

Appendix C. Additional description of methods used to quantify and classify the behavior of gannets at sea.

C.1 Foraging trip duration and range

Gannets forage almost exclusively during daylight (Ropert-Coudert et al. 2009). Therefore, we defined trip duration relative to available foraging time as the total daytime in each foraging trip. We defined daytime as the period between morning and evening civil twilight, which in turn is defined as the time at which the sun is 6° below the horizon (Phalan et al. 2007). We calculated foraging range as the median distance-by-sea of all putative foraging locations within a trip from the colony.

C.2 Dive type classification

For those birds equipped with TDRs, we calculated the within-trip dive rate as dives/trip duration, where dives were defined as bouts during which the depth was > 1.5 m. We classified dives according to their time-depth profiles as either V-shaped (rapid descent, followed almost immediately by a more gradual ascent) or U-shaped (rapid descent, followed by a period of constant or variable depth, then ascent). The two types of TDRs employed in the study recorded dive data differently: CEFAS G5 loggers were programmed to record depths exceeding 1.5 m at 10 Hz and at 1 point per minutes at other times, while MSR145 loggers recorded depth continuously at 1 Hz. We wrote an algorithm that identified bouts of depths > 1.5 m and flagged them as potential dives. It then calculated descent gradient (m/s), which was smoothed using LOWESS smoother with $f = 0.125$. Dives were then partitioned into three phases: (1) the plunge dive phase, lasting from the start of the dive to the last point when smoothed gradient was > 1.8 m/s; (2) the bottom phase, lasting from the last descent point to the last point when smoothed gradient was $\leq x$; and (3) the ascent phase, lasting from the last bottom point to the end of the dive. Dives in which the bottom time was > 2.7 seconds were classified as U-shaped (c.f. Garthe et al. 2000). Remaining dives were classified as V-shaped. The thresholds between dives phases were identified by examining plots of the variance in the dive gradient vs. the proportion of dive time elapsed. Equivalent categorisation of dives recorded using the two different logger types was ensured by re-sampling G5 data at 1 Hz and varying the threshold x until dives recorded at both resolutions were assigned the same classification. The value of x was -0.35 m/s for G5 data and -0.7 m/s for MSR145 data.

C.3 Scale of Area Restricted Search

Gannets frequently employ Area Restricted Search (ARS), which is characterised by a tortuous flight path (Hamer et al. 2009), to locate prey. In a hierarchical patch system, such as the marine environment, the scale of ARS is thought to match that of prey patches, which in turn is determined by prey type and environmental processes (Fauchald and Tveraa 2006). Individual consistency in the scale of ARS may therefore result from dietary specialisation or vice versa. We estimated the dominant scale of ARS in each foraging trip by identifying the scale at which

variance in the first-passage time peaked (Pinaud and Weimerskirch 2005, Hamer et al. 2009) To do this we used the R package ‘adehabitat’ (Calenge 2006) to calculate the first-passage time (FPT) (Fauchald and Tveraa 2003, Pinaud and Weimerskirch 2007). FPT is defined as the time taken for an animal to cross a circle of a given radius (Fauchald and Tveraa 2003). Direct movement results in low FPTs, while tortuous paths, characteristic of ARS, result in high FPTs. The scale of ARS can be estimated by calculating FPT, for a range of radii, at regular distance intervals along a track. A peak in the variance of FPT indicates the scale at which ARS-like movement occurs. Animals foraging in a hierarchical prey patch system, may undertake bouts of fine scale ARS, nested within bouts of larger scale ARS (Pinaud and Weimerskirch 2005). Gannets exhibit this behaviour during some but not all foraging trips (Hamer et al. 2009). We therefore restricted our analysis of repeatability to the largest ARS scale detectable within each foraging trip.

In order to estimate FPT we first transformed the longitude and latitude of tracking locations to North Pole azimuthal equidistant coordinates. Gannets frequently land on the sea, near the colony, prior to beginning foraging trips (Nelson 2001). These periods of foraging trip are not associated with prey acquisition so we removed locations < 1.5 km from the colony at which the speed was < 1 m/s. For each trip, we then identified other bouts during which the speed was < 1 m/s, when we assumed the bird was at rest on the water. Such bouts inflate FPT but are not associated with ARS. Hence, we re-assigned the time interval between these tracking locations, such that the resultant speed between locations within these bouts equalled the mean flight speed of gannets (15 m/s). Time intervals and speeds between other locations remained unchanged. We discretised the track to provide locations every 500 m and calculated the FPT across circles of radii $r = \{0.5, 1.0, 1.5 \dots 100\}$ km centred on each location. We then calculated the variance in FPT for each value of r ($\sigma^2 \text{FPT}_r$) and identified the dominant scale of ARS as the radius at which $\sigma^2 \text{FPT}_r$ reached a maximum.

C.4 Identification of putative foraging locations

Putative foraging locations were identified following Wakefield et al. (2013). Briefly, daytime GPS locations meeting any of the following criteria were assumed to indicate foraging: 1. tortuosity < 0.9 and speed > 1 m/s; 2. speed > 1.5 and < 9 m/s; or 3. tortuosity ≥ 0.9 and acceleration < -4 m/s². Speed and acceleration were calculated between L_{-1} and L_0 , where L_0 is the focal location and tortuosity is the ratio of the straight-line to along-track distance between L_{-4} and L_4 (i.e. 1 indicates a straight path and < 1 a curvilinear path).

C.5 Trip linearity

The degree of linearity of a foraging trip can be quantified by the sum of the distances between each location divided by the shortest path distance between the breeding site and the foraging area (Pettex et al. 2010). However, when bird locations are recorded at a high temporal resolution this also varies with flight mode. For example, if a bird’s track zigzags due to dynamic soaring the linearity index will decrease, despite the trip being highly directed. Hence, we devised a simple index κ to quantify trip linearity based on the shape of the track alone.

$$\kappa_j = 1 - \frac{A_j}{\pi \left(\frac{d_j}{2} \right)^2}, \quad (\text{C.1})$$

where A_j is the area of the minimum convex polygon enclosing all locations recorded during the j th trip and d_j is the maximum distance from the colony reached during that trip (locations transformed to Lambert azimuthal equal area projection).

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