

An exploratory telemetry study to assess distribution and habitat use of European Shags at Inishtrahull and Inishmurray SPAs.

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Executive summary

Telemetry data can facilitate exploring movement ecology and animal behaviour in a changing environment, as well as providing valuable insight about ecological traits. In this report, we analyse GPS tracking data and time-depth data from build-in sensors to describe the spatial distribution and habitat use of the European Shag, a coastal seabird species breeding across several islands in Ireland. The study focuses on exploring and analysing results from tagged individuals breeding in Inishtrahull and Inishmurray SPAs, aiming to identify important areas for the study species. For both colonies, we defined the home range and main core areas, and contrasted dive depth with oceanographic features. Individuals from Inishtrahull used foraging grounds located near the colony during chick-rearing. Dive depth did not differ significantly across substrate types, although most diving activity occurred over sandy substrate, and seabed relief did not appear to be relevant. In contrast, individuals tagged at Inishmurray showed a broader spatial distribution, using different foraging grounds and exploited a wide range of water depths. Significant differences in dive depth were found across substrates, with deeper dives over rocky substrates. In areas near the mainland, where substrate could not be classified, dives were consistently shallow mostly in areas off the coastline. Additionally, exploration of bathymetry and seabed relief showed potential preference for sloping terrain, depth contrasts over rocky substrate, and those marine areas with intermediate to deep waters. Overall, telemetry data identified marine areas of relative importance for the European Shags and explored the spatial distribution and habitat use for both colonies. By contrasting diving activity with oceanographic features such as substrate type and bathymetry, we assessed potential drivers of habitat selection, which turn, may be used to inform conservation planning.

Key words: European Shag, telemetry data, foraging areas, home range, spatial distribution, seabed substrate, bathymetry, TDR data, diving activity.

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Introduction

Understanding how animals interact with their environment can be improved using high-resolution tracking technologies. Advances in telemetry, remote sensing, and build-in sensors provide an improved way to explore animal movement and behaviour in more accurate spatial and temporal scales. These devices provide valuable information into how individuals use space, select habitats, and interact to oceanographic conditions.

Tracking data is particularly important for understanding the spatial distribution and identifying key foraging areas. When combined with depth information, such data can reveal detailed patterns of behaviour and habitat use, especially when studying the ecology of diving species. Therefore, the use of these technologies is highly relevant for conservation planning and site protection, especially when these are informed by understanding how species use the marine environment.

In this report, we focus on the European Shag *Gulosus aristotelis*, a coastal diving seabird breeding across several Irish islands and listed as a qualifying interest for multiple Special Protection Areas (SPAs), where the species occur on numbers of national importance. Therefore, for effective conservation measures, improving the understanding of its marine habitat use is essential, particularly at those sites.

This study explores telemetry data from European Shags tagged at Inishtrahull SPA and Inishmurray SPA in 2022 and at Inishmurray SPA in 2023. By analysing tracking data together with dive data from build-in pressure sensors, we aim to:

- (1) Describe the spatial distribution of birds breeding at these two SPAs;
- (2) Identify their home ranges and core areas, including those extending beyond existing SPA boundaries; and
- (3) Examine how oceanographic features define their habitat use, which may contribute to identifying marine areas of relative importance for breeding shags, while supporting conservation planning.

Methodology

Descriptions of the study species and the colonies included in this work are provided in Colhoun et al. (20XX) for the 2022 tracking, and in Colhoun et al. (2024) for the 2023 study. Additional details on device configuration, deployment procedures, and data retrieval methods are also available in those reports.

Data preparation

For each colony, telemetry data were processed using RStudio (RStudio 2025.09.2), following an adapted script based on the methodology in Saldanha et al. The resulting outputs were organised into three work packages:

1. Tracking data (GPS).

Containing (a) metadata from tagged individuals, (b) a cleaned tracking dataset obtained from the original files, and (c) a tracking dataset with 5-min interpolated positions.

2. Accelerometry data.

Containing cleaned accelerometry data merged with GPS positions.

3. Time-Depth Recorder data (TDR).

Containing (a) the original TDR data, (b) TDR data with accelerometry data and GPS positions, (c) TDR data with GPS positions, and (d) a summary of TDR data and selection of smoothed diving activity.

All mapping outputs were produced in QGIS (3.40.10-Bratislava) and organised in a GeoPackage, with all stored data projected in IREN95 / Irish Transverse Mercator (EPSG:2157).

Data analysis

TDR data

We analysed and summarised TDR data using the R package *diveMove* and attempted to correct pressure sensor shifts. Diving events were calibrated using the smoothing model *smooth.spline*, and dives were defined as minimum depth recordings of 1 m. Diving events longer than 100 seconds were discarded to align with the biological capacities of the study species and to remove outliers caused by potential pressure sensor shifts.

Spatial distribution

We explored the tracking data in QGIS and selected all GPS locations outside the SPA to assess spatial distribution beyond its boundaries. To calculate kernel densities, we used the R package *adehabitatHR*. We applied the “href” smoothing factor, a grid of 1000 for generating the kernel unit densities, and the functions “kernelUD” and “getverticeshr” to obtain kernel contours. Home range (95% kernel density) and core areas (50% kernel density) were defined for each colony, and the estimated areas were calculated in hectares (ha) using the QGIS function *area*.

Habitat use

To analyse habitat use and preferred foraging grounds across colonies, we assigned the seabed substrate type to each GPS location using QGIS, and selected depth data greater than 0.5m as an indicative of foraging activity. We tested the normality of the depth data using a Shapiro-Wilk test and assessed significant differences in diving depths across substrates using a non-parametric Kruskal-Wallis test. A post-hoc test was used to determine which specific groups are different from each other. We generated a summary output with statistical parameters for each colony and substrate type and visually explored the results using the R package *ggplot2*.

Finally, we explored oceanographic features around each colony by comparing bathymetry and depth data to detect relevant features that could explain observed patterns.

Results

This report includes the results from telemetry data obtained in 2022 for 9 and 3 European Shag individuals from Inishtrahull and Inishmurray, respectively. In 2023, a further 5 European Shags were tagged in Inishmurray, and data for these individuals are also included.

Accelerometry data and GPS datasets with interpolated points were cleaned and prepared for future use in studies targeting energy expenditure or behaviour classification. The resulting files can be found and explored within the respective work package.

Spatial distribution

Tagged individuals from Inishtrahull primarily used areas surrounding the colony, with occasional movements to the mainland. The estimated home range extended 2,203 ha beyond the SPA boundaries, within which 293 ha were identified as core areas (Figure 1).

In contrast, the home range defined for the Inishmurray population in 2022 covered a larger area than that of Inishtrahull, extending 6,859 ha beyond the SPA boundaries. Core areas within this range were also substantially larger, covering up to 1,557 ha (Figure 2).

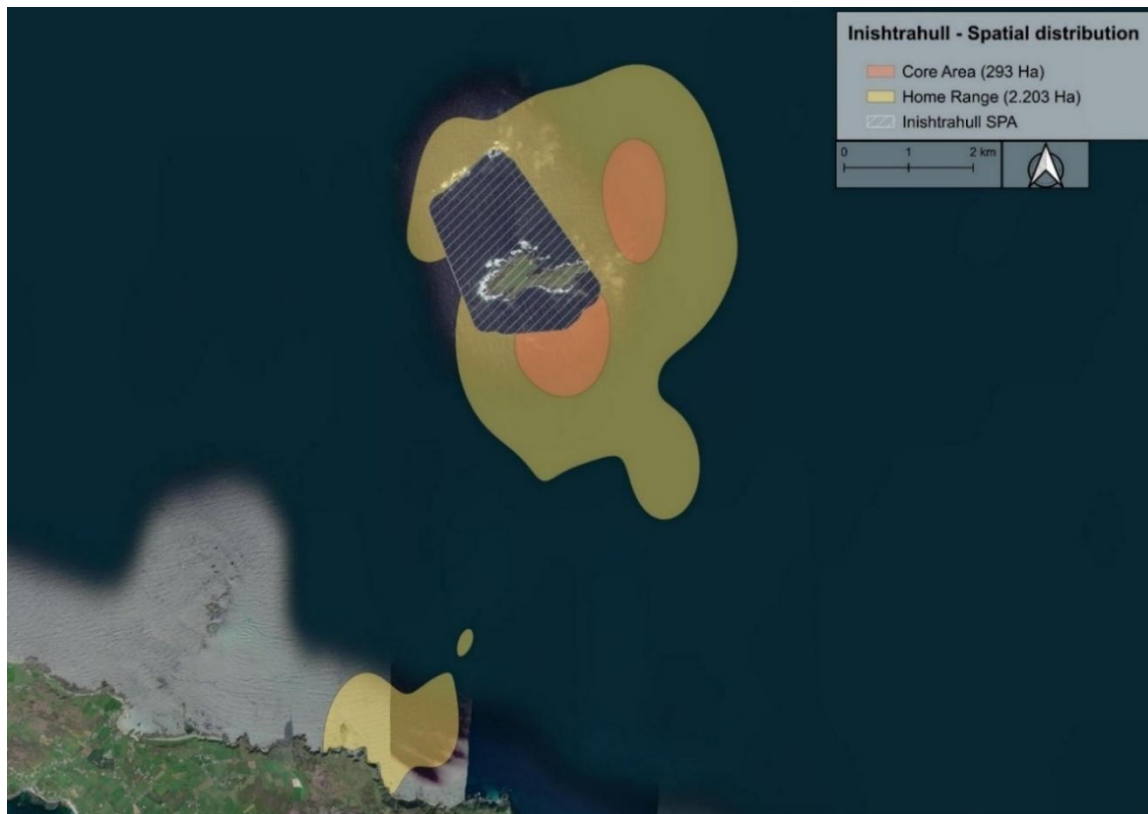


Figure 1: Home range and core areas beyond Inishtrahull SPA boundaries based on kernel densities obtained from tracking data. Map scaled at 1:60,000.

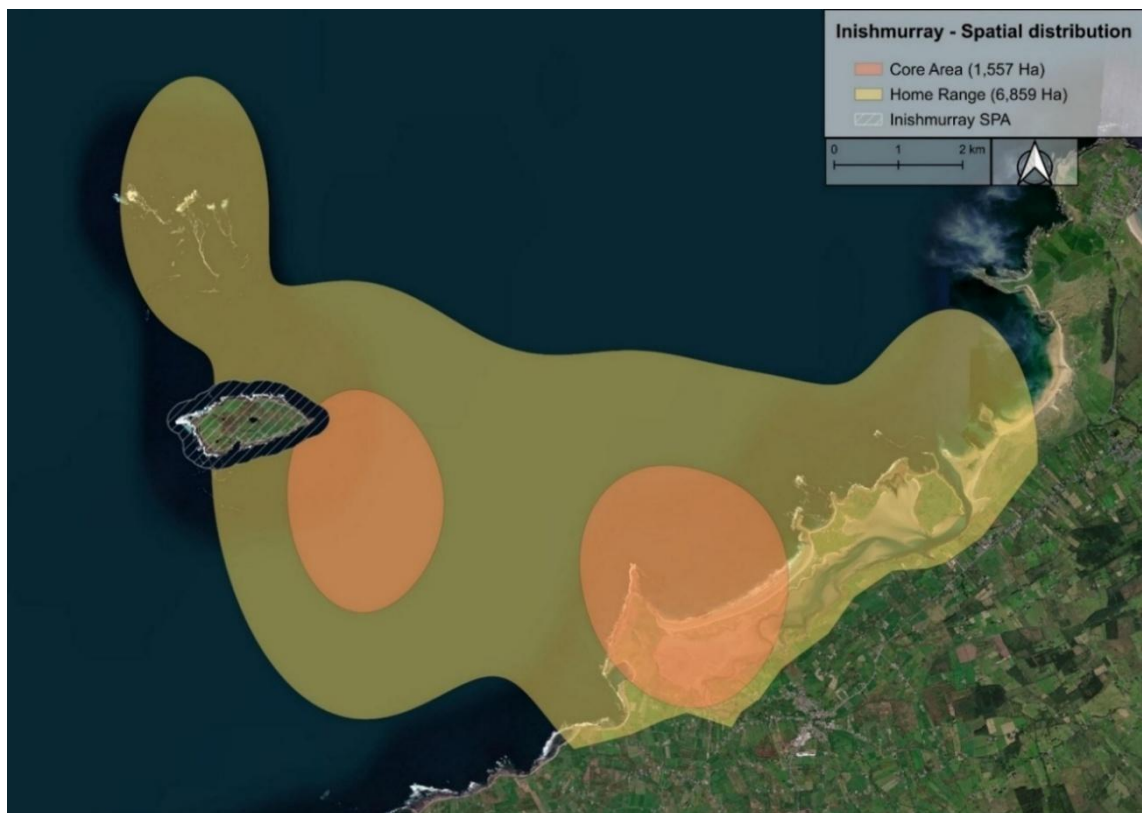


Figure 2: Home range and core areas beyond Inishmurray SPA boundaries based on kernel densities obtained from tracking data in 2022. Map scaled at 1:60,000.

In 2023, individuals from Inishmurray used similar areas as that of 2022, but with a wider distribution along the coastline and showed additional use of marine areas north of the colony. In this year, the home range extended over a larger area, reaching 14,149.8 ha beyond the SPA boundaries. Core areas within this range were also substantially larger, covering up to 4,050.4 ha (Figure 3).

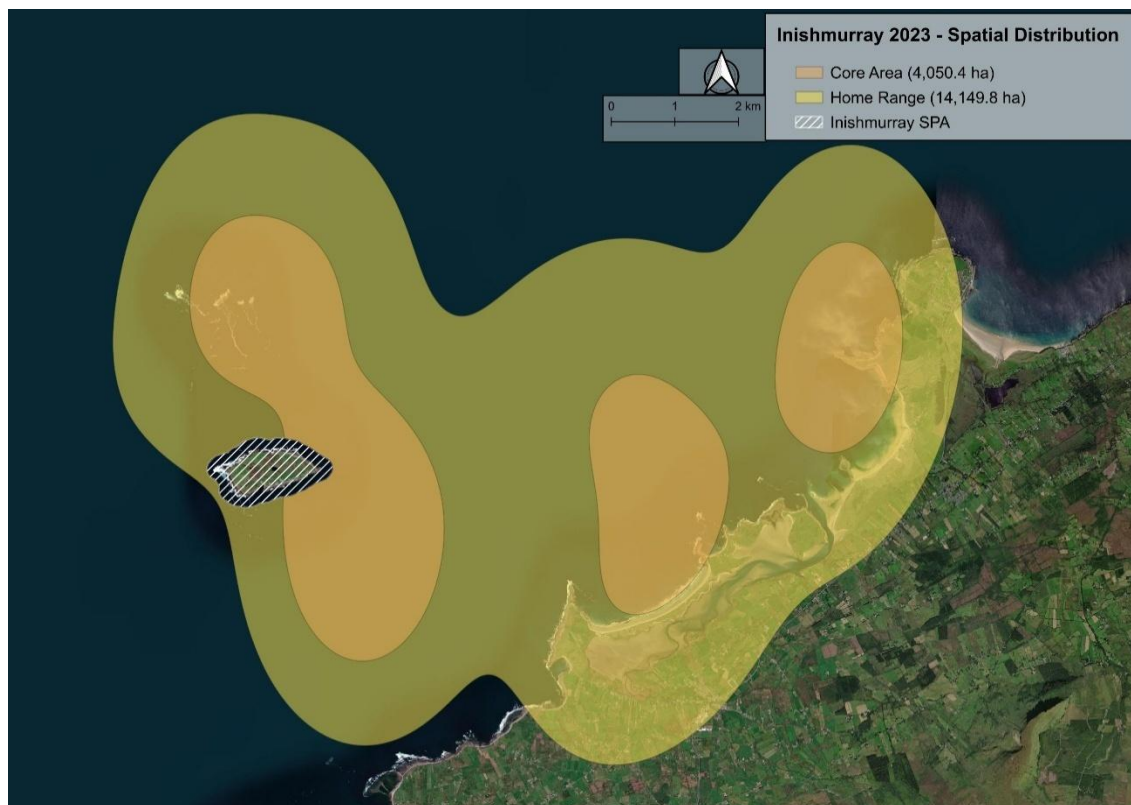


Figure 3: Home range and core areas beyond Inishmurray SPA boundaries based on kernel densities obtained from tracking data in 2023. Map scaled at 1:75,000.

Habitat use

Exploration of TDR data showed that, for both colonies, the core areas overlapped with the main foraging areas. European Shags from Inishtrahull used foraging areas near the colony and fed frequently in waters around 30 m deep, reaching maximum depths of 41 m. In contrast, individuals from Inishmurray travelled further and typically foraged in much shallower water around 4 m deep, although they reached depths up to 37.5 m. Results from the analysis of TDR data from individuals tagged in 2023 from Inishmurray, showed a wide range of depths. Most individuals foraged in waters around 15 m deep, with maximum dive depths reaching up to 52.7 m.

Assigning seabed substrate types to each GPS location revealed differences among colonies in habitat use and diving activity. Additional information on statistical tests and habitat use plots is provided in Appendix 1.

Inishtrahull

For Inishtrahull, there were no significant differences in diving depths across substrate types. The distribution of the observations recorded in each substrate type showed that most individuals foraged over sandy areas, followed by rocky substrate and coarse sediment (Table 1, Figure 4).

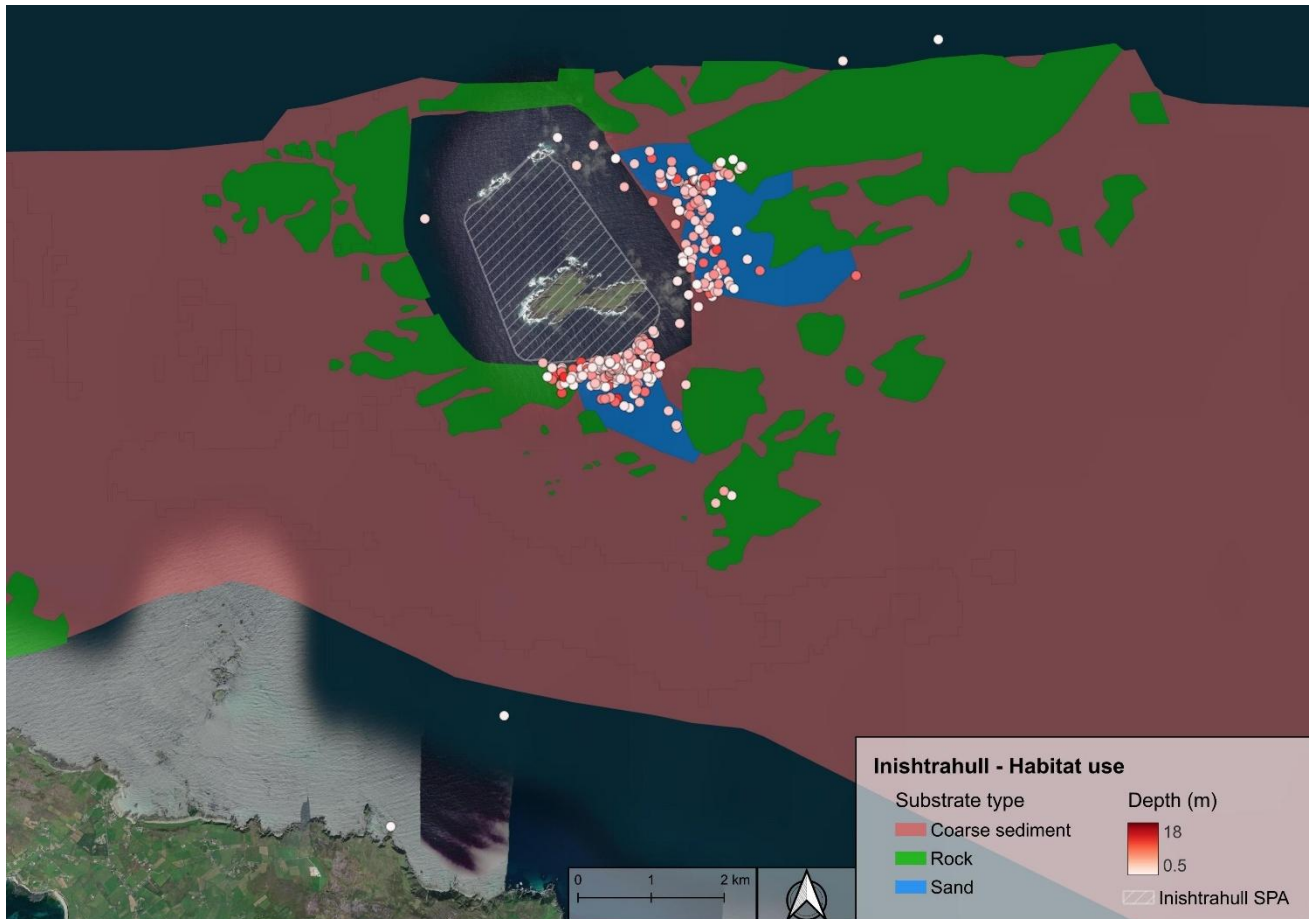


Figure 4: Seabed substrate types found in the surrounding area of Inishtrahull contrasted with GPS locations containing depth data from tagged individuals.

Table 1. Diving parameters for each seabed substrate in Inishtrahull.

Seabed Substrate	Num. Obs	Mean Depth (m)	SD($\pm$)	Min. Depth	Max. Depth
Coarse sediment	15	4.36	3.62	0.61	10.38
Rock	34	5.10	3.91	0.83	14.31
Sand	194	5.02	3.52	0.51	17.54

Note that these values are based on depth data linked to GPS locations, representing only a sample of the full diving activity recorded by the device.

Contrasting bathymetry with depth data revealed no clearly preferred seabed features, apart from the shallow-area relief near the colony. The deep channel between Inishtrahull and the mainland may serve as a potential flyway, connecting the colony with more distant foraging areas (Figure 5).

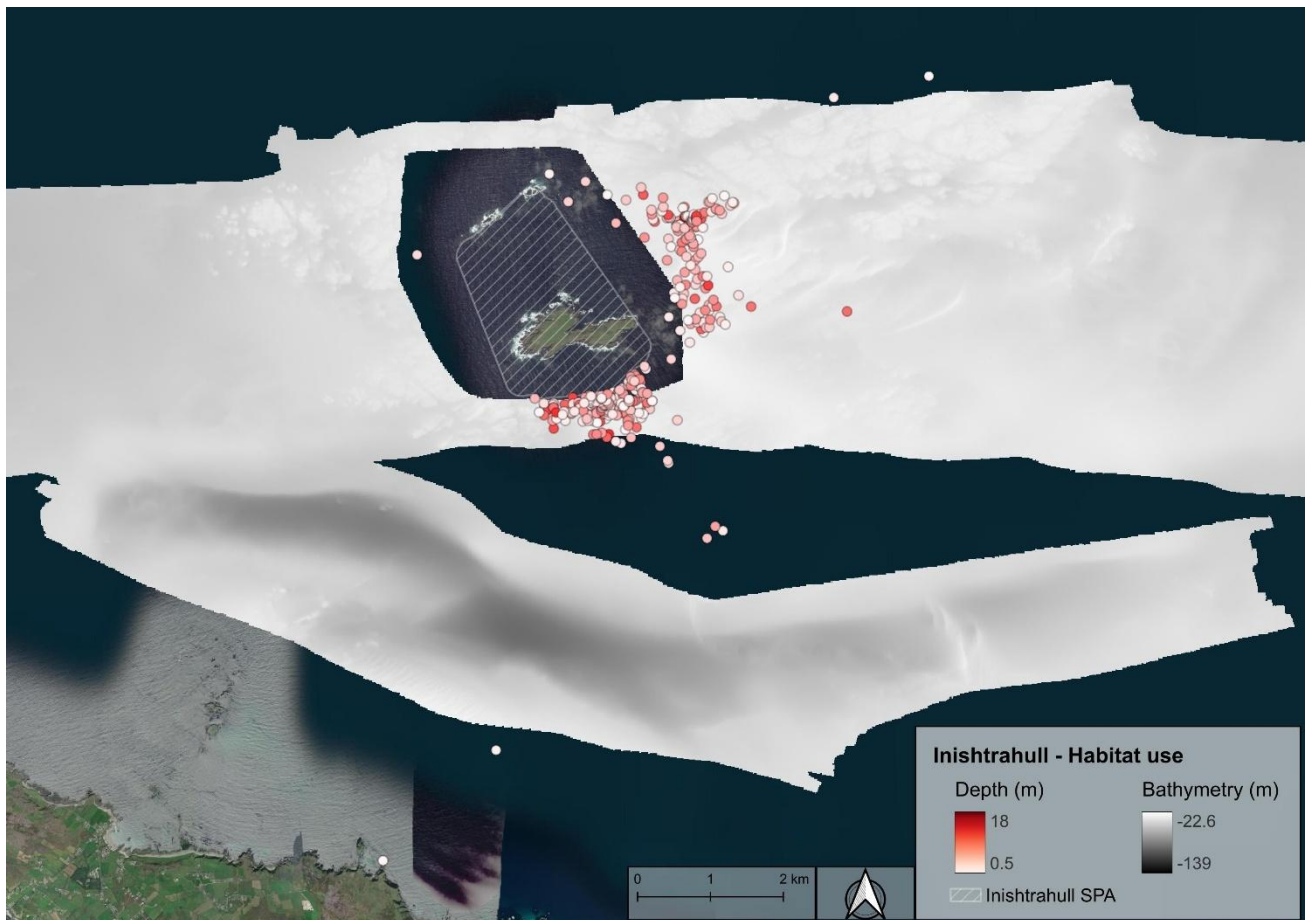


Figure 5: Bathymetry layer of the surrounding area in Inishtrahull contrasted with depth data from tagged individuals in Inishtrahull.

Inishmurray

In 2022, we found that individuals from Inishmurray often commuted to foraging grounds near coastal areas near the Streedagh Point Dunes SAC. In this area, they performed significantly shallower dives within the infralittoral zone off Streedagh Strand - where the substrate could not be classified - and on sandy substrates associated with intertidal sandflats. In contrast, deeper dives were recorded over rocky substrate located in the vicinity of the colony (Table 2, Figure 6).

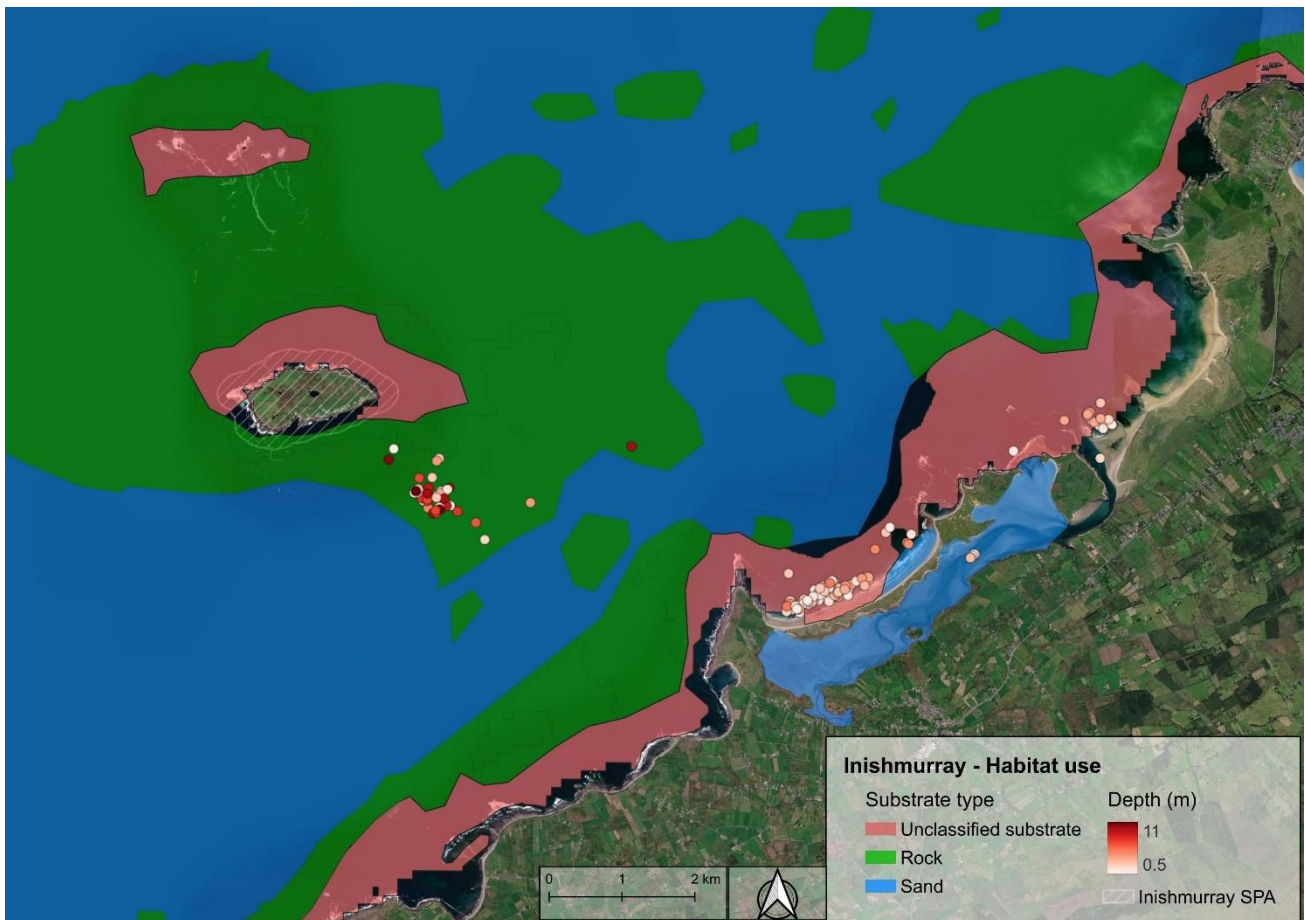


Figure 6: Seabed substrate types in the surrounding area of Inishmurray contrasted with GPS locations containing depth data from tagged individuals in 2022.

Table 2. Diving metrics for each seabed substrate in Inishmurray colony (2022).

Seabed Substrate	Num. Obs	Mean Depth (m)	SD($\pm$)	Min. Depth	Max. Depth
Unclassified	99	2.43	1.24	0.53	4.94
Rock	44	4.68	3.2	0.52	10.43
Sand	6	2.21	1.14	0.65	3.09

Note that these values are based on depth data linked to GPS locations, representing only a sample of the full diving activity recorded by the device.

Comparing the depth data collected over rocky substrate with the bathymetry data from Inishmurray, we identified specific seafloor features that may help explain the spatial distribution and diving activity recorded in the area (Figure 7).

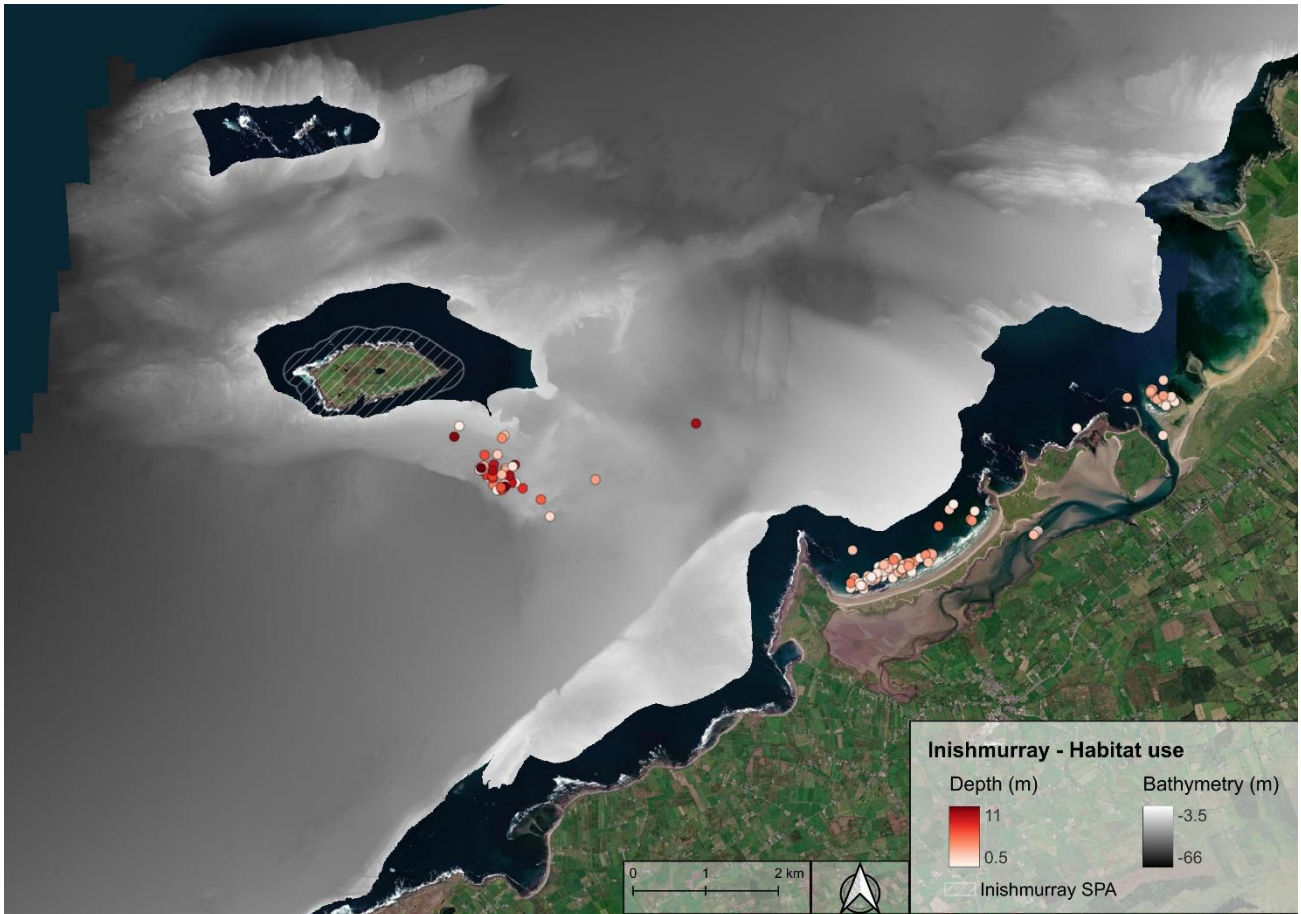


Figure 7: Bathymetry layer of the surrounding area in Inishmurray contrasted with depth data from tagged individuals in Inishmurray 2022. Note the depth contrast caused by sloping terrain where individuals use as foraging ground.

Similarly to 2022, results from 2023 showed consistent patterns in habitat use, and revealed new foraging areas. On the one hand, tagged individuals continued using foraging grounds close to the colony, often over rocky substrate, as well as areas along the coastline off Streedagh Strand, where individuals consistently performed shallow dives.

On the other hand, the additional tracking data identified foraging areas, including sites near the colony - where deeper dives were performed over rocky substrate – and an adjacent area west of Mullaghmore head, where substrate could not be classified. In this area, diving depth showed a clustered pattern, with shallow and deeper dives occurring in separate zones (Figure 8).

When comparing dive depths across substrate types, significant differences were found between dives over rocky substrate and those recorded in unclassified substrate. However, dives performed over sandy substrate did not differ significantly from those recorded over rocky substrate nor unclassified substrate (Table 3).

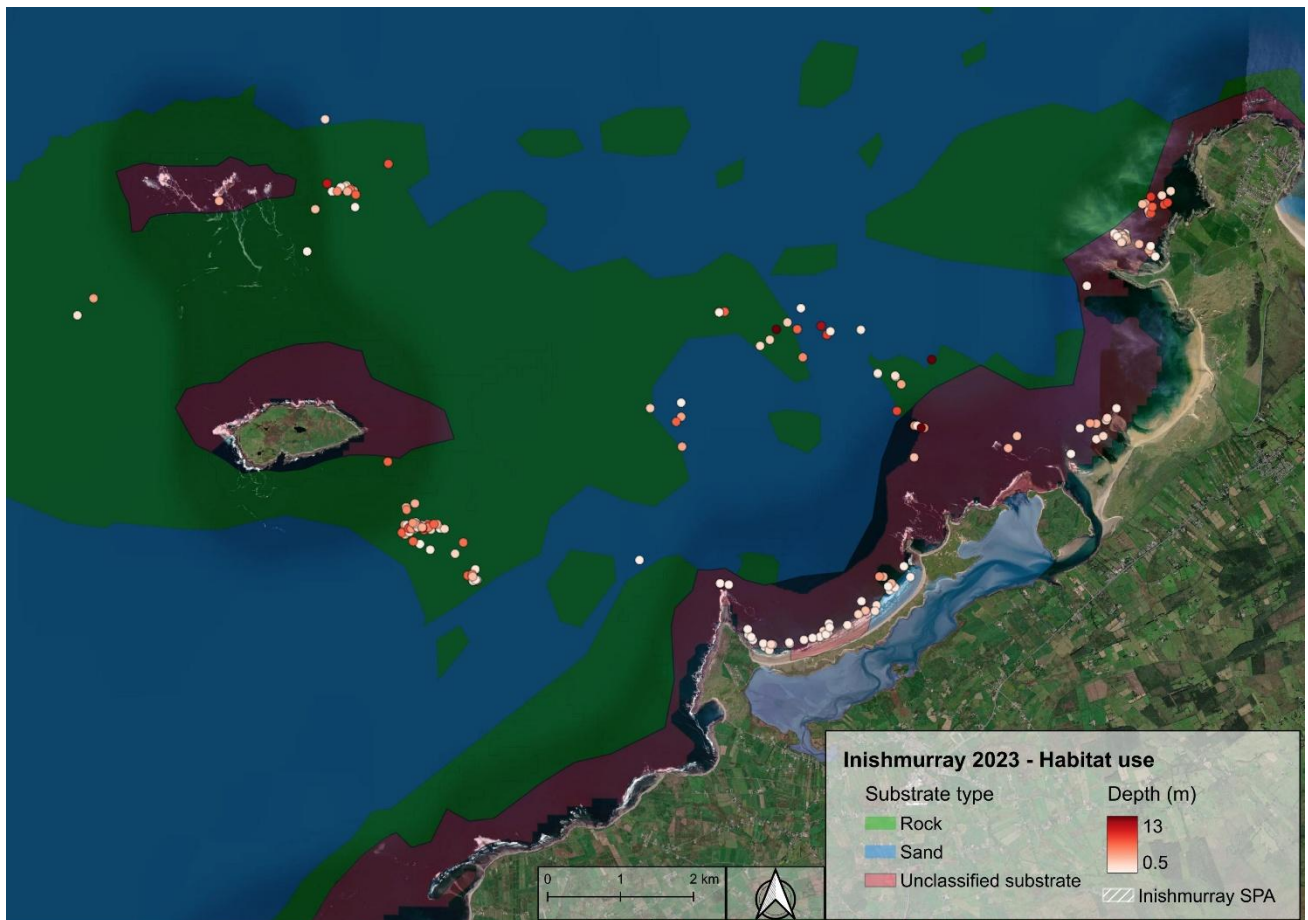


Figure 8: Seabed substrate types in the surrounding area of Inishmurray contrasted with GPS locations containing depth data from tagged individuals in 2023.

Table 3. Diving metrics for each seabed substrate in Inishmurray colony (2023).

Seabed Substrate	Num. Obs	Mean Depth (m)	SD($\pm$)	Min. Depth	Max. Depth
<i>Unclassified</i>	103	2.69	2.19	0.51	12.1
<i>Rock</i>	98	4.17	2.63	0.56	12.3
<i>Sand</i>	21	3.61	3.57	0.52	11.98

When comparing bathymetry with the additional tracking data, foraging areas located near depth contrasts and irregular terrain were particularly preferred, as well as those areas offering a range of intermediate to deep waters over rocky substrate (Figure 9).

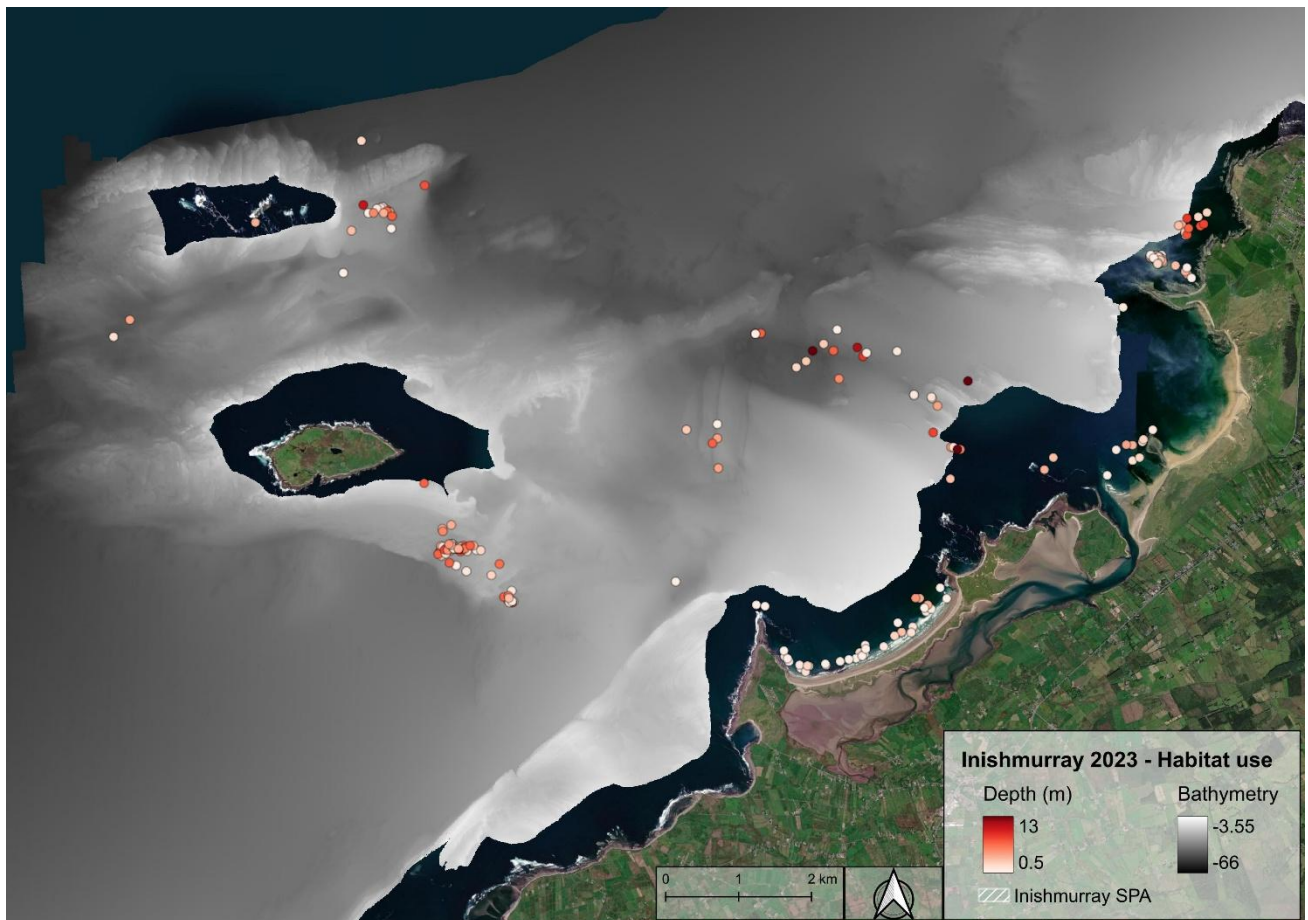


Figure 9: Bathymetry layer of the surrounding area in Inishmurray contrasted with depth data from tagged individuals in Inishmurray 2023.

Discussion

Data analysis focused on identifying marine areas of relative importance for birds breeding at these two island SPAs. From the tracking data, we defined the spatial distribution of European Shags breeding at both localities and identified their home ranges and core areas beyond the SPA boundaries. Moreover, by combining oceanographic features with depth data obtained from built-in pressure sensors, we provided useful insights into habitat use and foraging areas across different marine environments. In turn, this may help clarify the drivers of habitat selection and support conservation planning at other sites in the Republic of Ireland.

European Shags breeding on Inishtrahull showed a relatively small spatial distribution, with most observations clustered near the colony. These core areas likely represent the main foraging grounds during chick-rearing and may be influenced by the type of seabed substrate around the island. Frequent diving events over sandy seabed pockets near the colony suggest a preference for this substrate type, followed by rock and coarse sediments in circalittoral waters. This selection may be

driven by the presence of preferred prey for chick provisioning or by foraging strategies that benefit from substrate characteristics.

Further analysis of bathymetric data could clarify the importance of seabed relief in shallow areas. However, TDR data indicated that individuals from Inishtrahull may be foraging near the seabed or other intermediate depths between 20-30m. The deep channel between the mainland and Inishtrahull may also represent a biologically important feature, supporting nutrient upwelling and acting as a natural corridor for marine megafauna - both of which could support conservation planning. However, tracking data along the mainland coastline remain scarce, and additional tracking would help assessing the spatial use and relevance of these areas for the species.

In contrast, European Shags from Inishmurray showed broader spatial distribution and more variable habitat use. Tagged individuals frequently commuted long distances to foraging grounds along the mainland coastline and selected areas near the colony. Two of the main foraging areas were located off the Streedagh Point Dunes SAC and in a southern area from the breeding colony, both in 2022 and 2023. In 2022, individuals typically foraged in waters around 4m deep, although maximum recorded depths reached 37.5m. In contrast, data from 2023 showed a wider range of dive depths, with maximum values reaching 52.7 m. Depth data varied significantly across substrate type found in different foraging areas, which can be partially explained when considered alongside oceanographic features.

The substrate type at two of the main foraging areas near the mainland could not be classified. For the foraging area near Streedagh Strand, the similarity of dive depths to those recorded over sandy substrate, and the surrounding substrate composition, suggests that at least part of the area consists of shallow sandy substrate. The second main area near the mainland, located west of Mullaghmore head, lies adjacent to a rocky coastline and surrounded by rocky substrate. Considering the dive depths of one of the main clusters, the site may consist of deeper waters over sandy or rocky substrate. Shallower dives located on the second cluster may suggest shallower waters over sandy or mixed substrate. Across both years, visual inspection of the foraging area over rocky substrate, combined with the bathymetry data, revealed a potential preference over depth contrasts with a sloping seabed relief, which may concentrate nutrient flow and enhance foraging opportunities.

Overall, differences in dive depths between years in Inishmurray may also reflect variation in foraging strategies, combined with the availability of a wide variety of foraging grounds and potential preferred prey items. The larger 2023 tracking dataset reflects a wider range of accessible foraging grounds which could relate to seabed relief patterns, whereas the smaller sample size in 2022 may have captured a narrower set of behaviours.

Future work and recommendations

To optimise the use of the AxyTrek data collected, several datasets were prepared by combining the three parameters recorded by the device (location, acceleration, and depth). For future deployments, we recommend adjustments to the device configuration, such as continuous accelerometry recording and a higher GPS fix frequency, which may improve accuracy on behavioural analysis and increase dataset completeness. However, for any new data to be incorporated to this study, we advise maintaining consistency with the configuration previously used; this will prevent analytical challenges caused by mixed data samples.

Habitat use and the selection of foraging grounds could further be explored using Resource Selection Functions (RSFs), which compare used habitat (where animals were observed) with available habitat (what they could have used, given the landscape). These analyses would provide deeper insights into habitat preferences and could directly inform conservation planning for marine protected areas.

Moreover, a multi-year dataset across several colonies would improve the quality of behavioural classifications, estimates of energy expenditure (e.g., ODBA, VeDBA), and assessments of the spatiotemporal distribution of resting, foraging, and travelling behaviours for the species, which may also help identify priorities for conservation management. Therefore, we recommend expanding tracking effort on already studied sites, and acquiring new telemetry data from additional SPA of interest to be explored from the start.

In this context, other localities with established European Shag populations could be targeted for new tracking studies. Accessibility to the breeding areas should be assessed in advance to optimise the fieldwork effort and maximise the collected data while minimising disturbance at the breeding colony. Some of the islands within the Blasket Islands SPA could be considered as new study area, particularly given the new designated Marine National Park (April 2024), although accessibility at steep rocky ledges and cliffs must be considered. Similarly, conducting multi-year tracking - or long-term monitoring studies at the same colonies of study - could help identifying additional areas of interest and further understand demographic and ecological changes over time, driven by extrinsic and intrinsic factors. Other sites previously attempted, such as Inishkea, may expose a recurrent potential challenge to collect data due to the risk of losing the base station receiver at exposed locations.

References

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3. Saldanha, S., Cox, S.L., Militão, T. et al. Animal behaviour on the move: the use of auxiliary information and semi-supervision to improve behavioural inferences from Hidden Markov Models applied to GPS tracking datasets. *Mov Ecol* 11, 41 (2023). <https://doi.org/10.1186/s40462-023-00401-5>.
4. [Download Boundary Data | National Parks & Wildlife Service](#) for SPA shapefiles.
5. [Data Access and Download | Infomar](#) for Bathymetry and Seabed Substrate shapefiles.

Supplementary data

Appendix 1. Habitat use: additional results.

1.1 Tracking data from Inishmurray 2022 and 2023

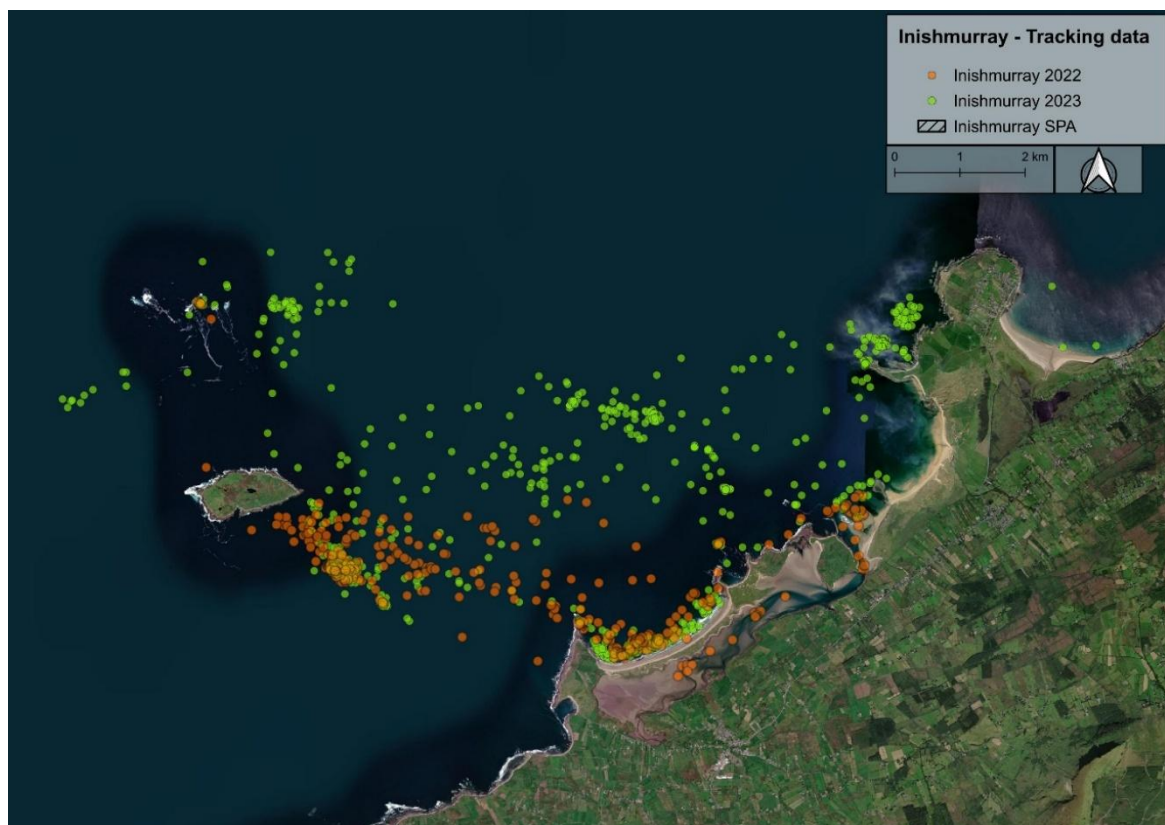


Figure 10: Multi-year tracking dataset from European Shags breeding in Inishmurray (2022- 2023).

1.2 Habitat use for Inishmurray 2022 and 2023

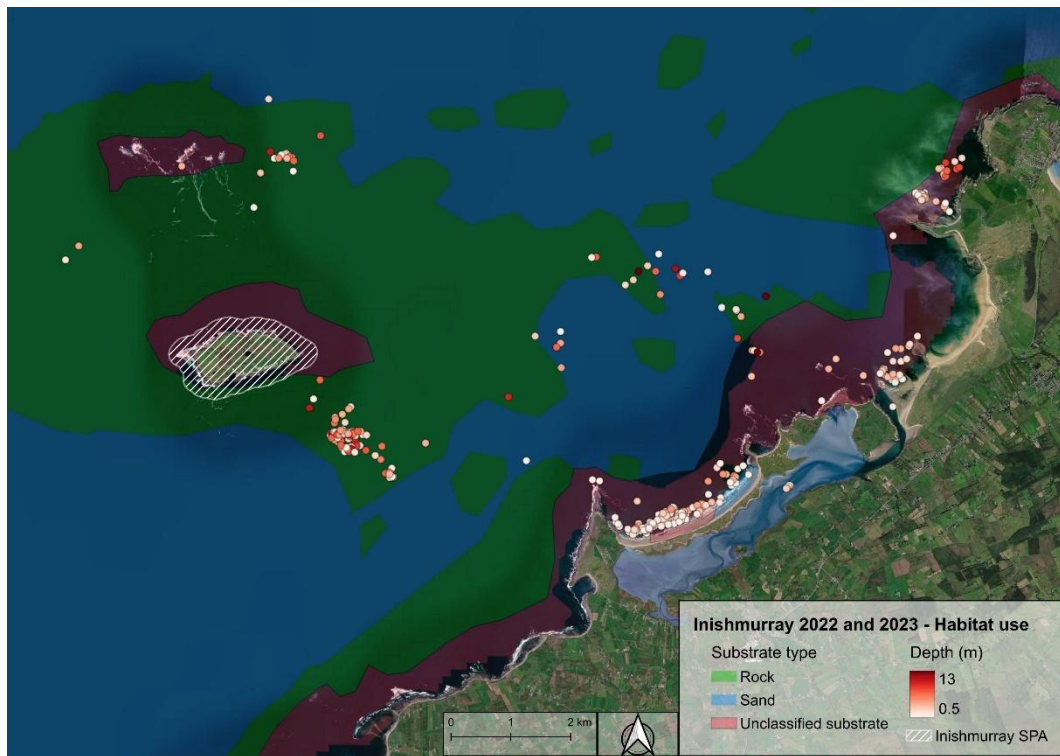


Figure 11: Seabed substrate types in the surrounding area of Inishmurray contrasted with GPS locations containing depth data from tagged individuals in 2022 and 2023.

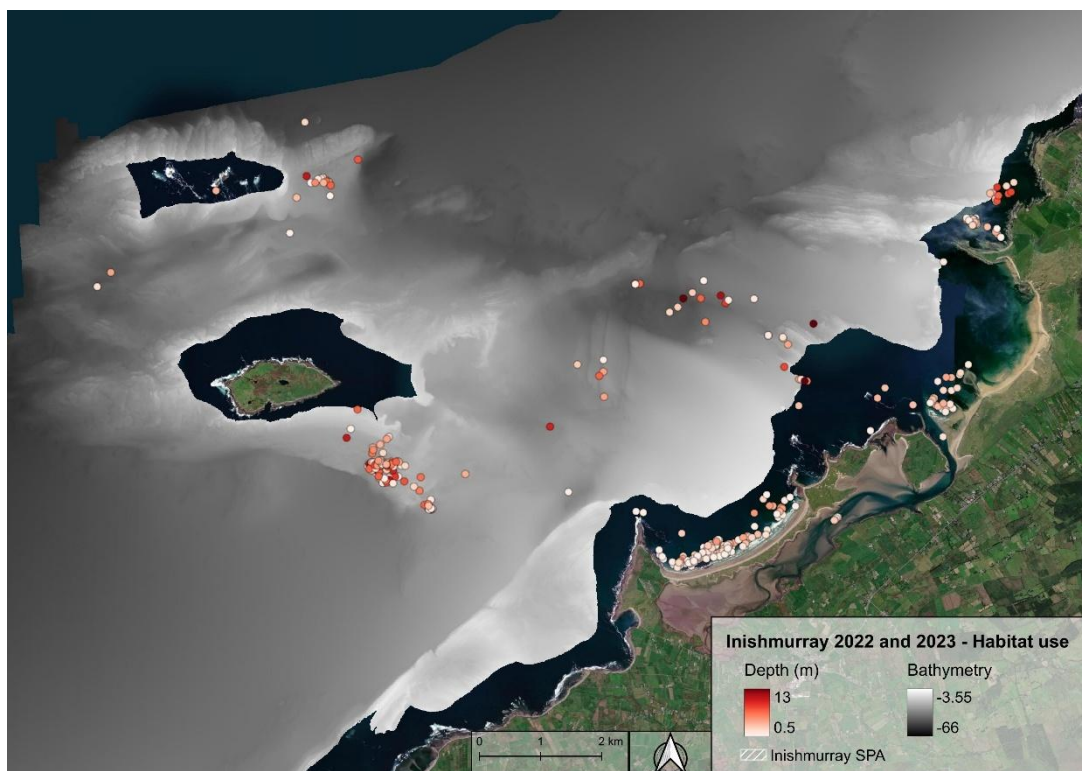


Figure 12: Bathymetry layer of the surrounding area in Inishmurray contrasted with depth data from tagged individuals in Inishmurray 2022 and 2023.

1.3 Statistical results

Table 4. Statistical test results for Inishtrahull and Inishmurray. Groups labeled with the same letter are not significantly different.

Inishtrahull				
<i>Kruskal-Wallis test's</i>		<i>Group</i>	<i>Mean rank Depth~substrate</i>	<i>Post-hoc result</i>
Critical Value:	0.8677346	Rock	122.3235	a
Degrees of freedom:	2	Sand	123.2062	a
P-value Chisq	0.6479982	Coarse sediment	105.6667	a
Inishmurray 2022				
<i>Kruskal-Wallis test's</i>		<i>Group</i>	<i>Mean rank Depth~substrate</i>	<i>Post-hoc result</i>
Critical Value:	12.92101	Rock	94.56818	a
Degrees of freedom:	2	Sand	61.83333	b
P-value Chisq	0.001564	Unclassified	67.10101	b
Inishmurray 2023				
<i>Kruskal-Wallis test's</i>		<i>Group</i>	<i>Mean rank Depth~substrate</i>	<i>Post-hoc result</i>
Critical Value:	17.9814	Rock	131.8367	a
Degrees of freedom:	2	Sand	103.4285	ab
P-value Chisq	0.0001245	Unclassified	93.7961	b

1.4 Dive depth across substrate types

Visual exploration of diving depth across substrate type for individuals breeding in Inishtrahull (Figure 13) and Inishmurray (Figure 14 and 15).

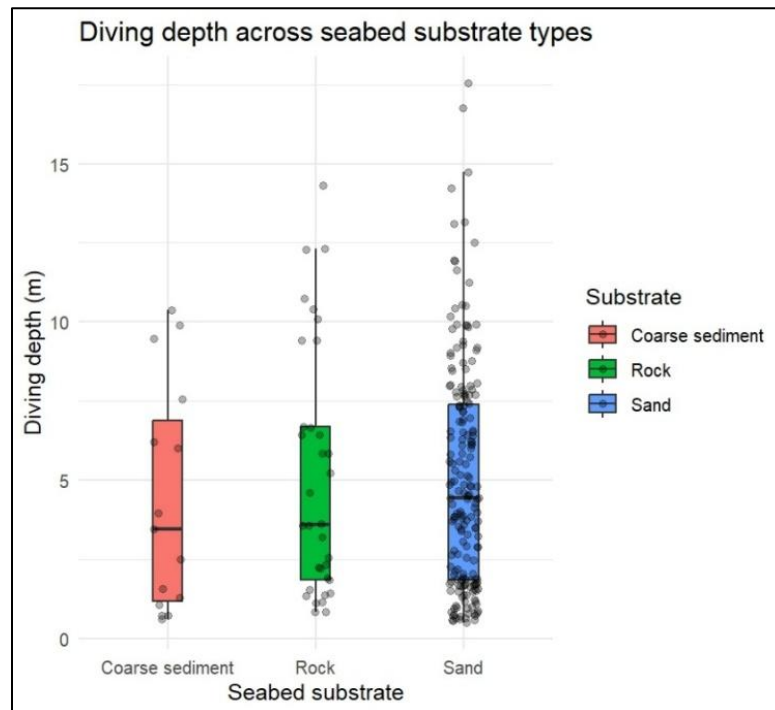


Figure 13. Boxplot showing depth data recorded for each substrate type used in the foraging areas of Inishtrahull.

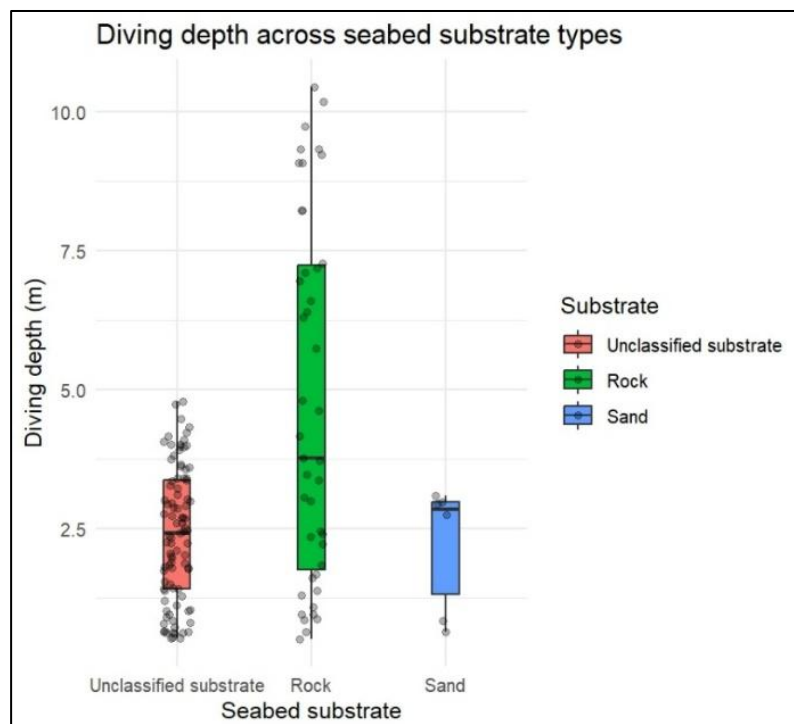


Figure 14. Boxplot showing depth data recorded for each substrate type used in the foraging areas of Inishmurray 2022.

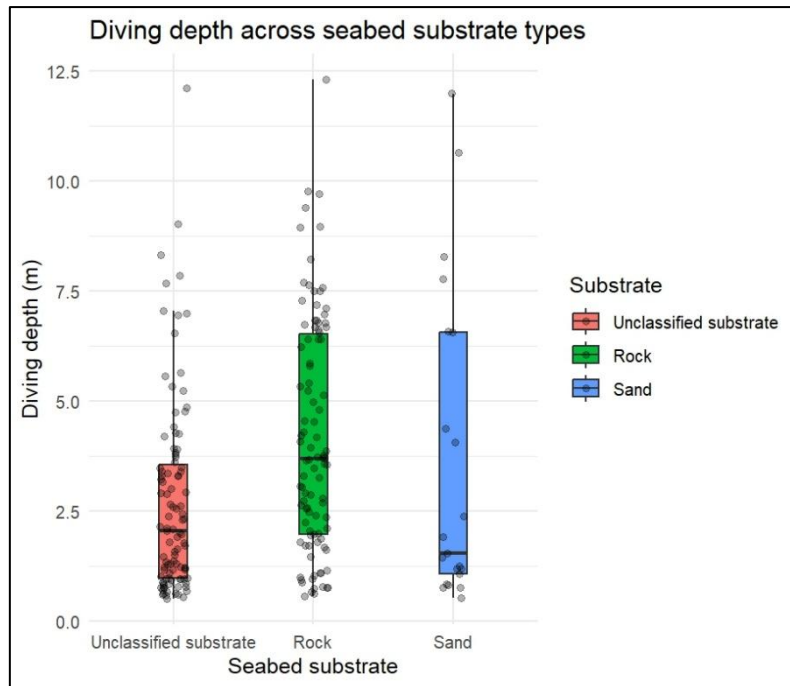


Figure 15. Boxplot showing depth data recorded for each substrate type used in the foraging areas of Inishmurray 2023.