Seabird tagging feasibility for the Sectoral Marine Plan for Offshore Wind Energy

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Executive summary

Following the completion of the ScotWind Leasing round, seabed Option Agreements were put in place for 20 new offshore wind farm projects in Scottish waters, with a capacity in excess of 27 GW. However, the Habitats Regulations Appraisal carried out in relation to the Sectoral Marine Plan (SMP) for Offshore Wind[1] highlighted the potential for significant, negative cumulative impacts on some populations of seabirds. Consequently, several of these lease areas, off Scotland's east coast, are considered to be under the highest levels of ornithological constraint, meaning developments cannot proceed unless evidence can be produced to demonstrate that impacts are at, or can be reduced to, an acceptable level. The SMP Roadmap of Actions highlighted the potential value of seabird tracking studies for producing this evidence. This report aims to build on the SMP Roadmap of actions by:

- Producing a summary timeline detailing the key tasks for a seabird tracking project from inception to delivery;
- Producing recommended protocols for tagging, covering tag types, capture and attachment methodologies;
- Identifying sites where additional tagging work is both feasible and necessary through consultation with local researchers, ringers and fieldworkers and site visits.

Whilst there has been extensive seabird tracking work at Scottish breeding colonies, most of this has taken place at sites where birds are less likely to be exposed to the impacts associated with the ScotWind projects. Consequently, given both the potential scale of tracking projects required, and the need to work at new sites, the Roadmap of Actions highlighted the need for a study to assess the feasibility of the proposed work. The key species of interest are gannet (*Morus bassanus*), kittiwake (*Rissa tridactyla*), herring gull (*Larus argentatus*), great black-backed gull (*Larus marinus*), guillemot (*Uria aalge*) and razorbill (*Alca torda*) breeding within the following Scottish Special Protection Areas (SPAs): St Abbs Head to Fast Castle, Forth Islands, Fowlsheugh, Buchan Ness to Collieston Coast, Troup, Pennan and Lions Heads, East Caithness Cliffs, North Caithness Cliffs, Copinsay and Fair Isle.

This report highlights the steps that must be taken when planning a successful tagging study, starting in the December prior to any fieldwork when tags must be ordered and permission to work at a site and deploy tags must be sought, through to the breeding season in the post deployment year when return rates should be assessed and any devices deployed over winter should be retrieved. We summarise the types of devices available and the strengths and weaknesses associated with these devices and highlight the methodologies that can be used to capture the species concerned and attach the selected devices. Finally, based on a review of existing and ongoing tagging studies, and visits to some of the key sites during autumn 2022, we make recommendations for work during the 2024 or any subsequent breeding season.

[1] Scottish Government's Sectoral Marine Plan for Offshore Wind Energy

At present, tracking studies are planned by a range of organisations for gannets (Forth Islands SPA), kittiwakes (St Abbs Head to Fast Castle SPA, the Forth Islands SPA, Fowlsheugh SPA and Buchan Ness to Collieston Coast SPA), guillemots (Forth Islands SPA and Buchan Ness to Collieston Coast SPA) and razorbills (Forth Islands SPA and Buchan Ness to Collieston Coast SPA). It is recommended that tracking studies on great black-backed gull are not undertaken at present as devices fitted with standard attachment methods are quickly removed by the birds and there are concerns about device effects associated with harnesses. Until such a time as the device effects associated with harnesses can be reduced to an acceptable level, deploying GPS tags on great black-backed gulls is unlikely to be considered a viable approach. Puffin was not considered for inclusion in this feasibility study, and tag effects are a known concern for this species. Following site visits in autumn 2022 and discussion with site staff, it is also advised that tagging gannets on Fair Isle SPA, or at Troup, Pennan and Lions Heads SPA is not feasible due to health and safety concerns. Given the locations of the Forth Islands SPA and St Abbs Head to Fast Castle SPA relative to the ScotWind sites and, the ongoing bird tagging work within these SPAs, it is felt that additional data collection at these sites to support ScotWind is less of a priority at present. However, it is recommended that additional visits to sites within Fowlsheugh SPA, Buchan Ness to Collieston Coast SPA, Troup, Pennan and Lions Heads SPA, East Caithness Cliffs SPA, North Caithness Cliffs SPA and Copinsay SPA are undertaken during the 2023 breeding season to further assess the feasibility of deploying tags at these sites in future years. Many of these visits are planned as part of ongoing work during 2023.

Contents

Introduction

The offshore wind industry is set to play a crucial role in Scotland's economy as part of efforts to generate 50% of Scotland's energy from renewable sources by 2030 and to reach Net Zero by 2045. This means that, as we emerge from the COVID-19 pandemic, the industry is likely to play a central role in a green economic recovery.

At present, there are six offshore wind farms in Scottish waters, including the world's first floating offshore wind project. A further five are either under construction or have been consented. Building on this success, the recently announced ScotWind Leasing Round aims to deliver additional energy from offshore wind. The Sectoral Marine Plan for Offshore Wind Energy (SMP) published in October 2020 set out the spatial Plan Options for a new round of offshore wind seabed leasing, known as ScotWind and managed by Crown Estate Scotland (CES). The SMP assessed the impact of up to 10GW of new development (Figure 1). In January 2022, CES announced that Option Agreements will be offered to 17 projects with a total stated capacity ambition of up to 25GW (Figure 1). Subsequently, three further projects, with a capacity in excess of 2GW were announced following the completion of a clearing round and 13 projects have been announced following the outcome of the Innovation and Targeted Oil and Gas (InTOG) Leasing Round. Whilst offshore wind energy offers the potential to mitigate the negative impacts of climate change by reducing reliance on fossil fuels, concerns remain over the potential for negative environmental impacts, particularly in relation to birds (Bradbury et al., 2014; Furness et al., 2013; Garthe & Hüppop, 2004). The key effects associated with offshore wind are believed to be collision with turbines, displacement, and barrier effects (Cook et al., 2018; Dierschke et al., 2016; Masden et al., 2012; Mendel et al., 2019; Thaxter et al., 2018). Prior to consent for a development being granted, the potential for these impacts to negatively affect populations, particularly those of designated features of protected sites, must be considered as part of the Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA) processes.

The Strategic Assessment for the Scottish Governments' SMP for Offshore Wind Energy (comprising Strategic Environmental Assessment (SEA), Habitats Regulations Appraisal (HRA) and a socio-economic impact assessment (SEIA)), assessed the option areas based on a 10GW scenario, highlighting the potential for negative effects in relation to the Plan Options (POs, Figure 1). The HRA highlighted potential cumulative ornithological impacts as a key constraint to the future delivery of offshore wind in Scottish waters. As indicated above, the ScotWind and INTOG Leasing rounds have option agreements for approximately 30GW, i.e a substantially greater amount of potential development than was assessed. In five of the POs (E3, NE2, NE3, NE4 and NE6), which include ScotWind leases option agreements with a combined capacity of up to 4.5 GW, it was determined that further empirical evidence was required before it can be concluded that the risk to seabird populations can be reduced or is at an acceptable level. An additional two sites (E1 and E2) were identified as needing strategic regional surveys and assessments to address uncertainties about the potential cumulative impacts on seabirds, particularly in the non-breeding season.

The SMP Roadmap of Actions[2] highlighted that collecting seabird tracking data offers a valuable opportunity to provide the empirical evidence to assess whether the risk to seabird populations from these developments can be reduced to an acceptable level, and to reduce uncertainties about potential cumulative impacts. In addition to establishing connectivity between seabird populations in Special Protection Areas (SPAs) and these POs, the data can be used to investigate seabird activity budgets and patterns in flight height, speed, and avoidance of existing offshore wind farms (Cleasby et al., 2015; Johnston et al., 2021; Masden et al., 2021; Ross-Smith et al., 2016). By collecting data from species from SPAs where there is likely to be connectivity with ScotWind POs, we will have greater power to investigate spatial and temporal patterns in these parameters, and better understand how they may be influenced by weather conditions. This will allow us to better quantify these parameters and consequently, reduce uncertainty surrounding assessments of key impacts, particularly collision risk mortality.

[2] The Sectoral Marine Plan Roadmap of Actions

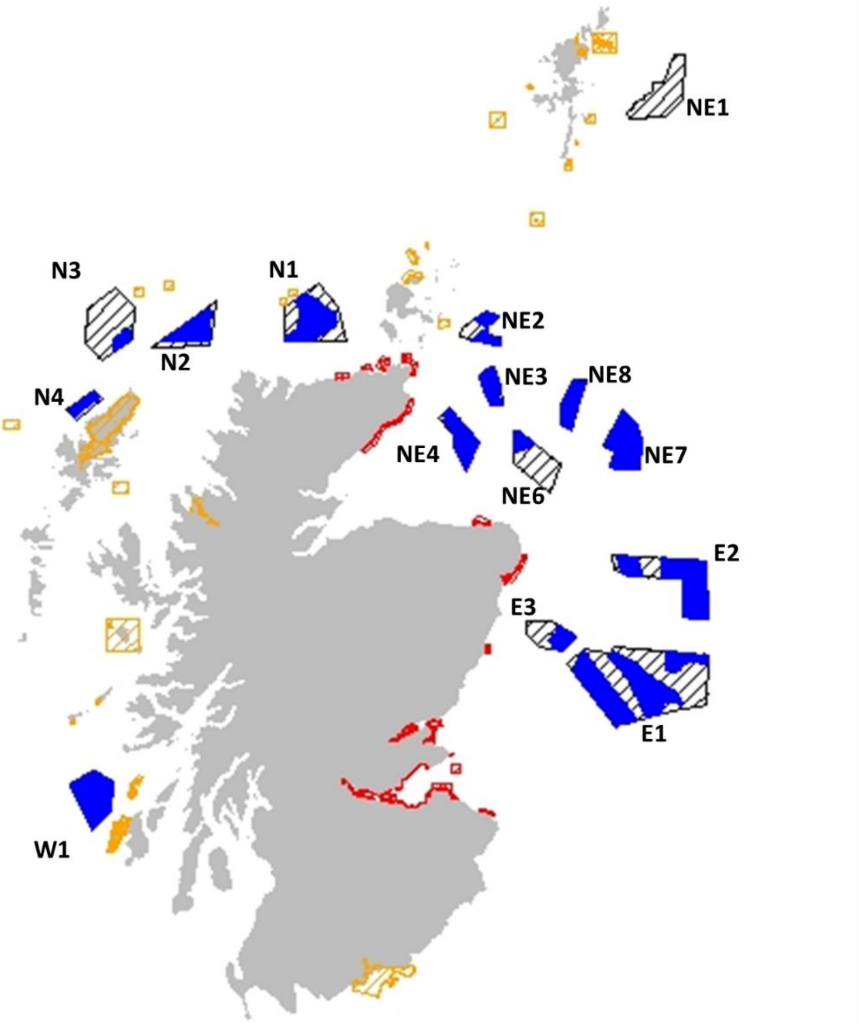


Figure 1 Plan Options identified as part of the Sectoral Marine Plan for Offshore Energy in October 2020 (black hatched shading) and subsequent ScotWind Lease Agreement Offers (blue solid shading) as of February 2022. Also shown are SPAs for which the Plan Strategic Assessment highlights the potential for negative impacts in relation to the plan options (orange), and including those for which the Habitats Regulations Appraisal concluded that it was not possible to conclude that there would be no adverse effects on site integrity resulting from development within POs (red) without the application of mitigation approach highlighted above (i.e. no development in E3, NE2, NE3, NE4 and NE6 until evidence can be produced to demonstrate the risks to seabirds are reduced, or are at an acceptable level).

At present, there are a number of ongoing seabird tagging studies during both the breeding and non-breeding seasons, often associated with post-consent monitoring programmes. These include studies in the Firth of Forth, Fowlsheugh and St Abb's Head. However, the collection of tracking data of relevance to many of the ScotWind Option Agreements is likely to require work in additional SPAs, particularly further north along North Sea coasts (Figure

1, Table 1). Whilst puffin was not considered for inclusion in this feasibility study, discussion about the practicalities of working on the species, particularly in relation to tag effects which are a known concern for this species, is included in the report as it co-occurs with the other auk species at several sites of interest. There may be a number of constraints to further work including the challenges of working at unfamiliar sites and the availability of suitably trained and qualified staff. Consequently, there is a need for a strategic overview of this work to ensure an optimal allocation of effort, and a careful consideration about at which sites and for which species tagging work is feasible. This report provides an overview of the feasibility of planning a strategic tagging programme in advance of any implementation and the necessary steps prior to a breeding season when tagging will occur. To achieve this, the report aims to:

- Produce a summary timeline detailing the key tasks for a tracking project from inception to delivery;
- Produce recommended protocols for tagging covering tag types, capture and attachment methodologies;
- Identify sites where additional tagging work is both feasible and necessary through consultation with local researchers, ringers and fieldworkers and site visits.

Table 1 SPAs and species for which additional tracking requirements were identified as part of the ScotWind Roadmap of Actions, highlighted cells (the last seven columns) indicate colonies at which a site visit is likely to be required in order to assess the feasibility of tagging one or more species.

	St Abbs Head to Fast Castle	**Forth Islands**	**Fowlsheugh**	**Buchan Ness to Collieston Coast**	**Troup, Pennan and Lion’s Heads**	**East Caithness Cliffs**	**North Caithness Cliffs**	**Copinsay**	**Fair Isle**
Gannet		✓			✓				✓
Great Black-backed Gull						✓		✓	
Herring Gull		✓	✓	✓					
Kittiwake	✓	✓	✓	✓	✓	✓	✓	✓	
Guillemot	✓	✓	✓	✓		✓			
Razorbill	✓	✓	✓	✓		✓			

Link to Roadmap of Actions and Marine Sectoral Plan

The Roadmap of Actions[3] to support the Marine Sectoral Plan highlighted four key outcomes that were required in order to assess whether or not the risk to seabird populations within Plan Options E3, NE2, NE3, NE4 and NE6 could be reduced to an acceptable level:

1. Reduced uncertainty over connectivity between plan options and designated features of SPAs in the breeding and non-breeding seasons
2. Reduced uncertainty over collision, displacement, and barrier effects in each plan option
3. Understanding of population-level impacts on the populations concerned
4. Understanding of the contribution of marine spatial planning and mitigation to reducing impacts and unlocking plan option potential for Offshore Wind Farms.

Seabird tracking studies, whether using GPS or geolocation tags, have the potential to feed into each of these. At a most basic level, GPS tracking would make it possible to establish connectivity between the Plan Options and SPAs during the breeding season, whilst geolocators would allow similar inferences to be made during the non-breeding season (subject to the greater degree of uncertainty surrounding fixes from these devices) (**OUTCOME 1)**. Geolocation tag data would also feed into the need to address uncertainties relating to seabird distributions within Plan Options E1 and E2 during the non-breeding season.

Data additional to location can be obtained from GPS tags combined with other sensors, notably information on flight heights and speeds. Similarly, by deploying time-depth recorders alongside geolocators or GPS tags, information on diving behaviour can be derived. As a first step, these data can be used to inform estimates of flight height and speeds used in collision risk models (Largey et al., 2021; Masden & Cook, 2016; Masden et al., 2021; Ross-Smith et al., 2016), reducing uncertainty in the outputs from these models. (**OUTCOME 2)**. These data can also be used to inform behavioural classifications using approaches such as Hidden Markov Models (HMMs) (Grecian et al., 2018; McClintock & Michelot, 2018) and Expectation Maximisation Binary Clustering (EMBC) (Garriga et al., 2016), and also to derive time-activity budgets and insight into changes in energetic budgets following construction of offshore wind farms, reducing uncertainty surrounding the predicted consequences of displacement and barrier effects (**OUTCOME 2**). By collecting data from multiple individuals and across multiple colonies, it will also be possible to obtain a greater understanding of variation in behaviour, energetics and links between individual condition and demography, improving our understanding of population-level impacts on the populations concerned (**OUTCOME 3**). Finally, through the analyses of data from tagged birds when within or in the vicinity of operational wind farms (e.g. Beatrice, Hywind, European Offshore Wind Deployment Centre) it will be possible to better understand how

[3] Roadmap of Actions to Support the Marine Sectoral Plan -

birds respond to wind farms, helping to determine how impacts can be reduced through possible mitigation measures and through careful marine spatial planning (**OUTCOME 4**).

Tagging Study Timelines

Carrying out an effective tagging study can be logistically challenging. Consequently, careful planning is required to ensure that all tasks are carried out in a timely manner. Sufficient time needs to be allowed for ordering tags, obtaining all necessary licences and permissions, and to safely deploy tags and monitor any potential tag effects. The exact timing of any tag deployment will depend on the species concerned and the attachment method used. However, indicative timelines are set out below (Figure 2).

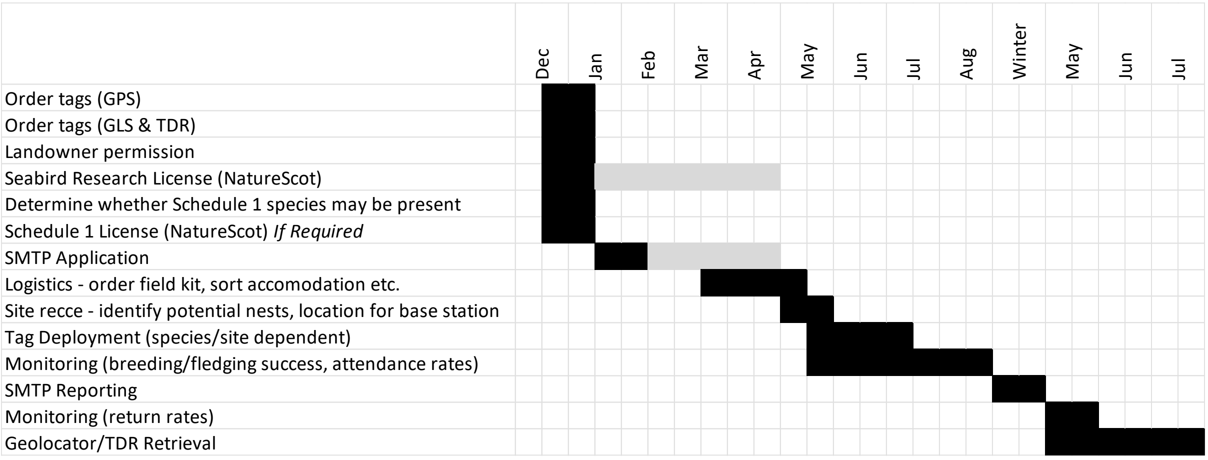


Figure 2 Gantt chart setting out indicative timelines for a successful tagging study. Black indicates timings in which work must be completed by those leading the tagging study and grey indicates time allowed for equipment delivery and for SMTP (Special Methods Technical Panel) and NatureScot to consider applications for tag deployment, and in the case of NatureScot carry out a Habitats Regulations Assessment to consider the effects of tagging at SPAs.

Planning

Tag orders

It is assumed that any tagging will take place during the seabird breeding season (Figure 2). Ideally, any tags should be obtained well in advance of deployment to allow time for testing, calibration and programming. This is particularly important where additional behavioural data are required from the tags, besides location information (e. g. flight heights and speeds, diving behaviour). Prior to placing tag orders, there should be informed discussions with project funders in relation to the trade-offs between battery life and the types of data that can be recorded (e.g. complete tracks vs high temporal resolution positional data). This will help to ensure that the objectives of any study are clear and the funders are aware of the capabilities of the tags chosen for the work.

At present, a key constraint is a global shortage of microchips following the disruption in supply chains caused the COVID-19 global pandemic. Tag manufacturers need to order microchips well in advance of constructing and delivering tags, which can contribute to long lead times on tag delivery. Discussions with a number of manufacturers (Ornitela, Lotek, Ecotone, and Migrate Technology) suggest that 12 weeks is a typical delivery time for tags. However, all companies indicated that February-May is their busiest period, and that longer lead times may be required for larger orders. Consequently, they advised that late January should be seen as a deadline for placing orders, and that for large orders (>80 tags), as early as the beginning of December would be advisable. If necessary (e.g. to allow time for some testing and programming) rolling delivery is possible with smaller batches of tags delivered as they become available. It should be noted that, as bespoke devices, these tags can have a limited shelf life and tag maintenance (e.g. ensuring batteries are charged) over a full year can be a very time-consuming task. Consequently, placing a bulk order with a view to having devices to deploy in subsequent years is not advised. It should also be noted that orders placed with companies outside the UK may be subject to import duties and have extended delivery times.

Landowner Permission

Permits to catch and ring birds in the United Kingdom are issued by the British Trust for Ornithology. However, these permits do not infer any right of entry onto land without the landowner's permission. Consequently, where necessary, permission to catch birds and deploy tags should always be sought prior to the start of any fieldwork. It is strongly advised that the owners of any land on which tagging work will take place are identified at an early stage (e. g. around the same time as tag orders and licensing) and approached to obtain permission for the proposed fieldwork. Developing a constructive relationship with any landowners will help with the successful delivery of any project, and feedback on the key findings from any work (e.g. maps of seabird tracks) is usually highly appreciated.

NatureScot Permission

Permission to deploy tags within an SPA must be obtained from NatureScot (or the appropriate Statutory Nature Conservation Body if elsewhere in the UK) prior to any fieldwork taking place. This permission should be sought by contacting licensing@nature.scot. The application should include sufficient information to enable NatureScot advisors to complete a robust assessment, including formal HRA record, of both the application itself, and any potential in-combination effects with other proposed work. This should include:

1. Full contact details of the individual who will be the licence holder; including full name, address (work or home), email address and telephone number.
2. If this is their first licence application for bird research, NatureScot require two references familiar with their work in this area and be able to vouch for their competence.
3. A short summary of the purpose of the proposed work and justification for why the research is necessary.

4. Details of the proposed activity requiring a licence, including species, numbers of individuals targeted, life stage and actions (e.g. disturb or take).
5. Details of alternatives to the proposed licensable activities in order to carry out the research that have been tried or considered, with an explanation of why these alternatives are not suitable.
6. Which months (inclusive) of the year is the work planned for? Provide start and finish dates if known.
7. Details of how many days will be spent in the field undertaking the work, how long is anticipated being on site each day and how long processing birds will take (if applicable). A worst and best case scenario is helpful for NatureScot to assess potential disturbance risk.
8. Location(s) proposed to undertake the work. The more details provided on this, the more specific NatureScot can be in their advice. Maps and locations (including a six-figure grid reference, e.g. NM123456) are helpful, particularly from a National Nature Reserve (NNR) management perspective.
9. Methods to be used and why.
10. Details of all researchers involved in the fieldwork, including how many people will be undertaking the work in the field at any one time. This enables NatureScot to assess potential disturbance risk. In addition, please detail the level of experience researchers undertaking the work have. If researchers have limited experience of working in seabird colonies/using the methods proposed, please provide details on how they will be supported/assisted.
11. What mitigation has been incorporated in the methods/experimental design to minimise potential risk of injury, mortality and disturbance of target and non-target species? Consideration should be given to potential risks to species at the target field site and also on transit to the target field site.
12. Details of the monitoring plan (of both target and non-target species) to ensure mitigation is proving effective and your research activities are not having a negative effect. Include how potential negative effects will be detected, and if detected, what actions will be taken. All negative impacts are required to be reported immediately to NNR staff (if the study location is within an NNR).
13. Any evidence underpinning the licence application, including reports, peer-reviewed scientific papers, etc.
14. Licence references for any previous and/or associated licence applications connected with the work.

For full details and any updates see NatureScot's Seabird Research Licence Applications

NatureScot currently advise allowing a minimum of three months for them to consider any applications, though contact at the earliest opportunity is preferable. Consequently, it is suggested that applications are submitted by mid-January at the latest for summer tagging work.

In addition to obtaining permission to work in an SPA, it is important to consider whether any schedule 1 species (e.g. Peregrine Falcon) may be disturbed by the proposed work, irrespective of whether or not the species is a feature of the SPA. Consequently, it is recommended that researchers contact local raptor study groups to determine whether there are any birds in the area that may be disturbed and, if necessary, apply for a schedule 1 licence.

Special Methods Technical Panel Permission

Any project involving the marking and/or fitting of any device other than a standard BTO metal ring, or the use of a non-conventional trap, as defined by the Ringers' Manual (Redfern & Clark, 2001) requires permission as a special method from the Special Methods Technical Panel (SMTP). There are currently 45 defined Special Methods which have been assigned to a 'Low', 'Medium', 'High' or 'Very High' risk category through discussion with the Home Office:

- Low risk (e.g. colour marks and feather clipping) – considered by the BTO Licensing Officer.
- Medium risk (e.g. swabbing, plucking feathers) – considered by the BTO Licensing Officer.
- High risk (e.g. wing tags, glued/taped devices, ring/flag/collar mounted devices, leg-mounted devices) – considered by Special Methods Technical Panel (SMTP) unless a similar project has already been approved, in which case approved by the BTO Licensing Officer.
- Very High risk (e.g. necklaces, harness-mounted devices) – considered by SMTP.

Initially, all applications are made to the BTO licensing officer, who then forwards these on to the Special Methods Technical Panel (SMTP) as appropriate. All applicants are asked to complete a detailed form highlighting:

1. project aims
2. location
3. people involved in all aspects of fieldwork and their relevant experience, including ringing permit details
4. proposed sample size for each combination of species, sex and age
5. the technical detail of the Special Method to be employed.

Where projects are considered by SMTP, they need to be supported by at least two members of the SMTP, plus the Chair of the SMTP, for approval to be granted. For higher risk and/or novel methods, the process may be discursive, with SMTP requesting further information from the applicant and, if required, steering them towards more appropriate alternative techniques.

Approval is only granted on condition that applicants have been suitably trained. Ideally, this training would be face to face with an experienced trainer, but for low-risk methods passive training is acceptable. However, for medium and high risk methods one-to-one field training from an experienced practitioner, and a reference from that practitioner is required as part of the application.

The outcome of the application will be communicated to the applicant by the BTO licensing officer. This will include details of any modifications to the proposed protocol and any reporting conditions. A report meeting the conditions set out in this permission must be submitted by the end of the licensing year in which the activity was completed. Requests for any renewal of the permissions for subsequent years is made at this stage.

For more information, please see the BTO's guidance on licencing and sampling methods.

Due to the discursive nature of the process, it is recommended that at least three months are allowed for applications, and that these are submitted by the end of January for summer tagging work.

Logistics

The logistics involved in planning and successfully delivering a tagging project should not be under-estimated. Noting that fieldwork may take place in a remote location, during peak holiday season, accommodation should be booked at an early stage. Ideally, this accommodation should be close (e.g. within 30 minutes' drive) to the field site, with sufficient parking for all project vehicles, and space for staff to relax at the end of a busy day in the field and somewhere suitable for storing all field equipment. Given the unpredictable nature of fieldwork, flexibility in timing is crucial. Consequently, holiday cottages, which can be let for 1-2 months (covering both tag deployment and monitoring for any tag effects), often make excellent options for accommodation during the field season.

At an early stage in the planning process, the availability of field staff, and contingency staff should be confirmed. A pre-season meeting should be held to outline plans for the field season. The status of ringing permits and any additional training needs (e.g. rope access, first aid training) should be discussed. Any personal field equipment needs including Personal Protective Equipment (e.g. suitable clothing and footwear, eye protection, gloves, etc) should also be identified. Risk assessments should be prepared and completed, and all field protocols should be checked to ensure that they are compliant with COVID and Highly pathogenic avian influenza (HPAI) requirements. These assessments should be kept under review in the event of circumstances changing closer to the field season.

An equipment inventory should be completed. This should cover all field equipment including ringing kit, harness material and optics (e.g. binoculars and/or telescopes) to be used for monitoring, as well as a first aid kit. Any additional equipment required should be ordered at as early a stage as possible. This should include ensuring that there is a backup phone for use in the field (e.g. in case batteries run out), and mobile internet dongle (if using base station to download data over the internet). Mobile phone coverage should be checked prior to the start of any fieldwork, and, in situations where coverage is very limited, or non-existent, alternative options should be considered to ensure the safety of field workers. Any need for lone working (e.g. during post-deployment monitoring visits) should be identified at this stage and appropriate protocols should be agreed and put in place.

At least one and, ideally two or three, recce visits should be undertaken. The first visit should be undertaken early on in the project to assess potential ringing sites, identify any access issues and consider possible locations for base stations (devices placed in the vicinity of the colony through which tag data are remotely downloaded). The second visit should take place once the breeding season is underway, with a third visit to help identify median laying dates particularly valuable for guillemots and razorbills due to their short chick-rearing period, compared to other seabirds. The aims of this visit should be to assess the status of the breeding season, with a view to identifying the optimal timing for deploying tags, and to identify a sample of nests to target for deploying tags. Ideally, tags should have been delivered by the time of this second recce visit. Assuming this is the case, these should be carried during the visit in order to check functionality, and if possible, to inform the deployment of the base stations, e.g. ensuring the base station can pick up a signal from the tag when the tagged bird is at the nest.

It is also important to engage with local stakeholders, including ringers and ringing groups, at an early stage. This serves two purposes. Firstly, these stakeholders are likely to have valuable local knowledge about sites that may be suitable for catching and tagging birds. Related to this, they may also be able to facilitate contact with local landowners, and make suggestions for locations in which equipment such as base stations could be deployed. Secondly, where a local ringing group has an existing ringing and colour-ringing scheme, these schemes should be used in preference to setting up a new project associated with the tagging work. Note though, that any rings used should be paid for as part of the tagging work. Where local ringing groups, or others, provide support to the project, an honorarium should be considered. If any volunteers assist with the tagging, they should be asked to complete risk assessments.

Immediately prior to deployment, the duty cycles and settings for the tags should be finalised and programmed. Fieldwork information sheets (key contacts, site information, medical details) and data collection sheets (e.g. for ringing details and tag settings) should be printed, and care should be taken to ensure suitable vehicles are available for the fieldwork. In the case of a multi-colony study, involving multiple research institutes, ideally a shared field protocol would be agreed in advance in order to maximise the value of any data collected, particularly in relation to the monitoring of device effects.

Delivery

Ahead of the tag deployment, a final briefing should be held for all field staff. Key expectations should be set out, and all staff should be clear about their roles and responsibilities in the field and Health & Safety requirements. During tagging sessions, all COVID and HPAI requirements should be followed, including cleaning and disinfecting kit when moving between sites to minimise the risk of HPAI transmission. If time and the project allow, training in the fitting of tags to birds may be offered to suitably experienced personnel by licence holders, with a view to increasing capacity for future tagging studies. Though note that any potential training, or increase in the number of people involved in the fieldwork, should be flagged to NatureScot as part of the application process in mid-January, to enable an accurate assessment of the potential for disturbance to be made. At the end of each tagging session, field backups of data sheets should be collected prior to leaving the site (e.g. through digital photographs of each data sheet). Where possible (e.g. for remote download GPS tags), as tags are deployed, the data obtained should be checked to ensure the tag is delivering as expected, and updates should be offered to project funders, and other interested stakeholders (if appropriate).

Following tag deployment, licence conditions for monitoring of possible tag effects should be followed. Monitoring requirements can be aided through annotated digital photographs which clearly identify the locations of any tagged and control nests. Should this monitoring involve any periods of lone fieldwork, lone fieldworker protocols must be put in place and followed.

Post-Field season

Following the completion of the field season, all data collected should be cleaned and backed up. The field kit should be sorted, cleaned and stored, with any broken or missing items noted, and replaced or repaired as required. Where data collection will continue over winter, and settings can be altered remotely, settings should be adjusted to facilitate prolonged data collection whilst preserving battery life.

All of the ringing data should be submitted to the BTO using the Demography Online (DemOn) portal[4], and any resighting and/or nest monitoring data should be analysed in preparation for the SMTP Reports, which must be submitted by the end of the licensing year in which the work was carried out. Feedback should be provided to funders (and other stakeholders, as appropriate) detailing the outcomes from the fieldwork. Where archival loggers (e.g. geolocators) have been deployed over winter, plans should be made to retrieve these the following breeding season.

[4] BTO Demography Online (DemOn) Portal https://app.bto.org/demography/bto/public/login.jsp

Tag types

Species considerations

There are a number of restrictions in relation to the types of devices that can be deployed on different species. The most widely known of these is the “3% rule” (Bodey et al., 2018; Geen et al., 2019), which states that tags must be no more than 3% of a bird’s body weight in order to minimise the risk of deleterious tag effects (Table 2). However, there are a number of other restrictions linked to the behaviour of the species concerned which influence how, and where a tag may be deployed (Vandenabeele et al., 2014, 2012, 2015). Typically, there may be requirements for leg or tail-mounted devices to be lighter than back-mounted devices (Table 2).

Table 2 Typical weights for each species considered in this project, associated 3% thresholds and indicative weight ranges that may be possible for different deployment options based on previous licences issued by the Special Methods Technical Panel of the BTO Ringing Committee.

	Average weight (g)	Weight range (g)	3% threshold; average (range) (g)	Weight range of approved back mounted devices (g)	Weight range of approved tail mounted devices (g)	Weight range of approved leg mounted devices (g)
Gannet	~3000[1]	-	90	15	3 – 41	10
Herring Gull	971[2]	757 – 1260[2]	29 (23 - 38)	12 - 23	-	-
Great Black-backed Gull	1560[2]	1290 – 1920[2]	46 (39 - 57)	23 - 25	-	-
Kittiwake	368[2]	310 - 434[2]	11 (9 - 13)	2 - 16[3]	4	2.4
Guillemot	891[2]	770 - 1010[2]	26 (23 - 30)	8 - 16	-	2.0 - 3.3
Razorbill	613[2]	525 - 705[2]	18 (15 - 21)	10 - 16	2	1.5 - 2.7
Puffin	387[2]	325 - 450[2]	11 (9 - 14)	3.4 - 8	2	1.5 - 3

[1]Birds of the Western Palearctic Vol. 1 Ostrich to Ducks [2]BTO Birdfacts [3]This value exceeds the 3% threshold of the upper weight range for kittiwake, and is likely to relate to a previous 5% threshold. Such a device is unlikely to be licensed at present.

Other species-specific considerations include:

Gannet: The tag must not impede their ability to dive, so tail mounting is most common. It must be waterproof to 30m and capable of withstanding impact. Tail mounts are temporary, so it should be assumed that data collection will be short-term. Keeping feather waterproofing intact is essential.

Herring Gull: Feathers are weak, so devices taped to feathers do not last long. Consequently, harnesses are preferable. As recapture is very difficult, archival tags are not suitable.

Great Black-backed Gull: Feathers are weak so devices taped to feathers do not last long. Great black-backed gulls have been shown to not tolerate harnesses so this method is unlikely to be suitable for tag deployment. As recapture is very difficult, archival tags are not suitable. Recent trials of tags on great black-backed gulls, both in the UK and Canada suggest that there is a high likelihood of deleterious tag effects (Maynard et al., 2022, 2021).

Kittiwake: Kittiwake may have a high likelihood of device effects (e.g. Clewley et al., 2022), consequently, devices should be kept as light as possible to increase chances of representative data. There is clear evidence of potential device effects from harness-mounted devices (Clewley et al., 2022) and concern about potential device effects from glue-mounted devices (UKCEH & RSPB unpublished data). Tape-mounted devices attached to birds tails, or leg-mounted devices, are believed to be least problematic at present.

Guillemot: Keeping feather waterproofing intact and maintaining neutral buoyancy is essential. As Harnesses and glue-mounting do not allow for this, tesa tape mounts to the back are recommended. Device must be light weight, hydrodynamic and waterproof to 150m+.

Razorbill: Keeping feather waterproofing intact and maintaining neutral buoyancy is essential. As Harnesses and glue-mounting do not allow for this, tesa tape mounts to the back are recommended. Device must be light weight, hydrodynamic and waterproof to 150m+.

Puffin: Does not readily accept tags, and many back mounted devices have caused issues (e.g. Harris et al., 2012). Keeping devices to the minimum size possible is recommended. Small leg-mounted devices are recommended. Device must be light weight, hydrodynamic and waterproof to 70m+.

Data considerations

The study aims will play a key role in determining which type of tag is chosen. At a high level, there may be a choice between using a geolocator, or a GPS tag. Geolocators estimate a birds location based on light intensity, with daylength used to estimate latitude and the timing of dawn, dusk, and midday used to estimate longitude. They tend to be cheaper and lighter than GPS tags and can be mounted on a leg ring so are less likely to cause tag effects than heavier tags mounted on a bird’s body. However, the spatial and temporal resolution of the data are far lower than is possible from GPS tags, with errors typically in the region of

~40 km and fixes limited to 2 per day (Rakhimberdiev et al., 2016). Consequently, geolocators tend to be favoured for collecting data on the distribution of birds outside the breeding season, particularly for smaller species (e.g. Buckingham et al., 2021), whilst GPS tags, which may be restricted to shorter-term attachment methods, are used for assessing distribution during the breeding season (Thaxter et al., 2015). However, geolocators do not provide information on a bird's latitude during the equinox due to daylength being constant at all latitudes. They are most useful for providing information on long distance migrations and an approximate location in winter. They are not sufficiently precise to determine whether a bird is within an offshore wind farm or not. Platform Transmitting Terminal (PTT) are also capable of estimating position using the Doppler effect and polar-orbiting satellites. However, the triangulated positions are only accurate to within >500 m and can only be estimated a few times a day. Consequently, as they lack the spatial and temporal resolution of GPS tags, and the advantages in terms of size and cost of geolocators, they are not considered further here.

Both GPS tags and geolocators can record additional data, and can be deployed alongside other tag types (e.g. altimeters and time-depth recorders) to provide further insights into bird behaviour (Table 3). Of particular value in the context of assessing impacts of offshore wind farms on seabirds is the potential for GPS tags to record information on flight heights (Ross-Smith et al., 2016) and speeds (Masden et al., 2021). It is also useful to note that manufacturers are looking to integrate different tag types, with notable examples including geolocators with integrated time-depth recorders, and GPS tags with integrated altimeters, time-depth recorders and/or accelerometers.

The volumes of data collected by GPS tags can have important implications for battery life. Many tags now come equipped with solar panels in order to help prolong battery life. To maximise the value of this, it is important to consider attachment methodologies. If feathers or tape obscure the panels, this will impair the ability of the tags to recharge and is likely to have implications for battery life. Consequently, solar panels are unlikely to be an advantage for species such as gannets or auks, where tags are deployed using tape.

An additional means to prolong battery life is the potential to use geofences. These can be used to vary the rates at which data are collected based on the location of the bird. For example, these can be set to record at a lower rate, preserving battery life, when the bird is at its nest. Conversely, a higher sampling rate could be set for periods when a bird is in a wind farm and higher resolution data to capture the movements of the birds in response to turbines may be valuable.

Table 3 Device types and associated capabilities * indicates not available as standard on all tags

Device Type	**Possible Attachment Methods**	**Download type – Remote (R) or Archival (A)**	**XY Location**	**Date-Time**	**Instantaneous Speed**	**GPS Altitude**	**Air Pressure**	**Water pressure**	**Temperature**	**Triaxial acceleration**	**Magnetometry**	**Light intensity**	**Dive duration**	**Wet/dry or salt water immersion**	**Gyroscope**	**Sound**	**Imagery**	**Presence**
GPS/GSM (transmitted via Mobile phone network)	Harness, glue or Tesa tape to back. Tesa tape to tail.	R	✓	✓	✓*	✓	✓*	✓*	✓	✓*	✓*	✓*	✓*	✓*	✓*			
GPS/VHF or UHF	Harness, glue or Tesa tape to back. Tesa tape to tail.	R	✓	✓	✓*	✓	✓*	✓*	✓	✓*	✓*	✓*	✓*	✓*	✓*			
GPS	Back or tail mount	A	✓	✓				*✓	*✓	*✓		*✓		*✓				
Geolocator	Leg mount	A		✓				✓*	✓*			✓		✓*				
Accelerometer	Back or tail mount	R/R								✓								
Time-depth Recorder	Leg mount	A		✓				✓	✓			✓*	✓*	✓*				
Salt-water immersion	Leg mount	A												✓				
Camera	Back mount	A															✓	
Acoustic	Back mount	A														✓		
Altimeter	Back mount	A/R					✓											
PTT	Back mount	R	✓															
Passive Integrated Transponders (PIT)	Leg mount	R																✓

Additional tag considerations

Additional considerations in relation to tag types relate to data retrieval and cost. In the case of geolocators and some time depth recorder tags, the bird must be recaptured in order to retrieve the tag and the data it holds. However, for GPS tags, the remote download of data, either to a base station or via the mobile phone (GSM) network is possible. The use of remote download tags significantly increases the chances of data retrieval, which may otherwise be subject to factors including bird mortality or movements away from the breeding colony (e.g. due to breeding failure), restrictive weather conditions, the potential impacts of HPAI, or birds becoming more wary of fieldworkers, and therefore harder to catch. For these reasons, archival GPS tags are often retrieved well before the battery is exhausted, limiting the quantity of data which may be collected. Furthermore, as data can be retrieved without having to re-enter the breeding colony, the use of remote download tags can also reduce the overall disturbance to that colony.

Remote download tags do however bring additional challenges. Firstly, the power required to transmit the data when GPS is combined with other sensors such as accelerometers means that a larger battery is required than if an archival tag were used. This potentially limits the spatial and temporal resolution of the data collected and/or the species on which these tags can be deployed. The use of solar panels can alleviate these issues but may introduce secondary issues including limitations on the attachment methodology and the potential for increased device effects. Where data are transmitted over the GSM network, this will incur an additional fee due to the associated network charges. Whilst tags which transmit over the 2G and 3G networks may be cheaper, these are being phased out meaning that, particularly in more remote locations, coverage may be severely restricted. Consequently, despite the additional cost, tags which transmit over the 4G network are preferable. Where tags transmit to a base station, it is necessary to find a secure location for this base station, where it will not be at risk of theft, vandalism, or damage from environmental conditions (e.g. strong wind). Mobile base stations are available from many manufacturers, though these will incur additional costs in relation to staff time. Devices are also available which are capable of transmitting data through the “Internet of Things”. However, as this requires them to be close to other devices connected to this network, at present, this technology cannot be considered reliable in remote areas.

Further details of available tag types are given in Appendix 1.

Capture methodologies

Most methods to capture seabirds at the breeding sites have been long established and are covered under conventional methods on a BTO ringing permit. More details can be found in Bub (1991) and Davis (1981). The most likely methods to be used for the relevant species in the proposed study are outlined below. All images relate to fieldwork carried out under license.

Noose pole

Suitable species: Guillemot, Razorbill, Kittiwake, Gannet

For species that sit tight to the nest or ledge when approached, a noose pole is likely the most effective method to capture them (Figure 3). This consists of a long pole with a single nylon noose secured to the end which is slowly placed over the head of the target bird and constricts as it is pulled tight or the bird flies off. The ringer can then quickly guide the bird to the ground, where the same or a second person may be waiting, to get the bird under control and extract from the noose. The type of noose used is not self-tightening, i.e. relaxes when not under pressure, and birds are typically restrained by the noose for <20 seconds so this method does not cause any harm. Seabirds also have very strong necks compared to most birds allowing safe use of this method.

Telescopic fishing poles are very suitable as they are easy to transport, strong and flexible. Poles up to 12m in length may typically be used but become more difficult to handle at greater lengths. The positioning of the noose on a 90° angle on the end may be helpful when catching birds sitting further back on ledges.

Noose poles may be operated from above or below cliffs. If working from above, immediately close to the edge, it is recommended that personnel are trained and competent to secure an anchor point and work off a rope and harness. It both makes the catching safer to undertake and may increase the number of birds which can be accessed safely.

Figure 3 Capturing kittiwakes with a noose pole (Photograph: BTO)

Hook / Crook

Suitable species: Guillemot, Razorbill, Gannet

Various hooks may also be used in a similar manner to noose poles. These are typically shorter and with a fixed hook on the end of a suitable width for the target species to restrain them either by the leg or neck. Hooks are very simple and effective when used in colonies where you can approach birds nesting on level ground such as Gannets, or auks nesting in boulders.

Fleyg net

Suitable species: Guillemot, Razorbill (in flight)

Fleyg nets consist of a triangular net mounted on to a hand held pole, typically 2-3m in length, and can be very effective at some sites for catching birds in flight. These are often used to capture auks in dense nesting areas around cliff tops. Since birds are captured in flight, a disadvantage is that it is unclear where the nest sites of captured individuals are, which may be important for subsequent monitoring or recapture if required, or indeed whether they are active, breeding individuals.

Purse net

Suitable species: Guillemot, Razorbill, Puffins (in crevices/boulders/burrows)

Purse nets are not commonly used, and do require an additional SMTP license, but may be effective in some situations. These nets are secured over holes or burrows and entangle the bird as they arrive or leave. Typically more effective for burrow nesting species but may be used for boulder nesting auks of interest in this study.

Walk-in trap

Suitable species: Herring Gull, Great Black-backed Gull

A variety of designs of trap may be used and secured over the nest, including a passive circular design with a funnel entrance or a box (Potter trap) design with a door which closes once the bird enters the trap, either triggered directly by the bird or remotely by the ringer. Walk-in traps can be very effective as birds continue to incubate their eggs once inside the trap and are unaware they are caught until disturbed so multiple traps can be placed at once (Figure 4). Traps do not catch on every attempt though and timing and placement are important. Different designs can also easily be used in different habitats with different substrates, i.e. there are options to secure them on rock as well as grass (Figure 4).

If set correctly, there is an extremely low risk of damage to the eggs from the adults trying to escape before being extracted but it is also possible to temporarily replace the clutch with dummy eggs for the trapping period to ensure no damage is caused.

These traps have been regularly used for Herring Gull and while they can work for Great Black-backed Gulls, this species is typically much more wary of novel objects around the nest and the other methods described below may be more effective.

Figure 4 Examples of walk-in traps placed over gull nests (Photograph: BTO)

Spring trap/Bow net

Suitable species: Herring Gull, Great Black-backed Gull

Large spring traps or bow nets may also be used to catch gulls on the nest and consists of a spring-loaded net on a frame secured flat to the ground. Their placement is similar to walk-in traps, going directly over an active nest and waiting for the target bird to incubate. It is best to be actively triggered by the ringer to ensure it is safe as the frame of the trap moves with considerable force and has potential to cause injury.

Noose carpet

Suitable species: Herring Gull, Great Black-backed Gull

This method requires an additional SMTP license. Noose carpets consist of a section of wire mesh which is covered in numerous overlapping nylon nooses. Flat square sections or circular designs may be placed near or over nests, or any area birds are likely to walk through. The noose carpets need to be well secured and observed so a bird can be extracted as soon as it becomes entangled.

Figure 5 Example of a noose carpet placed over a gull nest (Photograph: BTO)

Single noose

Suitable species: Herring Gull, Great Black-backed Gull, Kittiwake

A single noose made of lightweight synthetic string may also be used to trap birds on the nest, this requires an additional SMTP license but is particularly useful in situations where trapping equipment needs to be discrete. This method has been used successfully for Great Black-backed Gulls in particular but also other gulls including Kittiwake. A single noose can be spread over the nest cup and pulled tight once the bird has settled, temporarily restraining it until it can be extracted. The single noose may be operated by hand or via a remote operated pull cord held under tension on a trigger pin. The latter option is beneficial as the capture is more rapid and effective but also more complicated due to the additional components that must be considered when setting.

Figure 6 Example of a single noose set on a gull nest (Photograph: BTO)

Whoosh/cannon net

Suitable species: Herring Gull, Great Black-backed Gull

These methods require an additional SMTP license. Both whoosh and cannon nets are widely used to capture birds on the ground and operate by launching a net over a target area either using bungees or projectiles fired from cannons with explosive black powder, respectively. Neither method is regularly used for seabirds in breeding areas but could be effective for gulls at loafing spots or at pre/post breeding aggregations on fields, pools or beaches etc.

Tag attachment techniques

The ethical considerations for those undertaking biologging studies and the importance of not unduly impacting a bird's welfare have been widely discussed (McMahon et al., 2011; Wilson & McMahon, 2006). Furthermore, any impact on a bird's welfare may also cause biases in the data collected, undermining study aims. The attachment of devices to birds may have direct impacts on an individual's health and/or its behaviour, potentially resulting in impacts on fitness, i.e. reproductive success and survival. Recent reviews have summarised potential impacts of bio-logging in a range of avian taxa (Barron et al., 2010; Bodey et al., 2018; Geen et al., 2019) and have highlighted the attachment method as an important factor that should be carefully considered. The attachment method should be suitable to both the device type used and the species.

Body harness

Body harnesses are regularly used for terrestrial species, especially raptors (Kenward, 1985), and more recently they have been used successfully on large gull species (Clewley et al., 2021) (Figure 7). They have the advantage that they allow year round or multiple year tracking of the same individual. The harnesses are usually constructed from a low abrasion Teflon ribbon material and recommended to be fit as a thoracic cross-strap design (Thaxter et al., 2014). Extensive trials were carried out on Herring and Lesser Black-backed Gulls across multiple sites and years and found no detectable differences in return rates or productivity for birds with and without harnesses (Clewley et al., 2021; Thaxter et al., 2016). The current recommendation in the UK is also to use a weak-link design where the harness is held together by a single component designed to break over time allowing the harness to detach from the bird without the need for recapture. The duration of deployment will depend on the weak-link material used and can vary from months to four years or more; details of harness design are reported in Clewley et al. (2021). A disadvantage of this method is in the increased handling time required to ensure a safe fit for long term attachment. Typical attachment times for experienced fieldworkers are 15-20 minutes. There are options to reduce fitting time, for example using a 4-point device housing designed to accommodate the weak-link harness design specifically, but it is considered that c.10 minutes will be the minimum for this method.

This design has also been trialled on other gull species including Kittiwake and Great Black-backed Gull in 2021. However, for both species it was deemed not suitable due to concerns about feather abrasion in Kittiwakes (Clewley et al., 2022) and increased rates of nest failure in Great Black-backed Gulls (Langlois et al. in review). It may be possible to modify the design or field methods for these species to enable safe use of harnesses, but that is still to be determined with further trials.

For diving species or those with rapid flight, such as auks, harnesses are not currently permitted in the UK over concerns of detrimental impacts caused by abrasion or drag.

Figure 7 A GPS tag deployed on a Herring Gull using a body harness (Photograph: BTO)

Leg-loop harness

Leg-loops are an alternative design of harness that is positioned over the top of each leg placing the device in the centre of the lower back of the bird (Figure 8). This position avoids feather abrasion at the base of the wings for rapid flying species and has lower risk of impacts such as entanglement. A leg-loop design was trialled on Lesser Black-backed Gulls but judged to be inferior to body harness options due to reduced performance of the device (if solar powered due to shading) and reduced attachment duration (Thaxter et al. 2014). A trial of leg-loop harnesses on Kittiwake found them not to be suitable due to concerns with abrasion (Clewley et al. 2022). However, there are an increasing number of other waterbird species being successfully tracked in the UK using leg-loop harnesses which are constructed from different materials including silastic (Le Rest et al., 2019) and this may still be a viable method for some seabirds, pending further trials and evaluation.

There is also a cost to using leg-loops in terms of additional handling time, albeit less so than body harnesses, to ensure that the tension and fit is correct to reduce the likelihood of impacts directly from the harness. Typical fitting times for experienced fieldworks may be c.

10-15 minutes although this may be reduced to less than 10 minutes if little to no size adjustment is required and pre-sized harnesses are used.

Figure 8 A PTT tag deployed on a kittiwake using a leg-loop harness (Photograph: BTO)

Glue-mounting

Devices may be attached to the back of an individual using glue, most commonly superglue (cyanoacrylate). Recently this method has been used successfully on a range of waterbirds to attach GPS devices (Green et al., 2019) with typical deployment durations from 2-3 weeks up to several months depending on the specific attachment protocol and stage of moult of the bird (Figure 9). Attachment time for this method takes c. 10 minutes to ensure the device is fitted correctly, which will help maximise attachment duration as poorly fitted devices are likely to induce extra preening and removal of the device by the bird.

An area of feathers are trimmed on the back during attachment, which may interrupt waterproofing if not covered adequately by the device and section of fabric on the device base used to form the attachment surface. Glue-mounting has been carried out for Kittiwake (Wischnewski et al. 2017). However more detailed studies comparing at-sea behaviour of birds tagged with glue-mounted and tape-mounted devices, and at-colony behaviour of tagged and control birds, showed small negative effects of glue-mounted device deployment (Bogdanova et al., 2021a, 2022). Devices of different size and with different positioning on the body were used among the methods so further trials would be needed to tease apart the effects attributable to device size/type and to attachment location and method.

It is generally not considered suitable to use glue-mounting for diving species due to the risk of reducing plumage waterproofing, although it this has been trialled on Goosander (BTO, unpublished data).

Figure 9 A GPS tag deployed on a kittiwake using glue mounting (Photograph: BTO)

Tape-mounting

The most suitable and commonly used method to attach devices to auks and Gannet is to tape-mount. Strong adhesive tape, often produced by Tesa (Hamburg, Germany), is used to secure the device to several feathers either on the back or central tail (Figure 10). This may be further reinforced with super glue or cable or similar ties or to help increase deployment duration. Tape-mounting is a short-term method with devices attached typically for several days up to a week before being shed following the failure of the tape. It does have the advantage of being suitable for diving species and very quick to attach with fitting times being typically c. 5 minutes or less.

Figure 10 GPS devices deployed on the back of a guillemot (left) and tail of a kittiwake (right) using Tesa tape. (Photograph: UKCEH)

Leg (ring) mount

Long-term deployment of devices is also possible by fitting to plastic leg rings (Figure 11). These may be secured to the ring with small cable ties and marine-grade epoxy resin glue and remain attached for several years or more. However, this is currently most suitable only for very light devices, such as geolocators, or those which don’t require a good solar recharging position. This method is very quick to deploy on birds, by just fitting an additional leg ring, and can be used on any of the species of interest in this study, but due to the limitations of suitable devices is restricted to collecting low spatial and temporal resolution location data. Leg mount methods are useful for deploying other biologging devices, such as time depth recorders. Additionally, devices fitted to leg rings are not typically capable of transmitting data and require that the individual is recaptured again to retrieve data. Hence there is an increased amount of fieldwork needed and some attrition of loggers as not all birds return or can be recaptured. Ability to recapture birds is likely to vary by species (e.g. Buckingham et al., 2021), consequently, the potential impact on individuals of carrying devices for longer than originally intended needs careful consideration. Assessments of device effects typically have low statistical power (Cleasby et al., 2021), and to our knowledge, no studies have addressed the fitness consequences of birds carrying leg-mounted devices for longer than intended. However, leg-mounted devices are typically very light, and are less likely to have device effects than other attachment methodologies (Bodey et al., 2018; Geen et al., 2019). Consequently, the fitness costs of carrying devices for longer than intended may be negligible, though this would benefit from further testing as additional data become available.

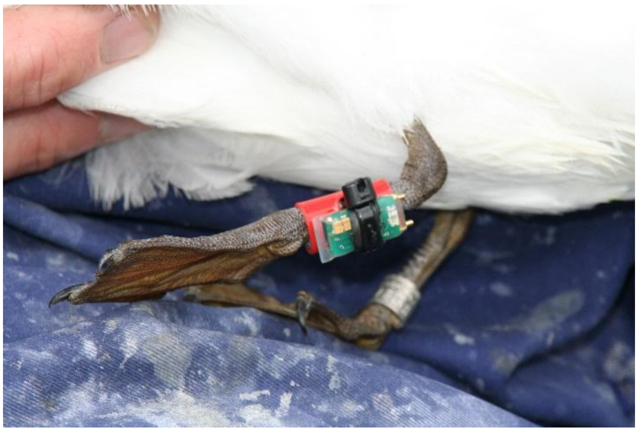


Figure 11 A geolocator deployed on leg ring (Photograph: UKCEH)

Existing and recent SMTP permissions for tagging focal species

Since 2010, 125 licences have been issued to deploy tags on gannets, kittiwakes, herring gulls, great black-backed gulls, guillemots, razorbills, and puffins in the UK and Ireland (Figure 12). Of these, 81 were still in place in 2022, though several have not deployed any devices in recent years. It should be noted that these studies may cover multiple sites across multiple years, and that several researchers may be covered to deploy devices under each licence. However, these studies provide a useful indication of the methods that have received approval in recent years and highlight where further innovation may be required. Whilst cancellation of a licence may reflect the ending of a project, it is important to note that in some instances, projects have been cancelled, or placed on hold, due to reported device effects. This is the case for trials of harness attachment methodologies for both kittiwake and great black-backed gull and glue deployments on kittiwakes.

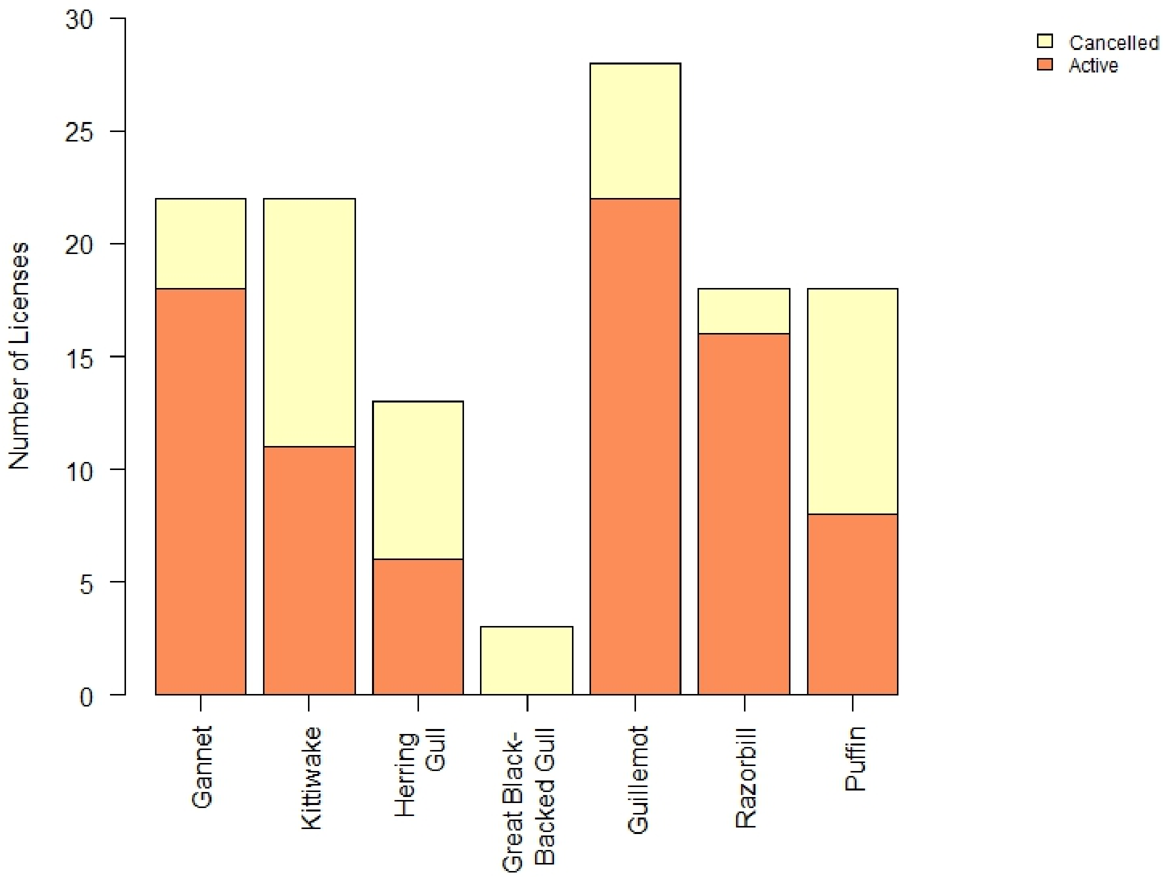


Figure 12 Number of projects for which SMTP permission has been granted to deploy devices on gannet, kittiwake, herring gull, great black-backed gull, guillemot, razorbill, and puffin since 2010, and the status of those projects

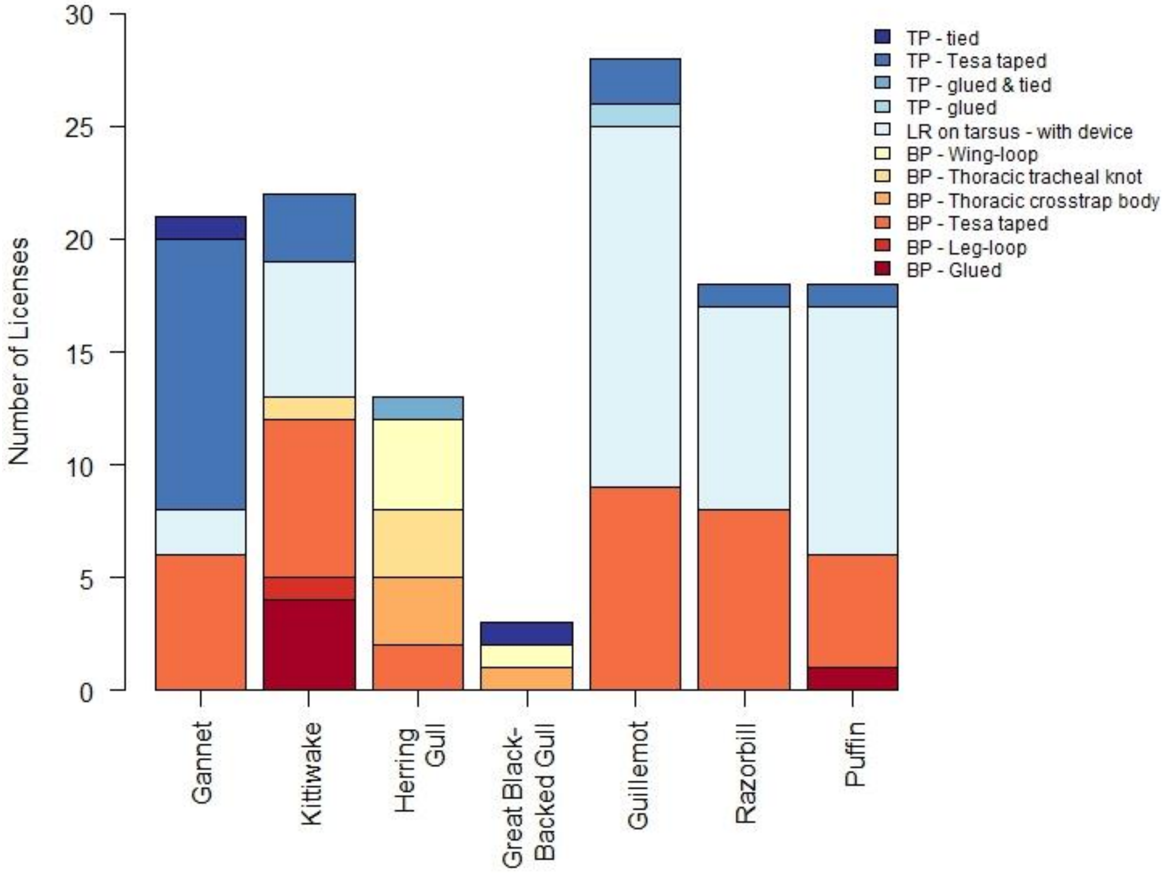


Figure 13 Number of projects licensed by the Special Methods Technical Panel to deploy devices on Gannet, Kittiwake, Herring Gull, Great-black-backed Gull, Guillemot, Razorbill, and Puffin since 2010, broken down by method, including Tailpack (TP), Leg-ring (LR) and Backpack (BP).

The most widely used approach has involved devices, such as geolocators or time-depth recorders, mounted on leg-rings (Figure 13). These devices provide information on behaviour and approximate location, both during the breeding and non-breeding seasons (Table 3). However, larger GPS devices are necessary for finer scale location data, such as foraging movements during the breeding season (Table 3). These have been deployed using either backpacks or tailpacks, and secured using harnesses, tape or glue (Figure 13).

With the exception of gannet (Figure 13), the greatest number of licenses for deploying GPS devices on the focal species have involved back-mounted devices (though note that this does not necessarily relate to the total number of individuals from each species). For kittiwakes and auks, the most widely licensed approach has been devices mounted on birds' backs using Tesa tape, though for kittiwakes, glue mounting has also been used.

Trials of thoracic tracheal knot backpack harnesses for kittiwakes and great black-backed gulls have been discontinued due to reported negative effects. For kittiwake, negative device effects were also reported when using a leg-loop backpack harness, through these were less severe than the reported effects of the thoracic tracheal knot harness, leading to suggestions that a modification of this design may be suitable (Clewley et al., 2022). A study using tesa tape backpack mounted devices in puffins has also been placed on hold whilst the SMTP consider evidence from associated monitoring studies.

Sample size analysis

GPS

Methods

The ability to determine a species' home range in relation to its breeding colony will be linked to both the number of birds which can be tracked, and the duration of any deployments. Several approaches have been developed in order to make inferences about the power of tracking datasets to quantify species home ranges (Beal et al., 2023; Soanes et al., 2013; Thaxter et al., 2017). We draw from the methods developed by Soanes et al. (2013) and (Thaxter et al. (2017) to make inferences about the benefits of prioritising a greater number of tag deployments (e.g. by using cheaper tags often with short term attachments) or longer term deployments (e.g. by using tags with solar panels to recharge batteries, which are often more expensive and require longer term attachment methods) in relation to defining a species home range.

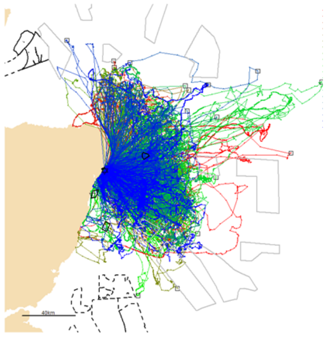
We considered four datasets in this analysis (Table 4). There were discrepancies between datasets due to differences in the technology and methodologies used. Three of the studies used IgotU tags, which require recapture of the bird to download data, while the fourth used UvA tags, which allow remote download, meaning tags remain on individuals for a longer period of time, giving more trips per individual (Table 4). In contrast, whilst datasets from IgotU tags had fewer trips per individual, tags were deployed on a greater number of birds, helping to increase the sample size. We standardised methodology as much as possible to allow for a fair comparison of results between species. Following Soanes et al. (2013), and in contrast to Thaxter et al. (2017), we use trips as the basis of our analysis, rather than days, given the shorter deployments of the tags considered here. Consequently, for consistency, we use number of trips for all datasets. All data analysis and processing was done in R 4.2.0 (R Core Team, 2022), and the analytical process followed is set out in Figure 14.

Table 4 Details of the four datasets used for this report, all data were collected during the chick-rearing period

Species	Colony	Device	Year/years	Number of birds	Number of Fixes	Number of Trips	Fix Rate
Kittiwake	Whinnyfold	UvA	2021	20	223172	1047	10 min/10 sec
Guillemot	Isle of May	IgotU	2010, 2012, 2013, 2014	80	131807	241	2 min
Razorbill	Isle of May	IgotU	2010, 2012, 2013, 2015	40	80309	192	2 min
Gannet	Bass Rock	IgotU	2015, 2016, 2018	50	457707	535	2 min

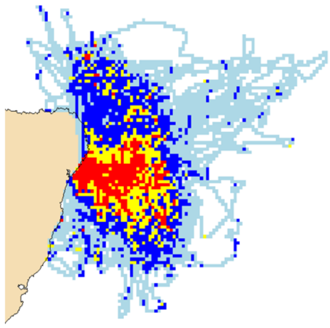
Processing

- Import data & summarise
- Clean data & plot tracks
- Remove erroneous tracks
- Record basic summary statistics



Analysis 1

- Create time in area grid
- Generate starting samples by identifying *X* birds which have a minimum of *Y trips*
- Core sample is the number of birds where *Y* is the median number of trips
- Upper and lower samples reflect *Y* is equal to upper and lower 95% CIs respectively



Analysis 2

- Bootstrap resample each of core, upper and lower samples,
- Attempt to fit one of six curves to each bootstrap sample, following Thaxter et al. (2017)
- Assess fit of each curve to each bootstrap sample using AIC
- For each bootstrap sample, back-transform model to estimate number of birds required for 95% occupancy
- For core, lower and upper samples, extract the number of birds required to estimate 95% occupancy in 25, 50 and 75% of bootstrap iterations

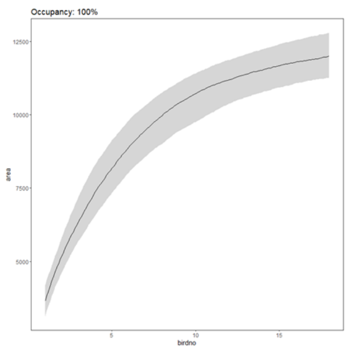


Figure 14 Schematic diagram of the method used to process and analyse data from different species to assess the sample size required to characterise area use of the population from which seabirds were tracked

Data processing

To identify trips, and exclude tracks restricted to movements around the colony, we defined a 1000m buffer around the centre of the tagging location. Drawing from previous analyses, sequential trips were identified when an individual left and re-entered this buffer (Figure 14). Only complete trips, where birds re-entered this buffer were included in the subsequent analysis. Once trips were assigned, datasets were examined for erroneous positions and trips by visual assessment of plots, and any erroneous positions were removed.

Analysis

Given that we needed to use an iterative sampling of a number of birds for a number of set trips, each bird has to have the same number of trips, to control for bias in results by individual bird behaviour (Soanes et al., 2013; Thaxter et al., 2017). We followed Thaxter et al. (2017) by defining an initial sample size for each dataset, employing a core sample (median birds, median trips), alongside a lower sample (fewer birds, more trips) and an upper sample (more birds, fewer trips) (Figure 14). All initially defined sample sizes can be found in Table 5.

Table 5 Starting sample sizes for respective datasets

Species	Colony	Sample	No birds	No trips
Kittiwake	Whinnyfold	Upper	20	26
Kittiwake	Whinnyfold	Core	18	30
Kittiwake	Whinnyfold	Lower	16	35
Gannet	Bass Rock	Upper	51	3
Gannet	Bass Rock	Core	37	6
Gannet	Bass Rock	Lower	27	9
Razorbill	Isle of May	Upper	36	3
Razorbill	Isle of May	Core	29	4
Razorbill	Isle of May	Lower	26	5
Guillemot	Isle of May	Upper	64	3
Guillemot	Isle of May	Core	49	4
Guillemot	Isle of May	Lower	26	5

Using a bootstrapping approach, we investigated the relationship between cumulatively increasing number of birds or trips and area used (km^2). For each bootstrap iteration, the algorithm selected a sample of birds providing the desired number of trips needed. The algorithm then sequentially added birds to the sample to yield a matrix of time spent in each 2 km^2 square each day, and then cumulatively summed the time for each square across days. We then ordered squares by the summed time spent in them (from greatest to least) such that the minimum number of squares needed to produce the desired occupancy levels could be calculated. We repeated this process for all birds sequentially added to the bootstrap for the given starting sample. For a desired sample of birds, occasionally more individuals were available than the number required because birds sometimes had the same duration of data available; in those instances, the algorithm randomly selected the desired number of birds from all those with available data. Because of computing time and the number of samples investigated, we limited analysis of each dataset to 1,000 bootstraps (Bogdanova et al., 2014). We used non-linear modelling to fit relationships between area use and the cumulative number of birds in each bootstrap. As with Thaxter et al., (2017) we considered six candidate models, with the most parsimonious for each bootstrap selected using Akaike's Information Criterion (AIC). Models where ΔAIC </= 2 were considered to be competitive. Using the best-fitting bird-area curve for each bootstrap, we estimated the area use of the populations together with the back-transformed number of birds needed to describe 95% estimated area use of the population (Soanes et al., 2013).

For respective populations, data for colony size was obtained using the Seabird Monitoring Programme database. For Bass Rock, we used the closest estimate which was from 2014. For the different species at Isle of May where multiple years of data were used, we took the average colony size during the years in which data was collected. For all combinations of increasing numbers of days and birds, we fitted curves. Box-and-whisker analysis was then used to assess the variance of back-transformed predictions of the number of birds needed (Borger et al., 2006). Where the number of birds included in the starting sample fell within or exceeded the interquartile range of the predicted number of birds, that number was interpreted as a minimum sufficient sample size to characterize area usage.

Results

Kittiwake

Data were collected from 20 GPS tagged birds at Whinnyfold in 2021. Tags remained attached to birds for 18 – 47 days, collecting data on 26 – 91 trips (Figure 15). The data were then used to create starting grids for the upper, core and lower starting samples (Table 5, Figure 16) with which to generate bootstrapped samples of the relationship between sample size and area usage. The resulting analyses suggested that a sample of 41 – 53 tagged birds are required for characterisation of area usage based on the upper IQR (Figure 17; Table 6).

Figure 15 Tracks collected from 20 GPS tagged kittiwakes at Whinnyfold in 2021, lines indicate individual birds and proposed (grey lines), consented (broken black lines) and built (solid black lines) offshore wind farms are shown.

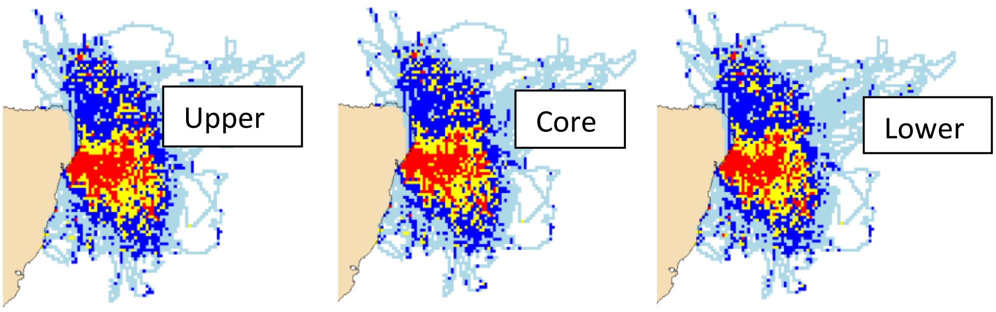


Figure 16 Upper, Core and Lower starting samples for analysis colours indicate 50% (red), 75% (yellow), 90% (dark blue) and 95% (light blue) area usage of tagged kittiwakes from Whinnyfold.

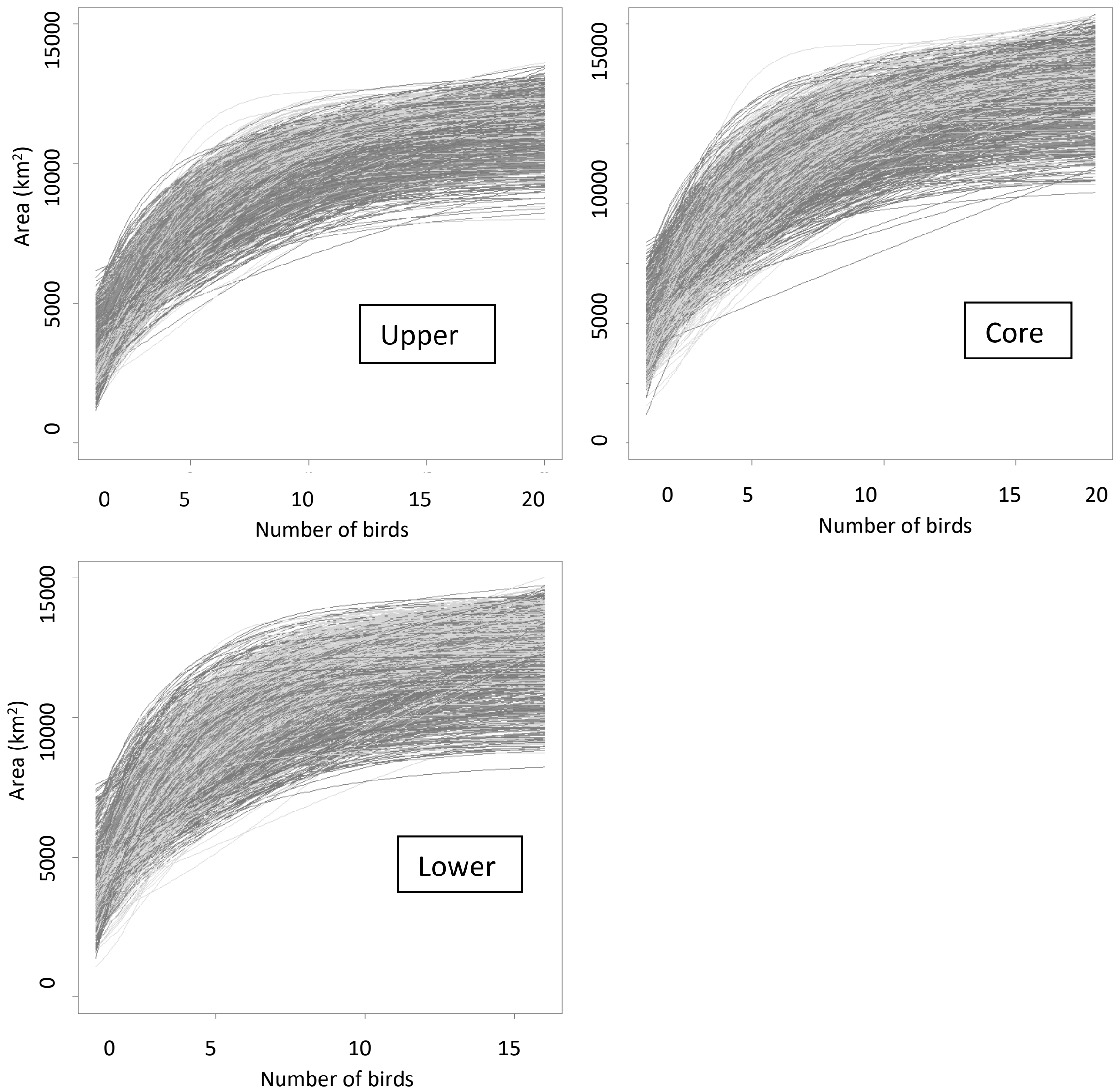


Figure 17 Bootstrap samples of the relationship between area use (based on 100% occupancy) and the number of kittiwakes tracked, based on upper (20 birds for 26 trips), core (18 birds for 30 trips) and lower (16 birds for 35 trips) starting samples

Table 6 Median and Inter-quartile ranges of number of kittiwakesrequired to characterize area usage using the upper, core and lower starting samples.

	Lower IQR	Median	Upper IQR
Upper	13	25	53
Core	11	21	47
Lower	9	17	41

Gannet

Data were collected from 50 GPS tagged birds at the Bass Rock between 2015 and 2018. Tags remained attached to birds for 3 – 31 days, collecting data on 2 – 34 trips (Figure 18). The data were then used to create starting grids for the upper, core and lower starting samples (Table 5, Figure 19) with which to generate bootstrapped samples of the relationship between sample size and area usage. The resulting analyses suggested that a sample of 119 – 261 tagged birds are required to provide characterization of area usage (Figure 20; Table 7).

Figure 18 Tracks collected from 50 GPS tagged gannets at the Bass Rock between 2015 and 2018, lines indicate individual birds and proposed (grey lines), consented (broken black lines) and built (solid black lines) offshore wind farms are shown.

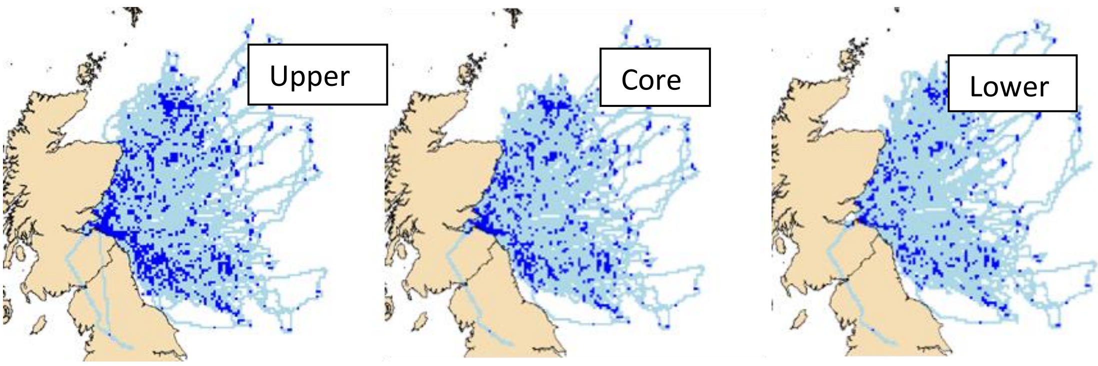


Figure 19 Upper, Core and Lower starting samples for analysis colours indicate 90% (dark blue) and 95% (light blue) area usage of tagged gannets at the bass rock.

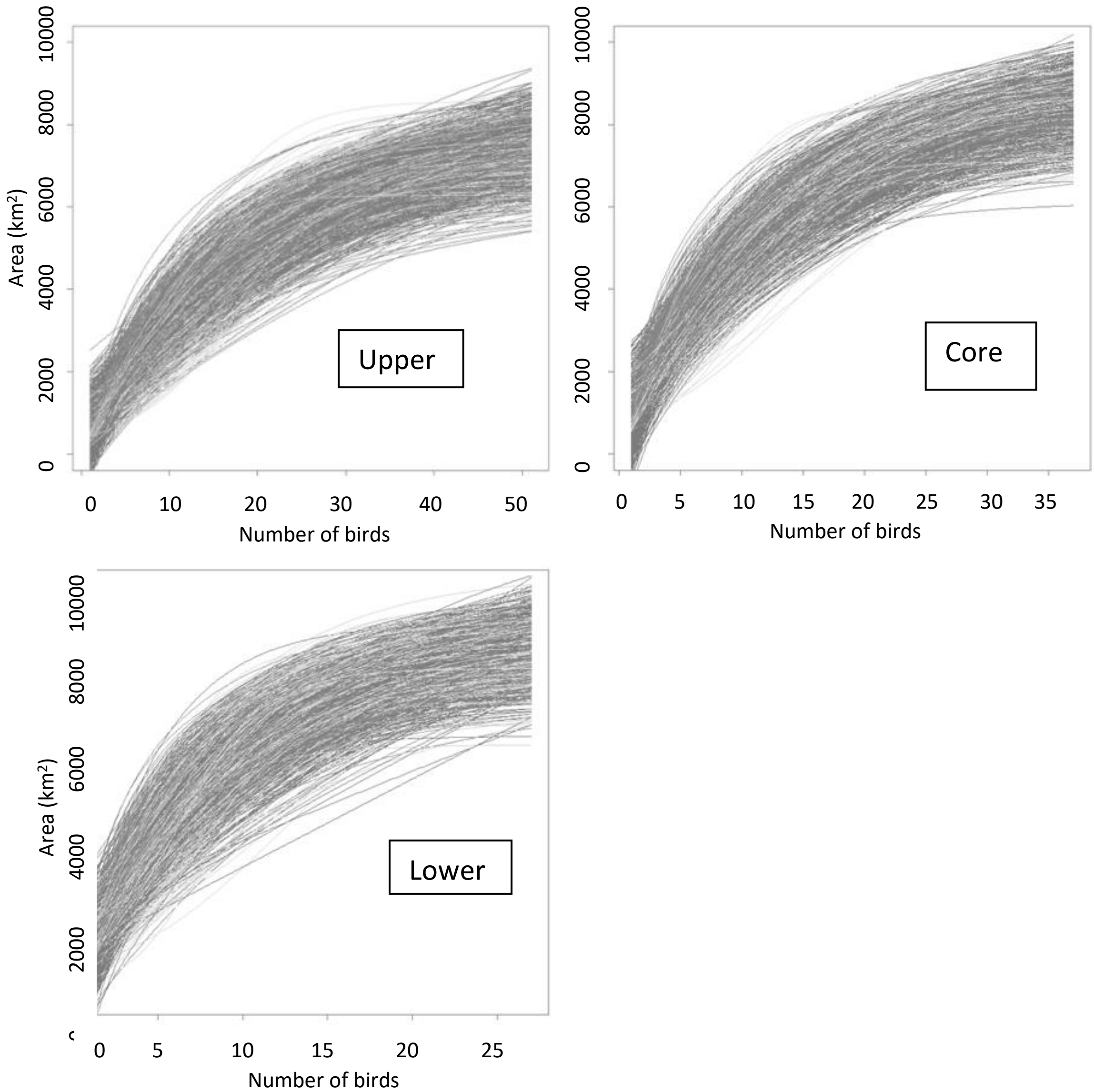


Figure 20 Bootstrap samples of the relationship between area use (based on 100% occupancy) and the number of gannet, based on upper (51 birds for 3 trips), core (37 birds for 6 trips) and lower (27 birds for 9 trips) starting samples

Table 7 Median and Inter-quartile ranges of number of gannets required to characterize area usage using the upper, core and lower starting samples.

	Lower IQR	Median	Upper IQR
Upper	50	86	261
Core	33	51	162
Lower	22	34	119

Guillemot

Data were collected from 80 GPS tagged birds on the Isle of May between 2010 and 2014. Tags remained attached to birds for 2 – 5 days, collecting data on 2 – 9 trips (Figure 21). The data were then used to create starting grids for the upper, core and lower starting samples (Figure 22) with which to generate bootstrapped samples of the relationship between sample size and area usage. The resulting analyses suggested that a sample of 102 – 138 tagged birds are required to provide characterization of area usage (Figure 23; Table 8).

Figure 21 Tracks collected from 80 GPS tagged guillemots at the Isle of May between 2010 and 2014, lines indicate individual birds and proposed (grey lines), consented (broken black lines) and built (solid black lines) offshore wind farms are shown.

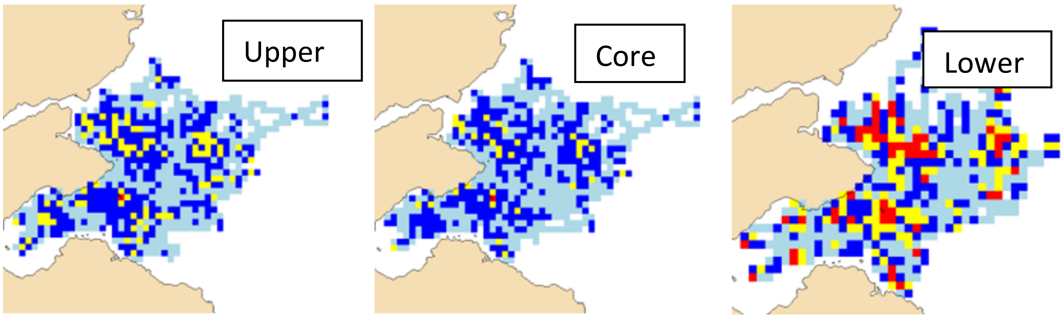


Figure 22 Upper, Core and Lower starting samples for analysis colours indicate 50% (red), 75% (yellow), 90% (dark blue) and 95% (light blue) area usage of tagged guillemots at the Isle of May.

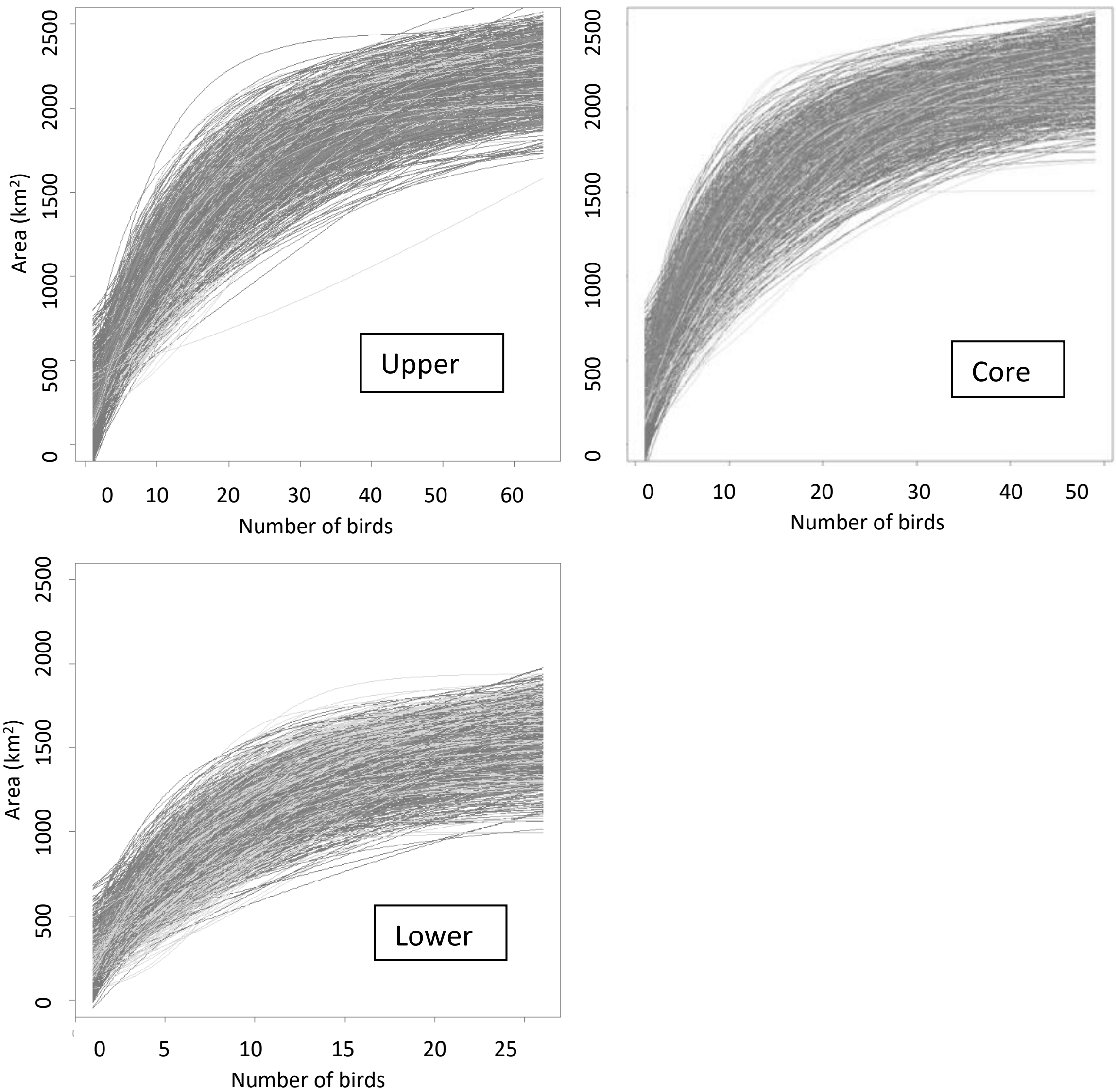


Figure 23 Bootstrap samples of the relationship between area use (based on 100% occupancy) and the number of guillemots, based on upper (64 birds for 3 trips), core (49 birds for 4 trips) and lower (26 birds for 5 trips) starting samples, each line indicates an individual bootstrap sample.

Table 8 Median and Inter-quartile ranges of number of guillemots required to characterize area usage using the upper, core and lower starting samples.

	Lower IQR	Median	Upper IQR
Upper	28	45	138
Core	22	36	114
Lower	19	33	102

Razorbill

Data were collected from 40 GPS tagged birds on the Isle of May between 2010 and 2015. Tags remained attached to birds for 2 – 9 days, collecting data on 2 – 15 trips (Figure 24). The data were then used to create starting grids for the upper, core and lower starting samples (Figure 25) with which to generate bootstrapped samples of the relationship between sample size and area usage. The resulting analyses suggested that a sample of 115 – 252 tagged birds are required to provide characterization of area usage (Figure 26; Table 9).

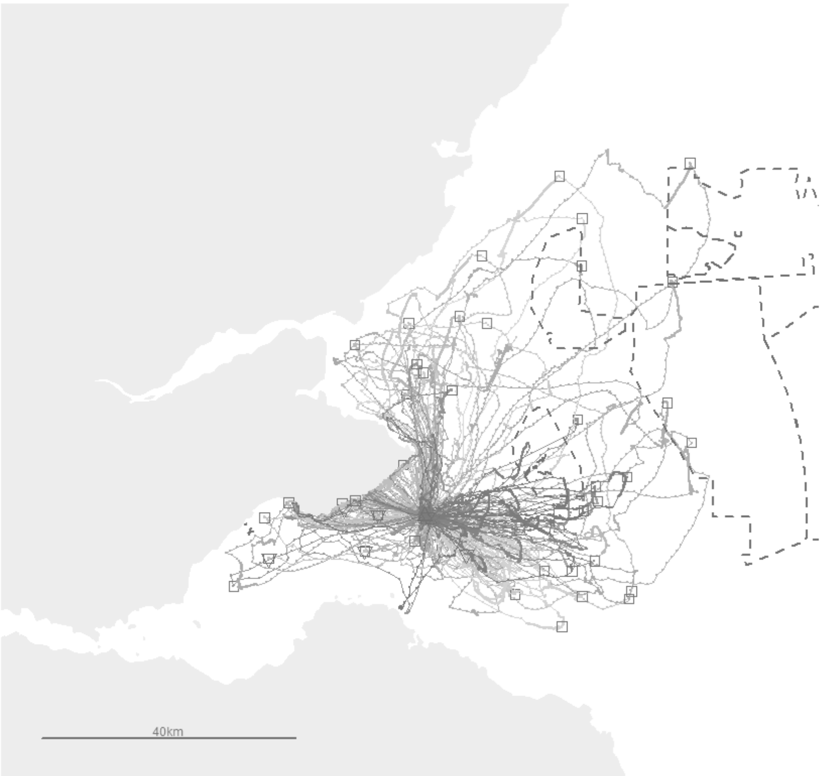


Figure 24 Tracks collected from 40 GPS tagged razorbills at the Isle of May between 2010 and 2015, lines indicate individual birds and proposed (grey lines), consented (broken black lines) and built (solid black lines) offshore wind farms are shown.

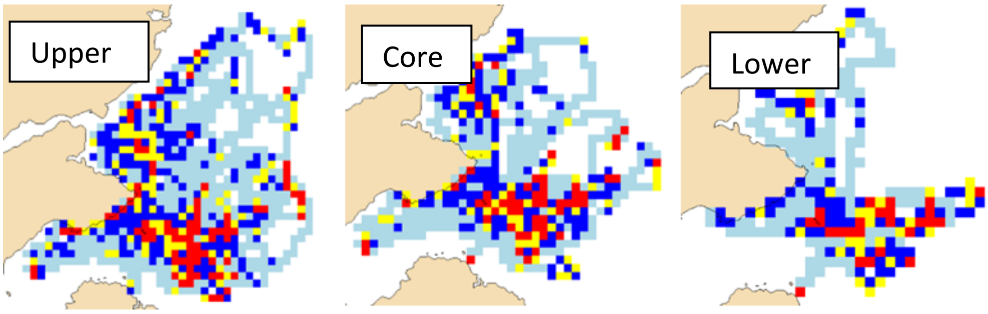


Figure 25 Upper, Core and Lower starting samples for analysis colours indicate 50% (red), 75% (yellow), 90% (dark blue) and 95% (light blue) area usage of tagged razorbills at the Isle of May.

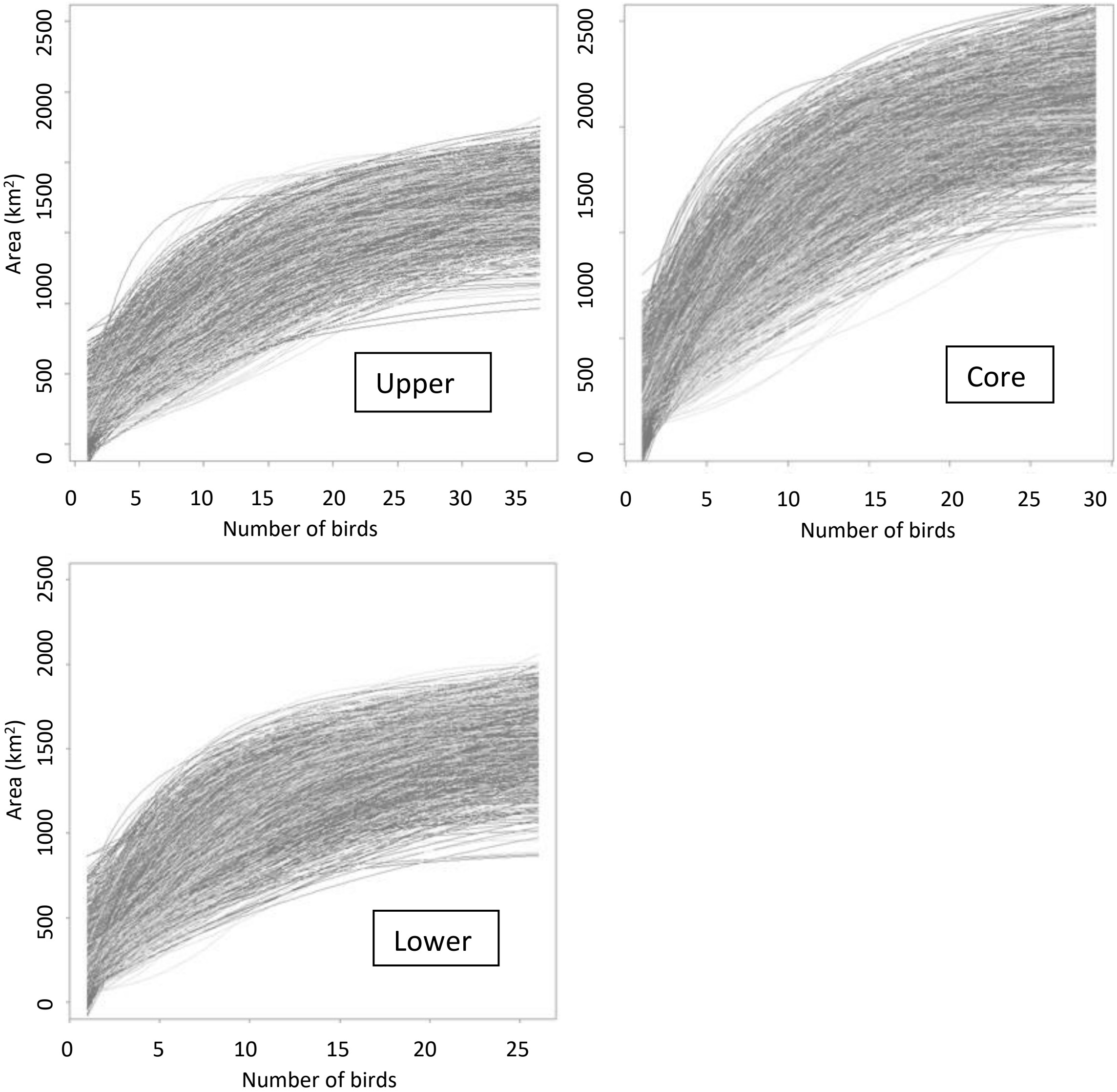


Figure 26 Bootstrap samples of the relationship between area use (based on 100% occupancy) and the number of razorbills, based on upper (36 birds for 3 trips), core (29 birds for 4 trips) and lower (26 birds for 5 trips) starting samples.

Table 9 Median and Inter-quartile ranges of number of razorbills required to characterize area usage using the upper, core and lower starting samples.

	Lower IQR	Median	Upper IQR
Upper	53	93	252
Core	36	55	153
Lower	20	37	115

Key findings

The power to characterise species' home ranges is influenced by both the number of birds tracked, and the duration of that tracking and/or the total number of complete tracks recorded. The longer the duration of the tracking and the more trips recorded per bird, the greater the power to characterize a species' home range. This has implications for the types of tags and attachment methods used. Where shorter term attachment methods (e.g. tesa tape) or GPS archival tags that must be retrieved are used, a greater number of birds must be tagged. However, in general a lower number of birds tracked for a longer duration (i.e. the lower samples in tables 7,8 and 9) had a greater power to quantify home ranges than was the case when a greater number of birds were tracked over a shorter time period (i.e. the upper samples in tables 7, 8 and 9). The analyses suggest that for the shortest deployment durations, in excess of 100 tags may be needed to adequately characterize population home ranges (i.e. the upper IQR estimates in tables 7, 8 and 9), far greater than can feasibly be deployed at a single colony in a single year. However, recent analysis has suggested that data can be combined across multiple years, and ensuring data are collected from a sufficient number of individuals is more important than ensuring data are collected in a single year (Beal et al., 2023).

Geolocators

Methods

To test whether we can determine the minimum sample size of individuals required to estimate the core areas used by common guillemots and razorbills during the non-breeding season, we used existing geolocation data from three major colonies along the east coast of Scotland (East Caithness Cliffs SPA, Buchan Ness to Collieston Coast SPA and Isle of May National Nature Reserve, within the Forth islands SPA) in two years (2017-18 and 2018-19). The data were collected as part of Hywind Scotland offshore wind farm's Ornithological Monitoring Programme and the SEATRACK project, in order to quantify the non-breeding distribution of these auk species considered to be highly vulnerable to displacement and barrier effects from offshore wind developments (Bogdanova et al., 2021b).

In total, 190 geolocators were deployed in 2017 and 193 in 2018, of which 96 and 83, respectively, were retrieved and successfully downloaded (representing 50% and 43% success rate). Sample sizes of deployments per colony and species are shown in Table 10. Retrieval rates for guillemots were higher than those for razorbills as the nesting locations favoured by razorbills, in crevices or on boulder beaches, were more challenging to capture birds in than the open ledges favoured by guillemots (Buckingham et al., 2021).

Table 10 Sample size of deployed and successfully downloaded geolocators for each species and colony. Note that the sample of successful retrievals in 2019 includes both loggers deployed in 2018 and loggers deployed in 2017 with data over two years.

Species and colony	2017 deployed	2018 Successful download	2018 deployed	2019 Successful download
a) Guillemot				
East Caithness	40	21	40	25
Buchan Ness to Collieston Coast	40	28	40	26
Isle of May	30	16	34	22
b) Razorbill				
East Caithness	30	15	30	7
Buchan Ness to Collieston Coast	20	5	19	8
Isle of May	30	11	30	11

The geolocation data were processed in R (version 3.6.1, R development core team2019). We used package GeoLight (Lisovski & Hahn, 2012) to convert light readings to twilight events using the threshold method (Ekstrom, 2004; Hill, 1994). We then used package probGLS (Merkel et al., 2016) to compute locations from the twilight events. This method incorporates remotely-sensed environmental data (such as sea surface temperature - SST) with light, activity and temperature recorded by the geolocator and involves an iterative forward step selection where each possible position is weighted using a set of parameters based on the species biology/behaviour (travel speed) and Sea Surface Temperature (SST). This results in reduction in the generally large location error associated with this type of logger, particularly during the equinox periods when day length is equal across all latitudes and hence light data alone cannot be used to reliably derive locations (Halpin et al., 2021; Merkel et al., 2016). The final locational dataset was subset to include only data during the non-breeding season (August to March in each year).

Utilisation distribution (UD) was determined for individual guillemots and razorbills from each colony by calculating the kernel density of their locations at sea. Locations were projected in Lambert azimuthal equal-area projection and kernel density was calculated in package adehabitatHR (Calenge, 2006), using a smoothing parameter *h* identified with the least-squares cross validation (LSCV) method (Worton, 1989). The 50% UD contours were extracted in adehabitatHR and used to define core areas used at sea.

To establish whether the sample size of tracked individuals was adequate to estimate the core wintering areas used by each population of each species during the non-breeding season, we examined the relationship between size of core areas and number of individuals using a resampling procedure. This procedure involved using each individual's core area (50% UD contour) and calculating the total cumulative area for each sample size of birds ranging from 1 to n (where n denotes the total number of birds for which we had data) 1,000 times, by choosing birds randomly without replacement (Manly, 2009). The distribution of these areas across the 1,000 resampling rounds was used to quantify the typical core area used for a given sample size of birds. The minimum adequate sample size for a given dataset (species-colony-year combination) is reached when the increase in median area with sample size levels off, suggesting that further addition of individuals would not result in a substantial increase in the size of the core population distribution (Soanes et al. 2013).

Results

Guillemot

East Caithness

In guillemots from East Caithness, the resampling procedure indicated a non-linear increase in the size of core areas used in each year with increasing sample size of birds (Fig. 27a, b). In both winter seasons for which we had data (2017-2018 and 2018-19), the increment in cumulative area size was larger with sample size of up to 6-7 birds, after which it was less than 5% with each additional bird (Fig. 27c, d). In 2017-18, randomized samples of 5 and 10 birds covered 51% and 74% of the area identified using all study birds, respectively (Fig. 27c). The corresponding figures for 2018-19 were 45% and 67%.

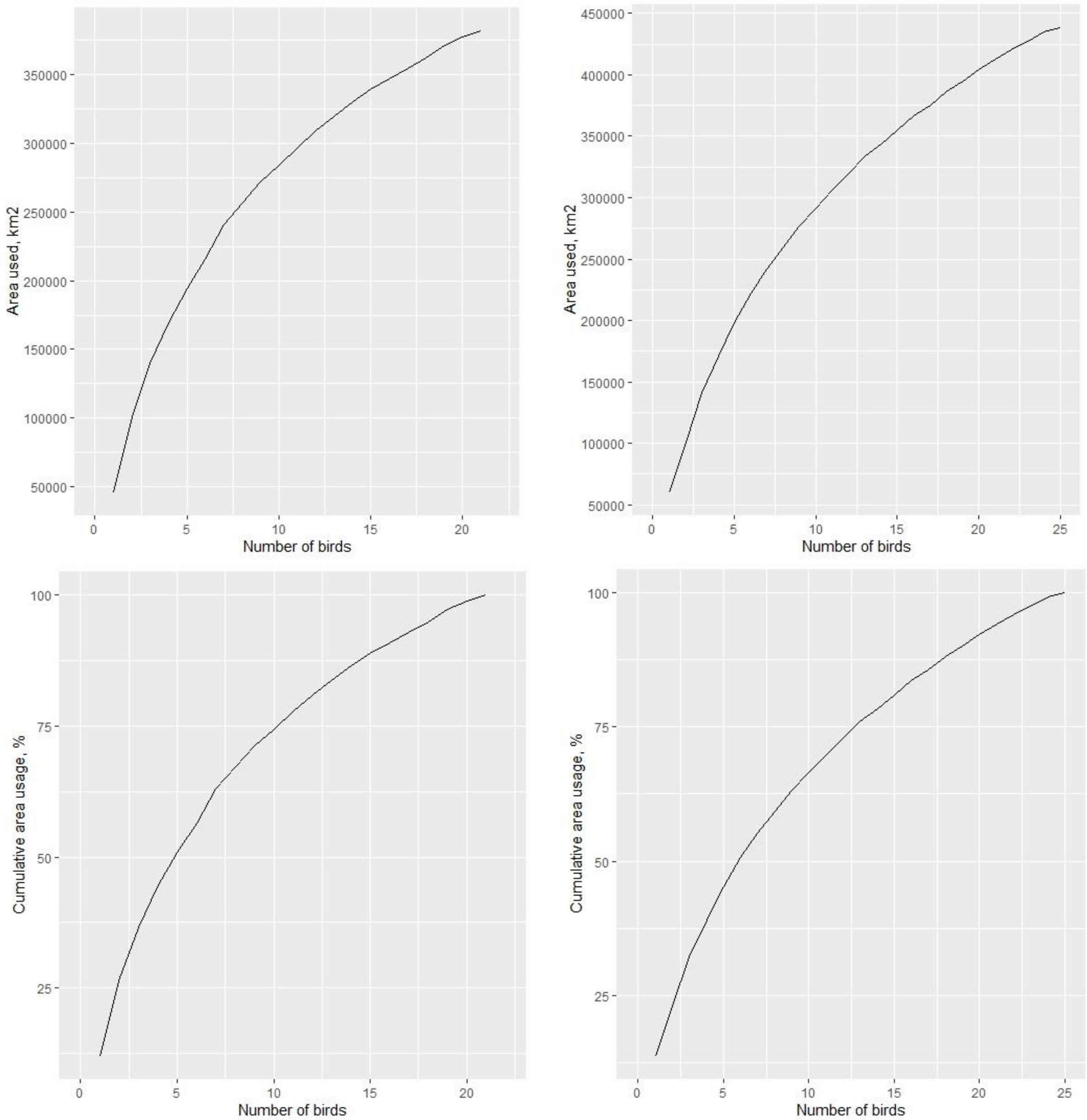


Figure 27 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in guillemots from East Caithness in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the

population in 2017-18; ; d) cumulative percentage of area used by the population in 2018-19.

Buchan Ness to Collieston Coast

In guillemots from Buchan Ness to Collieston Coast, a non-linear increase in the size of core areas with increasing sample size of birds was apparent (Fig. 28a, b). In both years, the increment in cumulative area size was larger with sample size of up to 5-6 birds, after which it was less than 5% with each additional bird (Fig. 28c, d). In 2017-18, randomized samples of 5 and 10 birds covered 43% and 62% of the area identified using all study birds, respectively, whereas in 2018-19 the corresponding values were 50% and 71%.

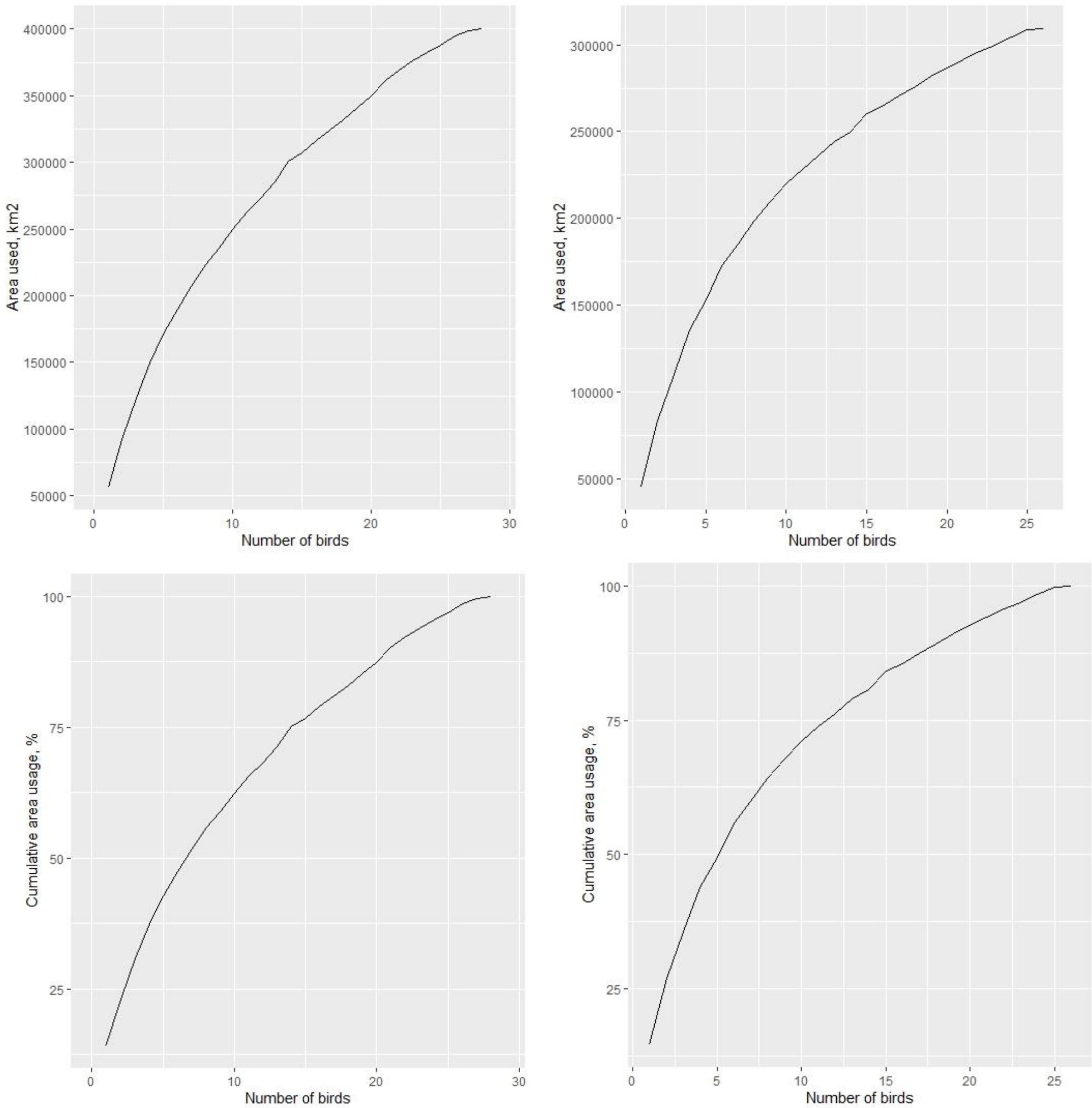


Figure 28 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in guillemots from Buchan Ness to Collieston Coast in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the population in 2017-18; d) cumulative percentage of area used by the population in 2018-19.

Isle of May

Isle of May guillemots showed a relatively gradual increase in size of core areas with increasing sample size of birds (Fig. 30a, b). In the 2017-2018 winter, when the sample size of tracked birds was smaller than in 2018-19 and at the other two colonies (n=16), the cumulative curve did not appear to level off (Fig. 30c). In 2018-2019, the increment in cumulative area size was slightly larger with sample size up to around 6 birds, after which it was less than 5% with each additional bird (Fig. 30d). Randomized samples of 5 and 10 birds covered 47% and 69% of the area identified using all study birds, respectively.

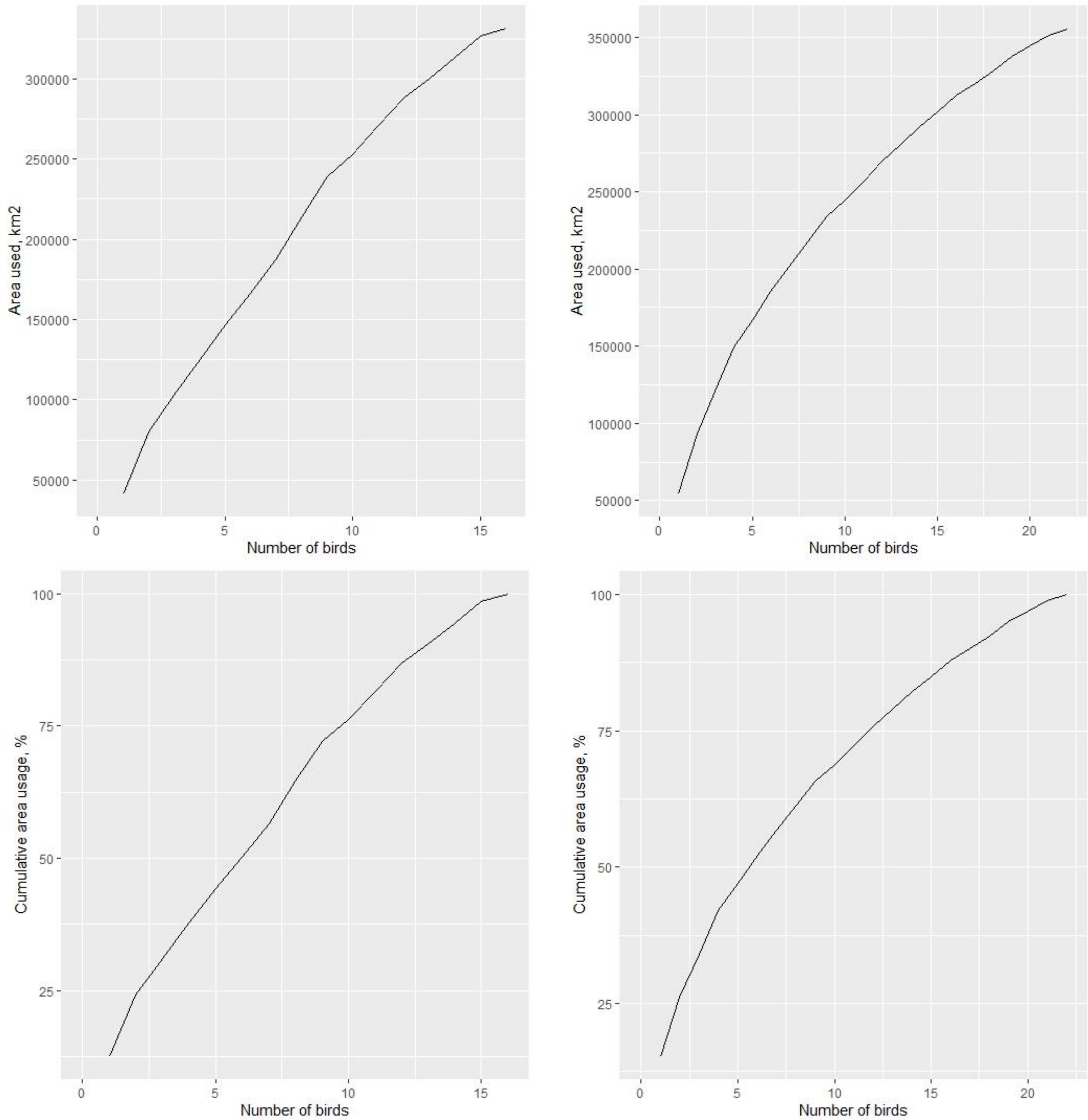


Figure 30 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in guillemots from Isle of May in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the population in 2017-18; d) cumulative percentage of area used by the population in 2018-19.

Razorbill

East Caithness

The increase in size of core areas with increasing sample size of individuals for East Caithness razorbills in 2017-18 and 2018-19 is shown on Fig. 31a and b. In 2017-2018, the increment in cumulative area size was larger with sample size up to 8 birds, after which it was less than 5% with each additional bird (Fig. 31c). Randomized samples of 5 and 10 birds covered 60% and 85% of the area identified using all study birds, respectively. In 2018-2019, when the sample size of tracked individuals was small (n=7), the cumulative curve did not approach a plateau (Fig. 31d).

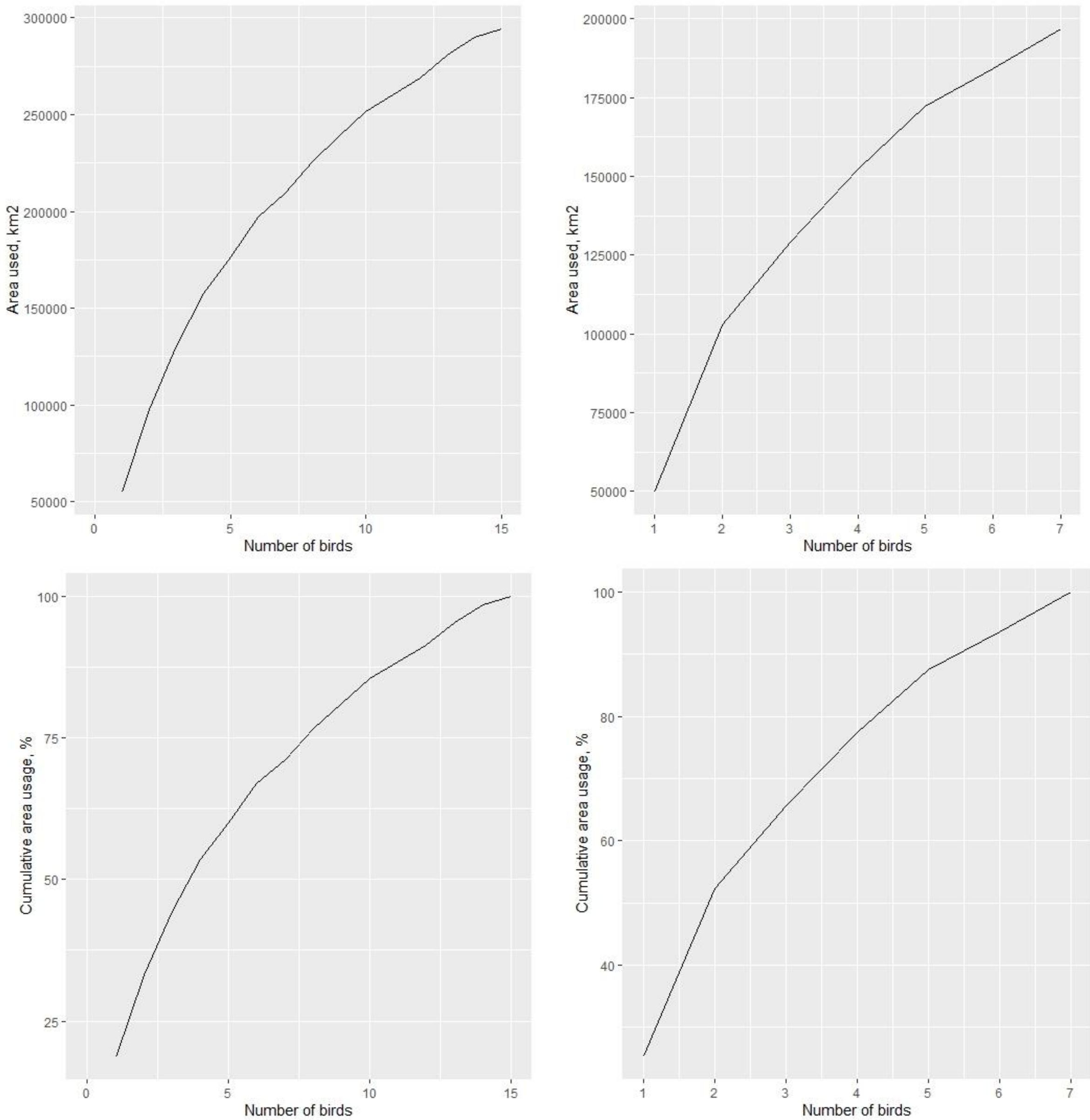


Figure 31 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in razorbills from East Caithness in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the population in 2017-18; d) cumulative percentage of area used by the population in 2018-19.

Buchan Ness to Collieston Coast

In 2017-2018, only five loggers were retrieved from razorbills at Buchan Ness to Collieston Coast. A gradual increase in the size of core areas with increasing number of individuals was observed (Fig. 32a) but, unsurprisingly, the cumulative curve did not level off given the small sample size (Fig. 32c). A similar result was obtained for 2018-2019, again reflecting the relatively small sample size of tracked birds in this year (Fig. 32b, d).

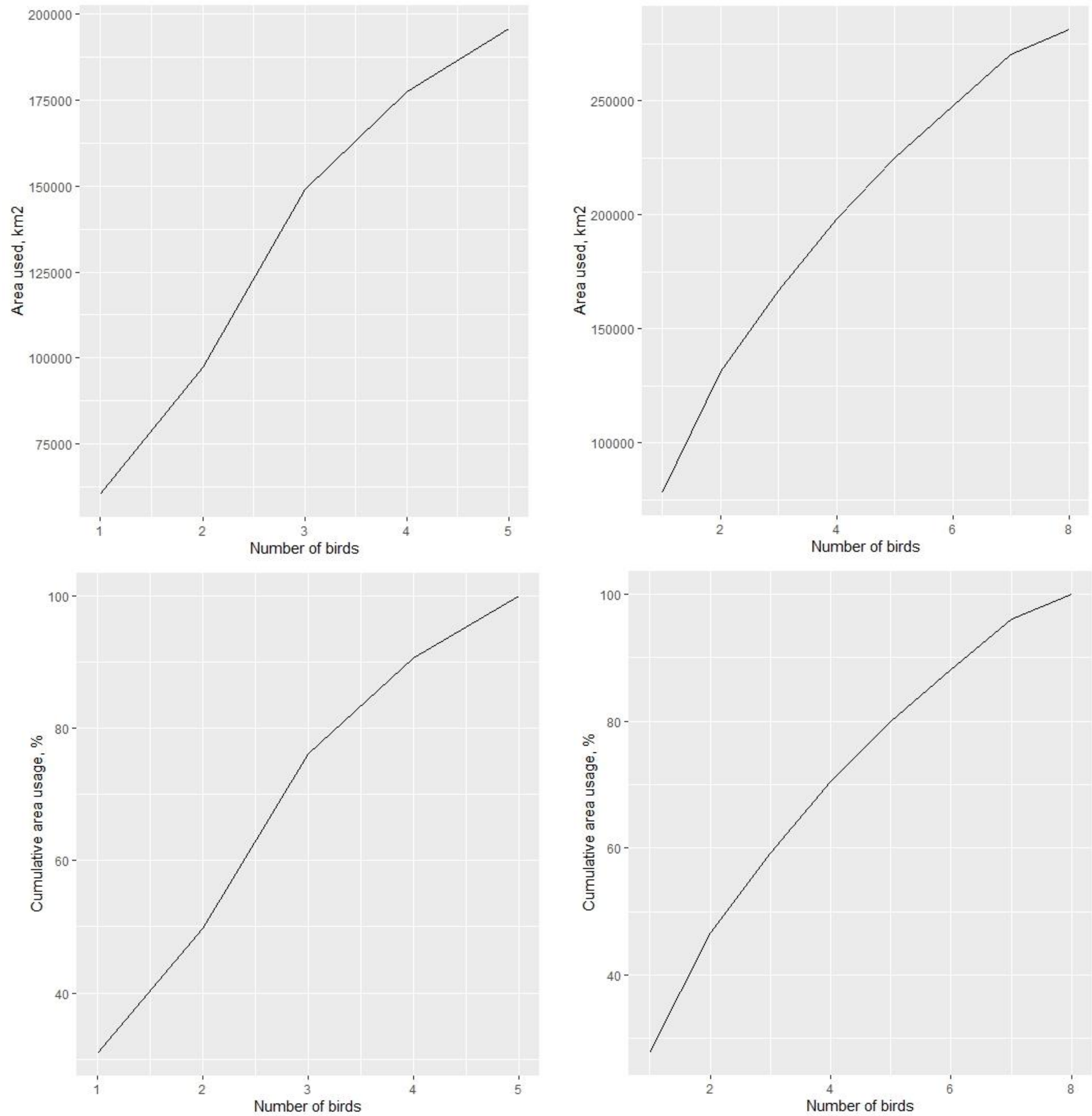


Figure 32 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in razorbills from Buchan Ness to Collieston Coast in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the population in 2017-18; d) cumulative percentage of area used by the population in 2018-19.

Isle of May

The increase in size of core areas with increasing sample size of individuals for Isle of May razorbills in 2017-18 and 2018-19 is shown on Fig. 33a and b. In 2017-2018, the cumulative curve did not appear to level off (Fig. 33c). In 2018-2019, the increment in cumulative area size was larger with sample size up to 8 birds, after which it declined to less than 5% with each additional bird (Fig. 33d). Randomized samples of 5 and 10 birds covered 70% and 99% of the area identified using all study birds, respectively.

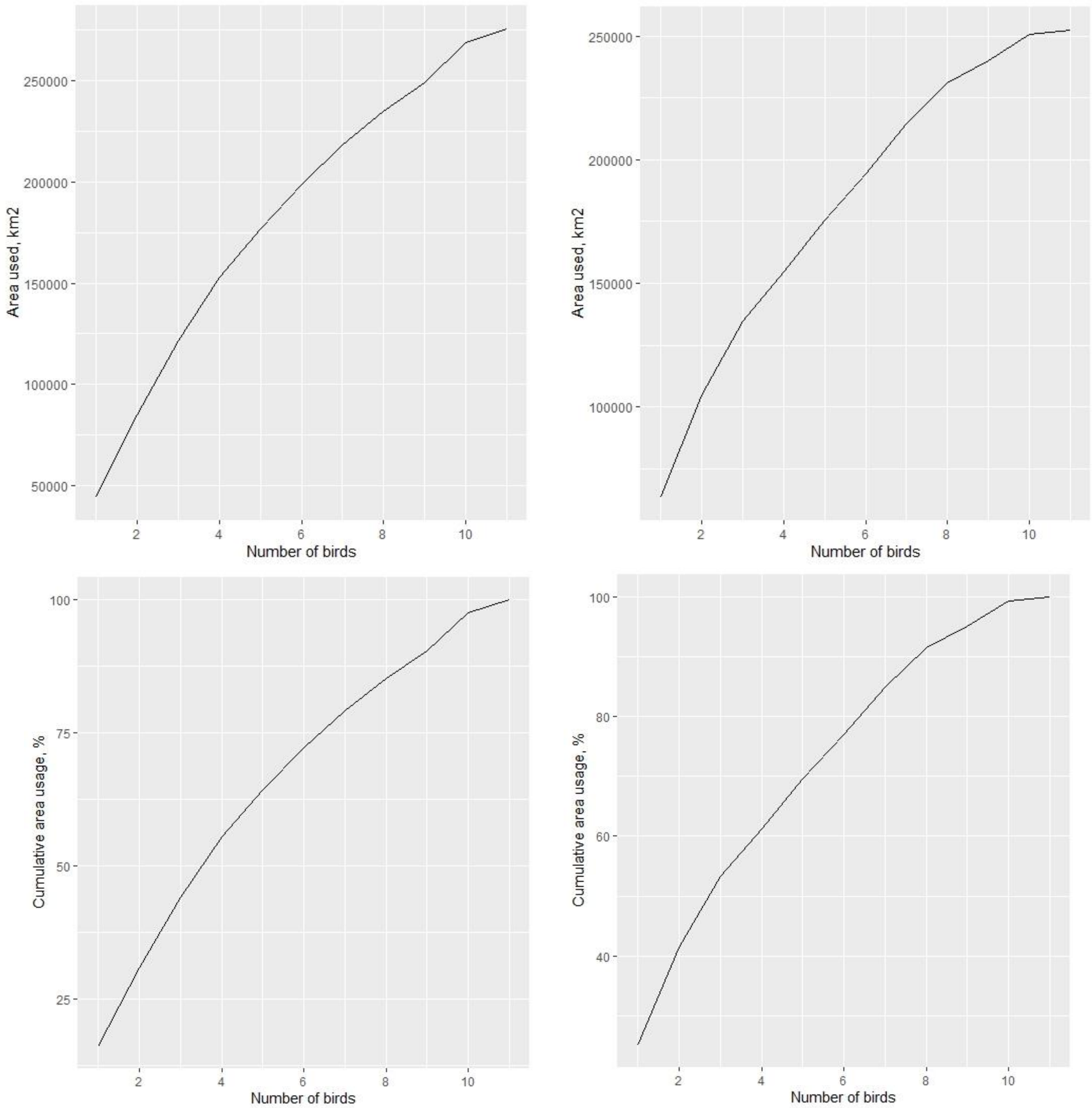


Figure 33 Relationship between core area used (50% UD contours) and sample size of birds estimated from a resampling procedure in razorbills from Isle of May in 2017-19. a) median area for each randomized sample size in 2017-18; b) median area for each randomized sample size in 2018-19; c) cumulative percentage of area used by the population in 2017-18; d) cumulative percentage of area used by the population in 2018-19.

Conclusions

The analyses of minimum adequate sample size of tracked birds for each species at each of the colonies and years generally showed a non-linear decline in rate of increase in area size with increasing sample size, except for cases where the sample sizes were very small (n<10). However, the cumulative curves did not level off for any of the datasets, suggesting that larger samples of birds (>30 birds) would need to be tracked in order to capture the population core wintering area. It is worth noting, however, that the method we used is relatively conservative since the cumulative area of individual UD contours is calculated to estimate the size of the population wintering area at each sample size of birds, as opposed to data from all birds within a sample size being pooled and population kernel contours then calculated.

Our results reflect the challenge in obtaining sufficiently large sample sizes of birds required to achieve a plateau in the cumulative curves. The larger sample sizes obtained for guillemots reflect the fact that more accessible birds were available and these were easier to recapture than razorbills. Where the sample sizes of tracked individuals were comparable, there was no indication of substantial inter-annual or between-colony variation in the relationship between area size and sample size.

Key considerations in identifying field sites

In planning a tagging study at a new site, there are a number of logistical and practical considerations that must be accounted for.

In terms of accessibility, it is important to identify the closest suitable parking area for vehicles, and note any restrictions associated with this. Given the potential need to transport substantial volumes of equipment to the tagging site, any special requirements for accessing this site (e.g. 4 wheel drive, a long hike, or boat) should be noted, alongside any restrictions related to the tidal cycle. Local stakeholders, including landowners and ringing groups, should also be identified, especially where site access will involve crossing privately owned land. Landowners may also be able to recommend alternative locations to park vehicles, allowing easier access to tagging sites. Given the potential for long, tiring days in the field, the closest settlements, and potential options for accommodation should also be highlighted.

It is also important to capture details of the site itself, as this will inform health and safety risk assessments, options for capturing birds, considerations in relation to tag types and data retrieval, and whether any additional permissions (e.g. Schedule 1) may be required. From a health and safety perspective, it is important to note the type of site (e.g. grass slope, sheer cliff, boulder field) and the type of substrate present (e.g. loose rocks, slippery grass, algae covered rocks) to highlight the potential for injury as a result of tripping or falling. It is also important to note whether there are any special considerations in relation to site access, e.g. the need for rope access, which may require special training prior to the fieldwork.

Identifying where birds are nesting is also important as this will inform whether they are accessible using a noose pole, or other standard methodology, or whether an alternative means of capturing the birds will be necessary. It is also important to determine whether it is possible to get a direct line of sight to the nest sites, both for the purposes of monitoring device effects (Figure 34), and also data retrieval, if using a remote download base station.

It is important to identify which species are present at the site, both in terms of the focal species of interest for tagging, and any other protected species which may be present, particularly raptors, or other Schedule 1 species. This should include identifying any particularly dense concentrations of birds, how many birds it may be feasible to catch at any site, and what methods may be most effective for doing so. Where archival devices are used, the potential for recapturing any birds should also be highlighted.

It is also important to consider what size of team may be suitable for each site. This is likely to be influenced, at least in part, by the availability of areas away from the main colony both to fit the tags and, to give the colony a break from any disturbance (e.g. whilst eating lunch).

Figure 34 Direct line of sight to nest sites of tagged birds for the purposes of monitoring device effects. (Photograph: BTO)

Special Protection Areas

St Abbs Head to Fast Castle

Existing Data

Kittiwake

Data collection was carried out in 2012, as part of the collaborative FAME and STAR tracking programmes (Wakefield et al., 2017) and 2021 as part of pre-construction data collection for an offshore wind farm (Table 11). In both years, birds were caught using a noose pole. In 2012, archival tags were taped to the back feathers of 15 birds. In 2021, remote download tags were used, with 26 taped to tail feathers and 13 glued to back feathers. Whilst the data collected as part of the FAME and STAR projects can be accessed from BirdLife International's Seabird Tracking Database, the data collected as part of pre-construction work for offshore wind farms are not.

Table 11 Kittiwake tagging protocol at St Abbs Head. Tag models used: IgotU GT-120 (Mobile Action Technology), nanoFix-GEO+RF (Pathtrack), UvA-BiTS (University of Amsterdam).

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012	Noose pole	IgotU	14.2	Taped to back feathers	2.6	1 min 40 sec	15
2021	Noose pole	Pathtrack/UvA-BiTS	4.0/9.0	Taped to tail feathers/ glued to back feathers	0.2 – 36.3	5 min/variable	26/13

Guillemot

In 2012, a single guillemot was tagged with an archival GPS device, which was taped to its back feathers (Wakefield et al., 2017) as part of the collaborative FAME and STAR tracking programmes. These data are freely available from BirdLife International's Seabird Tracking Database.

Table 12 Guillemot tagging protocol at St Abbs Head. Tag models used: IgotU GT-120 (Mobile Action Technology).

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012	Noose pole	IgotU	17.1	Taped to back feathers	4.1	1 min 40 sec	1

Work planned for 2023 breeding season

RSPB have plans to deploy up to 50 GPS tags on kittiwakes within the St Abbs Head to Fast Castle SPA during the 2023 breeding season, subject to any restrictions imposed due to the impact of HPAI.

Consideration for future work

GSM network coverage is likely to vary by provider. To highlight how coverage can vary with topography and the wider environment, we illustrate this using the Vodafone coverage checker as an example (Figure 35), thought both here, and at subsequent sites, other providers should be consulted and signal strength should be confirmed as part of site visits. Patterns in coverage are relatively consistent between the 2G, 3G and 4G networks, with a noticeable drop around St Abb’s Head, particularly for 3G coverage (Figure 35), likely reflective of overall topography. Consequently, a base station may be the most effective means for data retrieval.

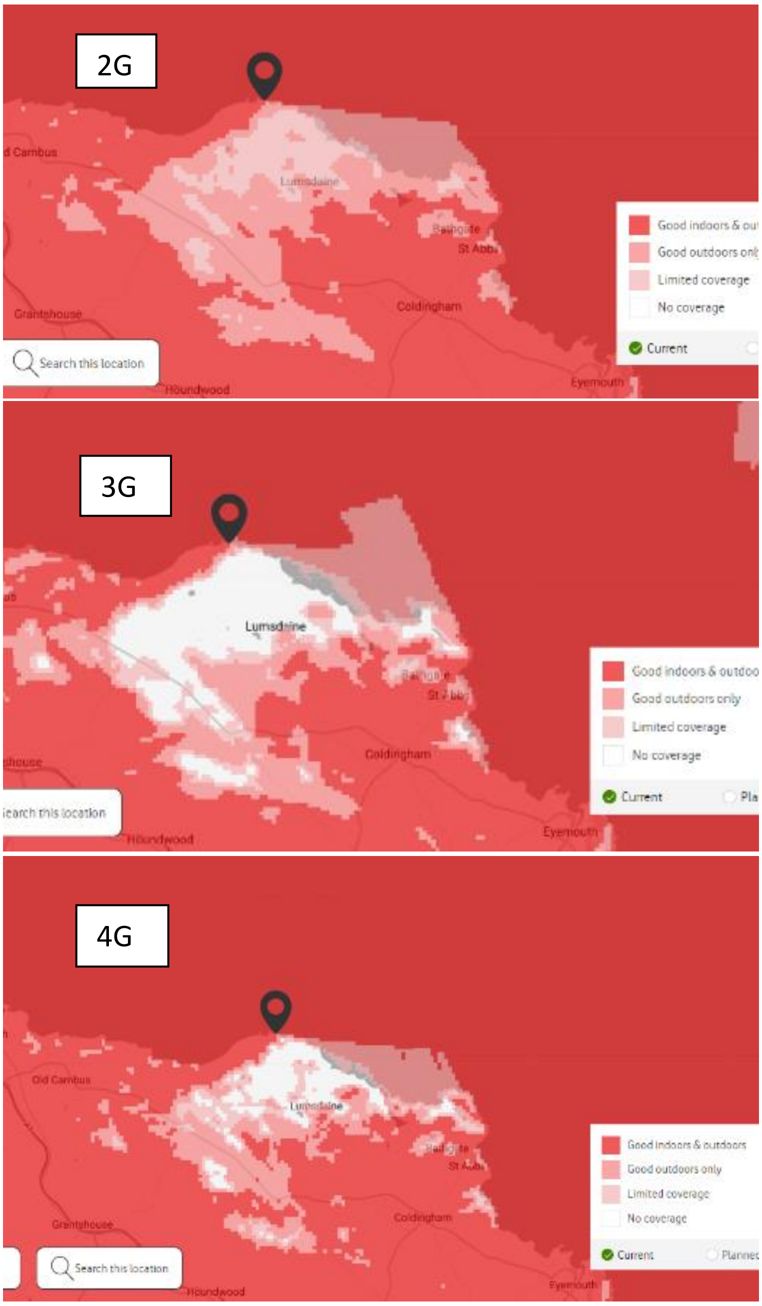


Figure 35 GSM network coverage for St Abb's Head to Fast Castle taken from [Vodafone's status checker website]

Forth Islands

Existing data

Gannet

Collection of movement data from gannets on the Bass Rock (grid ref NT602873), within the Forth Islands SPA, has been underway for some time with the first data collected in 1998 using PTT tags (Hamer et al., 2007) (Table 13). Since then, substantial numbers of devices have been deployed on a regular basis on both adult and immature birds (Grecian et al., 2018; Lane et al., 2020; Wakefield et al., 2013). In recent years, pressure sensors to record bird flight heights have also been deployed (Cleasby et al., 2015b; Lane et al., 2020). An additional study was carried out in 2022 in order to investigate the impact of HPAI (Jeglinski et al., 2023). Birds have been captured using noose poles, with devices typically attached with tape to birds' tail feathers.

Table 13 Gannet tagging protocol at the Bass Rock

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
1998	Noose pole	PTT	30	Taped to tail	5-21		17
2002	Noose pole	PTT	30	Taped to tail	5-21		14
2003	Noose pole	PTT	30	Taped to tail	5-21		9
2003	Noose pole	GPS	70	Taped to back	1-4	3 min	13
2010	Noose pole	GPS	37	Taped to tail		2 min	41
2011	Noose pole	GPS	37	Taped to tail		2 min	28
2015-19	Noose pole	GPS	37	Taped to tail		1-2 min	188 (adult)
2015	Noose pole	GPS	21	Taped to tail		2 min	21 (immature)
2015-2017	Noose pole	Pressure logger	18	Taped to tail			63 (adult)
2022	Noose pole	GPS	18	Taped to tail	18-101	15 min	10

To investigate movements outside the breeding season, substantial numbers of geolocators have been deployed on both adult and juvenile birds (Deakin et al., 2019; Grecian et al., 2019; Kubetzki et al., 2009; Lane et al., 2021) (Table 14).

Table 14 Geolocators recovered from gannets at the Bass Rock.

Years deployed	Number of geolocators recovered
2002-2004	34
2010-2014	44
2018-2019	73 (38 juvenile, 35 adult)

Herring Gull

In 2019, 5 GPS tags were deployed on herring gulls on three islands within the Forth Islands SPA (Isle of May (grid ref NT656992), Craigleith (grid ref NT552869) and Fidra (NT513867)). Birds were caught using walk in traps and tags were fitted using weak-link wing harnesses (Clewley et al., 2021), providing data on bird movements for in excess of 1 year (Table 15)

Table 15 Herring gull tagging protocol in the Forth Islands SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2019 (Isle of May)	Walk in trap	GPS	18	Wing-loop harness	1+ Year	30-60 min	2
2019 (Craigleith)	Walk in trap	GPS	18	Wing-loop harness	1+ Year	30-60 min	1
2019 (Fidra)	Walk in trap	GPS	18	Wing-loop harness	1+ Year	30-60 min	2

Kittiwake

GPS tracking on the Isle of May National Nature Reserve has been carried out since 2010. Breeding adults were captured at the nest with a noose at the end of an extendable pole, during either incubation or chick rearing. GPS devices were attached to back or tail feathers using waterproof Tesa tape or to back feathers using superglue, depending on the tag type and weight. From 2010 to 2014, archival tags were used therefore tagged individuals were recaptured for device retrieval. From 2018 onwards, remote-download tags were used, with data downloaded to base stations when the tagged birds were at the colony. The UvA-BiTS tags used in 2020 and 2021 had an accelerometer and altimeter added to the GPS unit, allowing a more detailed investigation of behaviours at sea and flight heights. Details of the tagging protocol used on the Isle of May are presented in Table 16. In 2022, no tracking work was undertaken due to the suspension of seabird catching and handling activities in Scotland, as part of measures to limit the spread of avian influenza.

The data collection in 2010 and 2018-21 formed part of the pre-construction monitoring for offshore wind farms in the Forth/Tay region and the resulting data are not currently freely available. The data collection in 2012-14 was part of two collaborative projects - FAME (Future of the Atlantic Marine Environment) and STAR (Seabird Tracking and Research) led by the RSPB. The data from these projects can be accessed from BirdLife International's Seabird Tracking Database.

Table 16 Kittiwake tagging protocol on the Isle of May. Tag models used: IgotU GT-120 (Mobile Action Technology); GiPSy-2 and GiPSy-3 (TechnoSmart); nanoFix-GEO+RF (Pathtrack), UvA-BiTS (University of Amsterdam).

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU/GiPSy	15.0/11.5	Taped to back feathers	0.7 – 2.8	1 min/1 min on 5 min off	27/9
2012	Noose pole	IgotU	14.2	Taped to back feathers	1.0 – 2.4	1 min 40 sec	17
2013	Noose pole	IgotU	16.4	Taped to back feathers	0.8 – 3.0	1 min 40 sec	22
2014	Noose pole	IgotU	15.3	Taped to back feathers	1.0 – 2.4	1 min 40 sec	11
2018	Noose pole	Pathtrack	4.1	Taped to back feathers	1.8 – 4.6	5 min	16
2019	Noose pole	Pathtrack	4.1	Taped to tail feathers	0.9 – 9.9	5 min/10 min	25
2020	Noose pole	UvA-BiTS	9.0	Glued to back feathers	5.4 – 36.8	variable	23
2021	Noose pole	Pathtrack/UvA-BiTS	4.0/9.0	Taped to tail feathers/ glued to back feathers	3.4 – 26.3	5 min/variable	37/13

To investigate movements outside the breeding season, substantial numbers of geolocators have been deployed on kittiwakes as part of the Seatrack project (Table 17).

Table 17 Geolocators recovered from kittiwakes on the Isle of May.

Years deployed	Number of geolocators recovered
2007-2021	102

http://seatrack.seapop.no/map/?species=rissa_tridactyla&?colony=isle%20of%20may

Guillemot

The guillemot is another key species included in the GPS tracking studies on the Isle of May and in the FAME and STAR projects. On the Isle of May, the species has been tagged since 2010. Chick-rearing adults were captured at the nest site with a noose at the end of an extendable pole. GPS tags were attached to back feathers using waterproof Tesa tape. As with kittiwakes, from 2010 to 2014 archival tags were used and individuals were recaptured to retrieve the devices. From 2018 onwards, remote-download tags were used, with data downloaded onto base stations located at the colony. The tags used in 2020 and 2021 had a time-depth recorder (TDR) integrated with the GPS unit, adding functionality useful for quantifying foraging behaviour. Details of the tagging protocol used on the Isle of May are presented in Table 18. As with kittiwakes, no tracking work was undertaken in 2022 due to the wider suspension of catching and handling seabirds as part of measures to limit the spread of avian influenza.

The data collection in 2010 and 2018-21 formed part of the pre-construction monitoring for offshore wind farms in the Forth/Tay region and the resulting data are not currently freely available. The data collected in 2012-14 as part of the FAME and STAR projects are available in BirdLife International's Seabird Tracking Database.

Table 18 Guillemot tagging protocol on the Isle of May. Tag models used: IgotU GT-120 (Mobile Action Technology); nanoFix-GEO+RF and nanoFix-GEO+RF with TDR (Pathtrack).

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU	15.0	Taped to back feathers	0.9 - 2.8	1 min	33
2012	Noose pole	IgotU	17.1	Taped to back feathers	0.6 – 3.9	1 min 40 sec	20
2013	Noose pole	IgotU	17.8	Taped to back feathers	1.2 – 3.7	1 min 40 sec	20
2014	Noose pole	IgotU	17.5	Taped to back feathers	1.9 – 2.9	1 min 40 sec	8
2018	Noose pole	Pathtrack	11.0	Taped to back feathers	0.5 – 10.0	5 min	24
2019	Noose pole	Pathtrack	11.0	Taped to back feathers	0.5 – 6.7	5 min	24
2020	Noose pole	Pathtrack +TDR	16.5	Taped to back feathers	0.3 – 11.4	5 min	25
2021	Noose pole	Pathtrack +TDR	16.5	Taped to back feathers	0.8 – 10.1	5 min	23

To investigate movements outside the breeding season, substantial numbers of geolocators have been deployed on guillemots as part of Seatrack and other (Buckingham et al., 2021; Harris et al., 2015) projects (Table 19).

Table 19 Geolocators recovered from guillemots on the Isle of May.

Years deployed	Number of geolocators recovered
2011-2014	70
2013-2021[1]	68
2017-2020	42

[1]http://seatrack.seapop.no/map/?species=uria_aalge&?colony=isle%20of%20may

Razorbill

The razorbill is another species included in the GPS tracking studies on the Isle of May and in the FAME and STAR projects. On the Isle of May, the species has been tagged since 2010 and the same capture and tag attachment methods used as for guillemots. From 2010 to 2014, archival tags were used and the tagged individuals were recaptured to retrieve the devices. From 2018 onwards, remote-download tags were used, with data downloaded onto base stations located at the colony. In 2020 and 2021, the tags had a time-depth recorder (TDR) integrated with the GPS unit, adding functionality required in order to quantify foraging behaviour. Details of the tagging protocol used on the Isle of May are shown in Table 20. As with the other species on the Isle of May, no tracking work was undertaken in 2022 due to measures to limit the spread of avian influenza in Scottish seabird colonies.

The data collection in 2010 and 2018-21 formed part of the pre-construction monitoring for offshore wind farms in the Forth/Tay region and the resulting data are not currently freely available. The data collected in 2012-14 as part of the FAME and STAR projects are available in BirdLife International's Seabird Tracking Database.

Table 20 Razorbill tagging protocol on the Isle of May. Tag models used: IgotU GT-120 (Mobile Action Technology); nanoFix-GEO+RF and nanoFix-GEO+RF with TDR (Pathtrack).

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU	15.0	Taped to back feathers	0.4 - 2.8	1 min	18
2012	Noose pole	IgotU	17.7	Taped to back feathers	0.6 – 3.0	1 min 40 sec	15
2013	Noose pole	IgotU	17.7	Taped to back feathers	2.5 – 5.0	1 min 40 sec	7
2014	Noose pole	IgotU	17.7	Taped to back feathers	2.4 – 2.9	1 min 40 sec	5
2018	Noose pole	Pathtrack	8.2	Taped to back feathers	0.3 – 9.7	10 min	14
2019	Noose pole	Pathtrack	8.2	Taped to back feathers	4.6 – 9.0	10 min	14
2020	Noose pole	Pathtrack +TDR	13.0	Taped to back feathers	0.3 – 12.9	5 min	15
2021	Noose pole	Pathtrack +TDR	12.8	Taped to back feathers	2.1 – 10.2	5 min	11

To investigate movements outside the breeding season, substantial numbers of geolocators have been deployed on razorbills on the Isle of May (Buckingham et al., 2021; St. John Glew et al., 2019) (Table 21).

Table 21 Geolocators recovered from razorbills on the Isle of May.

Years deployed	Number of geolocators recovered
2008	17
2015	9
2017-2020	22

Work planned for 2023

In addition to ongoing tagging projects on kittiwake, guillemot and razorbill on the Isle of May led by UKCEH, RSPB have plans to deploy up to 20 GPS tags on gannets at Bass Rock, within the Forth Islands SPA, during the 2023 breeding season, subject to any restrictions imposed due to the impacts of HPAI.

Consideration for future work

In addition to the Isle of May and the Bass Rock, a number of other locations within the Forth Islands offer the potential for tagging studies including, Craigleith (guillemot, razorbill, kittiwake, herring gull), Fidra (guillemot, razorbill, kittiwake, herring gull) and Inchmickery (grid ref NT206805: herring gull). Capture at The Lamb (grid ref NT535865) is not considered appropriate because of the likelihood of significant disturbance, particular to breeding cormorants. There are long-term ringing programmes on these islands undertaken by the Lothian Ringing Group, and liaison with this group is critical before any GPS tracking is undertaken. In all cases personnel should be aware of any other sensitive species that may be disturbed due to tagging activities. Permission will also need to be sought from landowners, which can be facilitated through the ringing group.

Access to these islands is by boat from North Berwick or Granton, the former limited by tidal conditions. These islands comprise sheer cliffs, firm sloping shorelines and grassy slopes. The substrate is mostly firm, grippy rock in areas away from grassy slopes. The terrain is complex with numerous small ledges, low cliffs, cracks and crevices. Birds could be targeted for tracking that avoids high cliffs. Clear line of sight to nests is sometimes possible but not for all options for tracking (e.g. those facing out to sea).

At each site there is the potential to catch good numbers of herring gull and kittiwake and more modest numbers of guillemot and razorbill, using standard approaches such as noose poles or walk in traps (for gulls), without the need for rope access. Once captured there is potential to fit tags away from the main colony. Whilst recapture of tagged birds is possible, the additional disturbance to the breeding colony makes this undesirable, and remote download systems are preferable. GSM Network coverage on the islands is generally good, making GPS GSM tags an option for these sites (Figure 36). However, 4G tags should be used as 3G coverage is very patchy. Confirmation of network coverage, from a variety of different providers, should also be sought prior to ordering tags. Alternatively, base stations would also offer a reliable option, and given the need for boat access to the islands, may also be located securely on the island.

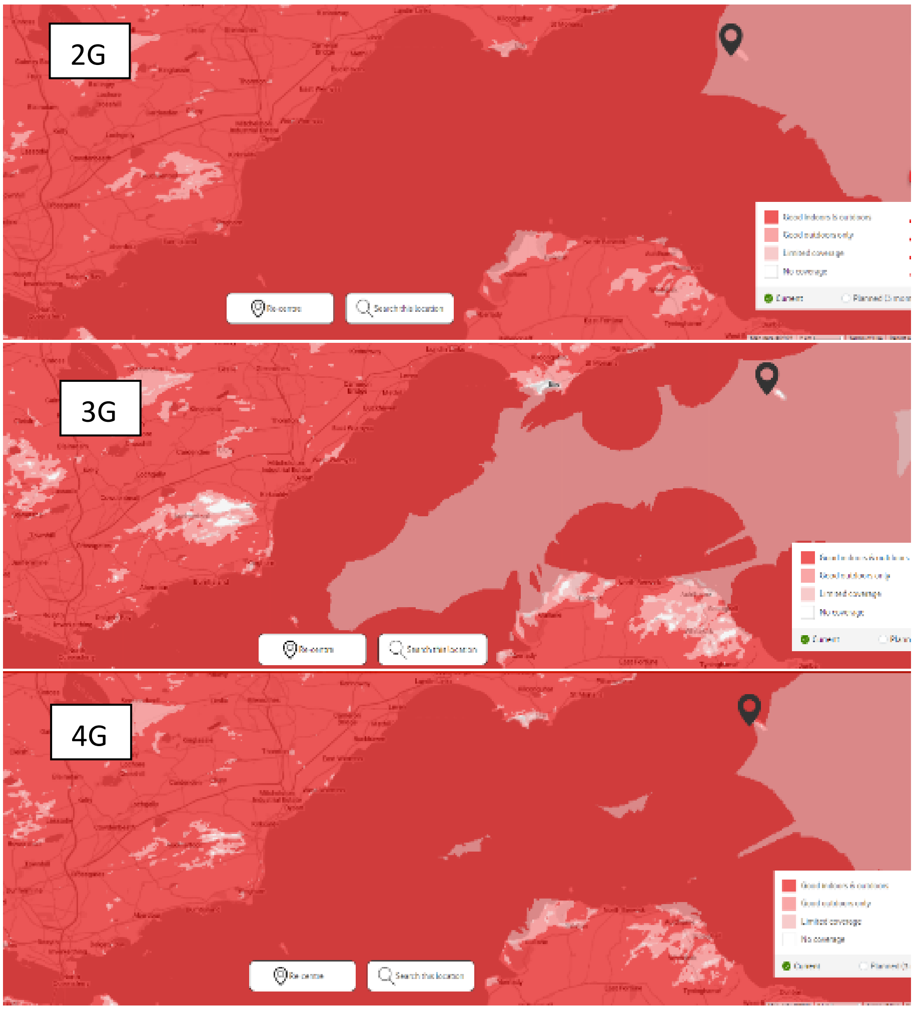


Figure 36 GSM network coverage for Forth Islands taken from [Vodafone's status checker website]

Fowlsheugh

Existing data

Kittiwake

In addition to previous tracking at Fowlsheugh, as part of the FAME and STAR projects, more recent tracking work has been carried out there funded by the Offshore Wind Industry (Table 22). Whilst data from the FAME and STAR projects are available in BirdLife International's Seabird Tracking Database, the data collected on behalf of industry are not available at present.

Table 22 Kittiwake tagging protocol at Fowlsheugh.

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012	Noose pole	IgotU	16.4	Taped to back feathers	0.8 – 3.0	1 min 40 sec	15
2021	Noose pole	Pathtrack/UvA-BiTS	4.0/9.0	Taped to tail feathers/ glued to back feathers	0.4 – 39.3	5 min/variable	26/14

Guillemot

Guillemots were previously tracked at Fowlsheugh as part of the FAME and STAR projects (Table 23). These data are available in BirdLife International's Seabird Tracking Database.

Table 23 Guillemot tagging protocol at Fowlsheugh.

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012	Noose pole	IgotU	17.1	Taped to back feathers	0.6 – 3.9	1 min 40 sec	10

Work planned for 2023

RSPB have plans to deploy up to 50 GPS tags on kittiwakes within the Fowlsheugh SPA during the 2023 breeding season, subject to any restrictions imposed due to the impact of HPAI.

Consideration for future work

Fowlsheugh is an RSPB reserve with good access and car parking. Permission should be sought from RSPB, as landowners, in order to carry out tagging studies at this site. Much of the site is characterized by sheer cliffs. Away from the existing tagging sites, the cliffs are less well populated with seabirds, which are often concentrated on central parts of the cliff and difficult to access from the top or bottom. As birds are often densely packed on narrow ledges, there is a significant risk of disturbance, meaning care would need to be taken. However, there are a number of sites that may be accessible from above using rope access, or below using boat access where both guillemots and kittiwakes are accessible. Public access, and particularly disturbance by photographers, may be an issue. There may be significant numbers of accessible razorbills close to the top of the cliffs. However, recapturing these birds to retrieve tags is likely to be challenging. Consequently, this site may be suitable for deploying remote download GPS on razorbills, but less suitable for archival tags like geolocators. Additional visits to confirm this during the 2023 breeding season, when birds will be present, would be valuable.

GSM network coverage at this site is good (Figure 37), meaning GPS GSM tags may be an option at this site. However, coverage should be confirmed prior to ordering any tags. This is particularly important given the potential for the topography of the site to interfere with the GSM signal.

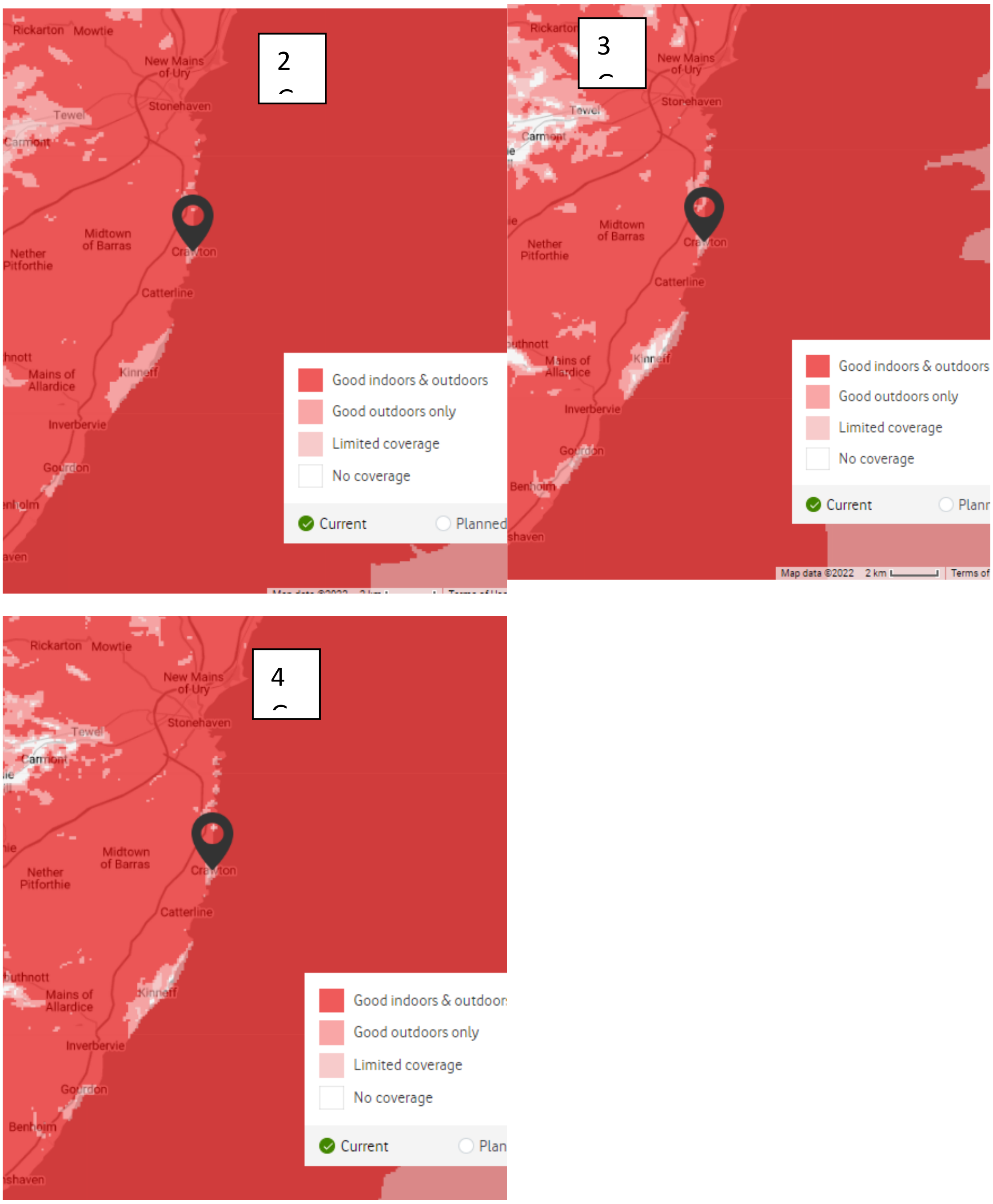


Figure 37 GSM network coverage for Fowlsheugh taken from [Vodafone's status checker website)]()

Buchan Ness to Collieston Coast

Existing data

Kittiwake

GPS tagging of kittiwake took place in two locations, Whinnyfold (grid ref NK077477) and Bullers of Buchan (NK109380), within the Buchan Ness to Collieston Coast SPA as part of the FAME and STAR projects in 2012 (Table 24). Birds were captured using a noose pole and tags were deployed by taping them to back feathers. Subsequently, in 2021, additional tagging work took place at Whinnyfold led by BTO on behalf of Vattenfall, with tags deployed using glue, allowing for longer term deployments. To test the potential for longer-term tag deployment, an additional 6 PTT tags were deployed in 2021, three using a thoracic harness and three using a leg-loop harness (Clewley et al., 2022). Following evidence of deleterious device effects, these were removed after 10 days.

Table 24 Kittiwake tagging protocol in Buchan Ness to Collieston Coast SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012 (Bullers of Buchan)	Noose pole	IgotU	14.2	Taped to back feathers		1 min 40 sec	5
2012 (Whinnyfold)	Noose pole	IgotU	14.2	Taped to back feathers		1 min 40 sec	20
2021 (Whinnyfold)	Noose pole	GPS	10.0	Glued to back feathers	18-47	10 sec – 10 min	20
2021 (Whinnyfold)	Noose pole	PTT	7.9	Thoracic harness	10		3
2021 (Whinnyfold)	Noose pole	PTT	6.8	Leg-loop harness	10		3

Guillemot

GPS tagging of guillemots took place in two locations, Whinnyfold and Bullers of Buchan, within the Buchan Ness to Collieston Coast SPA as part of the FAME and STAR projects in 2012 (Table 25). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 25 Guillemot tagging protocol in Buchan Ness to Collieston Coast SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012 (Bullers of Buchan)	Noose pole	IgotU	14.2	Taped to back feathers		1 min 40 sec	2
2012 (Whinnyfold)	Noose pole	IgotU	14.2	Taped to back feathers		1 min 40 sec	5

As part of a recent project to investigate wintering movements of guillemots (Buckingham et al., 2021), geolocators have been deployed on birds at Whinnyfold (Table 26).

Table 26 Geolocators recovered from guillemots in Buchan Ness to Collieston Coast SPA.

Years deployed	Number of geolocators recovered
2017-2020	55

Razorbill

As part of a recent project to investigate wintering movements of razorbills (Buckingham et al., 2021), geolocators have been deployed on birds at Whinnyfold (Table 27).

Table 27 Geolocators deployed on razorbills in Buchan Ness to Collieston Coast SPA.

Years deployed	Number of geolocators recovered
2017-2020	10

Work planned for 2023

Subject to any restrictions imposed as a result of the impacts of HPAI, BTO have plans to deploy 25 GPS tags and 30 geolocators on kittiwake, 25 integrated GPS and TDR tags and 30 integrated geolocators and TDRs on guillemots, 25 integrated GPS and TDR tags and 30 integrated geolocators and TDRs on razorbills at Whinnyfold, within the Buchan Ness to Collieston Coast SPA, during the 2023 breeding season. The BTO also intend to carry out a further harness trial, using a modified leg-loop harness.

In addition, BTO intend to assess the potential to deploy tags at other locations within the SPA, with a view to identifying additional sites for tagging studies in future breeding seasons.

Consideration for future work

There are two key sites for deploying tags within the Buchan Ness to Collieston Coast SPA, Bullers of Buchan and Whinnyfold.

Bullers of Buchan is characterized by granite cliffs, with some grassy gullies which allow access to the shore. Kittiwakes, guillemots and razorbills are all present, but birds are only really accessible from below. Access may be challenging as it involves scrambling over often wet and slippery rocks and poor line of sighe may make the use of remote download base stations challenging. Furthermore, access issues may make revisiting the colony to retrieve tags challenging. However, it would be worth revisiting this site during the 2023 breeding season to further assess potential options whilst birds are present.

At Whinnyfold there are a number of good options for catching kittiwakes, guillemots and razorbills. Substantial numbers of birds could be caught, and the availability of different sites means that it would be straightforward to minimise disturbance at any individual site. Potential catching options could be expanded further with the use of a boat, or through ensuring suitably trained personnel were able to offer rope access to help with the capture of birds. There is also a small colony of herring gulls that nest on a flat rock which is accessible at low tide, or with the use of a boat, which would be accessible for deploying GPS tags. There is good line of sight at this site, making the use of a remote download base station relatively straightforward. Whilst retrieval of archival tags is possible, the ease of this varies across the site.

There may be additional locations within the SPA where there are accessible birds, notably around Sands of Forvie National Nature Reserve (grid ref NK011250). It would be valuable to visit these sites, in addition to Whinnyfold and Bullers of Buchan, during the 2023 breeding season to assess this.

GSM Network coverage within the SPA is patchy, particularly towards the southern end (Figure 38). Consequently, given good potential options in relation to line of sight, remote download base stations are likely to be most appropriate within this SPA.

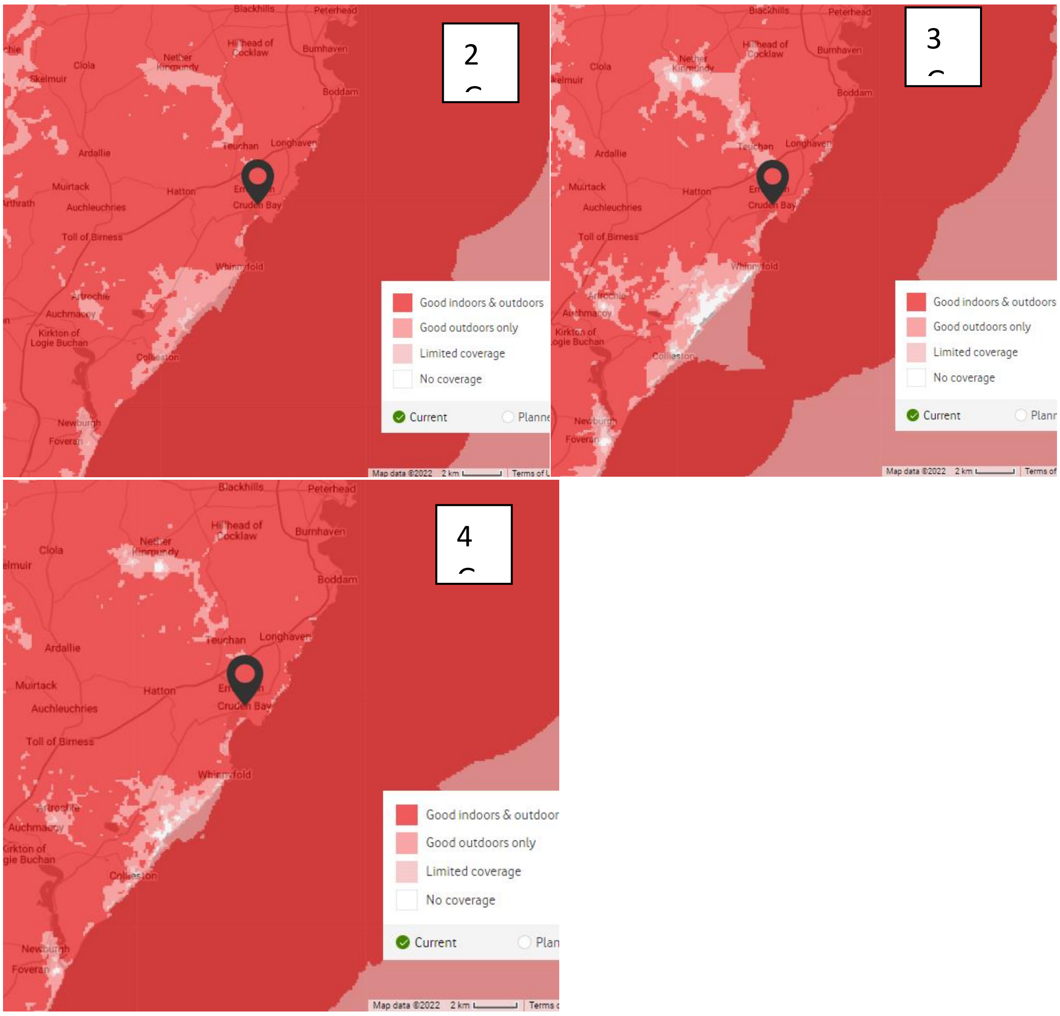


Figure 38 GSM network coverage for Buchan Ness to Collieston Coast SPA taken from [Vodafone's status checker website]

Troup, Pennan and Lion’s Heads

Existing data

None of the focal species have previously been tracked within the Troup, Pennan and Lion’s Heads SPA.

Work planned for 2023

At present, there is no additional tagging work planned for Troup, Pennan and Lion’s Heads SPA during the 2023 breeding season. However, BTO intend to undertake visits during the breeding season to assess the potential for tagging studies in future years.

Consideration for future work

Previous seabird ringing took place here in the 1970’s and 1980’s when large concentrations of auks and kittiwakes were accessible. However, the expansion of gannets appears to have led to the exclusion of auks from their previous nest sites. The site itself is characterized by very high cliffs, sheer in places, with evidence of erosion by gannets, likely resulting in large numbers of loose rocks. Most of the cliff faces appear to be inaccessible from above and below. However, there may be a small colony (~25 nests) of kittiwakes that is accessible at the bottom of the cliffs down a steep, grassy slope (Figure 39). During a visit in November 2022 a large number of dead gannets were visible above this site, suggesting there may be significant HPAI concerns. None of the gannets’ nest sites appear to be accessible. Viewing the site from the sea during the breeding season would be valuable to confirm this. Troup Head is an RSPB reserve, and permission must be sought from RSPB prior to any tagging activity that takes place at this site.

Figure 39 A small colony of kittiwakes may be accessible at the base of the cliff (Photograph: Ewan Weston)

There may be reasonable GSM coverage at the site (Figure 40), so GPS GSM tags may be an option for data retrieval at this site, though this would require careful consideration across a range of different providers. Alternatively a base station at the top of the cliffs may be suitable.

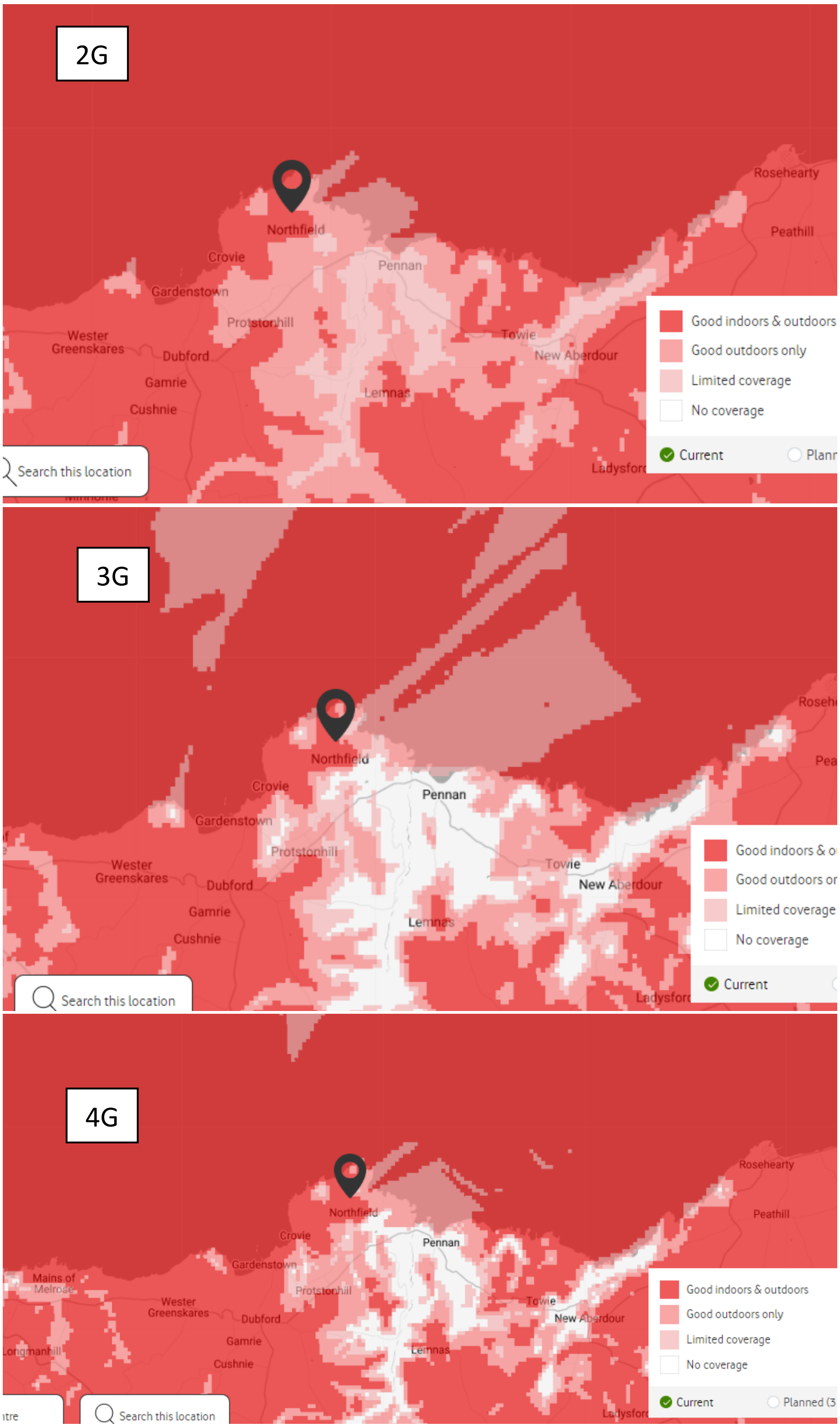


Figure 40 GSM network coverage for Troup, Pennan and Lion's Heads taken from [Vodafone's status checker website]

East Caithness Cliffs

Existing data

Herring gull

As part of work carried out in relation the Moray Firth Offshore Wind Farms, seven herring gulls were tracked within the East Caithness Cliffs SPA in 2014 (table 28).

Table 28 Herring gull tagging protocol in East Caithness Cliffs SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2014							7

Great black-backed gull

As part of work carried out in relation the Moray Firth Offshore Wind Farms, 11 great black-backed gulls were tracked within the East Caithness Cliffs SPA in 2014 (table 29).

Table 29 Great black-backed gull tagging protocol in East Caithness Cliffs SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2014							11

Guillemot

As part of a recent project to investigate wintering movements of guillemots (Buckingham et al., 2021), geolocators have been deployed on birds within the East Caithness Cliffs SPA (Table 29).

Table 29 Geolocators recovered from guillemots within the East Caithness Cliffs SPA.

Years deployed	Number of geolocators recovered
2017-2020	56

Razorbill

As part of a recent project to investigate wintering movements of razorbills (Buckingham et al., 2021), geolocators have been deployed on birds within the East Caithness Cliffs SPA (Table 30).

Table 30 Geolocators recovered from razorbills within the East Caithness Cliffs SPA.

Years deployed	Number of geolocators recovered
2017-2020	22

Work planned for 2023

At present, there is no additional tagging work planned for East Caithness Cliffs SPA during the 2023 breeding season. However, BTO intend to undertake visits during the breeding season to assess the potential for tagging studies in future years.

Consideration for future work

A key species for East Caithness Cliffs is great black-backed gull. However, numbers appear to have declined substantially in recent years, and very few accessible nests remain. Indeed, the number of great black-backed gulls colour-ringed in Caithness as a whole declined from 26 in 2016 to just 2 in 2019. Birds are increasingly concentrated on inaccessible, offshore stacks, meaning deploying any tags is likely to be very difficult, if not impossible.

There are three key sites for the remaining species (kittiwake, guillemot and razorbill) within the East Caithness Cliffs SPA – Berriedale Castle (grid ref ND158282), Ceann Ousdale (grid ref ND075183) and Badbea (grid ref NH026910).

Ceann Ousdale (Figure 41) offers the greatest potential for catching kittiwakes within the SPA, with around 60 readily accessible pairs, though this would need to be confirmed in the 2023 breeding season following the HPAI outbreak. However, the catching site would only be accessible by boat at low tide. Birds could be caught using noose poles, and a two-section ladder would improve access to nests. GSM Network coverage is poor, and the challenges of accessing the site make the use of archival tags undesirable. However, there are a number of potential options for deploying base stations in locations that would not require boat access.

Figure 41 Potential kittiwake tagging site at Ceann Ousdale, accessible only by boat at low tide (Photograph: Bob Swann)

Berriedale Castle (Figure 42) offers another potential site for tagging kittiwakes. However, this site has undergone substantial declines in recent years, and the presence of corpses in Autumn 2022 suggests that it may have been badly impacted by HPAI. The birds nest at the top of a steep, grassy slope. Consequently, rope access would be essential for catching birds. Again, GSM Network coverage is poor, though retrieving archival tags, whilst still challenging, may be more straightforward than is the case at Ceann Ousdale. However, line of sight is good, meaning a remote download base station would be suitable.

Figure 42 Kittiwake colony at Berriedale Castle. Birds nest in the cliffs above the river and a base station could be located close to the tower in the distance (Photograph: Bob Swann).

The final site in East Caithness SPA is at Badbea, where there is a mixed colony of kittiwakes, guillemots and razorbills (Figure 43). There are good numbers of both guillemots and razorbills that are likely to be readily accessible, though given the steep slope, rope access would be essential. There are fewer accessible kittiwakes at this site, and these should be accessed from below to avoid disturbing other birds. Again, GSM Network coverage is poor, making remote download base stations desirable at this site.

NatureScot are planning surveys of the East Caithness Cliffs colonies in June 2023 as part of the programme of monitoring being co-ordinated by RSPB to investigate the impacts of HPAI. Alongside these surveys, it would be advantageous to revisit all three of these sites during the 2023 breeding season in order to more clearly assess the number of accessible birds, and to better assess the impacts of HPAI on the breeding populations.

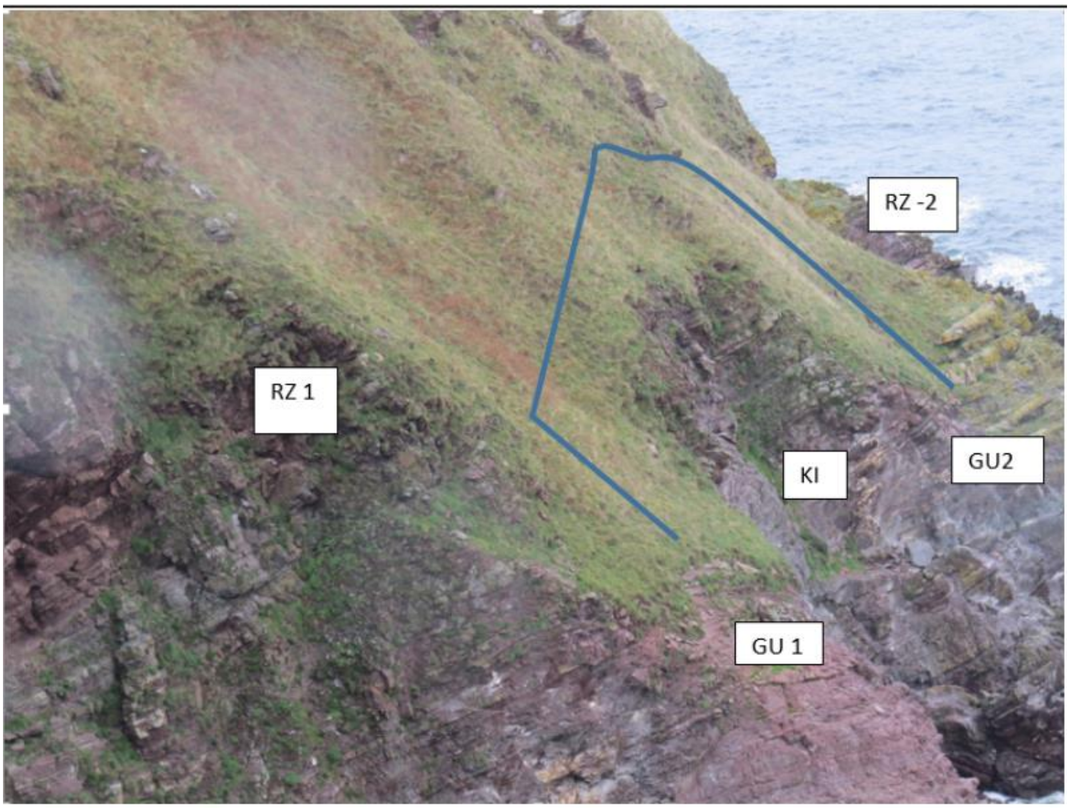
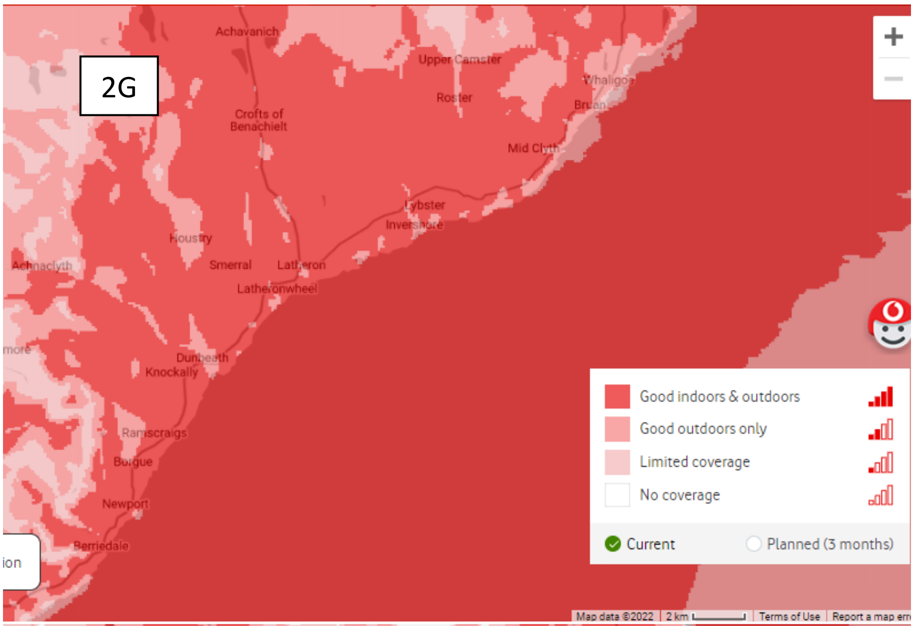
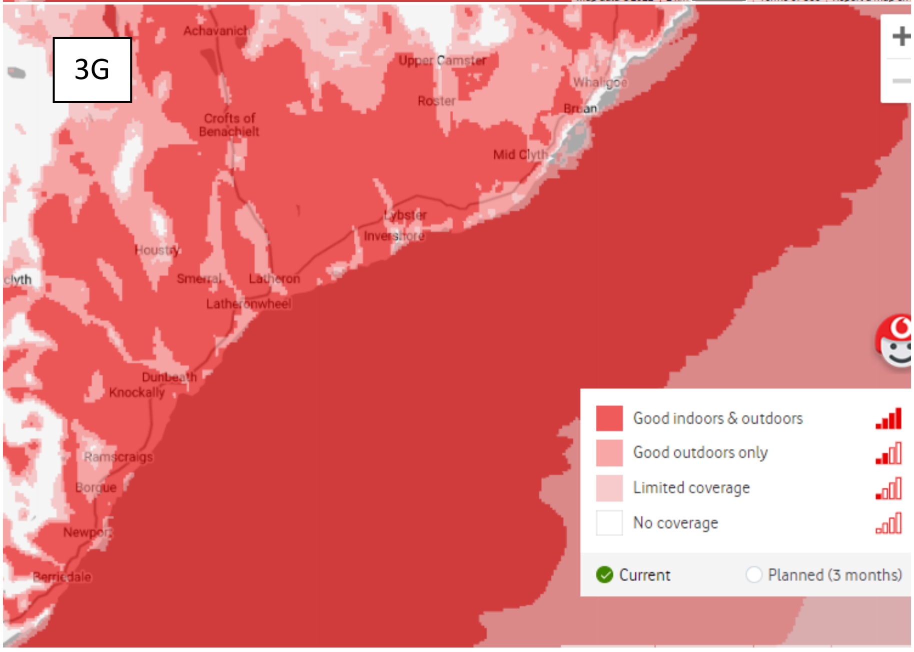


Figure 43 Mixed colony at Badbea (Photograph: Bob Swann)

As previously highlighted, GSM network coverage within the East Caithness Cliffs SPA is very patchy (Figure 44). Consequently, remote download base stations, rather than GPS GSM tags should be used within this SPA.


2G
Achavanich
Upper Camster
Whaligoe
Roster
Bruan
Crofts of Benachielt
Mid Clyth
Lybster
Inversanda
Houstry
Achnaclyth
Smerral
Latheron
Latheronwheel
Dunbeath
Knockally
Ramscraigs
Borgue
Newport
Berriedale
Good indoors & outdoors
Good outdoors only
Limited coverage
No coverage
Current
Planned (3 months)
Map data ©2022
2 km
Terms of Use

3G
Achavanich
Upper Camster
Whaligoe
Roster
Bruan
Crofts of Benachielt
Mid Clyth
Lybster
Inverstore
Houstry
Smerral
Latheron
Latheronwheel
Dunbeath
Knockally
Ramscraigs
Borgue
Newport
Berriedale
Good indoors & outdoors
Good outdoors only
Limited coverage
No coverage
Current
Planned (3 months)

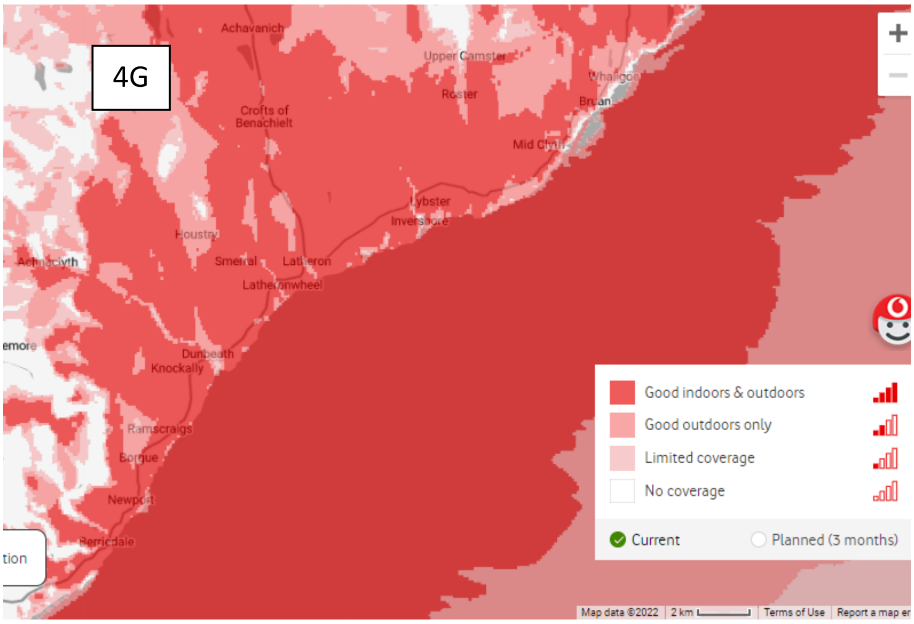


Figure 44 GSM network coverage for East Caithness Cliffs SPA taken from [Vodafone's status checker website]

North Caithness Cliffs

Existing data

No previous tracking of the focal species has taken place within the North Caithness Cliffs SPA.

Work planned for 2023

At present, there is no additional tagging work planned for North Caithness Cliffs SPA during the 2023 breeding season. However, BTO intend to undertake visits during the breeding season to assess the potential for tagging studies in future years.

Consideration for future work

On the mainland, the most accessible site for kittiwake is likely to be Drumhollistan (grid ref NC879647). However, due to the popularity of the area with birdwatchers and hikers, parking close to the site is extremely limited and, access is likely to involve a long walk over difficult terrain. Catching birds will require rope access and, as GSM Network Coverage is poor, a remote download base station is likely to be essential for data retrieval. Offshore, the island of Stroma may offer opportunities to tag some of the focal species. However, to assess this properly, it would be essential to visit the site during the 2023 breeding season.

As previously highlighted, GSM Network coverage within this SPA is very patchy (Figure 45), meaning the remote download base stations are likely to be required for any data retrieval.

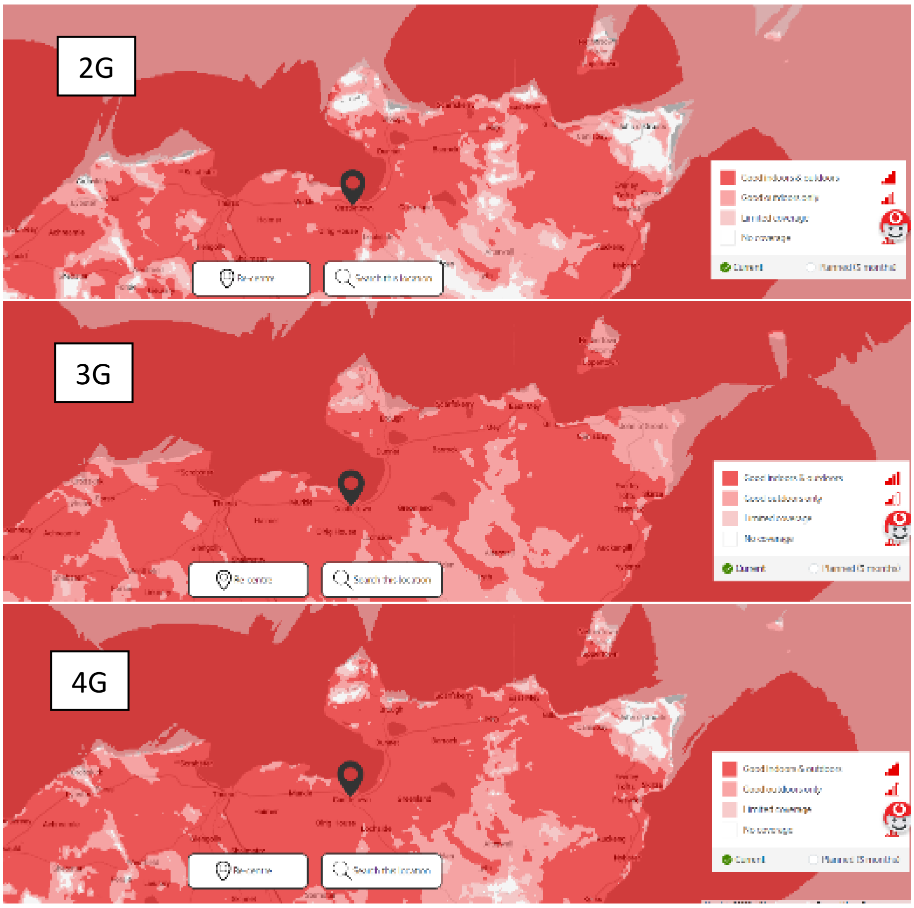


Figure 45 GSM network coverage for North Caithness Cliffs SPA taken from [Vodafone's status checker website]

Copinsay

Existing data

Kittiwake

GPS tagging of kittiwake took place on Copinsay as part of the FAME and STAR projects between 2010 and 2014 (Table 31). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 31 Kittiwake tagging protocol in Copinsay SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU	15	Taped to back feathers	1-2	1 min 40 sec	11
2011	Noose pole	IgotU	15	Taped to back feathers	1-2	1 min 40 sec	7
2012	Noose pole	IgotU	14.2	Taped to back feathers	2-3	1 min 40 sec	8
2014	Noose pole	IgotU	15.3	Taped to back feathers	2-3	1 min 40 sec	3

Guillemot

GPS tagging of guillemot took place on Copinsay as part of the FAME and STAR projects in 2012 and 2014 (Table 32). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 32 Guillemot tagging protocol in Copinsay SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2012	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	4
2014	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	5

Razorbill

GPS tagging of razorbill took place on Copinsay as part of the FAME and STAR projects between 2010 and 2014 (Table 33). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 33 Razorbill tagging protocol in Copinsay SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU	15	Taped to back feathers	1-2	1 min 40 sec	1
2011	Noose pole	IgotU	17.7	Taped to back feathers	1-2	1 min 40 sec	1
2012	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	6
2013	Noose pole	IgotU	17.7	Taped to back feathers	1-2	1 min 40 sec	3
2014	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	3

Work planned for 2023

At present, there is no additional tagging work planned for Copinsay SPA during the 2023 breeding season. However, there is an intention to carry out a full census of all seabirds nesting on Copinsay in the 2023 breeding season.

Consideration for future work

Copinsay is only accessible by boat and RSPB, who own the site, have a reliable contact who can provide this facility. Whilst there are no facilities on the site, it is possible to camp.

There are good options for tagging kittiwake, great black-backed gull and razorbill on Copinsay. However, both kittiwake and great black-backed gull appear to have been impacted by HPAI. The cliff nesting kittiwakes should be easily accessible for tagging purposes, with a good number of nests also visible from a distance for the purposes of monitoring any potential device effects. However, the population has declined substantially since the previous tagging work carried out as part of the FAME project, from about 7000 pairs to around 1000 pairs in recent years.

There are 16 apparently occupied territories for great black-backed gull on the flat, maritime grassland of Copinsay, with additional birds present on small islands to the west of Copinsay which accessible at low tide. Some of these birds are catchable, and should be visible at a distance for the purposes of monitoring device effects.

Razorbills nest in the boulder fields on the island and would be very accessible for the purposes of tagging. In contrast, the guillemots nest on cliffs in areas which whilst accessible by boat, would prove challenging to monitor for any device effects.

GSM Network coverage on Copinsay is poor (Figure 46), meaning that a remote download base station is likely to be required for data retrieval.

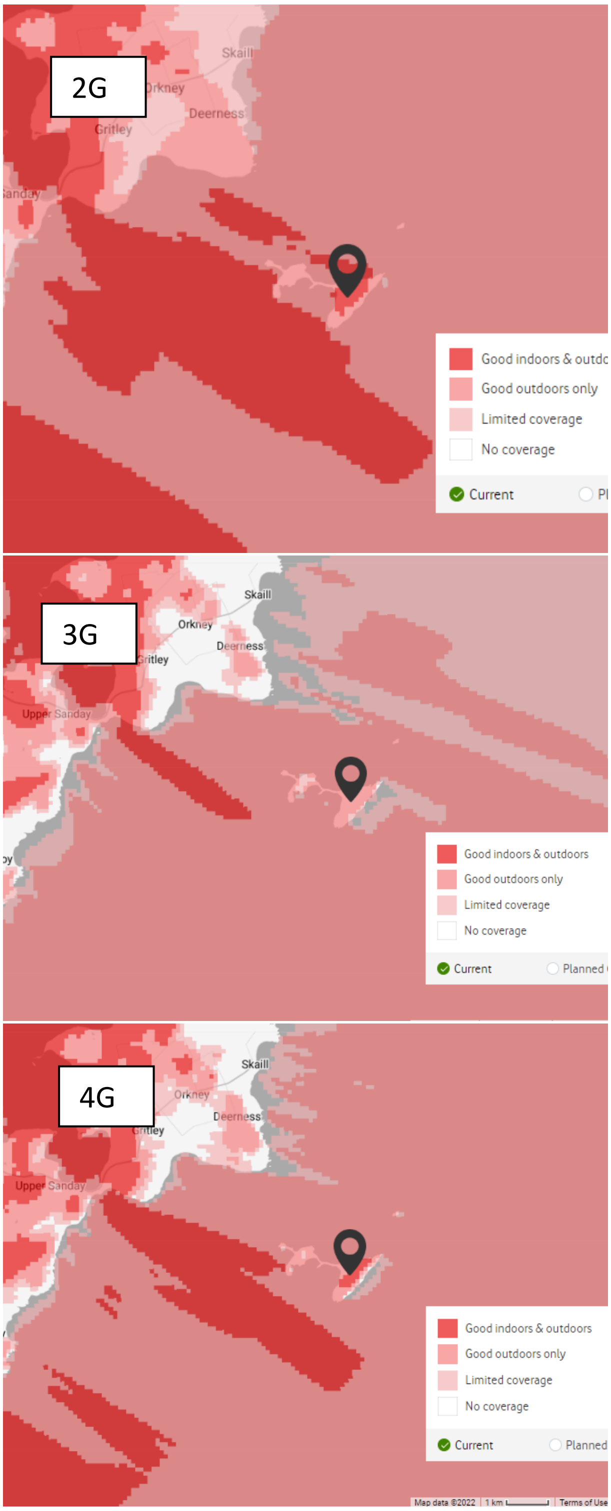


Figure 46 GSM network coverage for Copinsay taken from [Vodafone's status checker website]

Fair Isle

Existing data

Kittiwake

GPS tagging of kittiwake took place on Fair Isle as part of the FAME and STAR projects between 2010 and 2014 (Table 34). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 34 Kittiwake tagging protocol in Fair Isle SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2010	Noose pole	IgotU	15	Taped to back feathers	1-2	1 min 40 sec	2
2011	Noose pole	IgotU	15	Taped to back feathers	1-2	1 min 40 sec	4
2012	Noose pole	IgotU	14.2	Taped to back feathers	1-2	1 min 40 sec	5
2014	Noose pole	IgotU	15.3	Taped to back feathers	1-2	1 min 40 sec	2

Geolocators were deployed on kittiwakes on Fair Isle as part of a project to investigate the over winter distribution of birds from multiple colonies (Bogdanova et al., 2017; Frederiksen et al., 2012) (Table 35).

Table 35 Geolocators recovered from kittiwakes within the Fair Isle SPA.

Years deployed	Number of geolocators recovered
2017-2020	15

Guillemot

GPS tagging of guillemots took place on Fair Isle as part of the FAME and STAR projects between 2010 and 2014 (Table 36). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 36 Guillemot tagging protocol in Fair Isle SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2011	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	3
2012	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	7
2013	Noose pole	IgotU	17.7	Taped to back feathers	5	1 min 40 sec	1
2014	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	5
2015	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	2

As part of a recent project to investigate wintering movements of guillemots (Buckingham et al., 2021), geolocators have been deployed on birds within the Fair Isle SPA (Table 37).

Table 37 Geolocators recovered from guillemots within the Fair Isle SPA.

Years deployed	Number of geolocators recovered
2017-2020	15

Razorbill

GPS tagging of razorbills took place on Fair Isle as part of the FAME and STAR projects between 2010 and 2014 (Table 38). Birds were captured using a noose pole and tags were deployed by taping them to back feathers.

Table 38 Razorbill tagging protocol in Fair Isle SPA

Year	Capture method	Tag type	Average tag weight (g)	Attachment method	Tracking duration (days)	Sampling schedule	Number of birds
2011	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	22
2012	Noose pole	IgotU	17.7	Taped to back feathers	2-3	1 min 40 sec	23
2013	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	8
2014	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	17
2015	Noose pole	IgotU	17.7	Taped to back feathers	3-4	1 min 40 sec	7

As part of a recent project to investigate wintering movements of razorbills (Buckingham et al., 2021), geolocators have been deployed on birds within the Fair Isle SPA (Table 39).

Table 39 Geolocators deployed on guillemots within the East Caithness Cliffs SPA.

Years deployed	Number of geolocators recovered
2017-2020	11

Work planned for 2023

At present, there is no tagging work planned on the focal species on Fair Isle during the 2023 breeding season.

Consideration for future work

The landowner for Fair Isle is the National Trust for Scotland, who would need to be approached in relation to permission for any proposed tagging work. There is a boat available to help with access to some of the more sheltered bays and offshore islands. Reconstruction of the bird observatory, which may be available to provide accommodation for field staff, is underway.

Whilst both gannets and great skuas on Fair Isle have been affected by HPAI, none of the other seabird species showed obvious signs of the disease during the 2022 breeding season. Gannet ringing on Fair Isle has stopped due to health and safety concerns, meaning tagging projects are not feasible on this species. As with Copinsay, kittiwake populations have undergone substantial declines with roughly 1,400 birds present in 2010, down to 450 birds in 2021. Furthermore, the majority of these birds are present in study plots and it is likely that the wardens and National Trust for Scotland would be extremely reluctant to permit any tagging work on these birds. Consequently, as with gannets, tagging of kittiwakes on Fair Isle is unlikely to be feasible.

In 2021, there were approximately 18,000 guillemots and 2,000 razorbills nesting in a mixture of cliffs and boulder beaches. The East coast of Fair Isle is more reliably accessible than the West coast, with boulder beach colonies of mixed auks at the Ramnigeos, and smaller razorbill colonies at Mavers Geo and Busta Geo (Figure 47). These would all be visible from cliff tops using a scope for the purposes of monitoring potential device effects.

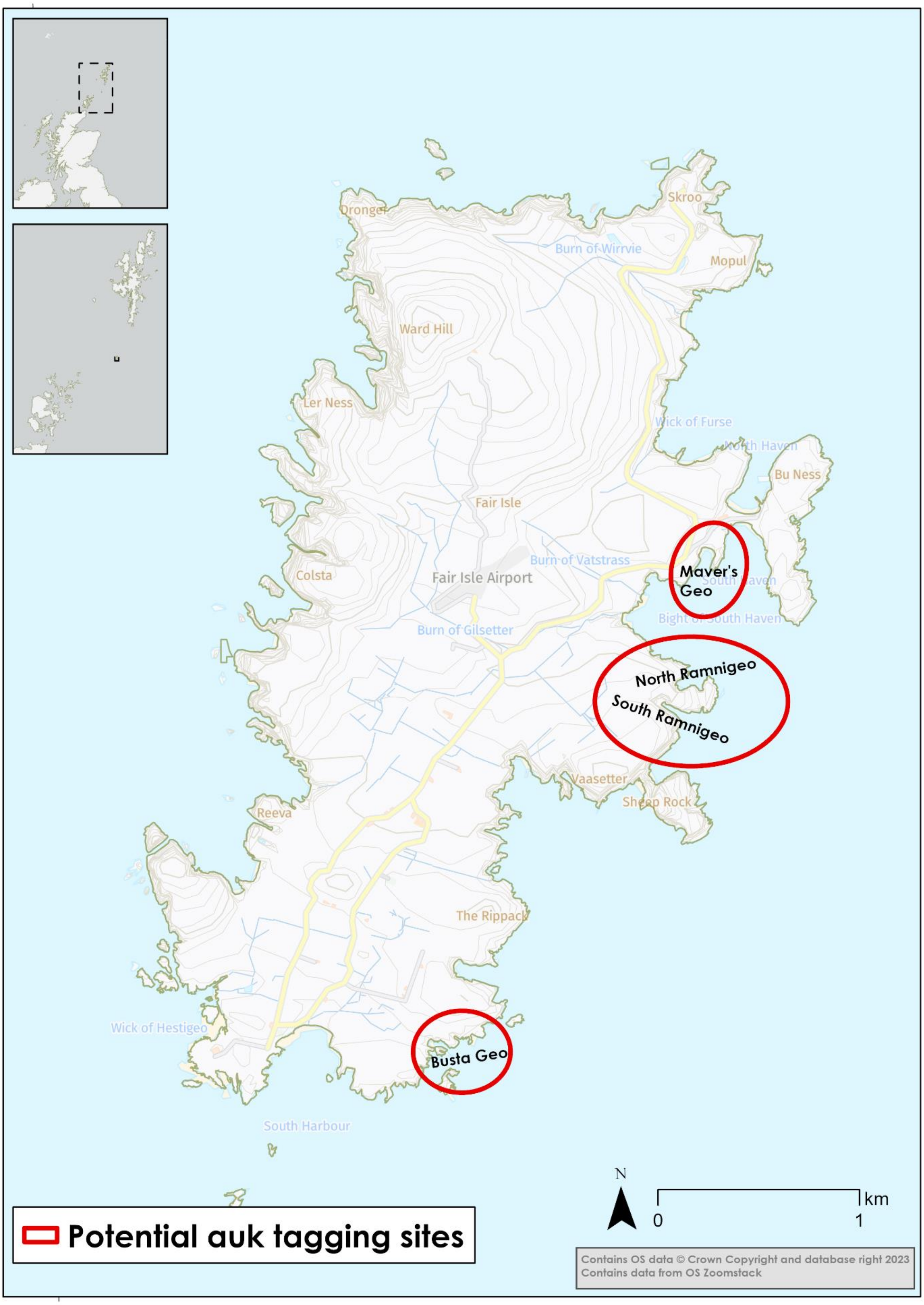


Figure 47 Map of Fair Isle, with potential auk tagging sites at Busta Geo, Mavers's Geo and North and South Ramnigeo highlighted.

GSM network coverage is patchy, particularly around the coasts (Figure 48), in areas where the majority of birds are located. Consequently, a remote download base station is likely to be required for data retrieval.

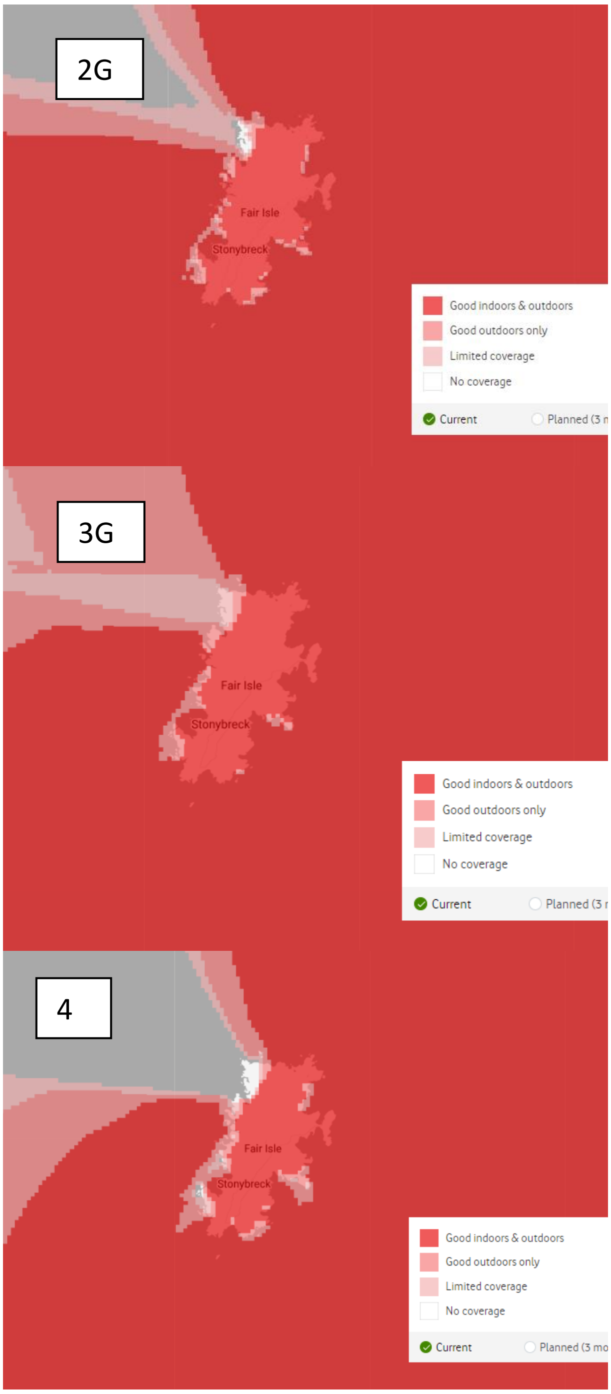


Figure 48 GSM network coverage for Fair Isle taken from [Vodafone's status checker website]

Conclusion and Recommendations

Data from tagging projects offer the potential to significantly reduce the uncertainty associated with assessments of the impacts of offshore wind farms on seabird populations. This relates to both a better understanding of the distribution of the species concerned, and a better understanding of how birds may interact with wind farms, and therefore the potential risks posed by collision and displacement. Consequently, new tracking data, both from the breeding and non-breeding seasons, will be valuable for helping to determine whether projects proposed for Plan Options NE2-NE6 and E3 can be released from the highest levels of ornithological constraint, as well as improving the evidence base available for impact assessments in these and other regions.

Extensive tracking data have been collected from colonies on the Scottish East coast of relevance to the ScotWind Plan Options. However, since the FAME and STAR projects were carried out between 2010 and 2015, the focus for much of this work has been colonies in and around the Firth of Forth in support of offshore wind farm developments proposed for that region. A key exception to this has been a geolocator study carried out at multiple sites between 2017 and 2020 on guillemots and razorbills (Buckingham et al., 2021). Consequently, there is a lack of more recent data for SPAs further north, which are of more relevance to the projects proposed as part of ScotWind.

Work proposed for Fowlsheugh and Buchan Ness to Collieston Coast SPAs in the 2023 breeding season will help to fill some of the data gaps, though additional data are required from sites further to the North. However, additional visits are required to these sites during the 2023 breeding season, both to confirm the availability of accessible nests, and to assess the feasibility of tagging work following the 2022 HPAI outbreak and any subsequent outbreaks in 2023. Following an initial assessment of sites in autumn 2022, colonies within East Caithness Cliffs and Copinsay SPAs should be prioritised for these assessments, with a view to carrying out tagging at these sites in the 2024 breeding season. Tagging work at Troup, Pennan and Lion's Heads SPA may be less feasible, though viewing the site from the sea during the 2023 breeding season would be valuable to confirm this. Similarly, a visit to Stroma, within the North Caithness Cliffs SPA, would also be valuable.

Any future projects, in addition to those planned for the 2023 breeding season, will require substantial planning time. Tag orders should be placed by December in the year before planned summer deployment in order to allow sufficient time for the delivery, testing and programming of any devices. This will require discussion of key study objectives (e.g. purely distribution data, or behavioural data such as flight heights in addition) well in advance of this so that an optimal solution can be agreed between the contractor(s) and their funder(s). Careful consultation and collaboration with other researchers carrying out related tracking work should be strongly encouraged to ensure the greatest value can be obtained from any data.

Of the species considered in this review, substantial GPS tracking work is already taking place on gannets at the Bass Rock. Capturing gannets within either the Troup, Pennan and

Lion's Heads SPA, or the Fair Isle SPA does not appear feasible. Consequently, it is recommended that no additional tracking work at either site is planned at the current time. Similarly, questions remain about the potential for device effects on both puffins and great black-backed gulls. Unless, and until, these questions can be satisfactorily addressed, it is concluded that GPS tracking data on these are unlikely to be available to support the ScotWind process. For future work, as set out in the Roadmap of Actions, exploring appropriate attachment methodologies for great black-backed gulls should be a priority.

For the remaining species, ensuring sufficient data are collected to characterize colony home ranges during the breeding season should be a priority. Sample size analysis suggests that increasing deployment duration is a key part of generating sufficient power to enable this. Consequently, archival GPS tags are not recommended and, given the patchiness of GSM Network coverage at many of the proposed field sites, tags that download data remotely to a base station are recommended. Such tags can potentially collect data for periods ranging from one month to in excess of a year (Figure 49). However, possible attachment methodologies for kittiwake, guillemot and razorbill mean that generating sufficient data to characterize home ranges in a single year is likely to be extremely challenging (Figure 49). This is not necessarily a problem given that recent analyses have highlighted that data collected across multiple years can provide a robust assessment of a species home range in relation to its breeding colony (Beal et al., 2023). Recommendations for GPS deployment on each species are as follows:

- Herring gull – GPS VHF with body harness
- Kittiwake – GPS VHF with tail mount and further trials of glue-mounting to birds' back to facilitate longer deployment
- Guillemot – GPS VHF back-mounted with Tesa tape
- Razorbill – GPS VHF back-mounted with Tesa tape

Tags should be deployed in the late incubation/early chick-rearing stage (Figure 49) to minimise the risk of desertion. Careful consideration should be given to deploying devices such as Time-Depth Recorders and altimeters alongside the GPS tags to collect additional behavioural data.

For geolocators, estimated wintering distributions did not reach a plateau, although analyses suggested they were levelling off when in excess of 30 geolocators were retrieved. Previous studies highlight that retrieval rates can vary between species, and may be lower for razorbills than is the case for guillemots (Buckingham et al., 2021). Such differences should be taken into account when planning geolocator studies. Whilst additional geolocator data for guillemots and razorbills would be valuable, the lack of a large-scale geolocator study to determine kittiwake non-breeding season distributions for Scottish breeding colonies mean this species should be prioritised. Tags should be mounted on leg rings and, as with GPS tags, deployed during the chick rearing period to minimise the risk of desertion. Tags should then be retrieved the following breeding seasons.

All existing and future tagging studies must be licensed by the SMTP and secure licences and permissions from NatureScot and local landowners where appropriate. All guidance put in place in response to HPAI must be followed and due consideration given to all aspects of Health & Safety during fieldwork.

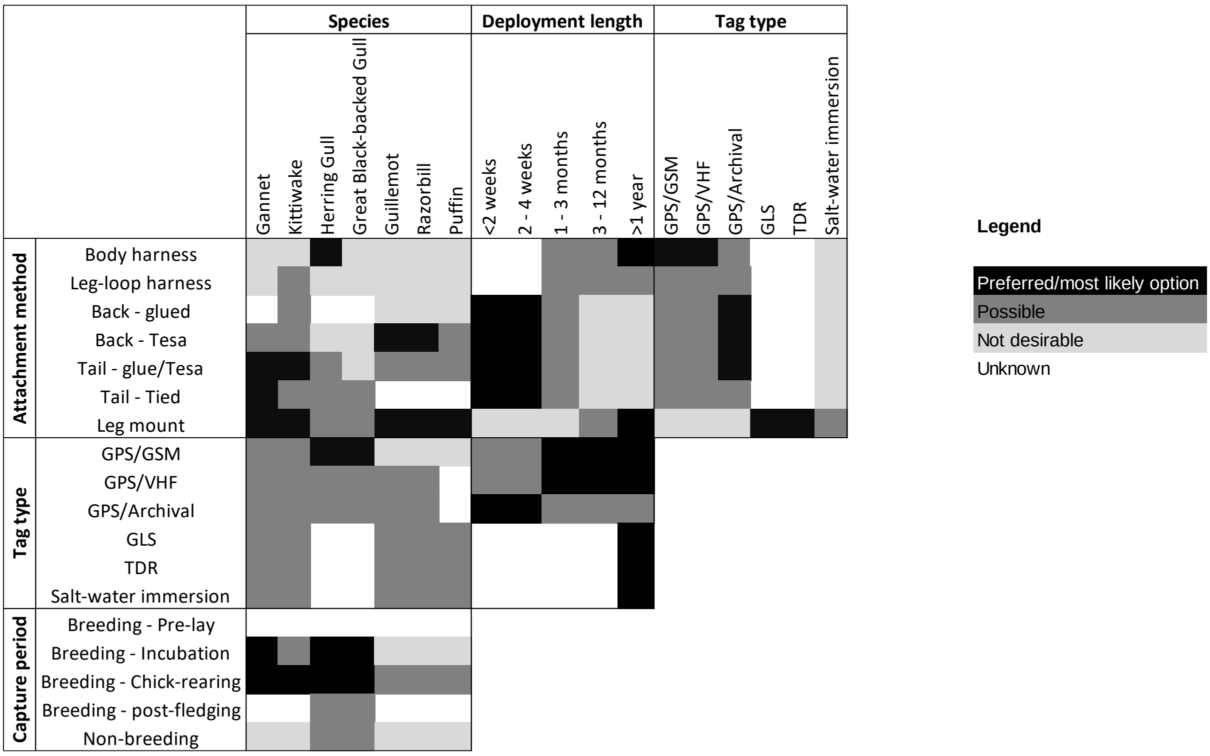


Figure 49 Decision matrix for species, tag types, attachment methodologies and deployment lengths.

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Appendix 1: Device manufacturers and tag types

Table A1. Potential device manufacturers and available models. Data collected (*optional extra): A) XY location; B) Date/Time; C) Instantaneous speed; D) GPS altitude; E) Air pressure; F) Water pressure/dive-depth; G) Temperature; H) Triaxial acceleration; J) Magnetometry; K) Light Intensity; L) Dive duration; M) Wet/dry or salt water immersion; N) Gyroscope

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging?	Geofence?
Ornitela	www.ornitela.com	OrniTrack-9, -10, -15, 20, 25	GPS/ GSM	10 - 25	37×19×12 to 61×25×20	Harness or glue to back	GANNE, HERGU, GBBGU, KITTI	A,B,C,D, G,H,J,K, *E	1 second to 10 days	*€880 - 1230 with 20% discount for >20 units	Yes	Yes

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging?	Geofence?
Ecotone Telemetry	https://en.ecotone.com.pl/,4,35.html	GPS-UHF (SRD) loggers	GPS/ UHF	5 - 15	26×16×10 to 38×23×19	Harness, glue or Tesa tape to back	All review species	A,B,C,D,L, *F,*G,*M	1 - 240 min	*No - option to 'Ask about price'	Yes	No
	https://en.ecotone.com.pl/,4,35.html	GSM-GPRS-UHF (LRD) loggers	GPS/ GSM	14 - 38	39×23×18 to 81×37×38	Harness, glue or Tesa tape to back	GANNE, HERGU, GBBGU	A,B,C,D, H,L, *E,*F, *G, *M	1 min - 24 hour	*No - option to 'Ask about price'	Yes	No
Movetech Telemetry	Movetech-telemetry.com	Flyway loggers	GPS/ GSM	18 - 50	57.5×26.5×14.5 to 87×40×30	Harness, glue or Tesa tape to back	GANNE, HERGU, GBBGU	A,B,C,D, G,H,	1 min - 10 day	£750 + VAT	Yes	No

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging ?	Geofence?
Techno Smart Collaborating with Milsar for GSM units	https://www.technosmart.eu/products/	Axy-5 models and AGM	Accelerometer/ Archival	2.5 - 4.5 to 60	15×10×4 to 22×13×10 to 70×41×14	Harness, glue or Tesa tape	All review species	G,H,J, *N,*E,*F	1 to 100 Hz	*No	No	No
	https://www.technosmart.eu/products/	Axy-trek mini and marine	GPS/ Archival	4.5 - 6 and 14 - 59	22×13×10 to 40×20×8 to 69×40×14	Harness, glue or Tesa tape	GANNE, KITTI, GUILL, RAZOR, PUFFI	A,B,G,H, *F,*K,*M	8 or 10 bits	*No	No	No
	https://www.technosmart.eu/products/	Axy-trek remote and Gipsy	GPS/ UHF or GPS/ GSM	9 - 59	24×14×10to 69×40×14	Harness, glue or Tesa tape	All except PUFFI	A,B,G,H, *F,*J,*K, *M, *N	8 or 10 bits	*No - possible similar to Milsar	Yes	No
Lotek / Biotrack	Lotek.com	LAT or ARCGEO	TDR/ Archival	7	11×38 to 13×44	Leg	GANNE, KITTI, GUILL, RAZOR	B,F,G,K, M	10 secs +	No	No - long-term battery	No

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging ?	Geofence?
	Lotek.com	LAT or ARCGEO	GLS + TDR/ Archival	6.2 - 10.6 or 3.4	11×38 to 13×44 or 21×9×9	Leg	GANNE, KITTI, GUILL, RAZOR, PUFFI	B,F,G,K, M	10 secs +	£100 - 120	No - long-term battery	No
	https://www.lotek.com/products/mk-geolocators/	MK3	GLS	<3	21×9×9	Leg	GANNE, KITTI, GUILL, RAZOR, PUFFI	B,G,K,M	10 secs +	£115 to £130 +VAT + £185 for software interface	No. 2-5 year lifespan	No
	Lotek.com	PinPoint VHF 240 / 350	GPS/ VHF	8 - 10 or 16-17	55×17×11	Tesa tape, glue or harness	GANNE, HERGU, GBBGU, GUILL, RAZOR	A,B,G,H	~5,500 positions	£1,072 per unit + VAT. + £735 base station + £215 download software	No	No
Milsar	milsar.com	NanoRadio Tag-3	GPS/ UHF	3.5	~25×10×10	Harness or glue	HERGU, GBBGU, KITTI	A,B,C,D	?	*€1000 + €1000 basestation	Yes	Yes
	Lotek.com	GsmTag-U9	GPS/ GSM and/or UHF	9.5 - 16	17×17×33 to 38×15×20	Harness or glue	HERGU, GBBGU, KITTI	A,B,C,D, G,H,J,N	5 min +	*€1350 + €60 GSM fee	Yes	Yes

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging?	Geofence?
Migrate Technology	migratetech.co.uk	Intigeo-W65A9-SEA or Intigeo-C65 or -C330	GLS	0.7 - 3.3	15×6×6 or 14×8×6 or 17×19×8	Leg	GANNE, KITTI, GUILL, RAZOR, PUFFI	B,K *G,*M	1 min	£100 - 120	No - long-term battery	No
PathTrack	pathtrack.co.uk	nanoFix-GEO+ RF	GPS/ UHF	4+	43x15x13	Harness or glue	HERGU, GBBGU, KITTI, GUILL, RAZOR	A,B,D, *M	5 min +	No	Yes	No
Druid Technology	druid.tech/en	Ultra	GPS/ GSM	1.4 - 3	19×14.5×6.8	Harness or glue	HERGU, KITTI	A,B,G,H, K	1 hour	*$999 - 1999	Yes	No
	druid.tech/en	Debut - Lego	GPS/ GSM	18.7	68×21×16	Harness	HERGU	A,B,G,H, K	1 min - 1 hour	*$499- 899	Yes	Yes
Interrex - same products as Druid Tech	interrex-tracking.com	Interrex	GPS/ GSM	8.4 - 9.8	43×25×12 to 43×25×30	Harness or glue	HERGU, KITTI	A,B,D,G, H,K,	5 min - 1 day	No - Druid Tech price = $899	Yes	No
	interrex-tracking.com	Omni	GPS/ GSM	10.2 - 15.2	50.8×24.2×12.8 to 51×24.2×20.4	Harness of glue	HERGU, KITTI	A,B,D,G, H,K	5 min - 1 day	No - Druid Tech price = $899		No

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging ?	Geofence?
UvA	https://www.uva-bits.nl/system/	UvA-BiTS	GPS/ VHF	7.2 - 22.5	57.5×26.5×14.5	Harness	HERGU, GBBGU	A,B,H, *E	1 sec +	*No	Yes	Yes
Microwave Technology	microwavetelemetry.com	GPS/GSM 20-70	GPS/ GSM	20 - 70	64×23×17 + antenna	Harness or glue	GBBGU	A,B,C,D, G	1 min +	*$3950 + $30 GSM fee	Yes	No
	microwavetelemetry.com	Solar Argos/ GPS PTTs	GPS/ PTT	17 - 70	62×17×17 to	Harness or glue	HERGU, GBBGU	A,B,C,D	1 min - 2 hour variable on battery	*$3650 - 4200	Yes	No
Global Messenger	http://en.hqxs.net/Default.html	HQBV0702	GPS/ VHF	2.2	7×12×18	Harness, possibly glue	HERGU, GBBGU (not dive proof)	?	4 hour - 12 hour	*No	Yes	No
	http://en.hqxs.net/Default.html	HQBG0804	GPS/ GSM	4.5	9×18×22.5	Harness, possibly glue	HERGU, GBBGU, KITTI (dive proof to 10m)	?	5 min +	*No	Yes	No
	http://en.hqxs.net/Default.html	HQBG1206	GPS/ GSM	6.7	12×20×32	Harness, possibly glue	HERGU, GBBGU, KITTI (dive proof to 10m)	?	4 hour	*No	Yes	No

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging?	Geofence?
	http://en.hqxs.net/Default.html	HQBG2009P	GPS/GSM	9	16×21×35	Harness, possibly glue	HERGU, GBBGU, KITTI (dive proof to 10m)	?	2 hour	*No	Yes	No
	http://en.hqxs.net/Default.html	HQBN2210	GPS/GSM	10	22×22×47	Harness, possibly glue	HERGU, GBBGU (dive proof to 10m)	?	5 min +	*No	Yes	No
	http://en.hqxs.net/Default.html	HQBG1512S	GPS/GSM	13	15×19×48	Harness, possibly glue	HERGU, GBBGU (dive proof to 10m)	?	1 hour	*No	Yes	No
i -gotU	https://www.amazon.com/i-gotU-GT-120-Travel-Logger-Software/dp/B001IMJV0E	GT120	GPS/Archival	~18	44.5×28.5×13	Tesa tape	GANNE, KITTI, GUILL, RAZOR	A,B	64,000 locations possible, 5 sec for 15hr to 1 hour for 2 months.	~$65 - 80	No	No

Tag Company	Website	Device name	Device type	Device weight (g)	Device size (mm)	Attachment method	Suitable for	Data collected	Data rate	Price on website (*subject to import	Solar recharging?	Geofence?
Debug Innovations Ltd	http://www.debuginnovations.com/mataki/home.html	Mataki-Lite	GPS/ VHF	3.5	34×21.75	Tesa tape	GANNE, KITTI, GUILL, RAZO, PUFFI	A,B,K	3184 locations possible	*No	No	No
	http://www.debuginnovations.com/mataki/home.html	Mataki-Classic	GPS/ VHF	10 +battery	44×21.75	Tesa tape	GANNE, KITTI, GUILL, RAZOR	A,B,E,G,K	932066 locations possible	*No	No	No
Cefas	https://www.cefastechnology.co.uk/products/data-storage-tags	CEFAS G5	TDR	2.7 - 6.5	8×31 or 12×36.5	Leg	GANNE, KITTI, GUILL, RAZOR, PUFFI	B,G,F,*L, *M	10 Hz	£280 + VAT for 10+ to £230 + VAT for 50+ Plus also £120 + VAT for unit to connect device to PC.	No	No

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