# Methods

## Data processing

Data were analyzed using R version 4.1.2 ([R Core Team 2021](#_ENREF_5)). Data from Rouzic, which are stored in the movebank database, were imported with the *move* R package ([Kranstauber *et al.* 2022](#_ENREF_3)) while data from Bass Rock were imported from csv files.

For both datasets, at-sea trips were discriminated from periods in the colony when the birds were > 1 km away from the colony for > 1h. At-sea locations were linearly interpolated with a 15min time resolution using the *pastecs* package ([Ibanez & Grosjean 2018](#_ENREF_2)). Trip characteristics (maximal distance to the colony, total trip duration and total distance travelled) and time spent in the colony between at-sea trips were averaged for each individual and then averaged by colony (Table 1).

Linear mixed models were fitted separately for each colony dataset to test whether log-transformed trip characteristics and nest attendance changed over time. Bird ID was included as a random effect.

## Inferring at-sea behavioural states

A 3-state hidden Markov model (HMM) was fitted to the entire at-sea interpolated location dataset, using the *moveHMM* package ([Michelot *et al.* 2016](#_ENREF_4)). The states reflected 3 different activities at sea: (1) resting, characterised by a small step length and low turning angle, (2) travelling, characterised by a long step length and low turning angle and (3) foraging, characterised by an intermediate step length and a large turning angle. A set of different initial parameters was used to ensure that the global minimum in negative log-likelihood had been reached. The model was validated with the visual inspection of pseudoresiduals. The Viterbi algorithm was used to classify the most likely behaviour at each location and proportions of each activity occurring during one at-sea trip were calculated, averaged by individual and then, by colony. Logistic regressions were fitted on activity proportions using the *glmmTMB* package ([Brooks *et al.* 2017](#_ENREF_1)), to account for zero-inflated data.

# Results

Northern gannets from Bass Rock and Rouzic did not change their spatial use over time and kept foraging in the same areas (Fig. 1). Birds from Rouzic did not change their at-sea trip characteristics over time (similar duration, maximal distance to the colony and total distance travelled; Table 2; Fig. 2), but they slightly decreased their time spent at the colony between at-sea trips (Table 2; Fig. 2). On the contrary, birds nesting in Rouzic spent the same amount of time attending their colony but increased the duration of their at-sea trips, travelling a bit further and longer in distance (Table 2; Fig. 2). Within at-sea trips, the birds maintained relatively the same proportion of time spent foraging, flying and resting on the water (Fig. 3; Table 2).

|  |  |  |
| --- | --- | --- |
|  | Bass Rock | Rouzic |
| Nb of individuals | 10 | 13 |
| Total number of trips | 310 | 257 |
| Tracking period | 11/08/2022 - 12/10/2022 | 24/08/2022 – 28/09/2022 |
| Maximal distance to the colony (km) | 98 ± 8 | 62 ± 4 |
| Total distance travelled (km) | 254 ± 21 | 171 ± 11 |
| Trip duration (h) | 19 ± 2 | 18 ± 1 |
| Time spent resting during a trip (%) | 20.9 ± 2.3 | 41.7 ± 2.9 |
| Time spent foraging during a trip (%) | 25.2 ± 1.2 | 20.1 ± 1.7 |
| Time spent flying during a trip (%) | 54.0 ± 2.1 | 38.2 ± 2.5 |
| Time at the colony between at-sea trips (h) | 16 ± 1 | 11 ± 1 |

Table 1: Sample size, at-sea trip characteristics, percentage of activities and colony attendance of Northern gannets nesting in Rouzic and Bass Rock. Results are shown as mean ± SE.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Bass Rock | | | | Rouzic | | | |
|  | Estimate ± SE | df | t or z-value | p-value | Estimate ± SE | df | t or z-value | p-value |
| Maximal distance | **0.009 ± 0.005** | **307** | **2.03** | **0.043** | -0.003 ± 0.006 | 238 | 1.73 | 0.60 |
| Total distance travelled (km) | **0.011 ± 0.0048** | **307** | **2.34** | **0.02** | 1.81e10-5 ± 6.0e10-3 | 201 | 0.003 | 0.99 |
| Trip duration (h) | **0.013 ± 0.004** | **307** | **3.29** | **0.001** | 0.011 ± 0.006 | 238 | 1.73 | 0.09 |
| Time at the colony between at-sea trips (h) | -0.003 ± 0.003 | 297 | -0.77 | 0.45 | **-0.015 ± 0.007** | **233** | **-2.14** | **0.03** |
| Proportion of a trip spent foraging | -0.0030 ± 0.0083 | 310 | -0.36 | 0.72 | -0.0087 ± 0.018 | 257 | -0.49 | 0.63 |
| Proportion of a trip spent resting | 0.0053 ± 0.009 | 310 | 0.62 | 0.54 | 0.010 ± 0.011 | 257 | 0.95 | 0.34 |
| Proportion of a trip spent flying | -0.0014 ± 0.007 | 310 | -0.20 | 0.84 | -0.013 ± 0.015 | 257 | -0.86 | 0.39 |

Table 2: Results from the models testing the effects of time on Northern gannet trip characteristics and nest attendance (linear mixed models) and proportion of time spent in 3 states (logistic regressions). Individual identity is included as a random effect. Significant results (p < 0.05) are in bold.

Figure 1: Tracks of Northern gannets nesting in (a) Bass Rock, Scotland and (b) Rouzic, Brittany, over time. (c-d) Rose diagrams showing the direction of at-sea locations. The centre of each rose diagram represents the colony location and each wedge represents the number of locations recorded in that direction over time.

*Chart, radar chart

Description automatically generated*

Figure 2: Trip characteristics and nest attendance of Northern gannets nesting in Bass Rock (dark blue) and Rouzic (cyan). The dots represent raw data and the line, predicted data ± SE.

Chart

Description automatically generated

Figure 3: Proportion of activities during an at-sea trips of Northern gannets nesting in Bass Rock (dark blue) and Rouzic (cyan). The dots represent raw data and the line, predicted data ± SE.

Chart, scatter chart

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# Data availability

GPS data from Northern gannets tracked in Rouzic, Brittany, are deposited on the Movebank website (Morus bassanus - Northern gannet - Rouzic France, managed by D. Grémillet & N. Courbin), and all statistical analyses can be found on the GitHub repository (https://github. com/auponchon/GannetsRouzic2022).

# References

Brooks, M., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, h.J., Maechler, M. & Bolker, B.M. (2017) glmmTMB balances speed and flexibility among packages for zero-inflated Generalized Linear Mixed Modelling. *The R Journal,* **9,** 378-400.

Ibanez, F. & Grosjean, P. (2018) pastecs: Package for Analysis of Space-Time Ecological Series. *R package version 1.3.21*.

Kranstauber, B., Smolla, M. & Scharf, A.K. (2022) move: Visualizing and Analyzing Animal Track Data.

Michelot, T., Langrock, R. & Patterson, T.A. (2016) moveHMM: an R package for the statistical modelling of animal movement data using hidden Markov models. *Methods in Ecology and Evolution,* **7,** 1308-1315.

R Core Team (2021) R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. Vienna, Austria.