Auk tagging project: final report, January 2023

CONTENTS

1 INTRODUCTION

Seabirds breeding in temperate regions such as western Europe have a clearly defined annual cycle. During the breeding season they are constrained to forage within a certain distance of their breeding site in order to make frequent visits to the nest (Daunt et al. 2002, Wakefield et al. 2013). During the non-breeding season, these central place constraints are relaxed, allowing seabirds to migrate to areas with potentially more favourable conditions. However, seabird mortality is generally highest in winter despite the lack of breeding season constraints (Mitchell et al. 2004, Acker et al. 2021). Seabirds may be exposed to a wide range of marine threats, such as extreme weather events, fisheries by-catch, harvesting, hunting, oiling events and marine renewable developments, which vary across both spatial and temporal scales (Dias et al. 2019). Many of these threats are localised and the probability of individuals from multiple populations encountering them during the non-breeding season will depend on the extent of aggregation at that time.

Shortly after completing breeding, most seabirds initiate feather moult, a process with high energetic requirements and in some species such as auks this involves a short period of flightlessness, limiting an individual's ability to move between locations and away from threats (Bridge 2006). Following the moult, seabirds may experience challenging winter conditions, with individuals exposed to prolonged periods of poor weather (Morley et al. 2016), lower food availability (Osborn et al. 1984), and shorter daylight hours in which to forage (Daunt et al. 2006, Moe et al. 2021). The moult and mid-winter periods are therefore thought to be key parts of the annual cycle when individuals may experience more hostile environmental conditions and/or energetic constraints (Burke & Montevecchi 2018), which could also make their populations more vulnerable to other marine threats at that time of year.

This study aimed to provide detailed data on the non-breeding season movements of adult common guillemots *Uria aalge* and razorbills *Alca torda*, with particular reference to UK populations likely to interact at some stage of the year with offshore wind farms in UK waters. The work was funded by Vattenfall, Hywind, and SEATRACK. The Vattenfall component of this collaboration was part of the Environmental Research and Monitoring Programme of the European Offshore Wind Deployment Centre (EOWDC).

Common guillemots and razorbills are among the seabirds considered most vulnerable to displacement by offshore wind farms (Furness et al. 2013, Peschko et al. 2020). Assessing impacts of displacement requires knowledge of the seasonal movements of different populations. Guillemots and razorbills in the UK breed from late March to early July. Following the breeding season, successful males continue to provide parental care to chicks for up to two months (Gaston and Jones 1998) and all adults of both species moult their primary and secondary feathers for a period of four to six weeks during August and September, rendering them flightless (Birkhead & Taylor 1977, Harris & Wanless 1990). They may be particularly vulnerable to marine threats during moult because they are unable to respond rapidly to disturbance and are already expending energy on moult and parental care. After the moult has been completed, during winter, auks are likely to experience poor weather conditions, high energetic costs, and limited food availability (Burke & Montevecchi 2018), so better understanding of the seasonal distributions and movements will help to inform appropriate conservation policy for these birds while they are away from their breeding colonies.

Movements during the non-breeding season are generally much less well understood than those during the breeding season due to the challenges of tracking seabirds over long periods of time. Until

recently, the best evidence on seasonal movements of common guillemots and razorbills came from ringing of chicks and adults at breeding colonies with subsequent recoveries of ringed birds, usually found dead during winter. Ring recoveries give a broad indication of seasonal movements of these birds, but ring recovery rates are low, at around 3% for common guillemot and for razorbill (Walker et al. 2020). Also, locations of recoveries tend to be biased to places where birds die close to people, such as in fishing nets, hunted, or washed up on sandy beaches (Wernham et al. 2002), so may not give accurate indications of the spatial distributions and seasonal movements of healthy birds. Ring recovery analysis has hinted at possible colony-specific differences in wintering areas (Mead 1974) but without providing a clear picture. In that context, Wernham et al. (2002) concluded in relation to possible colony-specific movement patterns "the present evidence is hardly compelling but the idea deserves further attention since guillemots from the different regions do have somewhat different recovery areas". This project has collected novel movement and behavioural data for common guillemots and razorbills over durations of up to several years using small geolocator tags. The new information allows more accurate attribution of any predicted impacts to appropriate populations ("apportioning") and the tracking data obtained from this study have been used in that regard by UKCEH working with BIOSS. This will reduce uncertainty in impact assessment, especially where this uncertainty requires more precautionary approaches to impact assessment to be followed.

Geolocator tags offer a simple and cost-effective method for long term tracking of individuals. The tags are small enough to be fitted to a leg ring. Geolocator tags record light intensity (and normally also sea surface temperature and in some cases behavioural parameters although the options for this were more restricted for the tags suitable for razorbills) on a time base memory chip, allowing day length and time of sunrise and sunset to be estimated. These data allow the location of the bird to be determined twice per day. The basic method of estimation provides locations that are rather imprecise. However, recent improvements in data processing methods as well as sea surface temperature (SST) data (since SST varies considerably among locations) can be used to further refine position estimates (Buckingham et al. 2022).

Leg-ring mounted tags are considered to have relatively low impacts on species that forage as wing-propelled divers (Geen et al. 2019). In a study of Manx shearwaters *Puffinus puffinus*, another seabird that uses wing-propelled diving, these tags have been found to have no adverse effects on foraging efficiency, trip duration or breeding success of breeding individuals (Gillies et al. 2020) and they have been used successfully on auks in several recent studies (e.g. Burke and Montevecchi 2018, Linnebjerg et al. 2018, St John Glew 2018, 2019, Bogdanova et al. 2020, Dunn et al. 2020, Merkel et al. 2021). Nevertheless, we looked carefully at the birds recaught after wearing a tag to assess whether there was any evidence of injury or harm.

Common guillemots (hereafter 'guillemots') breed in colonies on cliff ledges and under boulders at the foot of cliffs, particularly on islands that are predator-free. Razorbills breed mostly in the same kinds of boulder fields, but also breed on cliff ledges at some colonies. Adults of both species are long-lived, and come back to the same nest site year after year. A number of ringing groups regularly visit certain accessible colonies to ring guillemots and razorbills, and this study makes use of the considerable expert knowledge of bird ringers. For other colonies where no ringing was planned, professional ornithologists undertook the work. Together, we have attached tags to rings that are put onto the birds' legs when they are caught at their colonies, with the aim to catch the same individuals again in subsequent breeding seasons to recover the tag and download data on their daily locations

between breeding seasons. From the data, a PhD student funded by this EOWDC project, Lila Buckingham, based at the UK Centre for Ecology and Hydrology (UKCEH) Edinburgh and registered at the University of Liverpool has analysed the migration routes and wintering areas used by birds from different breeding areas. Lila's PhD thesis was submitted in 2022 and has been accepted by University of Liverpool for the degree of PhD.

The original aim of the EOWDC project was to deploy 350 geolocator loggers on breeding guillemots and razorbills at a range of colonies from north-east England to north Scotland in summer 2017 and smaller numbers in summer 2018. Because two other projects (Hywind and SEATRACK) were planning to deploy geolocators on auks at colonies in east Scotland in 2017 (East Caithness, Whinnyfold and Isle of May), we agreed a revision to this aim to include some colonies in the west of Scotland and to carry out the work as a collaboration with deployments and data from the Hywind and SEATRACK projects combined with the EOWDC deployments and data. We also agreed with Marine Scotland to include data from tags deployed by Marine Scotland at Orkney and Canna in 2014-16 in this study. At the start of the project we hoped to recover about 50% of the tags. The hope was that we could recover some after one year on the bird, and some after two or, at least in the case of guillemots possibly three years. It would be particularly useful to have data for two or three winters rather than for a single winter in order to assess how consistent individual birds are in their movement patterns in successive years. However, there is a balance to be struck since the chances of recovering tags are likely to decrease the more years after deployment, so recaptures were attempted after one year.

The initial focus of the work was to investigate the areas used for moulting in late summer, and wintering, by breeding adult guillemots and razorbills from different colonies. In 2019, we agreed a revision to the aims of the work, to include deployment of 66 Time-Depth Recorder (TDR) tags on guillemots that were also equipped with geolocators (one tag on a colour ring on each leg) at a subset of the study colonies. This allowed collection of data on diving behaviour of individuals throughout the autumn and winter, providing data that could be used to estimate daily energy expenditure of these birds. Because the TDR tags were deployed on birds that were also equipped with geolocators, we were able to assess time-energy budgets of individuals in different locations, and also to use the detailed TDR data to calibrate assessment of time budgets based on data collected by the geolocator tags. Half of the cost of tag purchase was provided by Marine Scotland Science and half by Vattenfall. We aimed to deploy TDR tags at four sites (Isle of May and Whinnyfold (east Scotland), Colonsay and Treshnish Isles (west Scotland)), this design allowing comparison of the activity budgets of birds likely to winter off west Scotland and those likely to winter in the North Sea. We also took appropriate feather samples from birds recaptured with TDR tags where licensing permitted this, in order to get some indications of likely winter diet in the different areas used by birds from these colonies.

2 FIELDWORK

In 2017, 436 geolocator tags were deployed, 269 on guillemots and 167 on razorbills, at eight different sites. There were no Health & Safety incidents at any of the colonies where fieldwork was carried out in 2017 (or in any subsequent year). We used two types of geolocator tag: Biotrack MK3006 tags and Migrate Technology Intigeo tags. The Migrate Technology tags (Photo 1) were deployed on razorbills at Canna, Foula, Fair Isle, Orkney, and Farnes. MK3006 tags were deployed on guillemots at all colonies and on razorbills at East Caithness, Whinnyfold, Isle of May and Treshnish. MK3006 tags have a battery life of up to five years while most of those deployed on razorbills have a two year battery life (razorbills being smaller we mostly deployed smaller tags on that species). Tags were deployed on colour rings,

attached by a cable tie through two holes drilled through each colour ring. The colour ring design is a tried and tested one developed by UKCEH at the Isle of May, and has been found to be successful for both auk species. Tag deployment was licensed by the British Trust for Ornithology (BTO). Further licensing by NatureScot (formerly Scottish Natural Heritage, SNH) was required where deployment was at colonies designated as Special Protection Areas (SPAs) for these species, and the required Appropriate Assessment concluded that there would be no adverse effect of the fieldwork on the integrity of these protected features, so the work could proceed.

The aim in 2018 was to recover a sample of these tags, and to deploy another sample of tags including at some colonies not included in the project in 2017. As in 2017, there were no Health & Safety incidents at any of the study colonies in 2018, and the fieldwork was highly successful in achieving our aims. Tags were recovered in 2018 from 118 guillemots and 47 razorbills tagged in 2017, mainly in late June during the chick-rearing period (Table 1). This represents a recovery rate of 44% of the tags deployed on guillemots and 28% of the tags deployed on razorbills, though with some variation among colonies (Table 1). We deployed a further 204 tags on guillemots and 172 on razorbills in June 2018 (Table 2), with the aim of recovering a sample of these in summers 2019 or 2020.

Photo 1. A geolocator attached to a leg ring on a razorbill.

Table 1. Recovery rate in 2018 of geolocator tags deployed on breeding adult auks in June 2017 (sites listed from northwest to southeast)

Colony	Tags from guillemots	% recovered	Tags from razorbills	% recovered	Ringing team
Canna, west Scotland	36 from 90	40%	4 from 20	20%	Highland Ringing Group
Foula, Shetland	13 from 40	33%	1 from 10	10%	Bob Furness
Fair Isle, Shetland	10 from 25	40%	9 from 21	43%	Bob Furness and Fair Isle Bird Observatory
Orkney	NA	NA	4 from 30	13%	Orkney Ringing Group
East Caithness, NE Scotland	20 from 40	50%	13 from 30	43%	Bob Swann/Mick Canham/UKCEH (Hywind funded)
Whinnyfold, E Scotland	24 from 40	60%	2 from 20	10%	Ewan Weston/UKCEH (Hywind funded)
Isle of May, E Scotland	14 from 30	47%	11 from 30	37%	UKCEH (Hywind/Seatrack funded)
Farne Islands, NE England	1 from 4	25%	3 from 6	50%	University of Newcastle and National Trust
TOTALS	118 from 269	44%	47 from 167	28%	

Table 2. New deployments in June 2018 of geolocator tags on breeding adult auks (sites listed from southwest to southeast)

Colony	Tags on guillemots	Tags on razorbills	Ringing team
Colonsay	30	9	David Jardine
Treshnish Isles	20	20	Treshnish Isles Auk Ringing Group
Canna	40	22	Highland Ringing Group
Shiant Isles	0	20	Shiants Auk Ringing Group
Orkney	0	22	Orkney Ringing Group
East Caithness	40	30	Bob Swann/Mick Canham/UKCEH
Whinnyfold	40	19	Ewan Weston/UKCEH
Isle of May	34	30	UKCEH
TOTALS	204	172	

In 2019, there were no Health & Safety incidents at any of the colonies where fieldwork was carried out, and the fieldwork was highly successful in achieving our aims. At most colonies, recovery of tags was carried out in late June, when birds were attending chicks. However, at Canna and Fair Isle some tags were recovered in late May during preliminary visits to check on the timing of breeding of the birds in order to determine the ideal dates for tag recovery in June. Recoveries of tags in May-June 2019 are summarised in Table 3. In total, 137 tags were recovered from guillemots and 82 from razorbills, both totals exceeding what had been achieved in 2018, and including sampling from several colonies that had not previously been included in the study. Although recovery rates varied between species and among colonies (Table 4), the overall recovery rate of tags deployed in 2017 and 2018 after the 2019 fieldwork season was 54% for guillemot (255 tags recovered from 473 deployments) and 38% for razorbill (129 tags recovered from 339 deployments). This reflects the fact that guillemots are easier to work with than razorbills, but recognising that to be the case from experience in 2018, a particular effort was made to increase the recovery of tags from razorbills and this was successful; for example, at Canna only 20% of razorbill tags deployed in 2017 were recovered in 2018 (Table 1), whereas in 2019 the recovery rate was increased to 50% (Table 4). Differences in recovery rates among colonies reflect a wide range of factors, including the breeding success of birds, the conditions at the colony (birds nesting in caves being potentially easier to recapture than those on ledges, but potentially more difficult for locating target individuals), the exact timing of visits to the colony and frequency of visits per summer, etc.

In 2019 we deployed 190 geolocator tags on guillemots and 61 Time-Depth-Recorder (TDR) tags on guillemots (Table 5). The final five TDR tags were delivered late by the manufacturer (CEFAS) and so could not be deployed in 2019. No razorbill tags were deployed because the battery life of those tags is limited to two years and the tags purchased for the project do not have sufficient battery life

remaining for further deployments. In contrast, the tags used on guillemots have a 5-year battery life so most of those could be deployed for another one or two years.

Table 3. Numbers of recoveries in May-June 2019 of geolocator tags deployed on breeding adult auks in June 2017 or June 2018 (sites listed from northwest to southeast)

Colony	Tags from guillemots	Tags from razorbills	Ringing team
Colonsay	14	1	David Jardine
Treshnish Isles	12	12	Treshnish Isles Auk Ringing Group
Canna	25	17	Highland Ringing Group
Shiant Isles	NA	13	Shiants Auk Ringing Group
Fair Isle	5	2	Fair Isle Bird Observatory
Orkney	NA	10	Orkney Ringing Group
East Caithness	27	7	Bob Swann/Mick Canham/UKCEH
Whinnyfold	27	8	Ewan Weston/UKCEH
Isle of May	27	11	UKCEH
Farne Islands	0	1	Newcastle University
TOTALS	137	82	

Table 4. Recovery rate of geolocator tags deployed on breeding adult auks in June 2017 or June 2018 (sites listed from northwest to southeast) and recovered in 2018 or 2019

Colony	Tags from guillemots	% recovered	Tags from razorbills	% recovered	Ringing team
Colonsay	14 from 30	47	1 from 9	11	David Jardine
Treshnish Isles	12 from 20	60	12 from 20	60	Treshnish Isles Auk Ringing Group
Canna, west Scotland	61 from 130	47	21 from 42	50	Highland Ringing Group
Shiants	NA	NA	13 from 20	65	Shiants Auk Ringing Group
Foula, Shetland	13 from 40	32	1 from 10	10	Bob Furness
Fair Isle, Shetland	15 from 25	60	11 from 21	52	Bob Furness and Fair Isle Bird Observatory

Orkney	NA	NA	14 from 52	27	Orkney Ringing Group
East Caithness, NE Scotland	47 from 80	59	20 from 60	33	Bob Swann/Mick Canham/UKCEH
Whinnyfold, E Scotland	51 from 80	64	10 from 39	26	Ewan Weston/UKCEH
Isle of May, E Scotland	41 from 64	64	22 from 60	37	UKCEH
Farne Islands, NE England	1 from 4	25	4 from 6	67	University of Newcastle and National Trust
TOTALS	255 from 473	54%	129 from 339	38%	

Table 5. New deployments in June 2019 of geolocator and TDR tags on breeding adult auks (sites listed from southwest to southeast)

Colony	Geolocator tags on guillemots	TDR tags on guillemots	Ringing team
Puffin Island, Anglesey	25		University of Liverpool
Colonsay	30	15	David Jardine
Treshnish Isles	30	15	Treshnish Isles Auk Ringing Group
Canna	11		Highland Ringing Group
East Caithness	30		Bob Swann/Mick Canham/UKCEH
Whinnyfold	29	15	Ewan Weston/UKCEH
Isle of May	35	16	UKCEH
Bempton	0		RSPB
Helgoland	5		University of Kiel
TOTALS	195	61	

Fieldwork in 2020 was severely impaired by Covid travel restrictions. It was initially impossible for local ringing groups to visit most sites. Covid restrictions on travel were relaxed just in time to allow very limited fieldwork at some of our study sites in 2020. Because time available was severely restricted, the focus of this effort in 2020 was on recovery of TDR tags, because we already had large samples of geolocator tag recoveries from the main colonies. We were able to recover TDR tags and geolocators from Isle of May, Whinnyfold, Colonsay, and Treshnish Isles, recover geolocators from guillemots at

Puffin Island, Anglesey and East Caithness, and attempt to recover tags from guillemots at Helgoland. No tags were deployed in 2020 apart from five deployed on guillemots at Helgoland. Despite the restrictions due to Covid preventing access to some colonies and limiting the time that could be spent at others during 2020 totals of 44 TDR tags and 135 geolocator tags were recovered from guillemots, and three geolocators were recovered from razorbills.

During 2021 Covid restrictions continued to limit fieldwork, but a further three TDRs were recovered from guillemots, along with 49 geolocators from guillemots and eight geolocators from razorbills. These additional retrievals brought the overall recovery rate to 77% of deployed TDR tags (47 recovered in 2020-2021 from 61 deployed in 2019) and 64% of deployed geolocators on guillemots (423 recovered in 2018-2021 from 665 deployed in 2017-2019), and 41% of deployed geolocators on razorbills (138 recovered in 2018-2021 from 339 deployed in 2017-2018). One tag was recovered from a guillemot at Puffin Island in 2022.

3 BIRD WELFARE AND TAG LOSS CONSIDERATIONS

Welfare of the birds is extremely important. It wasn't possible to robustly compare return rates in subsequent seasons of tagged birds with those carrying metal or colour-rings, so we are unable to establish whether tagged birds had a reduced over-winter survival rate associated with carrying this extra weight. However, we undertook sporadic observations of individuals that had carried tags the previous winter and found that their breeding behaviour and mobility appeared normal. Furthermore, all tagged birds that were caught were carefully examined for any leg injury caused by tags or colour rings they had been carrying, and no birds appeared injured.

Tag loss could be a welfare consideration if the colour ring on which the tag is mounted was able, as a result of wear or damage, to slip over the joint of the bird's leg and get caught or wedged, impeding movement or causing abrasion. However, we found no evidence of that being the case. However, if tags are lost after the completion of the study from any birds not recaptured, as a result of wear through cable ties or colour rings, and fall off the bird without causing entanglement then this would be a positive result. Most recaptured birds had colour ring and tag in good condition with minimal signs of wear. One razorbill caught at Fair Isle had worn completely through the base of the colour ring such that the ring could be removed without having to cut it (Photo 2). Clearly that ring was at risk of dropping off the bird in the near future. However, this was a unique case from the 384 tags recovered by 2019. As such, we did not have any evidence to suggest that loss of any tags or colour rings had occurred, although a robust analysis of colour-ring loss would require capture of individuals only carrying metal rings in order to read the unique combination and establish whether a proportion had formerly carried a tag, something we wished to avoid because of the extra disturbance this would have involved. A few tags had the gold pins or the acrylic corner of the tag partly abraded away (Photo 3), possibly relating to how individual birds behaved or to how far across rocks birds needed to travel between the sea and their particular nest site. Both of the most extreme cases of wear of tags in 2019 occurred with birds on Fair Isle, possibly relating to the fact that birds at that colony tended to move across many boulders between the sea and the nest, and so had particular scope for rubbing the colour ring and tag on relatively abrasive sandstone surfaces. Risk of tag loss in future was thought likely to increase with wear occurring to colour rings and cable ties. In 2020 and 2021, several birds at several sites were caught still carrying colour rings but with the geolocator tag missing. Some of these losses were from birds equipped with a TDR as well as a geolocator. Those birds had the geolocator on a plastic leg ring fitted above the BTO metal ring and this may have increased the rate of tag loss.

However, some loss was from birds equipped only with a geolocator and so we concluded that loss of geolocator tags was occurring, presumably in part as a result of wear of cable ties against rocks at colonies. This is likely to mean that many or most of the geolocators we failed to recover during the study will be lost at some point in the future. In conclusion, we found no evidence of any welfare issues and little evidence of any tag loss among surviving individuals up to three years after tag deployment, but suggestions of increasing tag loss after that.

In 2021, one bird equipped with a geolocator was found dead. Remains of this individual, which had been tagged at Treshnish Isles, were found in a white-tailed eagle *Haliaeetus albicilla* nest at an undisclosed site in Skye. The tag was recovered. As with several tags recovered in 2021, the battery of the tag was exhausted, so the tag had to be returned to the manufacturer to attempt download of data. Guillemots appear to be a relatively frequent prey of white-tailed eagles in Scotland (Scottish Raptor Study Groups, pers. comm.).

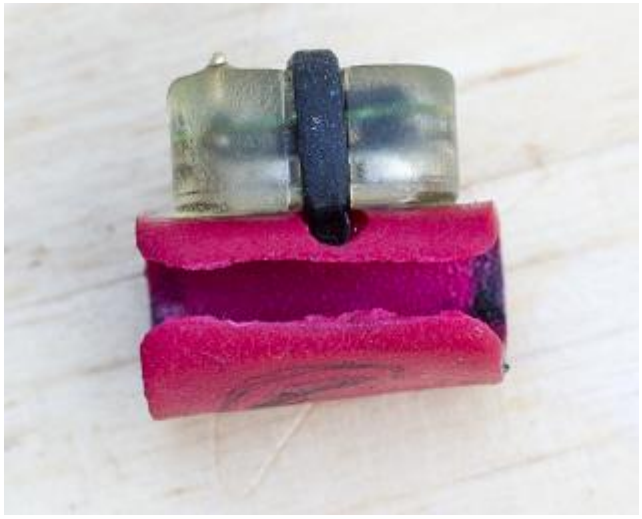


Photo 2. The most extreme case of colour ring wear of the tags recovered so far: a Fair Isle razorbill colour ring that had been on the bird for two years and had worn through completely along the part below the tarsus that would have been in contact with rocks as the bird moved over land.

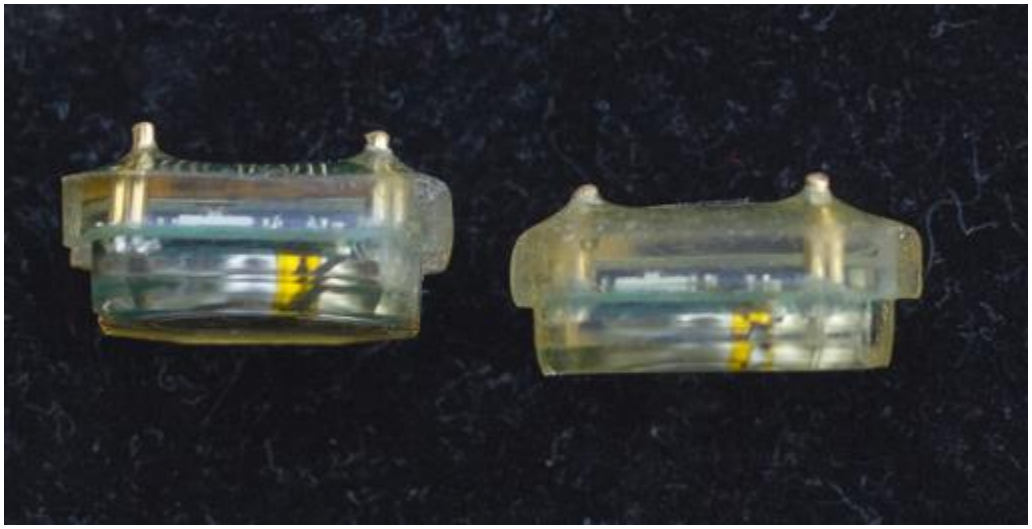


Photo 3. The most extreme case of wear of the gold pins and acrylic case of the tag (on the right, especially the left pin of this tag) compared with another (more typical) example of only very slight wear (tag on the left); both tags had been carried by guillemots for two years, and downloaded data successfully, although connecting a crocodile clip to the heavily abraded pin was difficult.

4 FIELDWORK IN DIFFERENT COLONIES

Differences in tag recovery rates among colonies were in part due to differences in environmental conditions; higher tag recovery rates are possible where birds are experiencing good food availability, and in consequence breeding success, nest attendance, and motivation of birds to remain at the nest are high. Conversely, in areas where some adults are not breeding and where breeding birds may have failed early in the season, tag recovery is much more difficult. Part of the variation is also due to differences in the way that fieldwork is carried out at different sites. At some sites (e.g. Isle of May) ringers are present continuously through the breeding season and can re-catch birds over a period of 1-2 weeks. At other sites (e.g. Canna and Orkney) ringers spend only a few hours on one or two days at the colony each year, so can only sample birds that happen to be present at the time. It is clear, however, that tag recovery has generally been higher from guillemots than from razorbills. This may have been because razorbills had less successful seasons than guillemots on average, with a higher rate of non-breeding and breeding failure at some colonies. However, we did not record extent of non-breeding and breeding success at most colonies, so it is not possible to test this assertion. A key factor is likely to be the differences in behaviour of these two species and the fact that many razorbills tend to be in hidden sites so tagged individuals can be difficult to relocate, whereas most guillemots are in sites where they are much more easily seen. Razorbills are also, on average, more difficult to catch than guillemots.

4.1 Puffin Island, Anglesey

This colony was added to the project in 2019, with fieldwork led by University of Liverpool and Steve Dodd from SCAN ringing group, who has been ringing seabirds including guillemots there for many years. 25 guillemots were tagged in June 2019. Breeding success of guillemots at this colony in 2019 appeared to be good. At Puffin Island, Anglesey, 8 geolocators were recovered from guillemots during 2020, a further four during 2021 and one in 2022, resulting in a total of 13 recovered from the sample of 25 tags deployed in 2019. This is the first sample of geolocator data from that colony.

4.2 Colonsay

Colonsay (Argyll) was added to the project in 2018, but guillemots and razorbills there have been ringed by David Jardine for many years and he has a long-term Retrapping Adults for Survival estimation (RAS) project onto which tagging has been added in 2018. Both species had good breeding seasons in 2018 and 2019. In 2019, 14 of 30 tagged guillemots and 1 of 9 tagged razorbills were recaptured, 30 geolocator tags were put onto guillemots, and 15 TDR tags were deployed on guillemots. During 2020, at Colonsay, nine TDRs (from 15 deployed in 2019) were recovered from guillemots (together with nine geolocators from these same birds) and 20 geolocators were recovered from guillemots that were not carrying TDRs. During 2021, an additional three geolocators were recovered from guillemots. In 2022, two more tags were recovered from guillemots early in the season, but fieldwork restrictions imposed by NatureScot in 2022 as a result of Highly Pathogenic Avian Influenza (HPAI) infections in many Scottish seabird colonies prevented further fieldwork during the chick-rearing period.

4.3 Treshnish Isles

Treshnish Isles Auk Ringing Group (TIARG) has been ringing auks on the Treshnish Isles each summer since 1971, with permission from the Hebridean Trust; annual reports of the bird ringing and survey work are available at http://tiarg.org. This colony was added to the tagging programme in 2018. The guillemots were caught at five accessible ledges/platforms of the Harp Rock colony at Lunga. Razorbills were caught from the boulder colonies on Lunga at Harp Rock (west coast), at 'shag alley' (east coast), and at the Boulder Beach (facing north-east). Guillemots and razorbills appeared to be having good breeding seasons at Treshnish in 2018 and 2019 (as usual), and timing of breeding was average. In 2019, 12 of 20 tagged guillemots and 12 of 20 tagged razorbills were recaptured, 30 geolocator tags were put onto guillemots, and 15 TDR tags were deployed on guillemots. During 2020, at Treshnish Isles, ten TDRs (from 15 deployed in 2019) were recovered from guillemots (together with ten geolocators from these same birds) and nine geolocators were recovered from guillemots that were not carrying TDRs. In addition, one geolocator was recovered from a razorbill. During 2021, an additional four geolocators were recovered from guillemots and two from razorbills. No fieldwork was possible at this colony in 2022 due to HPAI.

4.4 Canna

Highland Ringing Group has been ringing auks on Canna every year since 1971. Guillemots and razorbills had a very good breeding season at Canna in 2018, with large numbers of birds at colonies, high breeding success, and typical hatching dates. Breeding success was also good in 2019. In 2019, 25 tagged guillemots and 17 tagged razorbills were recaptured, bringing the total recoveries in 2018 plus 2019 to 61 from 130 guillemots and 21 from 42 razorbills. In addition, 11 tags were put onto guillemots. Covid resulted in no fieldwork at Canna in 2020 or 2021. In 2022, 10 tags were recovered from guillemots before the HPAI restrictions prevented further fieldwork.

4.5 Shiant Isles

Auks have been ringed at the Shiant Isles for many years http://shiantsaukringinggroup.blogspot.com and the colony was also included in GPS tracking work by RSPB. This site was added into the project in 2018. Breeding success of auks was good at this colony in 2018 and in 2019. In 2019, 13 out of the 20 razorbills tagged in 2018 were recaptured. Covid resulted in no fieldwork in 2020 or 2021. No fieldwork was possible at this colony in 2022 due to HPAI.

4.6 Foula

Birds were tagged at two colonies within Foula in 2017, one at Heddlicliff which is a scree cliff and boulder field on the east coast of the island, and one in boulders below the Sneck on the west coast of Foula. Thirteen tags were recovered from guillemots in 2018 and one from a razorbill. The access routes to both colonies have been subject to serious rock falls and landslides in the last two years. Therefore, for Health & Safety reasons we decided not to continue work in these colonies in 2019 and so no tags were deployed here in 2018. This decision was also informed by the poor breeding success and low colony attendance which suggested that further recoveries of tags would be difficult, and by the cost of travel to Shetland (particularly because in 2019 we were unable to combine fieldwork at Foula and at Fair Isle, because the Fair Isle Bird Observatory accommodation had been destroyed by fire).

4.7 Fair Isle

Fair Isle Bird Observatory burned to the ground in spring 2019. Despite this, the observatory staff have remained on the island in alternative accommodation, and have carried out as much fieldwork as possible. This included recovery of auk tags in summer 2019. Because of the loss of Observatory accommodation and because Observatory staff were able to carry out tag recovery fieldwork, we did not send fieldworkers to Fair Isle in 2019. Weather prevented fieldwork that required use of an inflatable boat except during one week, and so access to the auk colony at South Ramnigeo where most birds had been tagged was limited. In addition, the breeding success of auks was poor in 2019, as has been the case at Shetland colonies and Fair Isle in most recent years. Observatory staff recaptured 5 tagged guillemots and 2 tagged razorbills in 2019, bringing the totals recaptured in 2018 plus 2019 to 15 of 25 guillemots and 11 of 21 razorbills. Covid resulted in no fieldwork in 2020 or 2021. No fieldwork was possible at this colony in 2022 due to HPAI.

4.8 Orkney

Orkney Ringing Group have access to razorbill colonies at Muckle Skerry, Halcro Head, South Ronaldsay, and Swona. The razorbill breeding season in Orkney was poor in 2018 and in 2019, with birds breeding late and evidence of nonbreeding or early season breeding failure by many birds. Orkney Ringing Group noted that several tagged birds were present in the general vicinity of colonies, but not attending nest sites. In 2019, 10 tagged razorbills were recaptured, bringing the total for 2018 plus 2019 to 14 from 52 birds. Covid resulted in no fieldwork in 2020 or 2021. No fieldwork was possible at this colony in 2022 due to HPAI.

4.9 East Caithness

The breeding season at East Caithness was 1-2 weeks later than usual in 2018, and breeding numbers lower than anticipated. There was also some evidence of predation, possibly by foxes, resulting in certain sub-colonies having few or no birds present in 2018. In 2019, breeding occurred at a more typical time for the colony, and although there was again some evidence of predation, breeding success appeared normal and 27 tagged guillemots and 7 tagged razorbills were recaught. In addition, 30 tags were deployed. During 2020, at East Caithness, 32 geolocators were recovered from guillemots and two from razorbills. During 2021, an additional four geolocators were recovered from guillemots and two from razorbills. No fieldwork was possible at this colony in 2022 due to HPAI.

4.10 Whinnyfold

Breeding was also delayed by 2-3 weeks in 2018 at Whinnyfold. However, in contrast to East Caithness, it seemed that razorbills were harder hit than guillemots. Furthermore, razorbills had a poor breeding season in 2018, with widespread breeding failure. In 2019, breeding occurred 1-2 weeks earlier than in 2018, and success seemed normal (i.e. good), with razorbills having a markedly better year than in 2018, resulting in improved tag retrieval rates. In total, 27 tagged guillemots and 8 tagged razorbills were recaught. In addition, 29 tags were deployed as well as 15 TDRs. During 2020, at Whinnyfold, 13 TDRs (from 15 deployed in 2019) were recovered from guillemots (together with 11 geolocators from these same birds - two of the 13 birds had lost their geolocator tags) and another 12 geolocators were recovered from guillemots that were not carrying TDRs. During 2021, the final two TDRs were retrieved, along with one geolocator from these same birds (again, one individual had lost its geolocator), plus seven additional geolocators from guillemots. No fieldwork was possible at this colony in 2022 due to HPAI.

4.11 Isle of May

As with East Caithness and Whinnyfold, breeding was delayed by 2-3 weeks in 2018. Both species had moderate breeding seasons in 2018. In 2019, as with other east coast colonies, breeding returned to a more typical time and was only a few days later than the long-term average. Breeding success was also typical (i.e. good), and in total 27 tagged guillemots and 11 tagged razorbills were recaught. In addition, 35 geolocator tags were deployed as well as 16 TDRs. During 2020, at Isle of May, 12 TDR tags (from 16 deployed in 2019) were recovered from guillemots (together with 11 geolocators from these same birds - one of the 12 birds had lost its geolocator tag) and another 15 geolocators were recovered from guillemots that were not carrying TDRs. During 2021, one additional TDR was recovered along with its geolocator, along with four geolocators from guillemots. No more tags were recovered early in the 2022 season and HPAI restrictions prevented fieldwork during the chick-rearing period.

4.12 Farne Islands

Fieldwork at the Farnes was coordinated by Newcastle University. Of the birds tagged in 2017, one razorbill was recaught in 2019. Covid resulted in no fieldwork in 2020 or 2021.

4.13 Bempton

RSPB agreed in October 2018 to add the guillemot colony at Bempton to this project in 2019. Tags were made available to RSPB but unfortunately they were unable to arrange permission from Natural England in time to carry out deployments in 2019, so no birds were tagged at this colony.

4.14 Helgoland

The University of Kiel agreed in October 2018 to add the guillemot colony at Helgoland to this project in 2019. Ten tags were sent for deployment on guillemots. It was only possible to deploy five of these tags. The distribution of guillemots at Helgoland has altered with increasing numbers of gannets; the most accessible area where guillemots have been caught in the past is no longer suitable for catching guillemots. Unfortunately none of the deployed tags could be recovered in 2020, but the remaining five tags were deployed on guillemots at that colony with the aim of recovering some of those and the ones missed in 2020 in 2021. Although guillemot numbers at Helgoland have reached an all-time high, their accessibility has reduced.

4.15 Deployments of used tags on gannets

We made 30 of the tags recovered from razorbills or guillemots in June 2018 available to the University of Leeds research group working on gannets on the Bass Rock, and 26 of these were deployed on breeding adult gannets in August 2018, by PhD student Chris Pollock (who is NERC funded with a studentship that has Vattenfall and MacArthur Green as CASE partners), with the intention to recover the tags in summer 2019. Chris Pollock and Ruth Jeavons recovered 22 of these tags in summer 2019, which have provided useful data on the migrations and wintering areas of Bass Rock gannets during 2018-19. In 2019, 21 of these birds were re-tagged for the 2019-20 winter and another 15 gannets were tagged. Due to Covid restrictions in 2020, only one visit to the Bass Rock was possible late in the season in 2020 which limited the opportunity to recover tags. However, 14 tags were recovered during that visit. Two papers on the timing and routes of migration of these gannets compared with the timing and routes used by juveniles equipped with satellite PTTs have been published (details and links in section 8).

5 ANALYSIS OF DATA FROM RECOVERED TAGS

Guillemots

Maps presented in this report show 50% kernel density contours. These contours represent the main area of distribution. Since the accuracy of individual position fixes is relatively low, the raw data tend to indicate a larger geographical area than actually used by the birds. With the inclusion of SST data for position location, errors are reduced compared to geolocation by light data alone, but the 50% kernel density contour is thought to provide a good indication of the core distribution of the tagged birds as that cautious approach deals well with the large error in individual position estimates (Buckingham et al. 2022). During the non-breeding season, guillemots showed generally high levels of segregation among breeding colonies (all colony plots: figure 1a; individual colony plots: figure 2). Guillemots appear to spend a large proportion of their time during mid-winter (here classed as December) near their breeding colony, with most of the 50% kernel density contours remaining near the colony during this period (figure 1a; figure 2). Accordingly, guillemots breeding in the west of Scotland mostly wintered off the west coast in the Atlantic Ocean, and those breeding in the northern isles and in the east of the UK mostly wintered in the northern half of the North Sea. Colonies were fairly consistent in movements among our two years of tracking data, and further analyses will determine among-colony overlap and the differences between the two years tracked.

A small number of individuals from several colonies (Canna, Foula and Fair Isle) carried out a long-distance moult migration to high latitudes in the autumn before returning south for the winter (figures 1b; 2). This can also be seen from figure 3, which shows monthly movements of birds breeding at Fair Isle across the two years to give an indication of what these year-round data look like.

Razorbills

As for guillemot, maps show 50% kernel density contours as an indication of the core distribution of the tagged birds. Razorbills showed more admixing in mid-winter among breeding colonies than guillemots, with two clear hotspots apparent in December: one off the north coast of Scotland and one in the North Sea (figure 4a; 5). These hotspots appear to be consistent across years.

Razorbills generally showed less interesting individual variation in moult migration, tending to simply migrate to their wintering grounds (figure 4b); however, one individual from Fair Isle did appear to do a longer moult migration and travelled north to the waters off Iceland in the 2017 autumn, before returning to the northern North Sea for the remainder of the winter.

Discussion

We have found that razorbills show fairly high levels of aggregation among breeding colonies in mid-winter, whereas guillemots show more segregation by breeding colony. This may mean that razorbills are more vulnerable to offshore threats at a meta-population level, if such threats happen to overlap with their hotspots.

The interesting individual variation we have found, with some individuals undertaking a moult migration to high latitudes, is consistent with previous findings from the Isle of May, where Harris et al. (2015) tracked one guillemot to moult in the Barents Sea during August-October 2013. These long-distance movements for such short periods of time are remarkable, given how high wing-loading is in the guillemot.

The large numbers of tags recovered and the geographical spread of study colonies provides an outstanding data set to achieve the aims of this project. A paper comparing the nonbreeding season patterns of aggregation and colony-specific distribution of guillemots and razorbills has been published in Marine Ecology Progress Series (Buckingham et al. 2022).

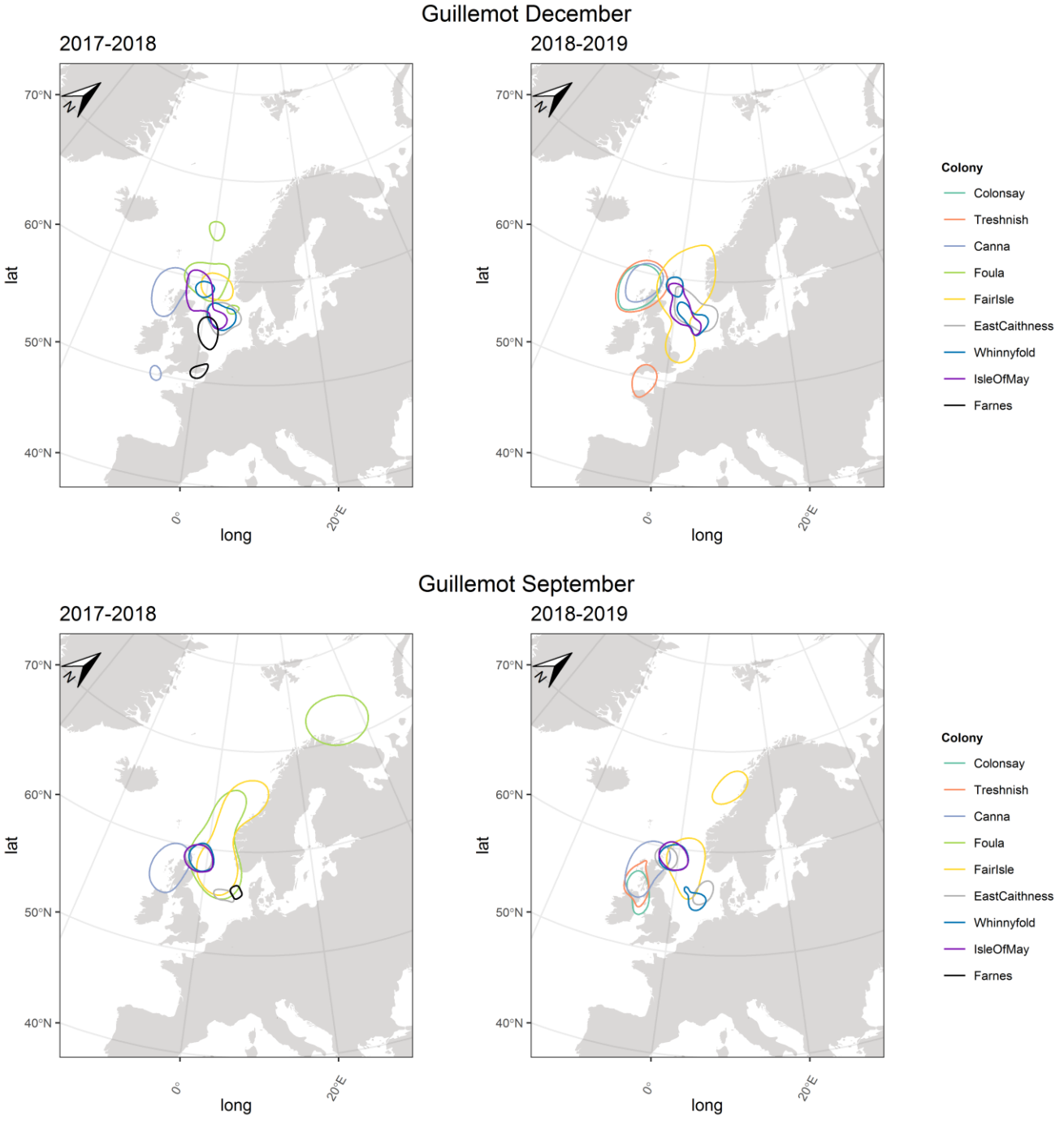
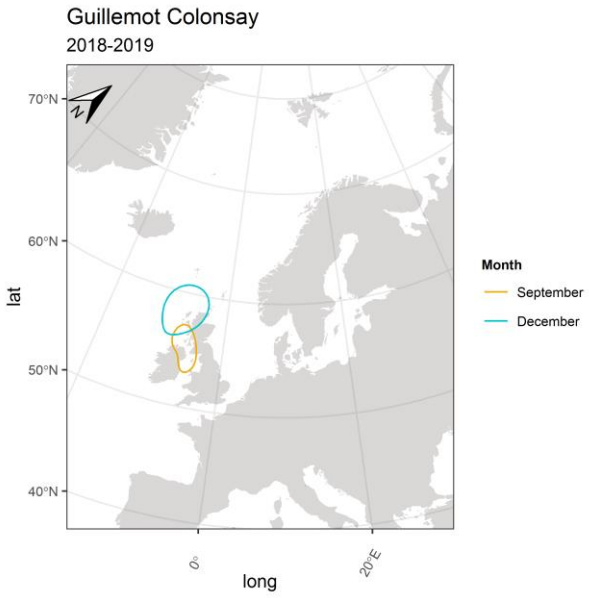
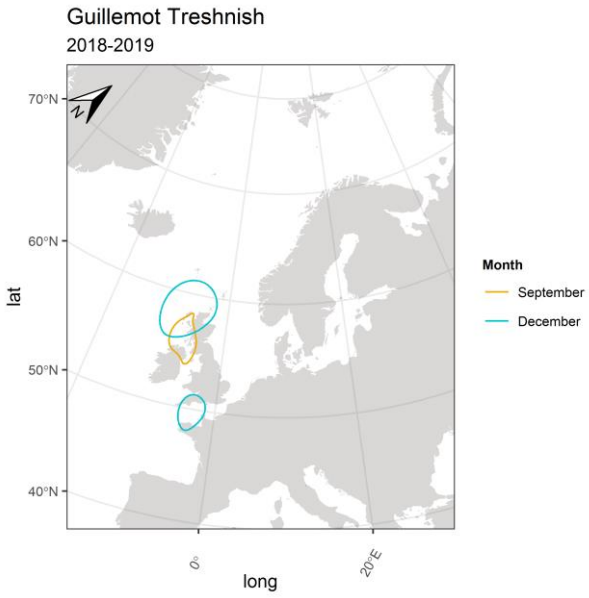


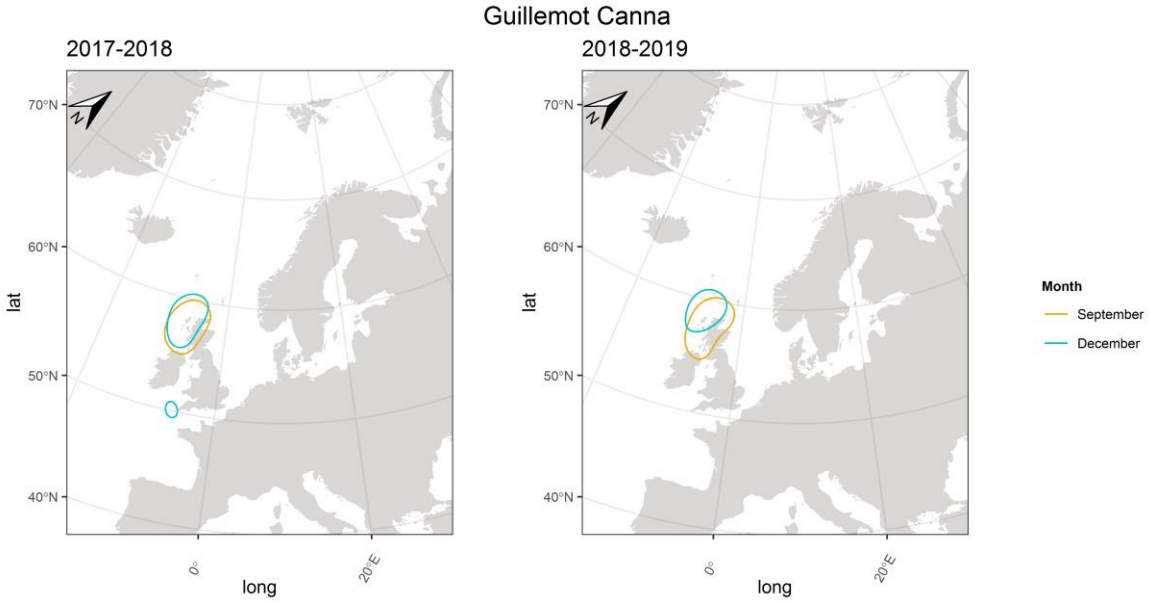
Figure 1. 50% kernel density contours for a) autumn (September) and b) mid-winter (December) distributions for guillemots tracked, with all breeding colonies shown and years tracked separated.



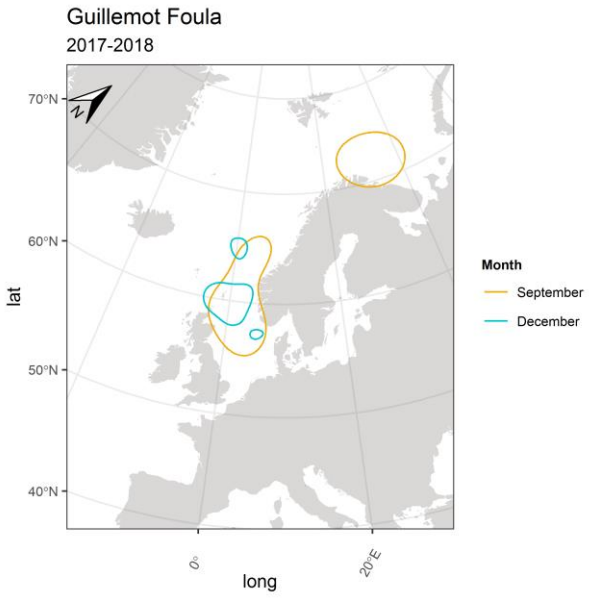
a. Colonsay guillemots tracked from 2018-19 (n = 14).



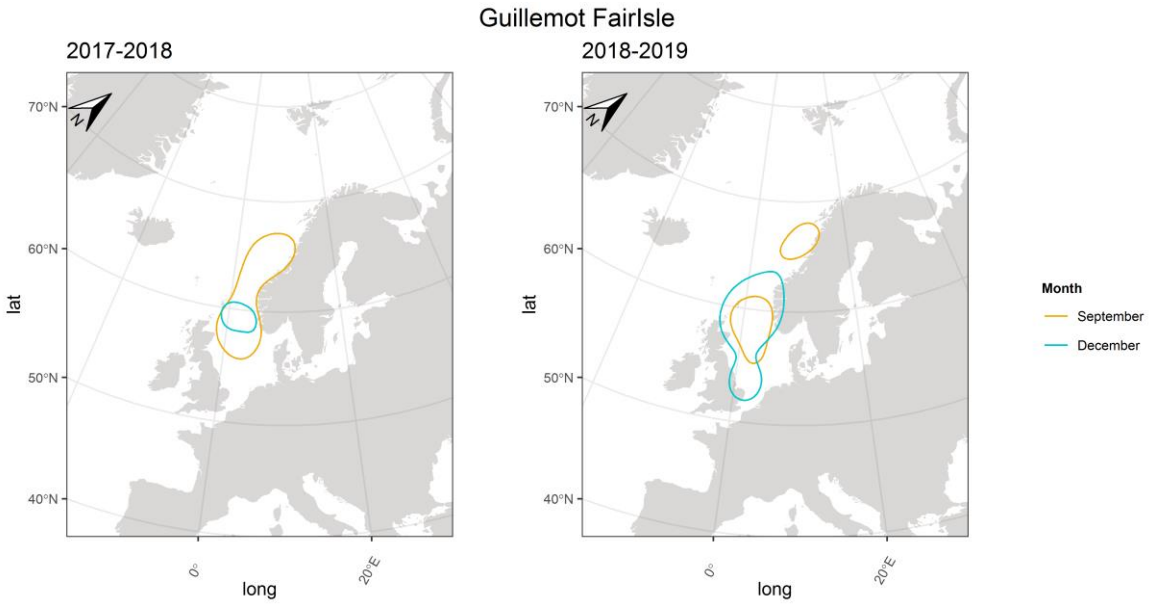
b. Treshnish guillemots tracked from 2018-19 (n = 12).



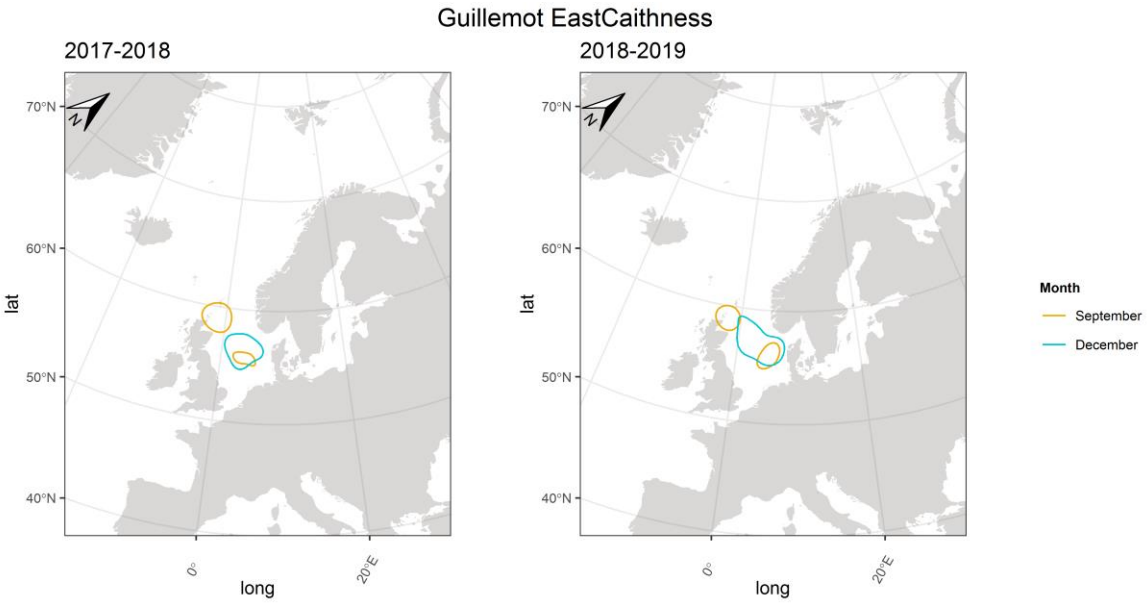
c. Canna guillemots tracked from 2017-18 (n = 44) and 2018-19 (n = 25).



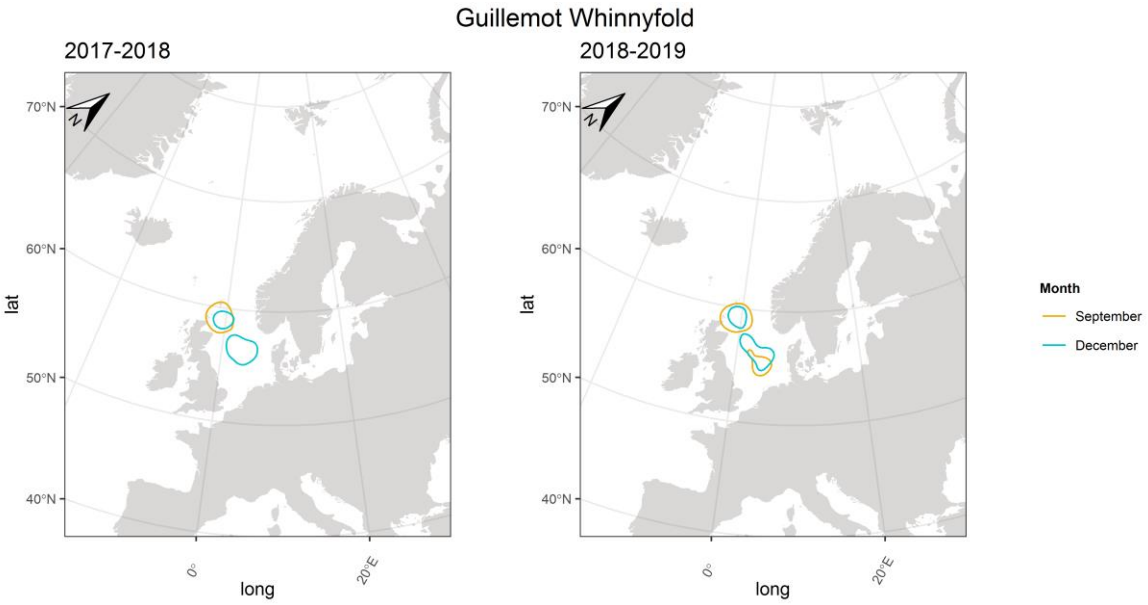
d. Foula guillemots tracked from 2017-18 (n = 13).



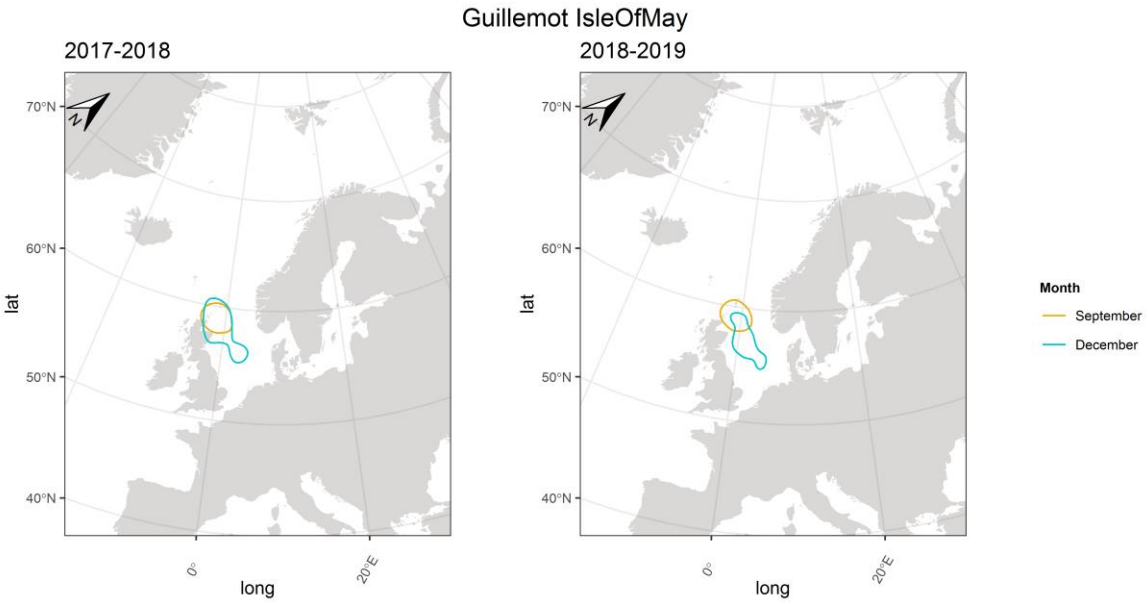
e. Fair Isle guillemots tracked from 2017-18 (n = 15) and 2018-19 (n = 5).



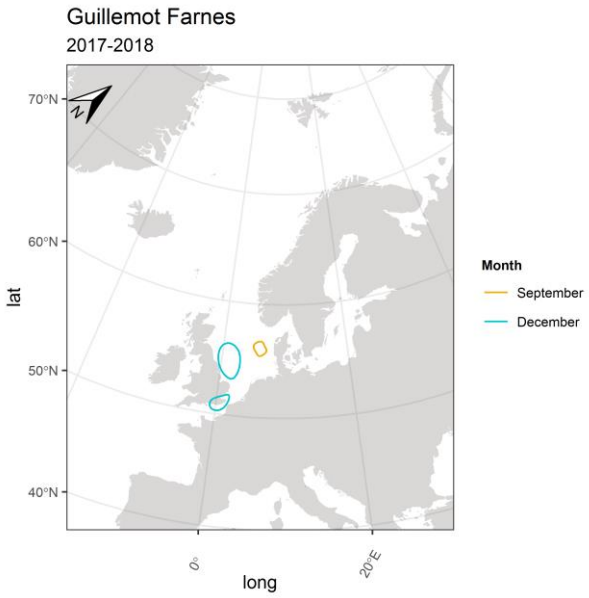
f. East Caithness guillemots tracked from 2017-18 (n = 21) and 2018-19 (n = 25).



g. Whinnyfold guillemots tracked from 2017-18 (n = 28) and 2018-19 (n = 26).

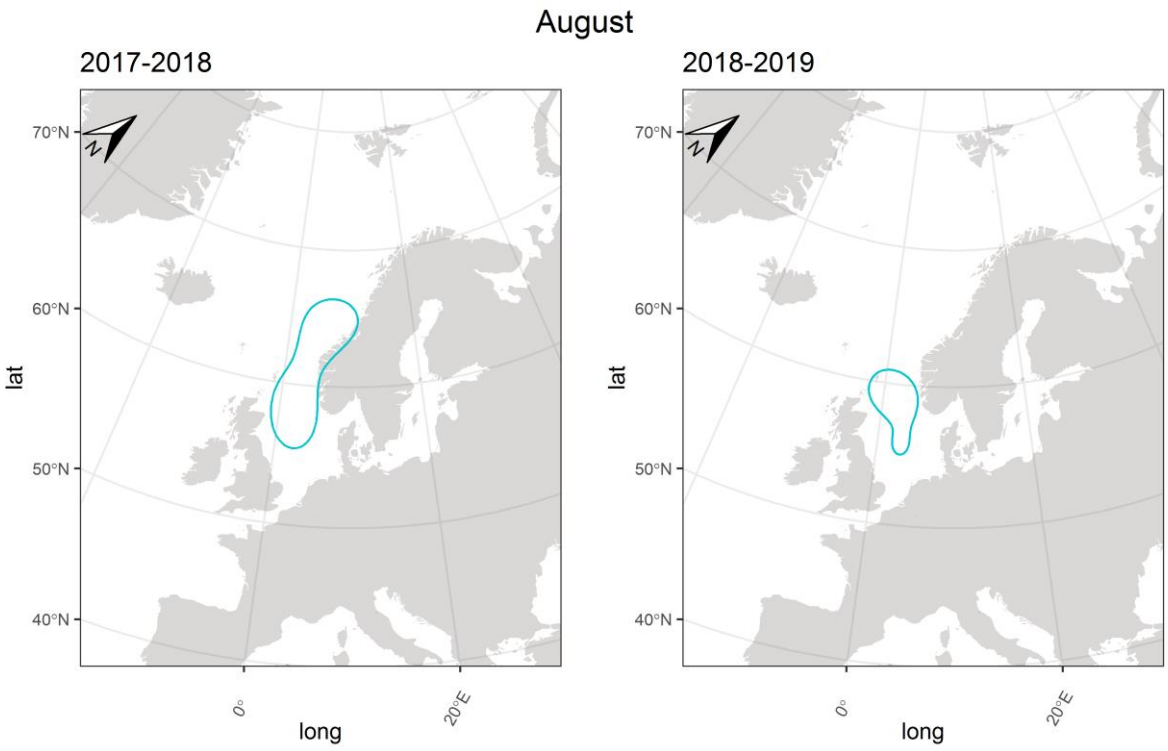


h. Isle of May guillemots tracked from 2017-18 (n = 17) and 2018-19 (n = 23).

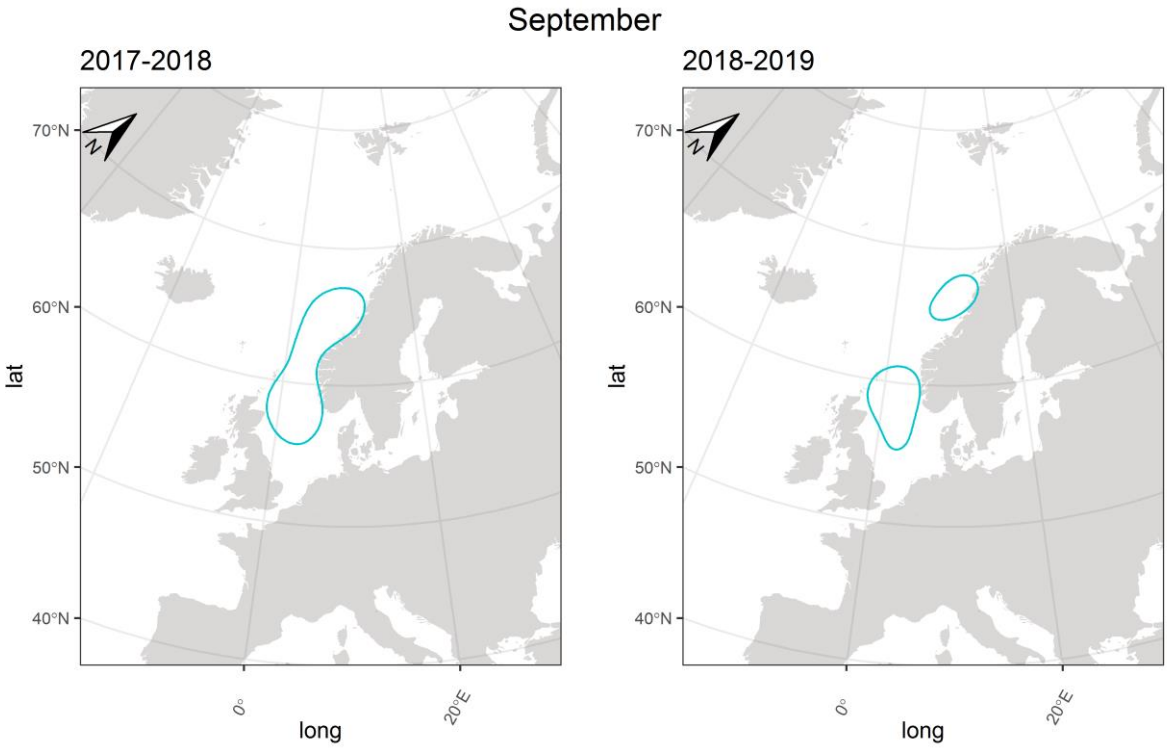


i. Farnes guillemots tracked from 2017-18 (n = 1).

Figure 2. Moult (September) and winter (December) 50% kernel density contours of guillemots for each colony (a-i) organised clockwise from southwest-southeast.

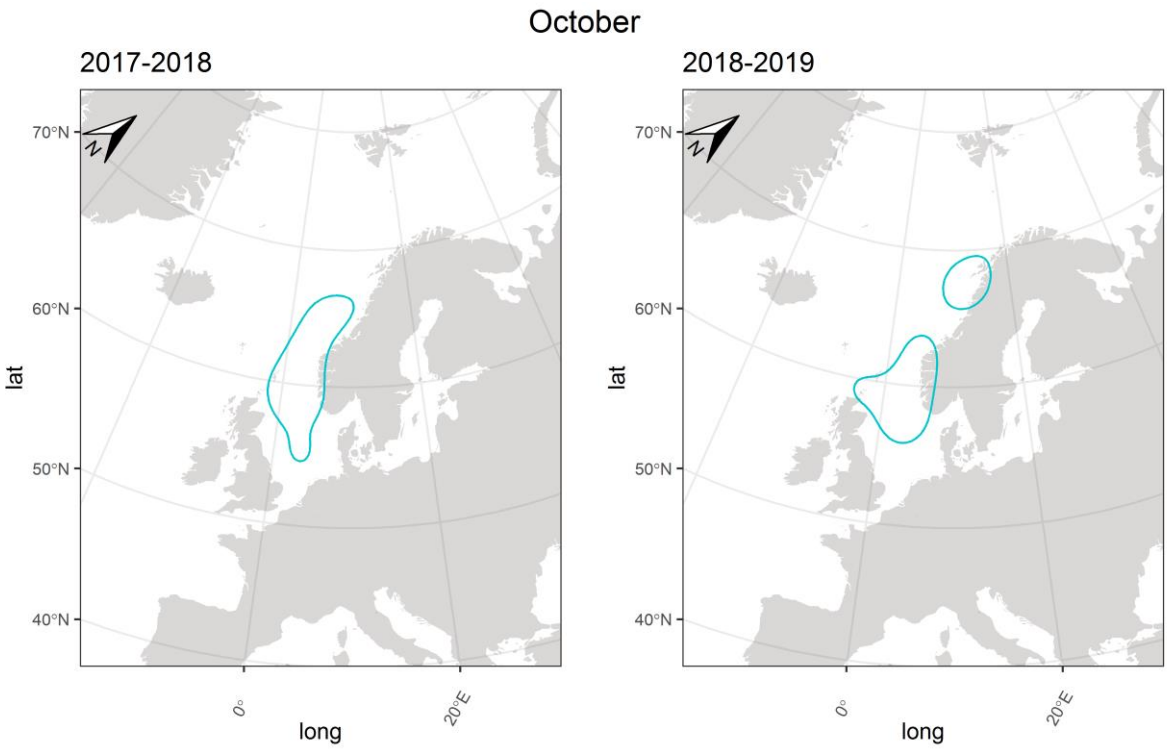

August
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

a.

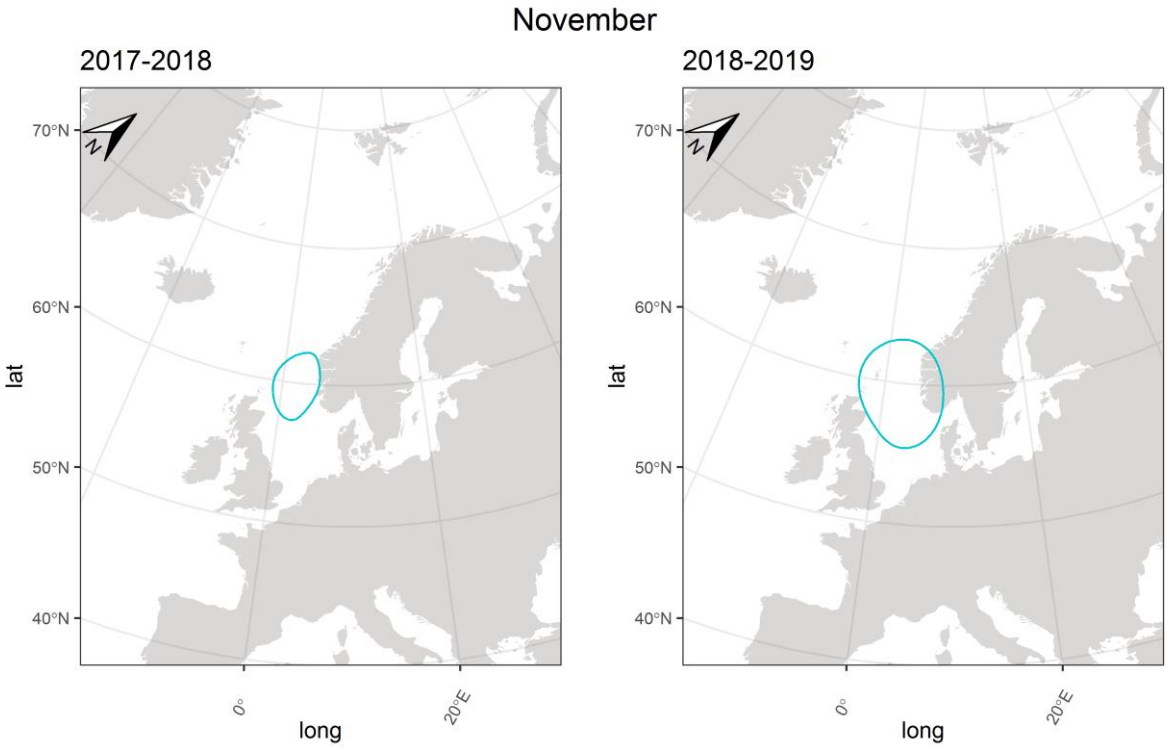

September
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

b.

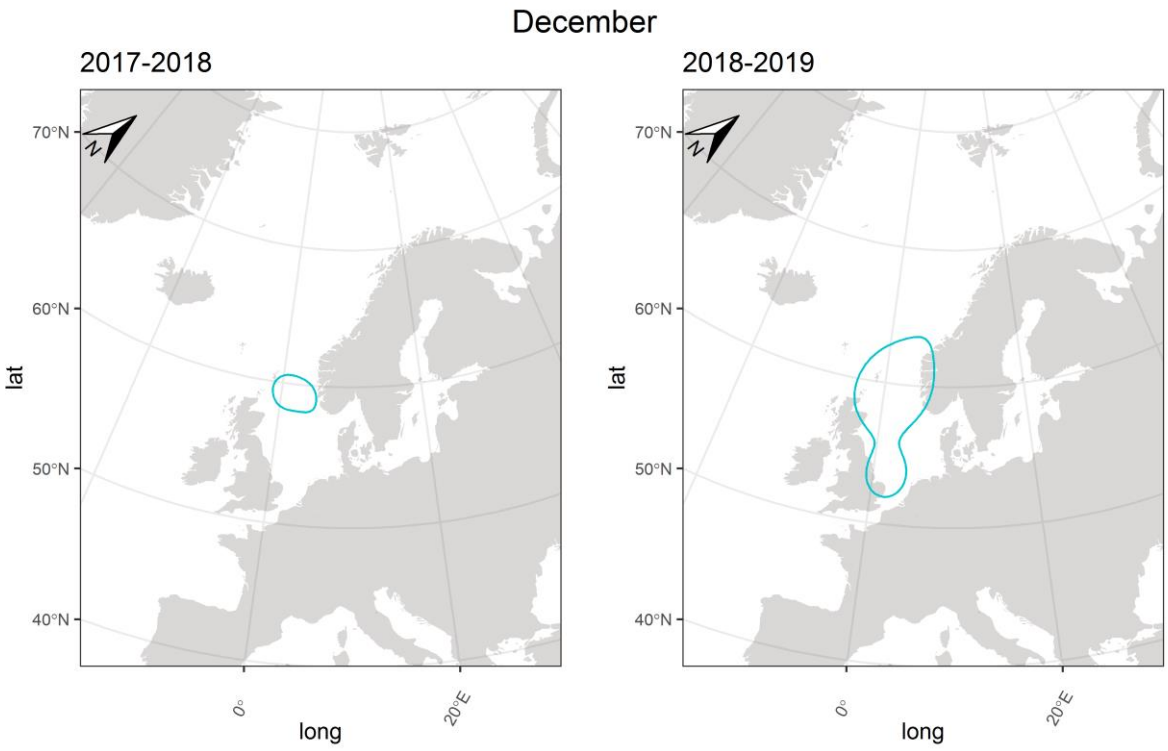
c.


October
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

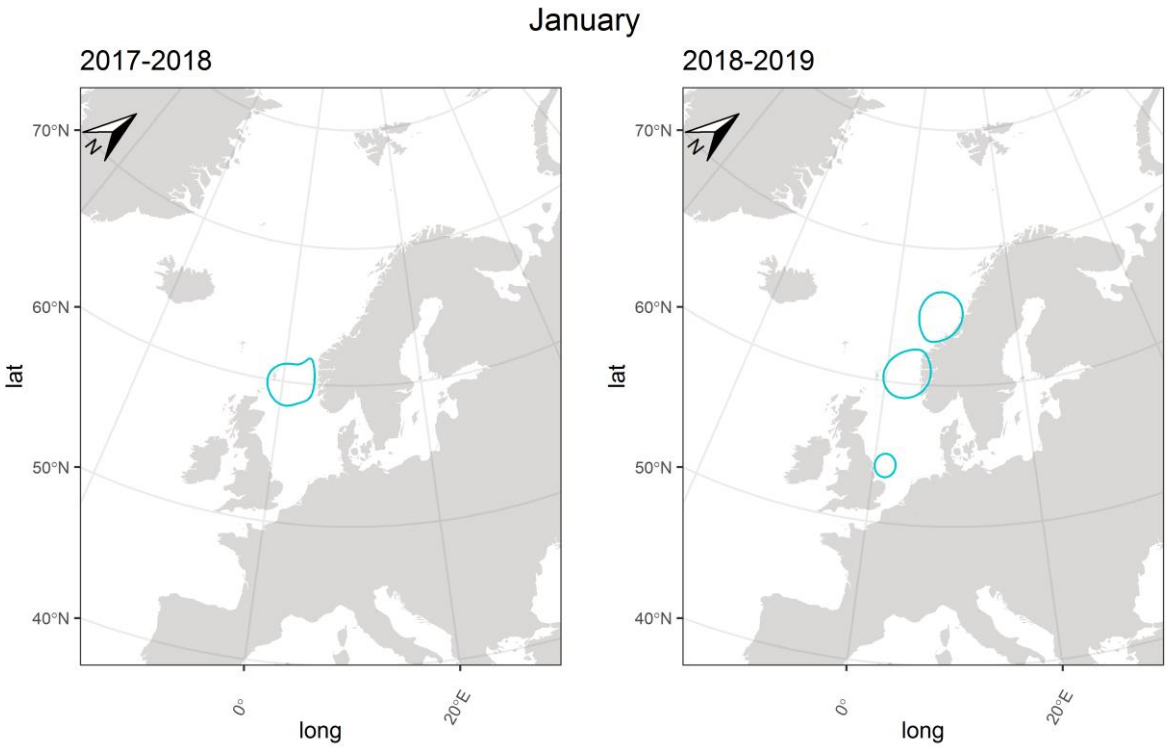
d.

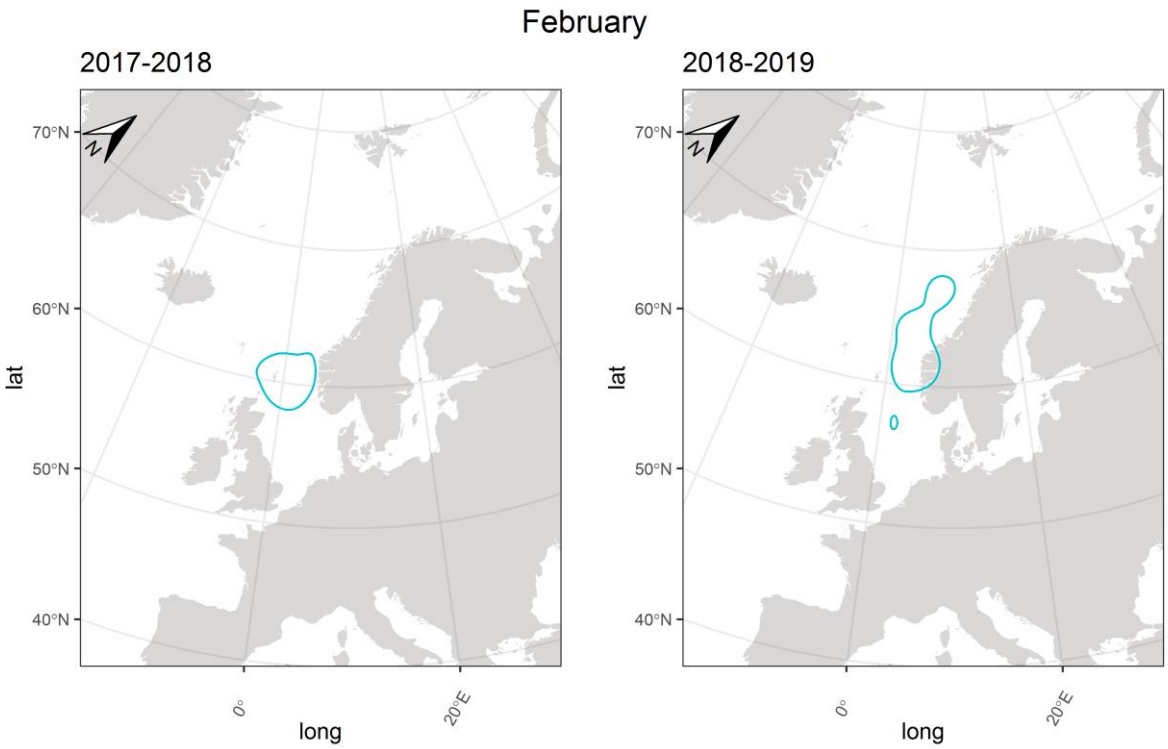

November
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

e.

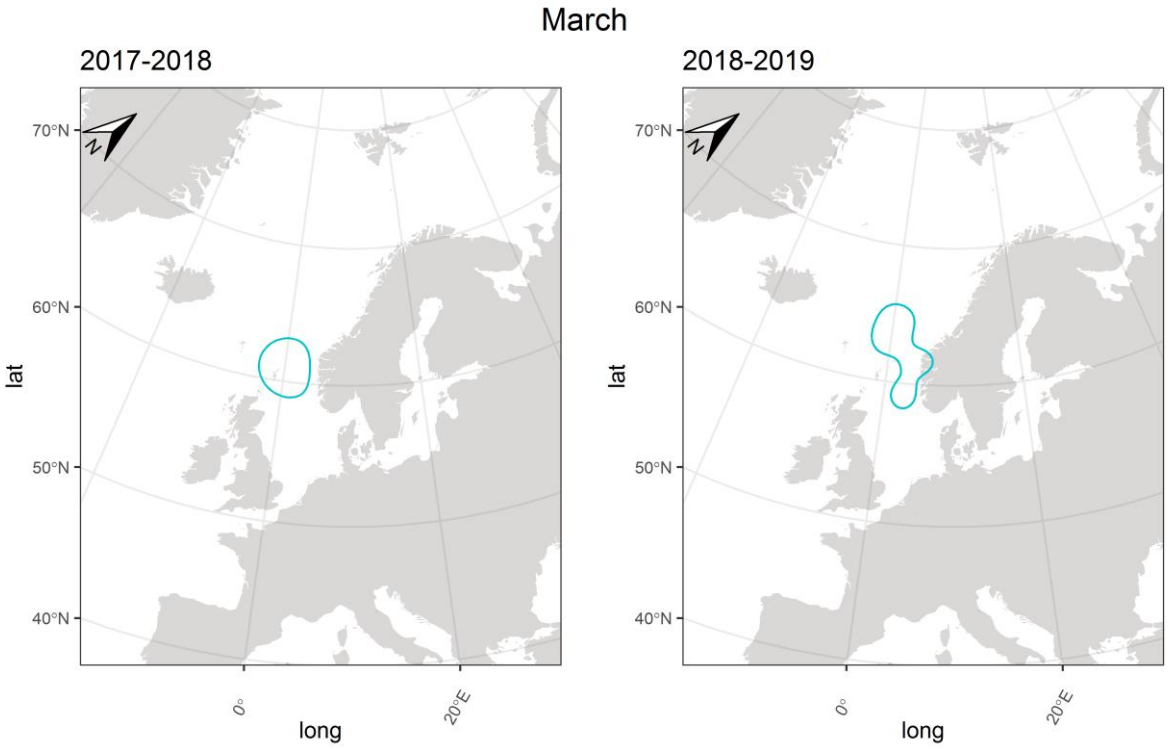

December
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

f.


January
2017-2018
2018-2019
70°N
60°N
50°N
40°N
lat
0°
20°E
long

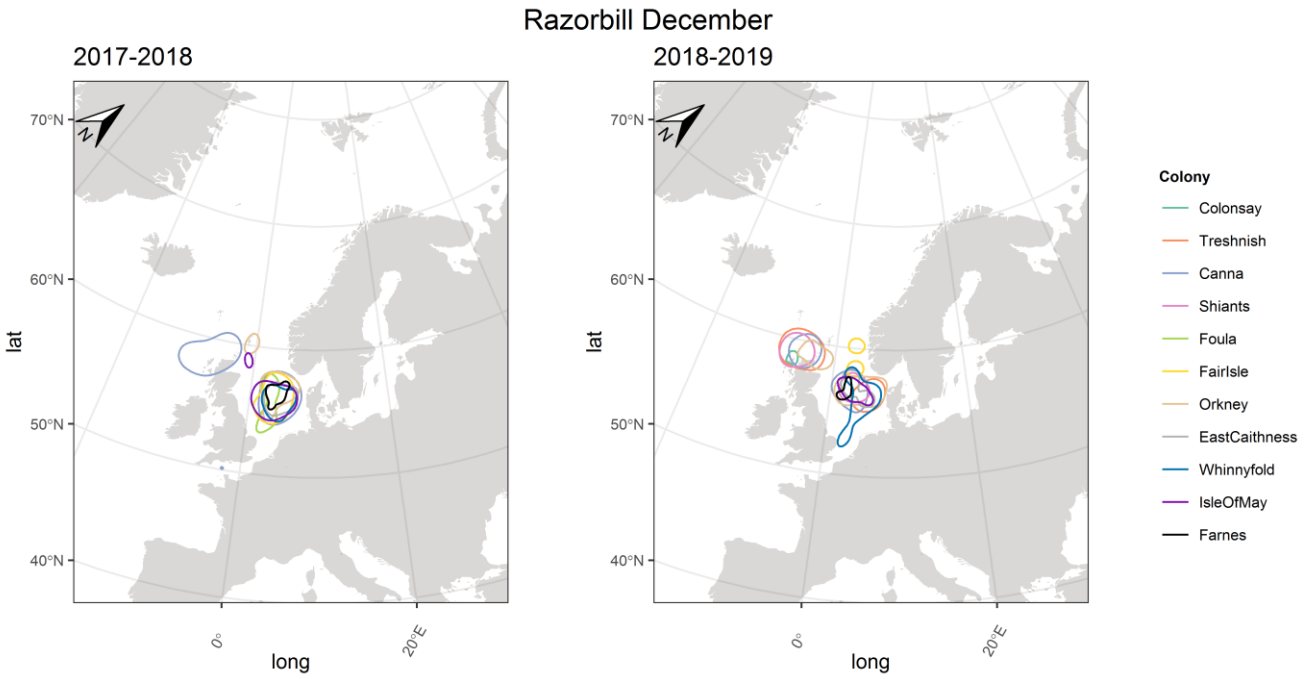


g.

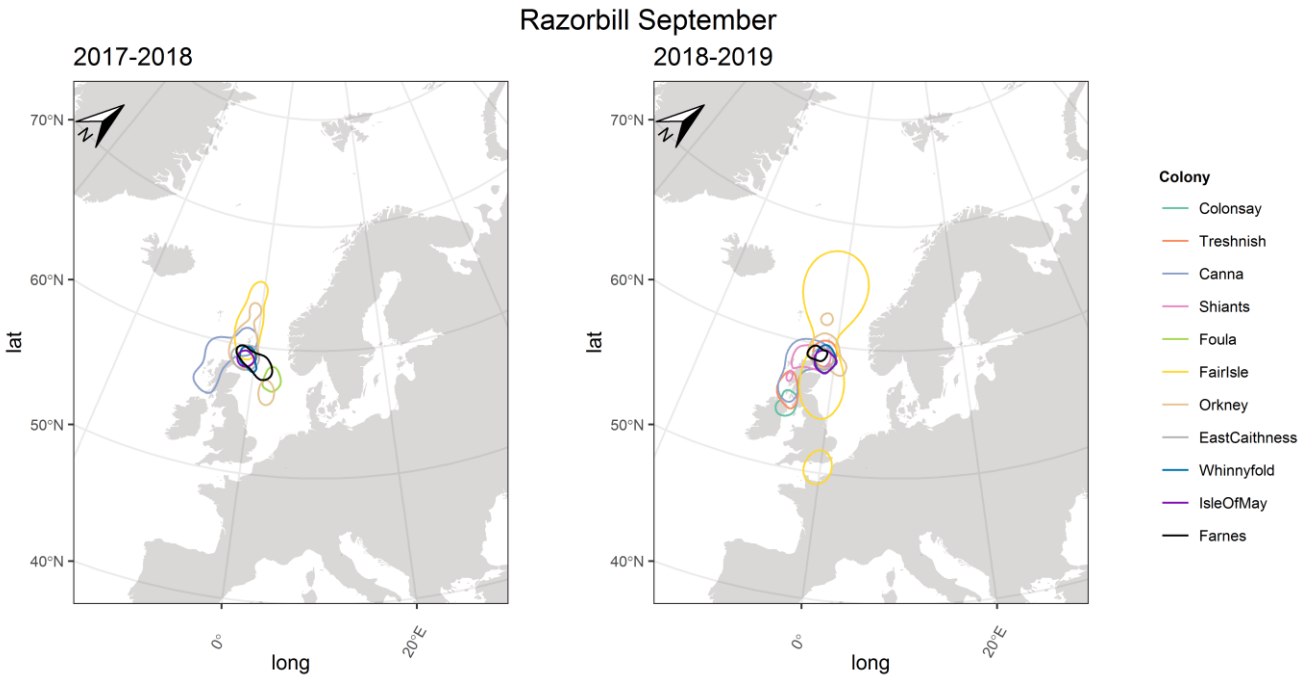


h.

Figure 3. Monthly movements through the non-breeding season (panels a-h: August-March) in guillemots breeding at Fair Isle across two non-breeding seasons. Contour lines show 50% kernel density areas.

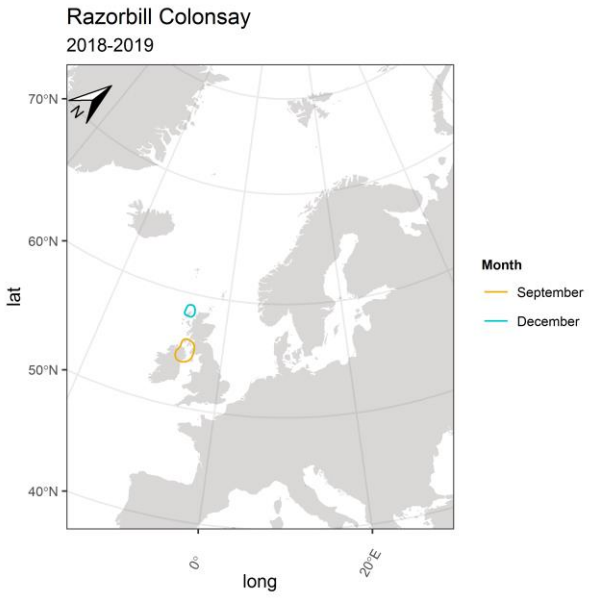


a.

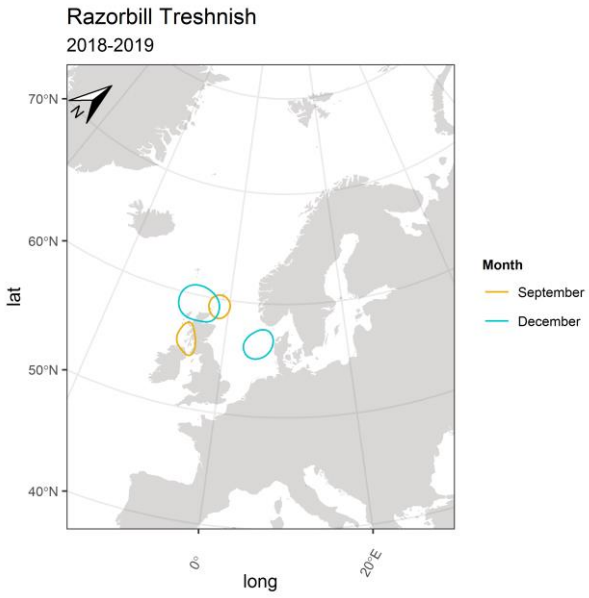


b.

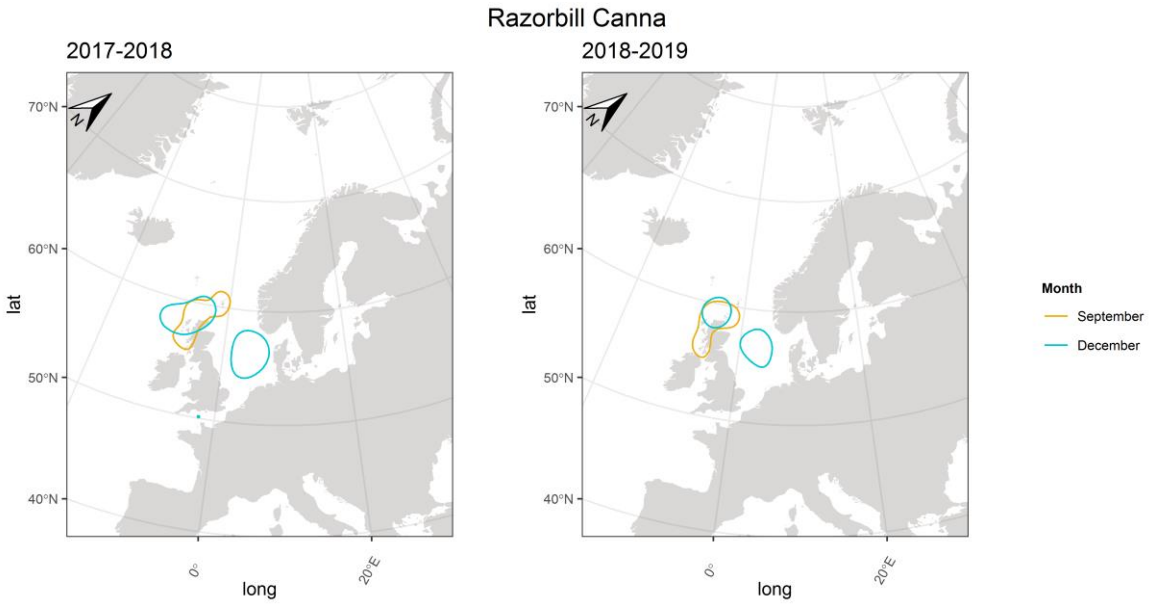
Figure 4. 50% kernel density contours for a) autumn (September) and b) mid-winter (December) distributions for razorbills tracked, with all breeding colonies shown and years tracked separated.



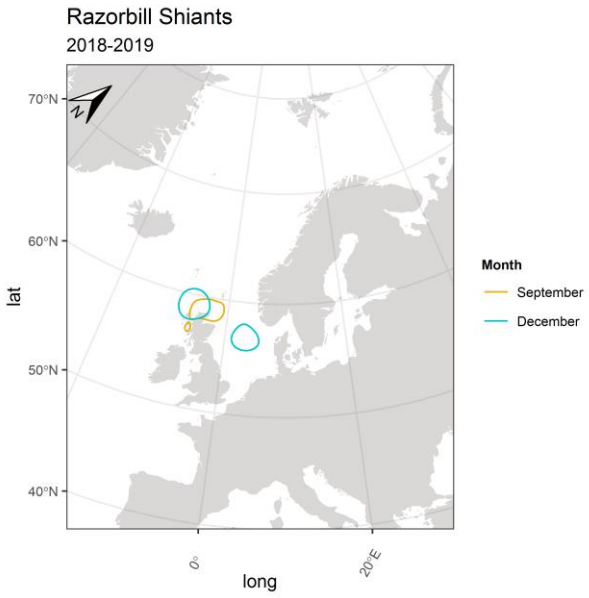
a. Colonsay razorbills tracked from 2018-19 (n = 1).



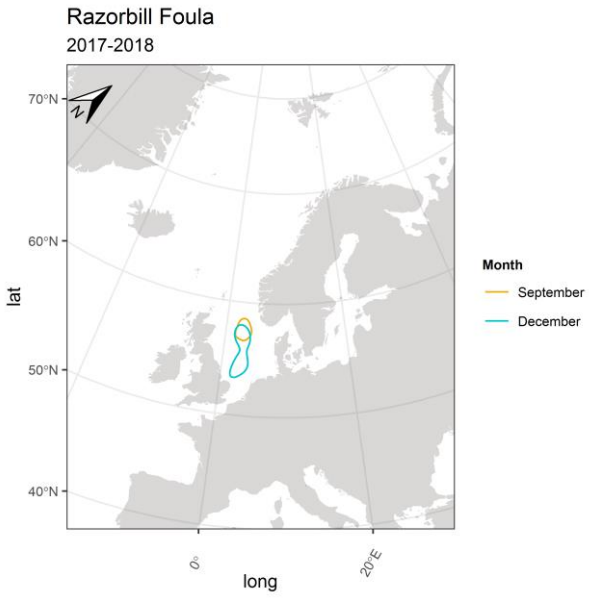
b. Treshnish razorbills tracked from 2018-19 (n = 11).



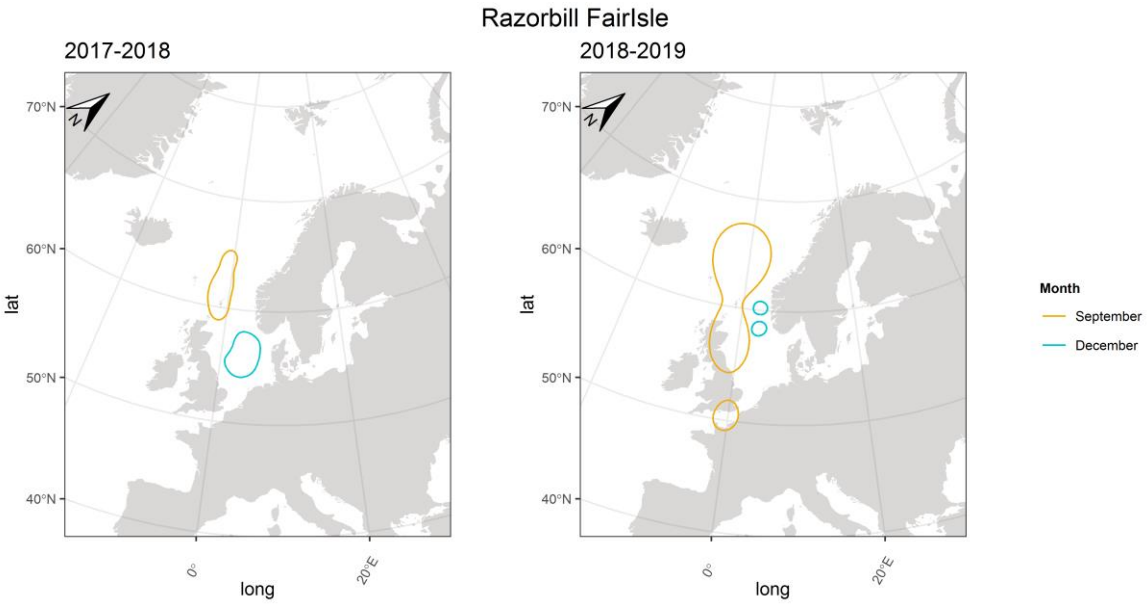
c. Canna razorbills tracked from 2017-18 (n = 7) and 2018-19 (n = 15).



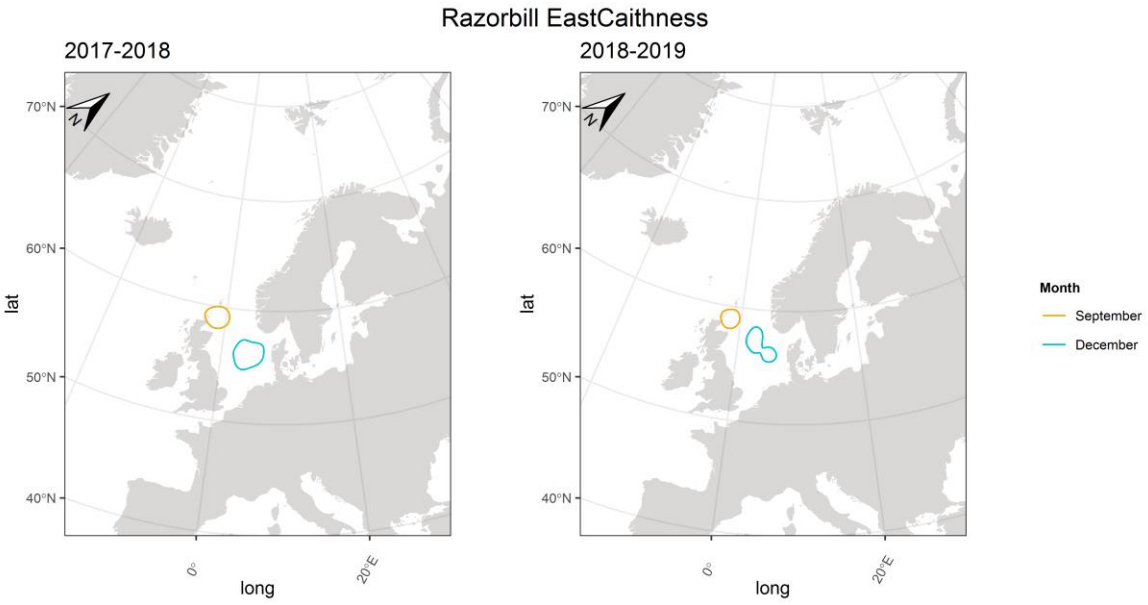
d. Shiants razorbills tracked from 2017-18 (n = 13).



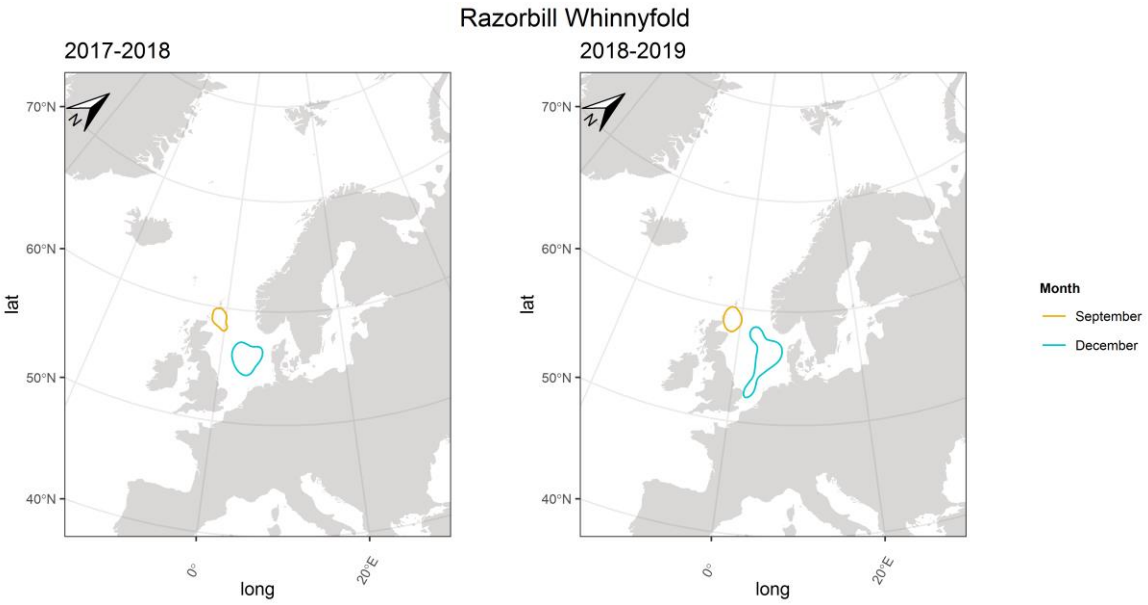
e. Foula razorbills tracked from 2017-18 (n = 1).



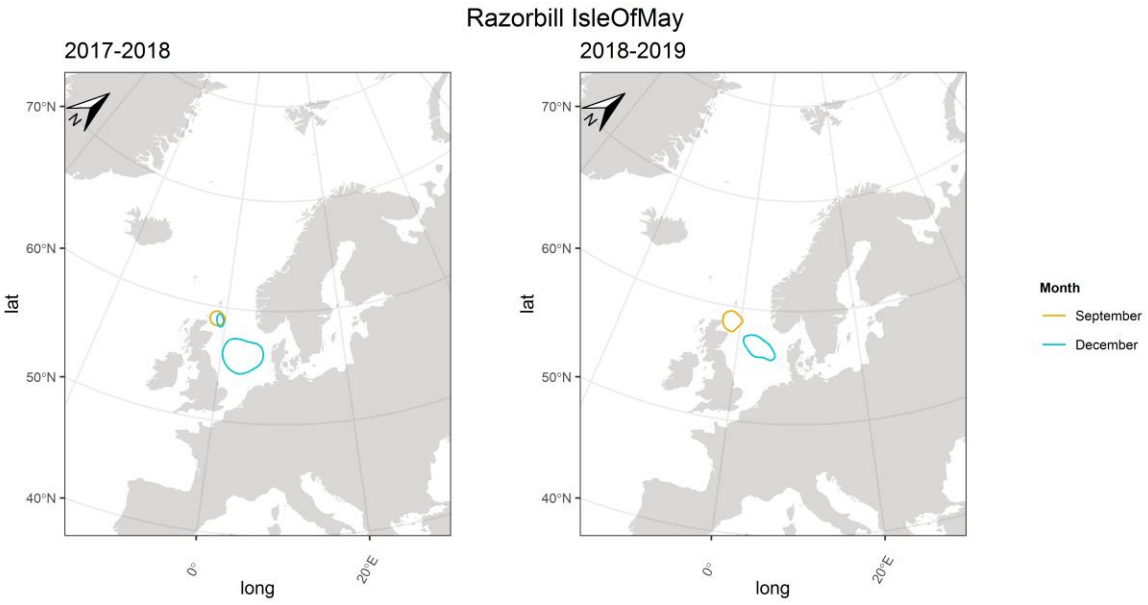
f. Fair Isle razorbills tracked from 2017-18 (n = 11) and 2018-19 (n = 2).



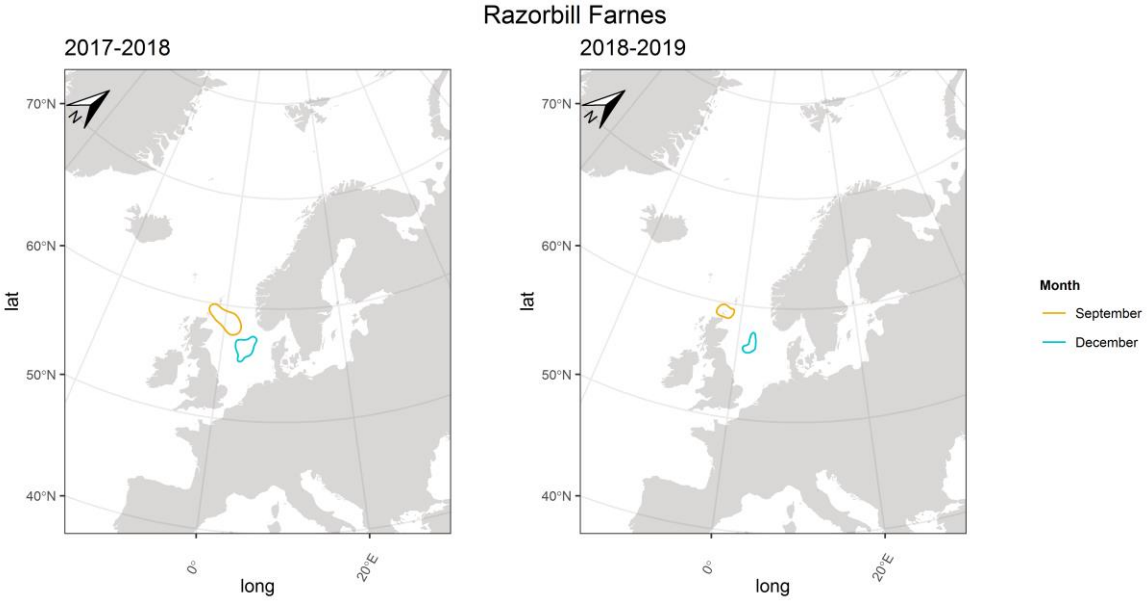
g. East Caithness razorbills tracked from 2017-18 (n = 15) and 2018-19 (n = 7).



h. Whinnyfold razorbills tracked from 2017-18 (n = 5) and 2018-19 (n = 8).



i. Isle of May razorbills tracked from 2017-18 (n = 11) and 2018-19 (n = 11).



j. Farnes razorbills tracked from 2017-18 (n = 4) and 2018-19 (n = 1).

Figure 5. Moult (September) and winter (December) 50% kernel density contours of razorbills for each colony (a-j).

6 ANALYSIS OF TRACKING DATA IN RELATION TO OTHER DATA SETS

We updated the methods we used to process the geolocation data over the winter of 2019-20 using a package in R that incorporates the sea surface temperature recorded by the tags and uses an algorithm to determine the most likely track for each tracking event (probGLS; Merkel et al. 2016). This approach is considered to be a more defensible method of estimating the distribution of these birds.

In addition, during the 2019 field season, we deployed time-depth recorders (TDRs) plus geolocators on guillemots from four of our study colonies (Colonsay and Treshnish, located on the west coast of Scotland, and Whinnyfold and the Isle of May, on the east coast of Scotland). This novel method of biologging resulted in high-resolution activity data, allowing us to investigate non-breeding season guillemot behaviour with greater precision than previous studies. We also collected feather samples from birds on recovery of a tag (at three of the four colonies where we had licences to do so), enabling us to investigate differences between colonies in diet during the post-breeding moult, using stable isotope analysis. We quantified non-breeding distribution, foraging behaviour and activity budgets of 39 individual guillemots from July – March and used feather stable isotope signatures to infer diet during the post-breeding moult. We calculated energy expenditure and investigated whether the peak (an indicator of the potential vulnerability to marine threats) varied between colonies. Individuals were spatially segregated according to the coastline they breed on, with west coast guillemots distributed off the west coast of the UK and east coast guillemots distributed off the east coast. Diet and behaviour were more similar in guillemots that shared a breeding coastline than those that did not, as west coast guillemots foraged at a lower trophic level, spent less time diving, and engaged in more pelagic foraging than east coast guillemots. However, energy expenditure was remarkably similar between colonies, peaking during late February/early March, indicating that, during our study period, there was high synchrony between colonies in the timing of potential vulnerability to threats. Therefore, any anthropogenic changes that result in decreased food availability or increased energy expenditure during late winter may have greater impacts on energy balance, with consequences for population dynamics. This study has been published in Journal of Avian Biology (Buckingham et al. 2023).

7 REFERENCES

Acker, P., Daunt, F., Wanless, S., Burthe, S.J., Newell, M.A., Harris, M.P., Grist, H., Sturgeon, J., Swann, R.L., Gunn, C., Payo-Payo, A. and Reid, J.M. 2021. Strong survival selection on seasonal migration versus residence induced by extreme climatic events. Journal of Animal Ecology 90: 796–808.

Birkhead, T.R. and Taylor, A.M. 1977. Moult of the guillemot *Uria aalge*. Ibis 119: 80–85.

Bogdanova, M.I., Buckingham, L., Newell, M.A., Wanless, S., Harris, M.P., Andrews, C., Morley, T., Weston, E., Swann, R., Canham, M., Bennett, S., Cox, N., Quintin, M. and Daunt, F. 2020. Overwintering distributions of common guillemot and razorbill populations in eastern Scotland. UK Centre for Ecology & Hydrology.

Bridge, E.S. 2006. Influences of morphology and behavior on wing-molt strategies in seabirds. Marine Ornithology 34: 7–19.

Buckingham, L., Bogdanova, M.I., Green, J.A., Dunn, R.E., Wanless, S., Bennett, S., Bevan, R.M., Call, A., Canham, M., Corse, C.J., Harris, M.P., Heward, C.J., Jardine, D.C., Lennon, J., Parnaby, D., Redfern, C.P.F., Scott, L., Swann, R.L., Ward, R.M., Weston, E.D., Furness, R.W. and Daunt, F. 2022. Interspecific variation in non-breeding aggregation: a multi-colony tracking study of two sympatric seabirds. Marine Ecology Progress Series 684: 181-197.

Burke, C.M. and Montevecchi, W.A. 2018. Taking the bite out of winter: Common murres (*Uria aalge*) push their dive limits to surmount energy constraints. Frontiers in Marine Science 5: 63.

Daunt, F., Benvenuti, S., Harris, M.P., Dall'Antonia, L., Elston, D.A. and Wanless, S. 2002. Foraging strategies of the black-legged kittiwake *Rissa tridactyla* at a North Sea colony: evidence for a maximum foraging range. Marine Ecology Progress Series 245: 239–247.

Daunt, F., Afanasyev, V., Silk, J.R.D. and Wanless, S. 2006. Extrinsic and intrinsic determinants of winter foraging and breeding phenology in a temperate seabird. Behavioural Ecology and Sociobiology 59: 381–388.

Dias, M.P., Martin, R., Pearmain, E.J., Burfield, I.J., Small, C., Phillips, R.A., Yates, O., Lascelles, B., Borboroglu, P.G. and Croxall, J.P. 2019. Threats to seabirds: A global assessment. Biological Conservation 237: 525–537.

Dunn, R.E., Wanless, S., Daunt, F., Harris, M.P. and Green, J.A. 2020. A year in the life of a North Atlantic seabird: behavioural and energetic adjustments during the annual cycle. Scientific Reports 10: 5993.

Furness, R.W., Wade, H.M. and Masden, E.A. 2013. Assessing vulnerability of marine bird populations to offshore wind farms. Journal of Environmental Management 119: 56–66.

Gaston, A.J. and Jones, I.L. 1998. The Auks: Alcidae. Oxford University Press, Oxford.

Geen, G.R., Robinson, R.A. and Baillie, S.R. 2019. Effects of tracking devices on individual birds - a review of the evidence. Journal of Avian Biology 50: 2.

Gillies, N., Fayet, A.L., Padget, O., Syposz, M., Wynn, J., Bond, S., Evry, J., Kirk, H., Shoji, A., Dean, B., Freeman, R. and Guilford, T. 2020. Short-term behavioural impact contrasts with long-term fitness consequences of biologging in a long-lived seabird. Scientific Reports 10: 15056.

Harris, M.P. and Wanless, S. 1990. Moult and autumn colony attendance of auks. British Birds 83: 55–66.

Harris, M.P., Wanless, S., Ballesteros, M., Moe, B., Daunt, F. and Erikstad, K.E. 2015. Geolocators reveal an unsuspected moulting area for Isle of May common guillemots *Uria aalge*. Bird Study 62: 267-270.

Linnebjerg, J.F., Frederiksen, M., Kolbeinsson, Y., Snaethórsson, A.Ö., Thórisson, B. and Thórarinsson, T.L. 2018. Non-breeding areas of three sympatric auk species breeding in three Icelandic colonies. Polar Biology 41: 1–11.

Mead, C.J. 1974. The results of ringing auks in Britain and Ireland. Bird Study 21: 45-86.

Merkel, B., Phillips, R.A., Descamps, S., Yoccoz, N.G., Moe, B. and Strøm, H. 2016. A probabilistic algorithm to process geolocation data. Movement Ecology 4: 26.

Merkel, B., Descamps, S., Yoccoz, N.G., Grémillet, D., Fauchald, P., Danielsen, J., Daunt, F., Erikstad, K.E., Ezhov, A.V., Harris, M.P., Gavrilo, M., Lorentsen, S.H., Reiertsen, T.K., Systad, G.H., Þórarinsson, Þ.L., Wanless, S. and Strøm, H. 2021. Strong migratory connectivity across meta-populations of sympatric North Atlantic seabirds. Marine Ecology Progress Series 676: 173-188.

Mitchell, I.P., Newton, S.F., Ratcliffe, N. and Dunn, T.E. 2004. Seabird Populations of Britain and Ireland. T & AD Poyser, London.

Moe, B., Daunt, F., Bråthen, V.S., Barrett, R.T., Ballesteros, M., Bjørnstad, O., Bogdanova, M.I., Dehnhard, N., Erikstad, K.E., Follestad, A., Gíslason, S., Hallgrimsson, G.T., Lorentsen, S.H., Newell, M., Petersen, A., Phillips, R.A., Ragnarsdóttir, S.B., Reiertsen, T.K., Åström, J., Wanless, S. and Anker-Nilssen, T. 2021. Twilight foraging enables European shags to survive the winter across their latitudinal range. Marine Ecology Progress Series 676: 145-157.

Morley, T.I., Fayet, A.L., Jessop, H., Veron, P., Veron, M., Clark, J. and Wood, M.J. 2016. The seabird wreck in the Bay of Biscay and Southwest Approaches in 2014: A review of reported mortality. Seabird 29: 22–38.

Osborn, D., Young, W.J. and Gore, D.J. 1984. Pollutants in auks from the 1983 North Sea bird wreck. Bird Study 31: 99–102.

Peschko, V., Mercker, M. and Garthe, S. 2020. Telemetry reveals strong effects of offshore wind farms on behaviour and habitat use of common guillemots (*Uria aalge*) during the breeding season. Marine Biology 167: 118.

St John Glew, K., Wanless, S., Harris, M.P., Daunt, F., Erikstad, K.E., Strøm, H., Speakman, J.R., Kürten, B. and Trueman, C.N. 2019. Sympatric Atlantic puffins and razorbills show contrasting responses to adverse marine conditions during winter foraging within the North Sea. Movement Ecology 7: 1–14.

St John Glew, K., Wanless, S., Harris, M.P., Daunt, F., Erikstad, K.E., Strøm, H. and Trueman, C.N. 2018. Moult location and diet of auks in the North Sea inferred from coupled light-based and isotope-based geolocation. Marine Ecology Progress Series 599: 239–251.

Wakefield, E.D., Bodey, T.W., Bearhop, S., Blackburn, J., Colhoun, K., Davies, R., Dwyer, R.G., Green, J.A., Grémillet, D., Jackson, A.L., Jessopp, M.J., Kane, A., Langston, R.H.W., Lescroël, A., Murray, S., Nuz, M. le, Patrick, S.C., Péron, C., Soanes, L.M., Wanless, S., Votier, S.C. and Hamer, K.C. 2013. Space partitioning without territoriality in gannets. Science 341: 68–70.

Walker, R.H., Robinson, R.A., Barimore, C.J., Blackburn, J.R., Barber, L.J., McCambridge, H.E., Green, R.M., de Palacio, D.X., Grantham, M.J., Griffin, B.M., Schäfer, S., Woodward, I.D. and Leech, D.I. 2020. Bird ringing and nest recording in Britain and Ireland in 2018. Ringing & Migration 35: 35-82.

Wernham, C.V., Toms, M.P., Marchant, J.H., Clark, J.A., Siriwardena, G.M. and Baillie, S.R. 2002. The Migration Atlas: movements of the birds of Britain and Ireland. T & AD Poyser, London.

8 PRESENTATION OF THIS PROJECT TO CONFERENCES AND WORKSHOPS

29 August 2018. University College Cork. Invited presentation by Francis Daunt 'Demographic consequences of individual variation in foraging and migration.' The Auk tracking project formed a significant part of the presentation.

3-6 September 2018. Liverpool. The Seabird Group. *14th International Seabird Group Conference*. Poster by Lila Buckingham. 'Putting auks on the map: a multi-colony tracking study of winter distribution'.

10 September 2018. Battleby. SNH. Floating Offshore Wind and Ornithological Impact Assessment. Oral presentation by Francis Daunt 'Tracking seabird movements'. The Auk tracking project formed a significant part of the presentation.

2 October 2018. Victoria Quay, Edinburgh. Marine Scotland Science. *First Scottish Marine Energy Research (ScotMER) Symposium: Marine Renewables and Seabirds*. Oral presentation by Bob Furness and Lila Buckingham 'A teamwork approach to track auk movements in the nonbreeding period'. The talk was attended by the Minister (Paul Wheelhouse) who commented that our project represented an outstanding example of what can be achieved when the renewables industry and Marine Scotland work together with local Scottish bird experts.

11 October 2018. Peterborough. British Ornithologists' Union. Conference *Seabirds: Towards* sustainable futures for renewable energy. Oral presentations by Bob Furness 'Addressing key challenges in seabird-renewables interactions' and by Francis Daunt 'Seabirds and marine renewables: population and meta-population level issues'. The Auk tracking project formed a significant part of the broader presentations.

30 October 2018. Glasgow. Hosted by Scottish Power. *Third Strategic Ornithology Monitoring and Research Workshop*. Oral presentation by Mark Trinder. 'Strategic research to reduce consenting risk'. The Auk tracking project formed a significant part of the broader presentation.

17 November 2018. Carrbridge. Scottish Ringers Conference. 50 years of seabird ringing at Canna. Oral presentation by Bob Swann. The talk included an overview of the auk tracking project, and presentation of maps showing distributions of guillemots and razorbills from Canna based on the 2018 tag recoveries and preliminary analysis of the location data. This was well received by Scottish Ringers and gave other ringing groups an opportunity to see the excellent results coming from the project; others present at the talk included Bob Furness (Foula, Fair Isle), Colin Corse (Orkney), Simon Foster

(Canna), Ewan Weston (Whinnyfold), David Jardine (Colonsay) and Lila Buckingham (Treshnish Isles) so this meeting also provided an opportunity for those taking part in auk fieldwork to discuss that.

7-11 January 2019. Canterbury, Kent. NERC Postgraduate Workshop on Statistics in Ecology. Poster by Lila Buckingham. 'Putting auks on the map: a multi-colony tracking study of winter distribution'. This poster was awarded the prize for the best poster presentation at the workshop.

16 March 2019. Oban. Scottish Ornithologists Club/Argyll Bird Club/BTO Conference. Invited presentation by Lila Buckingham. 'Putting auks on the map: a multi-colony tracking study of winter ranges'. (described as 'the talk of the day' in a review of the conference published in *The Eider*).

26-28 March 2019. Warwick. BOU Conference. Poster by Lila Buckingham. 'Individual variation in migration of guillemots and razorbills: insights from a multi-colony tracking study'.

28 May 2019. Inverness. WREN workshop (Working to Resolve Environmental Effects of Wind Energy, which is under the remit of the International Energy Authority and US Department of Energy). Oral presentation by Bob Furness 'A teamwork approach to track auk movements in the nonbreeding period'.

27-29 August 2019. CWW Conference, Stirling. Oral presentation by Lila Buckingham: 'Putting Auks on the Map': preliminary results from the project were presented at this international conference.

30 October 2019. SNH Seminar Series. Oral presentation by Bob Furness: Seabird conservation.

1 November 2019. Edinburgh University EUBAP. Oral presentation by Lila Buckingham: 'Marked differences among sympatrically-breeding species in winter overlap'. Afternoon seminar series for students and staff.

15-17 November 2019. Scottish Ringers' Conference. Oral presentation by Lila Buckingham: 'Putting auks on the map: A multi-colony tracking study of winter ranges'. This talk provided an excellent opportunity to show preliminary maps of distributions to the multiple ringing groups present at the annual meeting, who are integral to the project.

19 November 2019. ScottishPower Renewables Offshore Wind and Ornithology Conference, Glasgow. Oral presentation by Lila Buckingham: 'Marked species differences in among-colony overlap in winter distribution: Implications for effects on meta-populations from offshore renewable developments'.

27 November 2019. SAGES Conference, Edinburgh. Plenary lecture by Bob Furness. SNH's marine conservation strategy. Auk tracking project included as an example of good practice.

9-12 December 2019. British Ecological Society Annual Meeting. Poster presentation by Lila Buckingham: 'Marked differences among sympatrically-breeding species in winter mixing: Implications for understanding threats to meta populations'.

7-8 December 2019. BTO Annual Conference, Swanwick. The auk project formed a significant part of the content of the 2019 Witherby Memorial Lecture, given by Bob Furness.

23 July 2020. Multi-colony tracking reveals species difference in winter mixing. SEGUL Symposium 2020. Oral presentation by Lila Buckingham.

9 November 2020. Interspecific variation in winter aggregation: threat implications for meta-populations. University of Liverpool and University College Cork symposium. Oral presentation by Lila Buckingham.

11 November 2020. Interspecific variation in winter aggregation: threat implications for meta-populations. UKCEH Students' Day 2020. Oral presentation by Lila Buckingham.

14-18 December 2020. Interspecific variation in winter aggregation: threat implications for meta-populations. BES Annual Meeting, virtual. Oral presentation by Lila Buckingham.

12 March 2021. Non-breeding distribution, behaviour and energetics in guillemots from four colonies. SEGUL Symposium 2021. Oral presentation by Lila Buckingham.

6 October 2021. Interspecific variation in non-breeding aggregation: a multi-colony tracking study of two sympatric seabirds. 3rd World Seabird Conference. Oral presentation by Lila Buckingham.

2 November 2021. Non-breeding movement, behaviour & energetics of common guillemots and razorbills. SEATRACK Conference 2021. Oral presentation by Lila Buckingham.

13-17 December 2021. Spatial variation in diet and energetic budgets of common guillemots *Uria aalge* throughout the non-breeding season: implications for vulnerability to marine threats. BES Annual Meeting 2021. Oral presentation by Lila Buckingham.

4 March 2022. Non-breeding movement, behaviour and energetics of common guillemots and razorbills. Cheshire and Wirral Ornithological Society Annual Meeting. Invited talk by Lila Buckingham.

4-8 April 2022. A novel vulnerability assessment of non-breeding season displacement impacts of offshore wind farms on common guillemots and razorbills. 6th Conference on Wind energy and Wildlife impacts. Oral presentation by Lila Buckingham.

22-25 August 2022. A novel vulnerability assessment of non-breeding season displacement impacts of offshore wind farms on common guillemots and razorbills. Seabird Group Conference, University College Cork. Oral presentation by Lila Buckingham, which won the prize for best student talk.

3 October 2022. Non-breeding movement, behaviour and energetics of common guillemots and razorbills. North East Scotland Branch, SOC, Aberdeen. Invited talk by Lila Buckingham.

7-8 December 2022. SPR Conference on seabirds and offshore wind, Glasgow. Oral presentations on use of the geolocator data for apportioning impacts of displacement to guillemot and razorbill populations by Adam Butler, and on assessing impacts of displacement on guillemot populations by Bob Furness.

9 PUBLISHED OUTPUTS

Buckingham, L. 2022. Population variation in seabird non-breeding season ecology: implications for vulnerability assessments. PhD thesis, University of Liverpool. *Lila Buckingham submitted her PhD thesis to University of Liverpool in May 2022. It has been accepted by University of Liverpool for the award of the degree of PhD. The thesis is on temporary embargo until the third substantial paper has been submitted for publication, but will then be made public at the university library web page as a pdf.*

Buckingham, L., Bogdanova, M.I., Green, J.A., Dunn, R.E., Wanless, S., Bennett, S., Bevan, R.M., Call, A., Canham, M., Corse, C.J., Harris, M.P., Heward, C.J., Jardine, D.C., Lennon, J., Parnaby, D., Redfern, C.P.F., Scott, L., Swann, R.L., Ward, R.M., Weston, E.D., Furness, R.W. and Daunt, F. 2022. Interspecific variation in non-breeding aggregation: a multi-colony tracking study of two sympatric seabirds. Marine Ecology Progress Series 684: 181-197. *A paper comparing the nonbreeding season movements of guillemots and razorbills from the different colonies*. https://doi.org/10.3354/meps13960

Buckingham, L., Daunt, F., Bogdanova, M.I., Furness, R.W., Bennett, S., Dunn, R.E., Wanless, S., Harris, M.P., Jardine, D.C., Newell, M.A., Ward, R.M., Weston, E.D. and Green, J.A. 2023. Energetic synchrony throughout the non-breeding season in common guillemots from four colonies. Journal of Avian Biology. *A paper presenting the nonbreeding season energy budget assessments for guillemots based on the time-depth recorder plus geolocator data from birds tracked from four colonies.* http://onlinelibrary.wiley.com/doi/10.1111/jav.03018/abstract

Furness, R.W. and Buckingham, L. 2019. Tracking guillemots and razorbills using geolocators. Fair Isle Bird Observatory Report No 70: 150-152. *A brief outline of this work with particular emphasis on the fieldwork results from Fair Isle.*

Two papers based on re-deployment of our used geolocator tags, were published:

Lane, J.V., Pollock, C.J., Jeavons, R., Sheddan, M., Furness, R.W. and Hamer, K.C. 2021. Post-fledging movements, mortality and migration of juvenile northern gannets. Marine Ecology Progress Series 671: 207-218. Post-fledging movements, mortality and migration of juvenile northern gannets (int-res.com)

Pollock, C.J., Lane, J.V., Buckingham, L., Garthe, S., Jeavons, R., Furness, R.W. and Hamer, K.C. 2021. Risks to different populations and age classes of gannets from impacts of offshore wind farms in the southern North Sea. Marine Environmental Research 171: 105457. Risks to different populations and age classes of gannets from impacts of offshore wind farms in the southern North Sea | Elsevier Enhanced Reader

Raw and processed TDR and stable isotope data are freely available from Zenodo (https://zenodo.org/record/7327472#.Y8aQrHbMK4s). Processed geolocator data will also be made available from Zenodo following submission of the third manuscript, with raw geolocator data made available through SEATRACK (seapop.no).