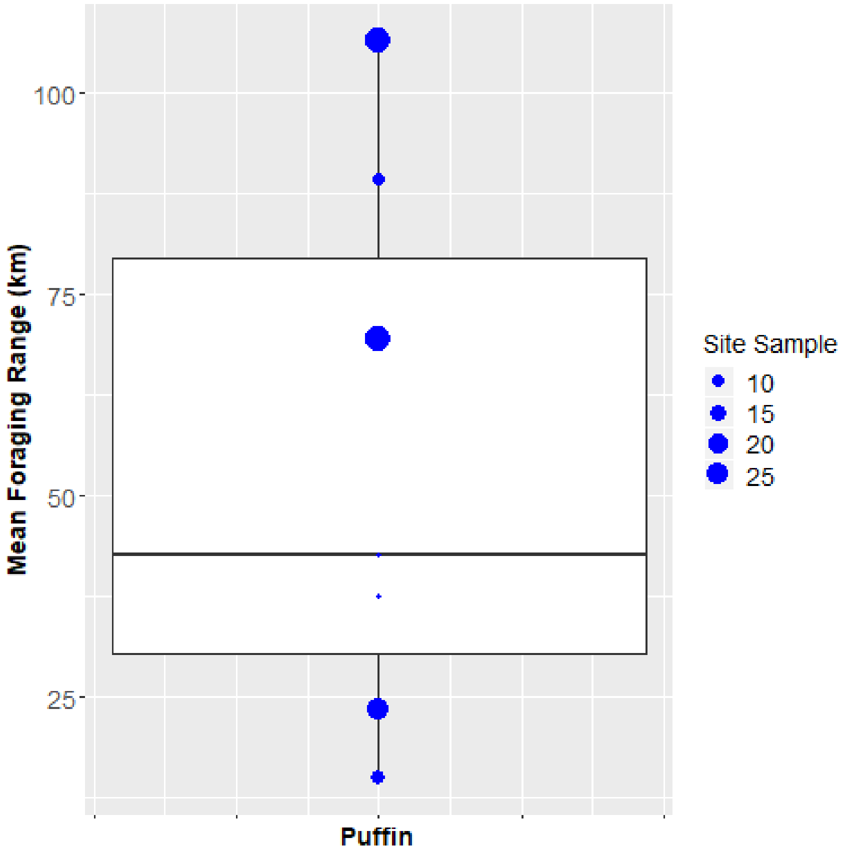


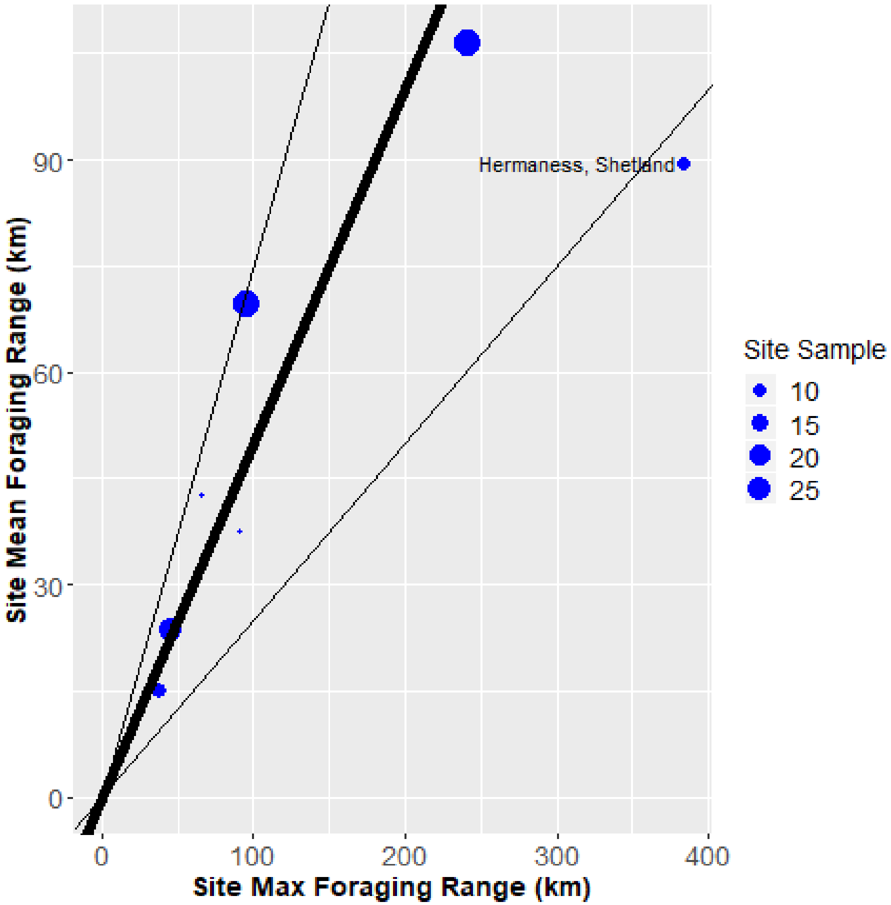
The mean representative foraging range is shown in blue and the black outer line denotes the maximum representative foraging range, shown around each SPA for which the species is a feature in its own right or as part of a seabird assemblage.

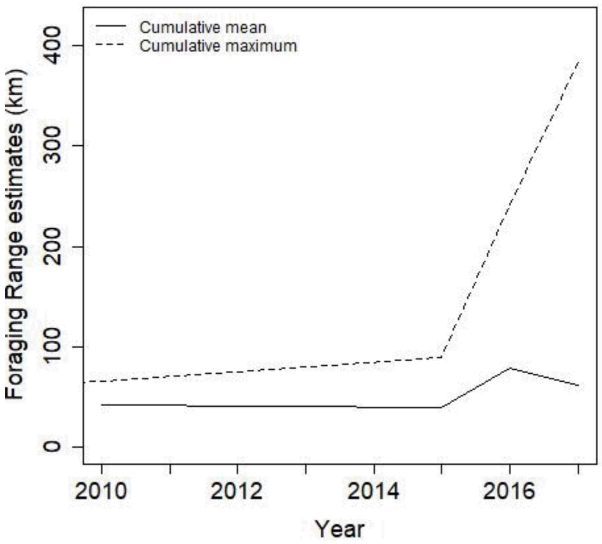
Specific SPA foraging range statistics

SPA Name	Site Name	Max.Max (km)	Mean (km)	Sample (no. birds)	References
Fair Isle	Fair Isle	241.7	106.5	29	374
Forth Islands	Isle of May	65.5	42.6	7	163,351
Foula	Foula	95.4	69.5	29	374
Hermaness, Saxa Vord and Valla Field	Hermaness, Shetland	383.3	89.5	11	374
The Shiant Isles	The Shiant Isles	45.7	23.4	23	374

Graphs


Mean Foraging Range (km)
100
75
50
25
Puffin
Site Sample
10
15
20
25


Site Mean Foraging Range (km)
90
60
30
0
Hermaness, Shetland
0
100
200
300
400
Site Max Foraging Range (km)
Site Sample
10
15
20
25



Further information

- The foraging range estimates for Atlantic puffin presented in Thaxter *et al.* (2012) was based on indirect measurements. However, studies using GPS tags have subsequently taken place at eight sites, including five in the UK, enabling foraging range estimates based on direct measurements to be presented here.
- As was the case for common guillemot and razorbill, foraging distances travelled by Atlantic puffin from Fair Isle are higher than those at most other sites (RSPB dataset), although they are not as exceptional when compared to other sites as those of the other two auk species.
- Observations of birds carrying fish have been made at distances of 250 km from the Faeroe Islands (Harris & Wanless 2011), offering further speculative evidence that Atlantic puffins forage at longer distances than the other auk species. Hence the distances observed from Fair Isle and Hermaness should not necessarily be considered exceptional until more data and data from additional colonies have been collected, particularly data from colonies where local prey availability may be greater.
- No information available on differences between m/f or between breeding stages.

APPENDIX 2: FORAGING RANGES DATASET

Woodward et al
2019 Appendix 2 Sea