BERWICK BANK WIND FARM

OFFSHORE ENVIRONMENTAL IMPACT ASSESSMENT

APPENDIX 11.4, ANNEX E: ANALYSIS OF GANNET GPS TRACKING DATA FROM THE BASS ROCK COLONY

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1. INTRODUCTION

1. Marine Scotland Science (MSS) in their Scoping representation and advice (16th December 2021) advised that whilst displacement and barrier effects would be assessed using the NatureScot Matrix Approach for gannet, further analysis should be undertaken making use of the extensive GPS tagging data from the Bass Rock colony (within the Forth Islands SPA). The purpose of the analysis was to explore the proportion of foraging trips that enter the proposed Development Array Area, and to break this down by sex and breeding stage.

2. The MSS advice has been addressed by undertaking an analysis of all available GPS tracking data on breeding adult gannets from the Bass Rock to estimate behavioural states using Hidden Markov Models (Grecian *et al.* 2018), and the proportion of time spent in each behavioural state within and outwith the proposed Development Array Area, split by sex. The approach was discussed and agreed through the Ornithology Road Map process (RM6, Technical Appendix 11.8).

3. Data were collated from GPS tags deployed on adult gannets annually during the breeding season on the Bass Rock from 2010 to 2019. These data were compiled through BirdLife International's seabirdtracking.org database and received from Keith Hamer and Jude Lane from Leeds University. More recent data were not included as they were provided in their raw form and not processed to a suitable point for inclusion in the current analysis.

2. METHODS

2.1. DATA PROCESSING

4. During data processing, foraging trips were defined as periods when birds were more than 10 km from the colony and lasting more than 40 minutes as per Grecian *et al.* (2018). All other locations were classified as either colony attendance or rafting (Carter *et al.* 2016) and were therefore excluded from this analysis.

5. To remove irregularities in satellite uplink time all data were interpolated to 2 min intervals using the R package adehabitatLT v. 0.3.23 (Calenge 2016).

6. Distances travelled by birds within these two-minute intervals were examined; there were some instances where birds were estimated to have travelled much greater distances than physically possible, potentially due to glitches in GPS signalling. As such, any distance that was more than double what a bird could fly in 2 minutes was removed. This was based on calculating the distance covered by birds flying at a speed of 14.9 m/s and then doubling this to account for any potential tailwind effects a bird may experience.

2.2. COMPARISON OF TIME SPENT WITHIN VERSUS OUTSIDE THE PROPOSED DEVELOPMENT ARRAY AREA

7. We aimed to identify whether the amount of time gannets spent inside the proposed Berwick Bank Development Array Area differed from time spent outside it. To do this we sampled with replacement (Efron 1993) 1,000 polygons of the same shape and size as the proposed development Development Array Area from the entire area encompassed by the tracks from all of the tagged birds (Fig. 2.1). Within each of these sampled polygons, we recorded the number of interpolated points, each of which represent a 2-minute interval. This was undertaken because a direct comparison of observations within and outside the proposed Development Array Area would be biased towards a greater number of observations outside the footprint, due to the large range of gannets compared to the size of the proposed Development Array Areat. Care was taken to ensure the sampled polygons did not overlap with the footprint itself, nor fell outside the range of the birds.

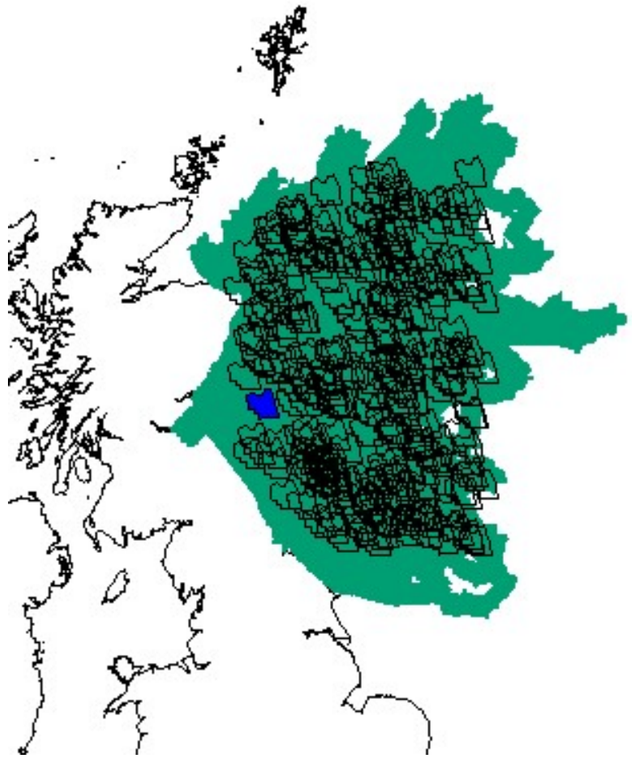

Figure 2.1: Example of distribution of samples of 2-minute observations taken from polygons of the same shape and size as the footprint from the area travelled by adult gannets. Green areas are gannet tracks plotted in 2-minute intervals. Blue polygon represents the Berwick Bank footprint.

8. The total number of two-minute observations counted in each sample over the study period was recorded and presented as a distribution of observations. This was then compared with the number of observations counted within the proposed Development Array Area.

2.3. HIDDEN MARKOV MODELLING

9. We used Hidden Markov Models (HMMs) to examine the at-sea behaviour of adult gannets, using the R package moveHMM version 1.8 (Michelot *et al.* 2016). Three underlying states were characterised to describe the movement of an individual by estimating step length and turning angle between two 2-minute intervals.

10. States were described based on *a priori* understanding of gannet behaviour (Pohle *et al.* 2017, Bennison *et al.* 2017). During a foraging trip individuals will generally behave in three ways: (i) direct flight to and from foraging areas (large step length and small turning angles), (ii) slow and tortuous flight while foraging within an area (short step lengths and large turning angles), and (iii) rest on the sea surface (short step lengths and small turning angles).

11. We used a gamma distribution to describe the step lengths and a von Mises distribution to describe the turning angles. Initial parameter values for step and turning angle were taken from Grecian *et al.* (2018) and are presented in Table 2.1.

12. To assess differences in movement patterns between sexes, we included the effect of year and sex (male, female or unknown) as covariates in the HMM framework. These covariates were included within the HMM as a logistic regression that expresses the transition probabilities of the underlying state process as a function of the covariates. This allowed us to examine the importance of the covariates on the probability of switching between states (Towner *et al.* 2016). We used model selection to identify the model with the lowest AIC value (Grecian *et al.* 2018) (lowest AIC = 7827.77, next lowest AIC = 7839.01).

13. We used the Viterbi algorithm to estimate the most likely sequence of movement states to have generated the observations based on the fitted model (Zucchini *et al.* 2009).

14. Finally, we used a series of linear models with a Gaussian error structure to examine the differences between proportion of time spent in each state within and outwith the Proposed Development, and whether proportion of time spent by each individual in a behavioural state could be explained by sex, using package stats v. 4.2.0 in R. The models assumed a Gaussian (normal) error structure and covariates were determined to have a significant effect on the response when the probability of an effect occurring by chance was < 5% (i.e., $p < 0.05$).

Table 2.1: Initial step and angle parameters (mean + SD) used to characterise behaviours in HMM (Grecian *et al.* 2018).

	Resting	Foraging	Transiting
Step	0.03 ± 0.02	0.41 ± 0.54	1.66 ± 0.43
Angle	0 ± 22.3	0 ± 1	0 ± 27.1

2.4. ESTIMATION OF HOME RANGE SIZE

15. Home range of gannets was estimated using a Minimum Convex Polygon (MCP) approach (Nilsen *et al.* 2008) using the package adehabitatHR (Calenge 2006) in R. An MCP is the smallest polygon in which no internal angle exceeds 180 degrees and which contains all points. It is easy to compute from coordinates and is appropriate for presence-only data.

16. Home ranges were estimated both for each track individually and with all tracks pooled. This allowed a comparison between the area of the footprint and the gannet home ranges.

3. RESULTS

17. Data were collected from 682 foraging trips from adult breeding gannets over 8 years between 2010 and 2019. Foraging trips comprised tracks from 154 females, 142 males and 386 of unknown sex (Table 3.1 & Table 3.2.).

Table 3.1: Number of foraging trips collected in each year by sex of bird.

Year	Female	Male	Unknown
2010	0	0	137
2011	0	0	28
2012	92	74	0
2015	0	0	129
2016	0	0	47
2017	0	0	35
2018	31	39	10
2019	31	29	0
Total	154	142	386

Table 3.2: Proportion of tracks that enter the proposed Development Array Area during the trip, broken down by sex and behaviour. Percentages in column 3 are calculated from the total number of tracks (both within and outside the proposed Development Array Area) Percentages in columns 4-6 are calculated from number of tracks that enter the proposed Development Array Area as a proportion of total number of tracks.

Sex	Total # tracks	# tracks that enter Development Array Area	# of tracks that include foraging within Development Array Area	# of tracks that include resting within Development Array Area	# of tracks that include transiting within Development Array Area
Female	154	64 (41.5%)	40 (26%)	16 (10.4%)	63 (41%)
Male	142	33 (23.2%)	23 (16.2%)	9 (6.3%)	31 (22%)
Unknown	386	82 (21.2%)	31 (8%)	15 (4%)	82 (21.2%)
Total	682	179 (26.2%)	94 (14%)	40 (6%)	176 (26%)

3.2. COMPARISON OF TIME SPENT WITHIN VERSUS OUTSIDE THE PROPOSED DEVELOPMENT

18. Of the 1,000 sampled polygons, 863 overlapped with the distribution of adult gannet tracks and did not overlap with the Berwick Bank proposed development Development Array Area itself (Figure 2.1) and are therefore presented as a histogram in Figure 3.1. A total of 6% (55) of samples had a greater number of observations than the Proposed Development Array Area which had 9010 observations, and 94% (808) had a smaller number of observations.

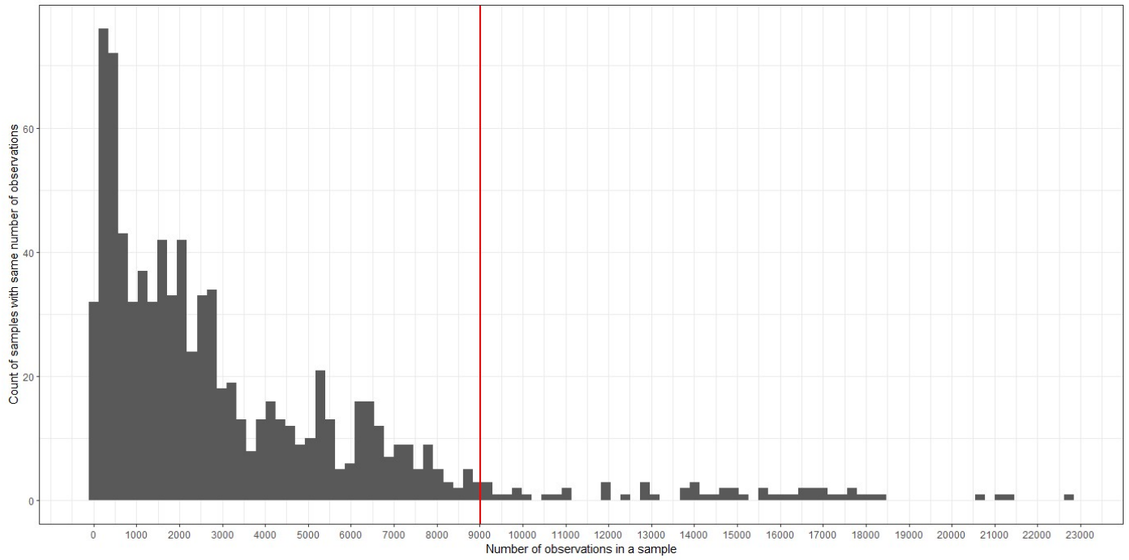

Figure 3.1: **Histogram of counts of interpolated GPS points from polygons sampled from the full range of adult gannet foraging trips. The red line indicates the number of observations counted in the proposed Development Array Area (9,010 observations).**

3.3. HIDDEN MARKOV MODELLING

19. The final model (i.e., that which had the lowest AIC value) included sex, but not year as a fixed term in the model.

20. The HMM decomposed the tracking data into three distinct states, capturing clearly identifiable movement patterns that we use here as proxies for three behavioural modes: resting, foraging, transiting from colony to foraging sites. Histograms of step length and turning angle estimated for each three states are presented in Figure 3.2.

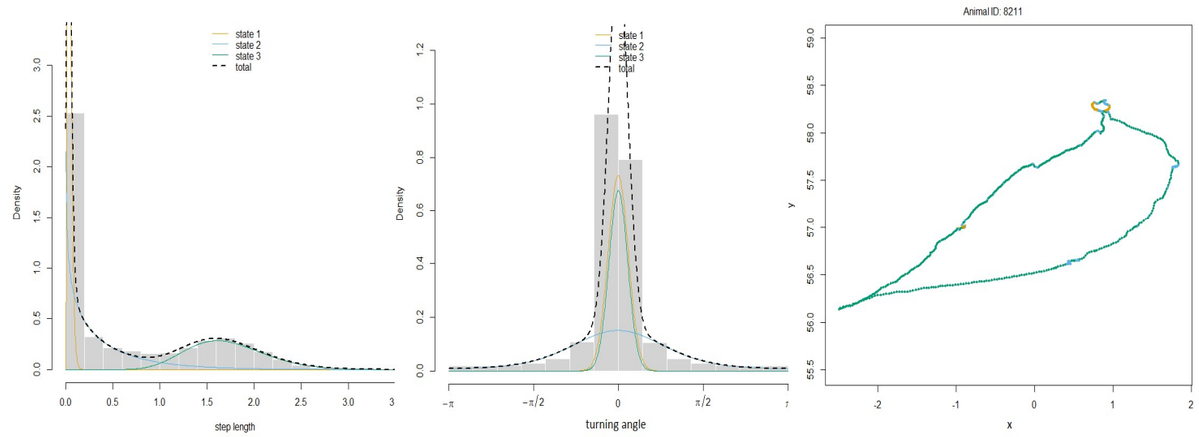

Figure 3.2: **Distributions of step length left panel) and turning angle (middle panel) estimated by the HMM, and example track decomposed into three states (right panel). State 1 = resting, state 2 = foraging and step 3 = transiting.**

3.3.2. DECOMPOSITION OF STATES ACROSS WHOLE AREA

21. The proportion of time spent in each behavioural state did not differ significantly between males, females or unknowns, with the exception of transiting behaviour, where males spent 10.5% less time transiting than females across trips on average (glm: estimated average proportion time spent transiting/female = 0.295 (st.error = 0.01), estimated average proportion time spent transiting/male = 0.264 (st.error = 0.01), p = 0.04).

22. The proportion of 2-minute intervals spent in each state across the whole area is separated by sex and presented in Table 3.3, Figure 3.3 and Figure 3.4.

Table 3.3: **Absolute proportion of 2-minute intervals spent by male, female, unknown and all birds in each estimated behavioural state. The calculations in this table pool all points together and do not control for individual differences in proportions of time spent in each behavioural state.**

Behavioural state	Female (mean)	Number of points	Male (mean)	Number of points	Unknown (mean)	Number of points	All (mean)	Number of points
Foraging	0.4	56731	0.392	47857	0.336	114833	0.362	219421
Resting	0.328	46501	0.351	42860	0.349	119027	0.344	208388
Transiting	0.272	38579	0.257	31396	0.315	107667	0.293	177642

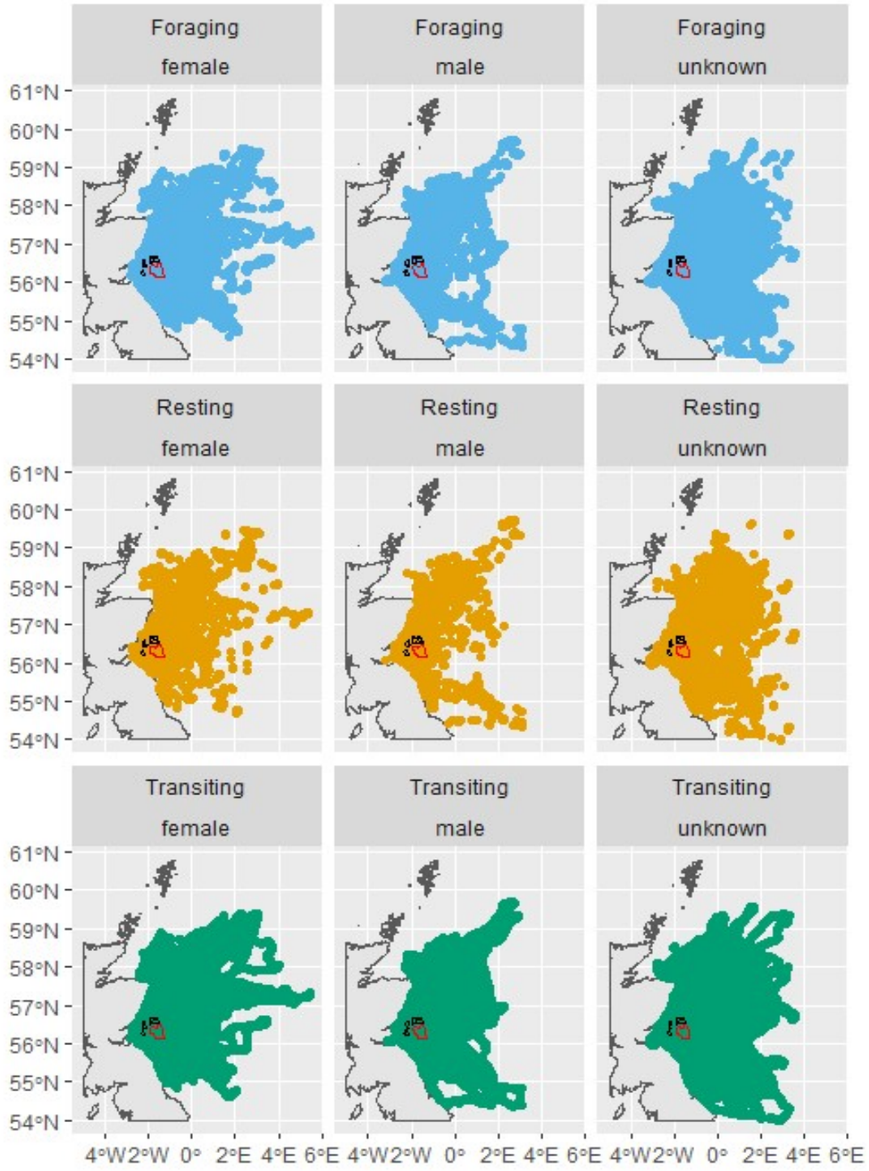

Figure 3.3: **Tracks decomposed by sex (female, male and unknown) and behavioural state (foraging, resting, and transiting). Red polygon denotes the proposed Development Array Area, and black polygons denote surrounding developments of Inch Cape, Neart Na Gaoithe and Seagreen Alpha and Bravo OWFs.**

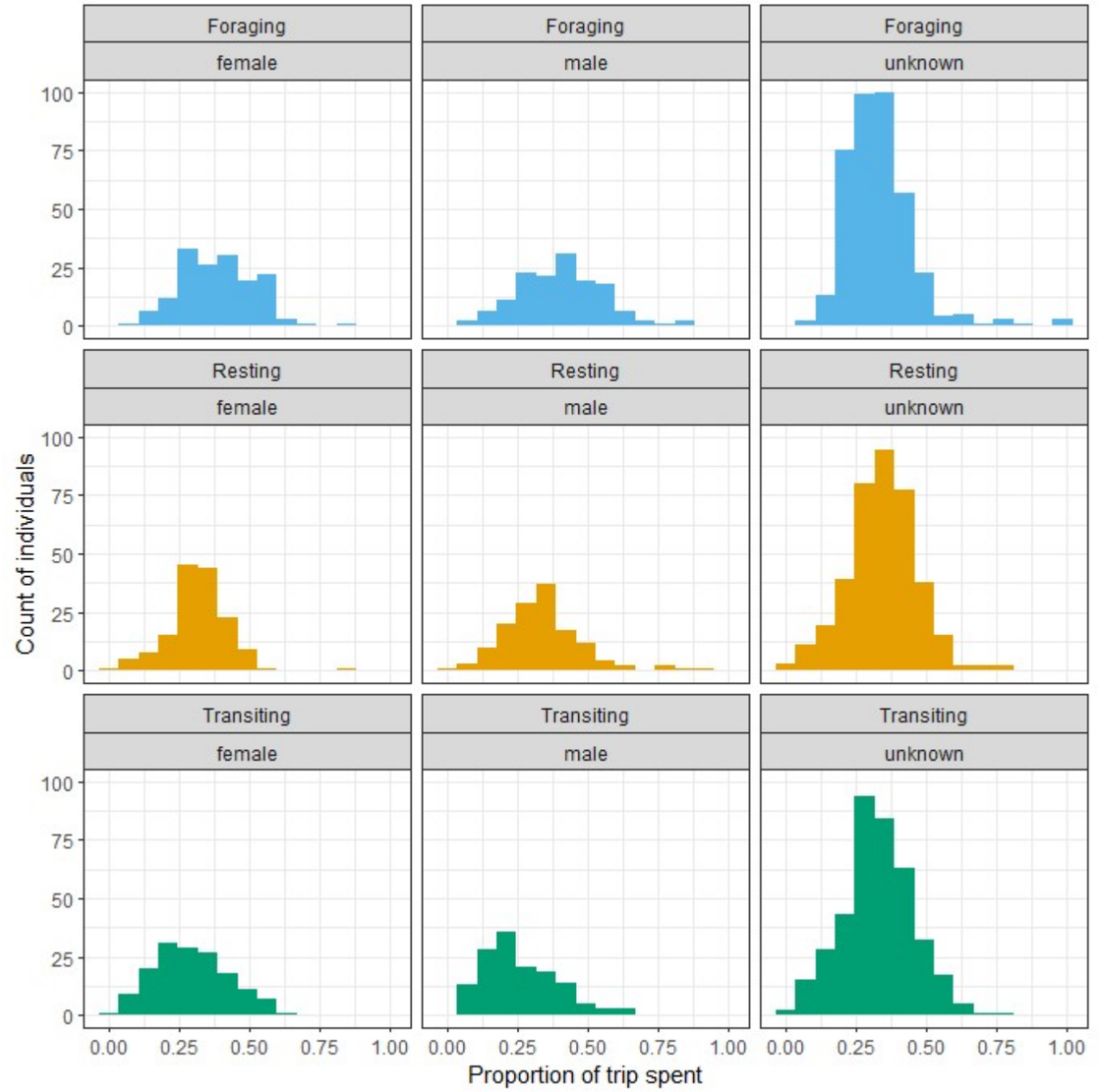

Figure 3.4: **Distributions of proportion of time spent by individuals in each behavioural state, separated by sex.**

3.3.3. DECOMPOSITION OF STATES WITHIN PROPOSED DEVELOPMENT ARRAY AREA ONLY

23. When observations (i.e., estimated behavioural state at each 2-minute interval point) were clipped to include those which took place within the Proposed Development only, males spent on average 38% more time foraging within the Proposed Development Array Area than females across all years combined (glm: estimated average proportion time spent foraging/female = 0.404 (st.error = 0.04), estimated average proportion time spent foraging/male = 0.560 (st.error = 0.05), p = 0.02).

24. We examined the proportion of time spent in each behavioural state by individuals within the Proposed Development Array Area. All birds spent more time transiting through the site than foraging on average (females: +68%, males: +3%, unknown: +135%), and this effect was significant for females and unknown birds (glm: females foraging = 0.404 (st.error = 0.05), females transiting = 0.680 (st.error = 0.04), p = < 0.001. unknown foraging = 0.338 (st.error = 0.05), unknown transiting = 0.797 (st.error = 0.03), p < 0.001). Males spent 56% less time on average resting than foraging (glm: males foraging = 0.560 (st.error = 0.07), males resting = 0.244 (st.error 0= 0.11), p = 0.01).

25. The proportion of 2-minute intervals spent in each state within the proposed Development Array Area is separated by sex and presented in Table 3.4 and Figure 3.5, Figure 3.6 and Figure 3.7.

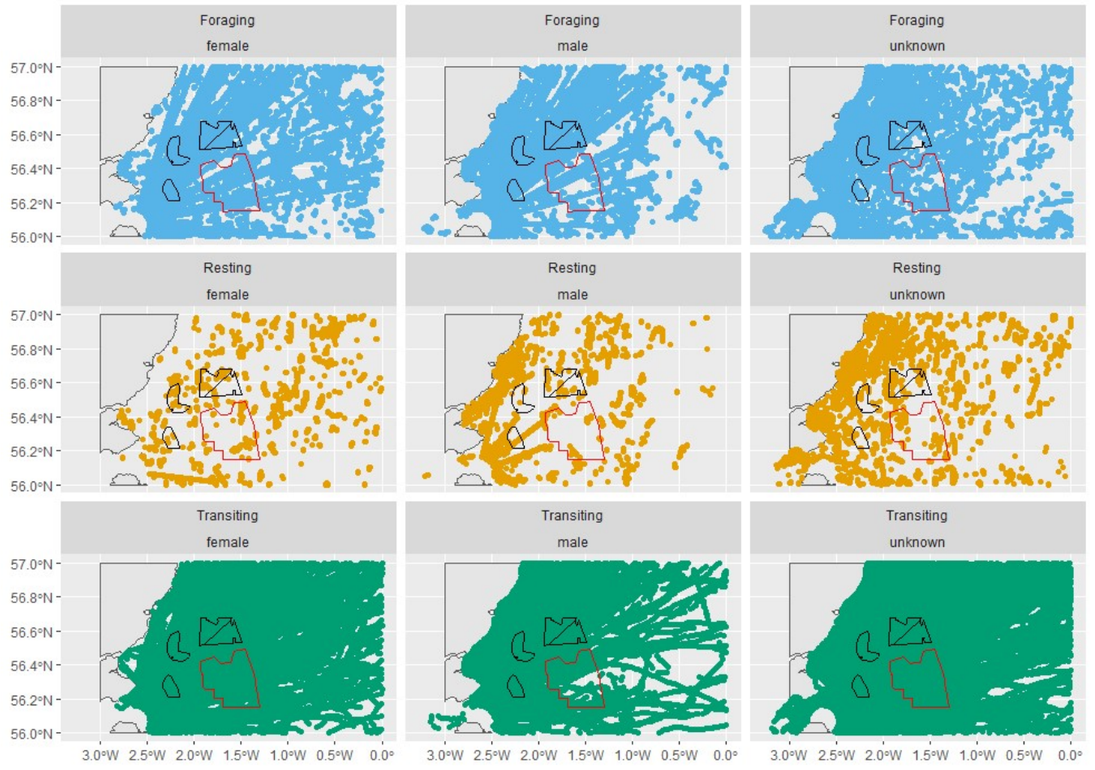

Figure 3.5: Tracks separated by sex (female, male and unknown) and behavioural state (foraging, resting and transiting). Red polygon denotes the proposed Berwick Bank Array Area, and orange polygons denote surrounding developments of Inch Cape, Neart Na Gaoithe and Seagreen OWFs.

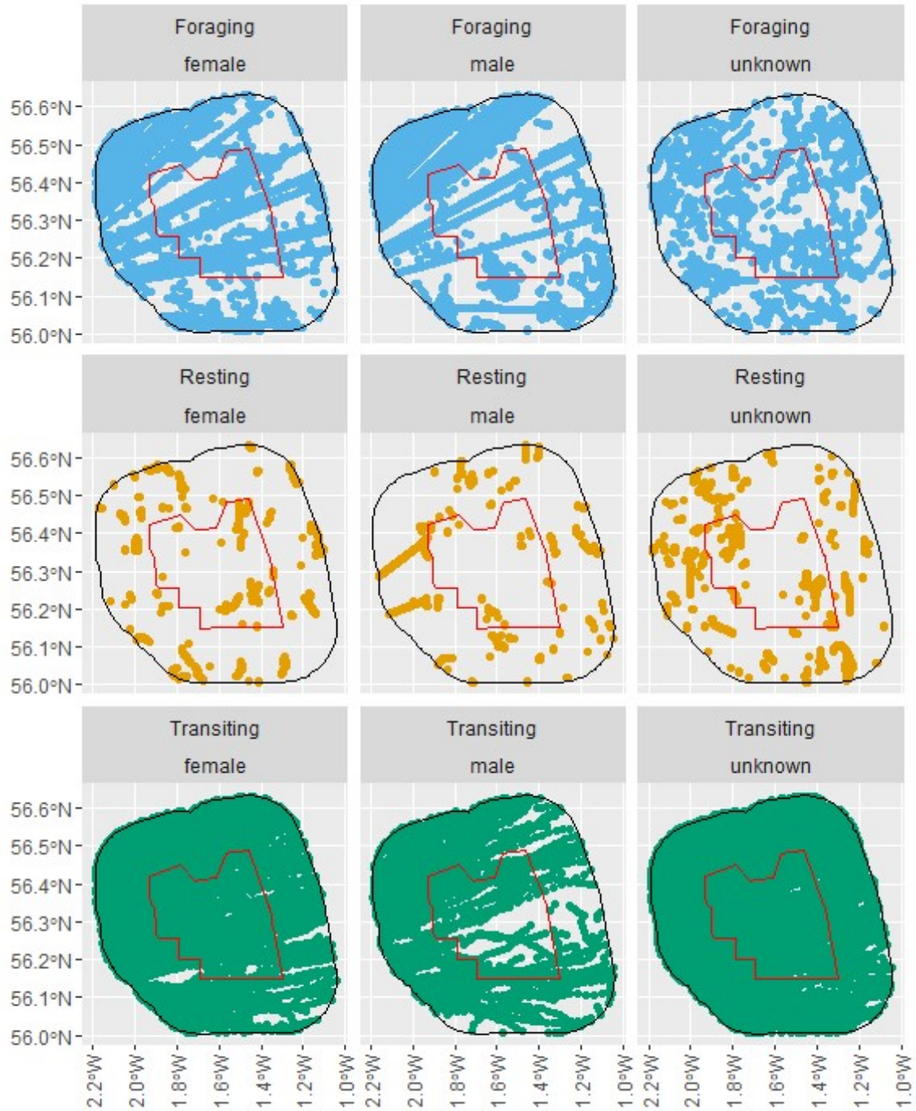

Figure 3.6: **Tracks separated by sex (female, male and unknown) and behavioural state (foraging, resting, and transiting within the proposed Berwick Bank Array Area (red polygon) and 16km buffer.**

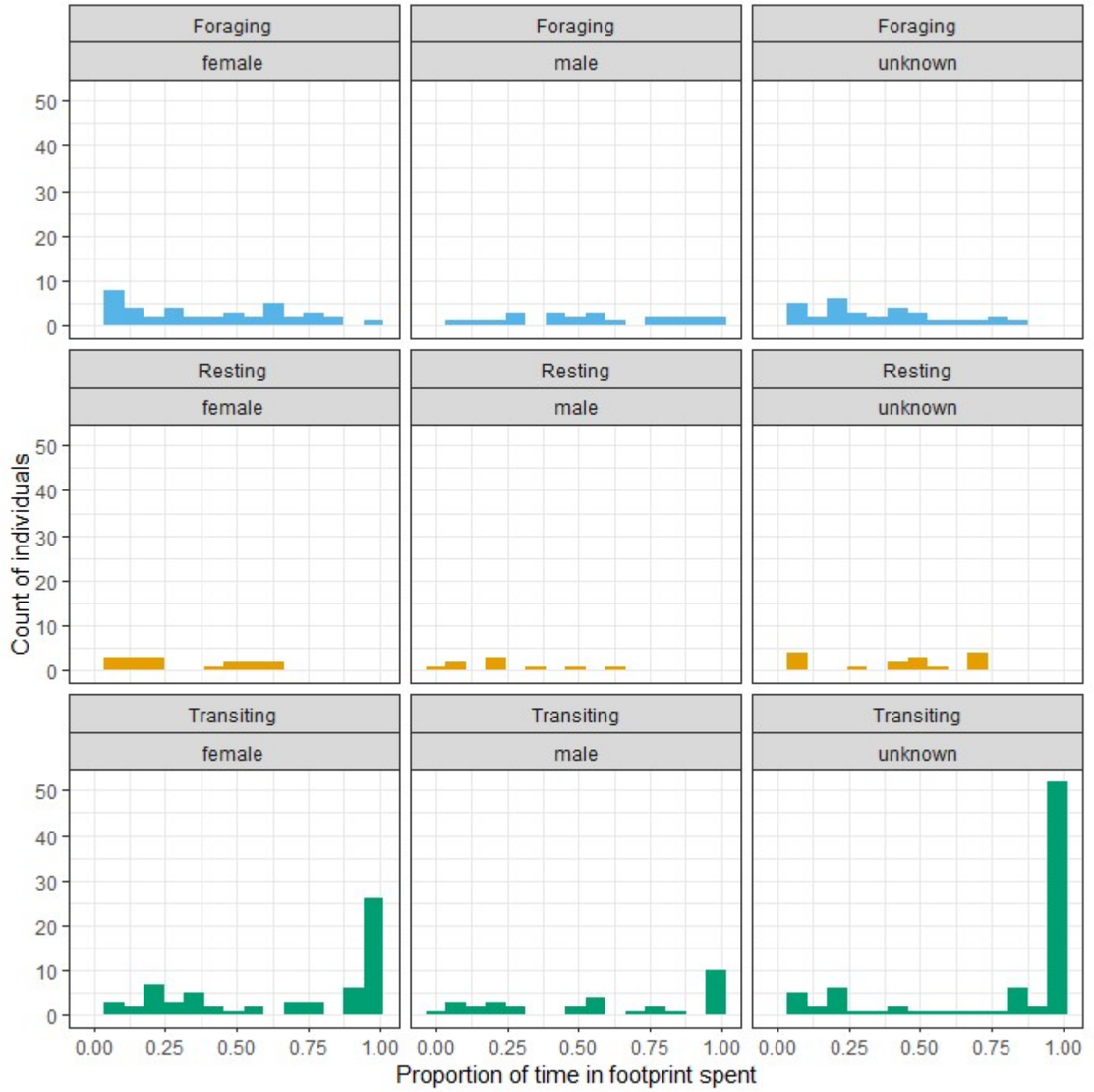

Figure 3.7: **Distributions of proportion of time spent by individuals in each behavioural state within the proposed Development Array Area, split by sex.**

Table 3.4: **Absolute proportion of 2-minute intervals spent by male, female, unknown and all birds in each estimated behavioural state across the proposed Berwick Bank Array Area. The calculations in this table pool all points together and do not control for differences between individual tracks in proportions of time spent in each behavioural state.**

Behavioural state	Female (mean)	Number of points	Male (mean)	Number of points	Unknown (mean)	Number of points	All (mean)	Number of points
Foraging	0.449	1535	0.59	886	0.272	1112	0.392	3533
Resting	0.231	790	0.126	189	0.341	1395	0.263	2374
Transiting	0.32	1092	0.284	426	0.387	1585	0.344	3103

3.4. ESTIMATION OF HOME RANGE SIZE

26. Across individual tracks, the median home range was 3,909 km^2, (2.5% - 97.5% quantiles = 58 – 25,877 km$^{2)}$. The area of the proposed Development Array Area is roughly 1,010 km^2. The median home range was therefore 3.87 times greater than the area of the Proposed Development, increasing to 25 times greater for birds at the 97.5th quantile of the distribution of home range sizes.

27. When all tracks were pooled together, the home range of foraging adult gannets from the Bass Rock was 134,311km^2, which is 133 times greater in size than that of the proposed Berwick Bank Array Area.

4. CONCLUSION

28. Overall, the proposed Development Array Area comprised a very small component (0.7% of the size of the full home range estimated from all tracks pooled together) of the range of adult gannets foraging from the Bass Rock. Furthermore, the quantity of interpolated points was significantly higher outside the footprint than within. This made it difficult to statistically assess the difference in its use in comparison with the full range of gannets. Overall, this suggests that the proposed Development Array area is of low importance when viewed in the wider context of gannet home ranges.

29. Of 682 total tracks, 503 (74%) did not enter the proposed Development Array Area at all. The proportion of tracks where transiting behaviour was seen within the Proposed Development between 21 and 41% of total tracks (depending on sex), whereas between 8% and 26% of total tracks both entered the Proposed Development and included foraging behaviour. This suggests that the proposed Development Array Area may not be a key foraging site for adult gannets breeding on the Bass Rock and is more likely to be used for transiting.

30. Statistically significant differences were found between sexes for some behavioural states; males spent 10.5% less time than females in transit throughout the entire range and also spent on average 38% more time foraging within the proposed Development Array Area than females. Females spent significantly more time transiting through the proposed Development Array Area than foraging compared to males. In fact, on average, birds spent more time transiting than foraging within the proposed Development Array Area, this effect was most pronounced in unknown sex birds and least pronounced in males

31. Birds spent more time in the proposed Development Array Area than 94% of sampled areas of a similar size, within the gannet home range. This may be due to the proximity of the proposed Development Array Area to the Bass Rock colony, meaning that birds may be more likely to pass through the proposed Development Array Area while transiting between the colony and a foraging location.

5. REFERENCES

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