Supplement 2. Corroborating the use of dive activity with EMbC and use of EMbC to avoid spurious zero values in binary models

In the quickly expanding field of animal tracking, it has become increasingly common to assign behavioural states (e.g. foraging versus travelling) to segments of animal trajectories. Different statistical techniques are available, such as first passage time (Fauchald and Tveraa 2003), Lévy walk (Sims et al. 2008) or state-space models based on hidden Markov models or Bayesian approaches (Jonsen et al. 2003, 2013), and – the most recently developed method – expectation-maximization binary clustering (EMbC) (Garriga et al. 2016b). EMbC has been shown to be useful across a broad range of species and comes with the advantage of requiring less supervision, less a-priori assumptions and less computational power than the other approaches (Garriga et al. 2016b).

Expectation-Maximization binary Clustering (EMbC) uses velocity and turning angle to classify movement data into four different clusters aligned with likely behavioural states: low velocities and low turns (LL; which could be interpreted as resting behaviour), low velocities and high turns (LH; intensive search), high velocities and low turns (HL; travelling or relocation) and high velocities and high turns (HH; extensive search) (Garriga et al. 2016b). We analysed our GPS dataset in the EMbC R-package (Garriga et al. 2016a) and ran the stack clustering function (stbc) separately for each of the three species. This procedure accounts for potential among-individual behavioural differences by annotating behavioural states for each individual. We applied pre- and post-smoothing to annotate the different behavioural states to account for temporal autocorrelation present in tracking data (Garriga et al. 2016b). Using the smth function, we applied a running time-window of 1 hour in the pre-smoothing process, and the default likelihood of delta = 1.0 for post-smoothing.

EMbC led to stable clustering of the four different states (Figure 1). In our dataset, diving particularly corresponded with EMbC states LL (low speed, low turning angle) and LH (low speed, high turning angle) (Figures 2-4) i.e. those states that indicate searching and resting behaviour, but not travelling. This correspondence indicated that diving behaviour per se was a good predictor for foraging activity. However, figures also revealed that individuals of all three study species often remained close to previous dive-locations without any further dive activity before either resuming foraging behaviour or travelling to another area (e.g. Figures 2d, 3d, 4d). We interpret this as post-dive resting behaviour at the surface. As a consequence, our dataset was subject to assigning spurious zero values whenever birds remained at a previous dive location (i.e. coded as “1” and assumed to reflect foraging) for a post-dive rest (i.e. coded as “0”, assuming no foraging). Furthermore, when we retained these post-dive resting periods, there was limited correspondence between the proportion of dive events and EMbC states LL and LH (Figure 5, left side). Because we were interested in whether birds were diving at a given location or not, this period of resting was not required in our modelling to answer where birds dive and hence forage and its inclusion was likely to lead to further problems with the binary response model to investigate environmental covariates at foraging locations.

We therefore used the EMbC output of models to remove all “false-0” signals associated with a period of rest after diving activity for the following statistical procedures (i.e. modelling of inter- and intraspecific habitat preferences and inter-specific overlap in daily foraging activities), i.e. all cases where recorded dive events were followed directly by EMbC states LL and LH (assuming the birds were resting near previous dive locations). If dive events were followed by EMbC states HH and HL, these time-stamps were kept as “true-0”-signals, as birds were apparently more mobile (as indicated by higher speed) and either kept searching for food or transiting to other locations. After applying this filter and removing the post-dive resting periods, we obtained a substantially better fit of EMbC states LL and LH and dive events (Figure 5, right side).

Interestingly, a considerable amount of assumed foraging locations based on the dive events coincided with the HL cluster (HL high velocity, low turning angle; 21% in cape petrels; Figures 3b, 5). Such dives during apparent transiting periods have also been described in albatrosses and gannets (Weimerskirch and Guionnet 2002, Tremblay et al. 2014) and might reflect opportunistic foraging on floating prey encountered while commuting. On the other hand, we also observed instances in which the EMbC output suggested searching behaviour and subsequent resting, while no single dive occurred. This may suggest a case where birds were feeding at the surface without submerging their back and thus the GPS-logger with the wet-dry sensor to register the dive (i.e. we would have underestimated foraging behaviour here). Yet, it may also suggest a bird simply resting at the surface and drifting on the water (see Figure S2.4c). Overall, while EMbC output and recorded dive events generally showed a high level of correspondence, the recorded dive data appear to be the better indicator of foraging behaviour and hence we used these in our analysis.

Figure S2.1. EMbC Cluster semantics. Bivariate (speed / turn) scatter-plots showing the expectation maximization clustering into four clusters. Plot a) shows the data of all southern fulmars, b) of all cape petrels and c) of all Antarctic petrels. EMbC was run as stack-cluster (accounting for among-individual effects) with pre-smoothing applied. This stage of smoothing is reflected in plots a-c. Plot d) shows an example one of an individual cape petrel (multiple foraging trips included) after post-smoothing.

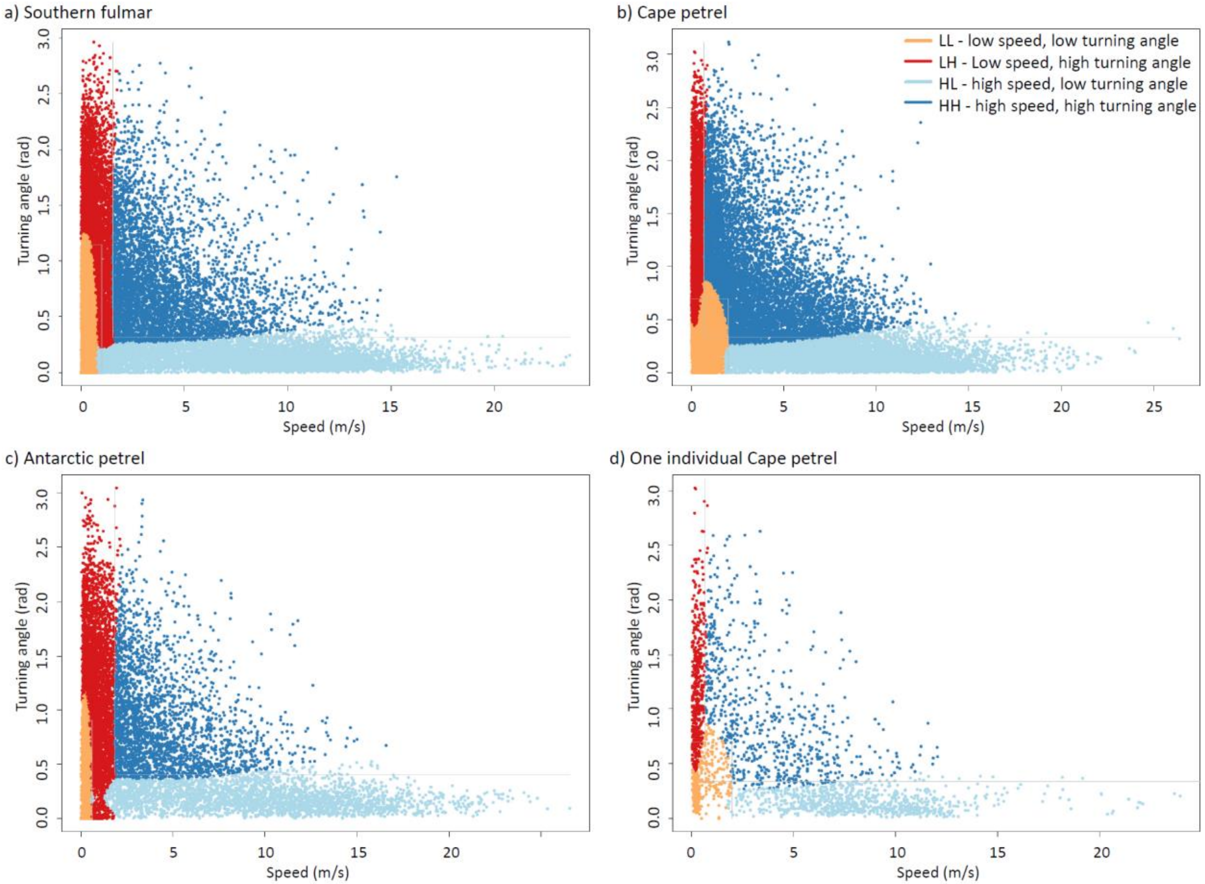


Figure S2.2. a) Example of a southern fulmar foraging trip during incubation and the assigned EMbC states (see colour legend). The size of dots indicates presence (large dots) or absence (small dots) of dive events. Red squares mark areas that are shown in detail in b–d. b), c) and d) show apparent foraging activity (indicated by dive events), in the case of d) followed by extended resting behaviour (EMbC states LL and LH). Time stamps refer to UTC time.

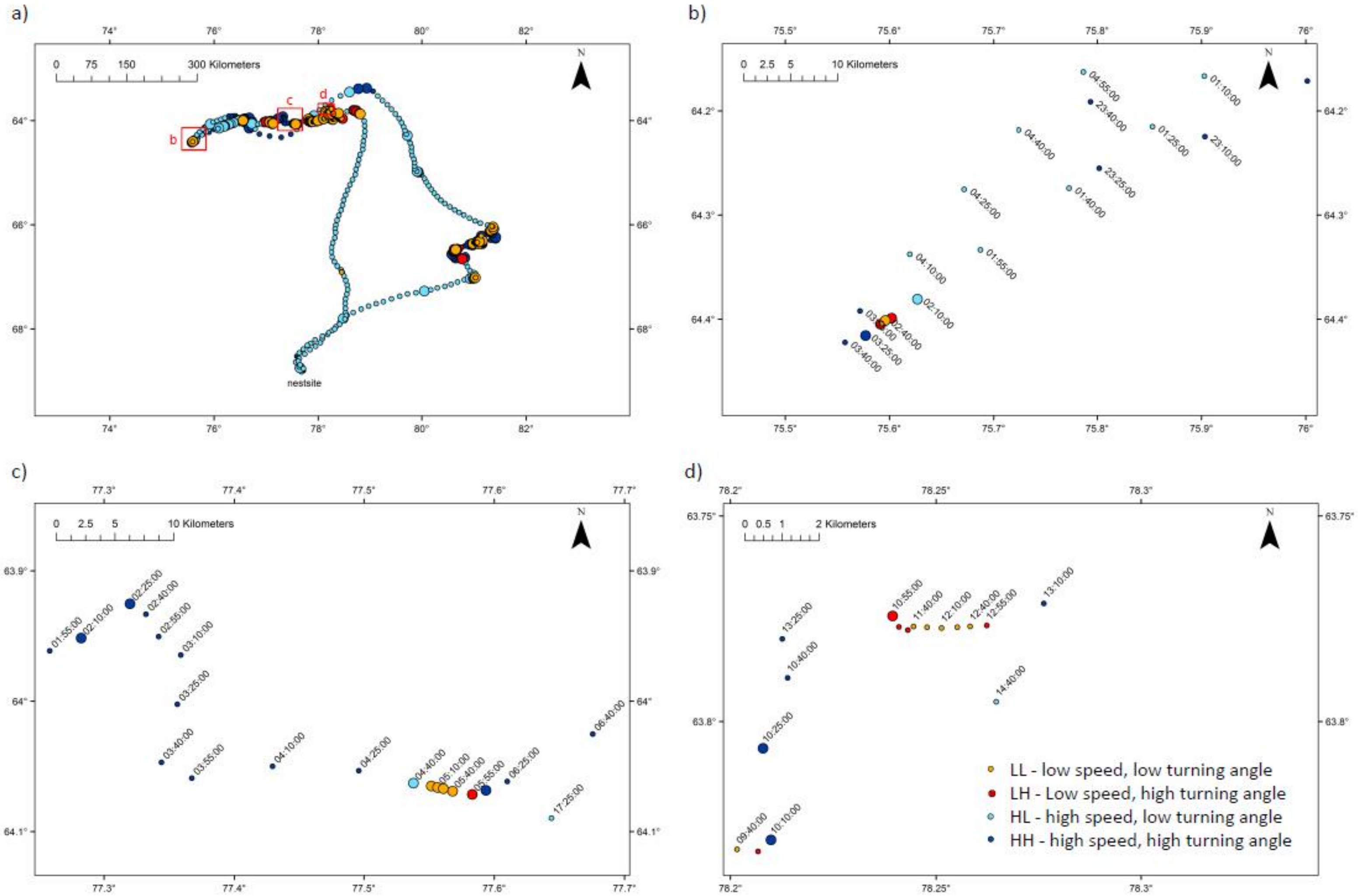


Figure S2.3 a) Example of a cape petrel foraging trip during incubation and the assigned EMbC states (see colour legend). The size of dots indicates presence (large dots) or absence (small dots) of dive events. Red squares mark areas that are shown in detail in b–d. b), c) and d) show apparent foraging activity (indicated by dive events), in c) and d) followed by resting behaviour (EMbC states LL or LH). Time stamps refer to UTC time.

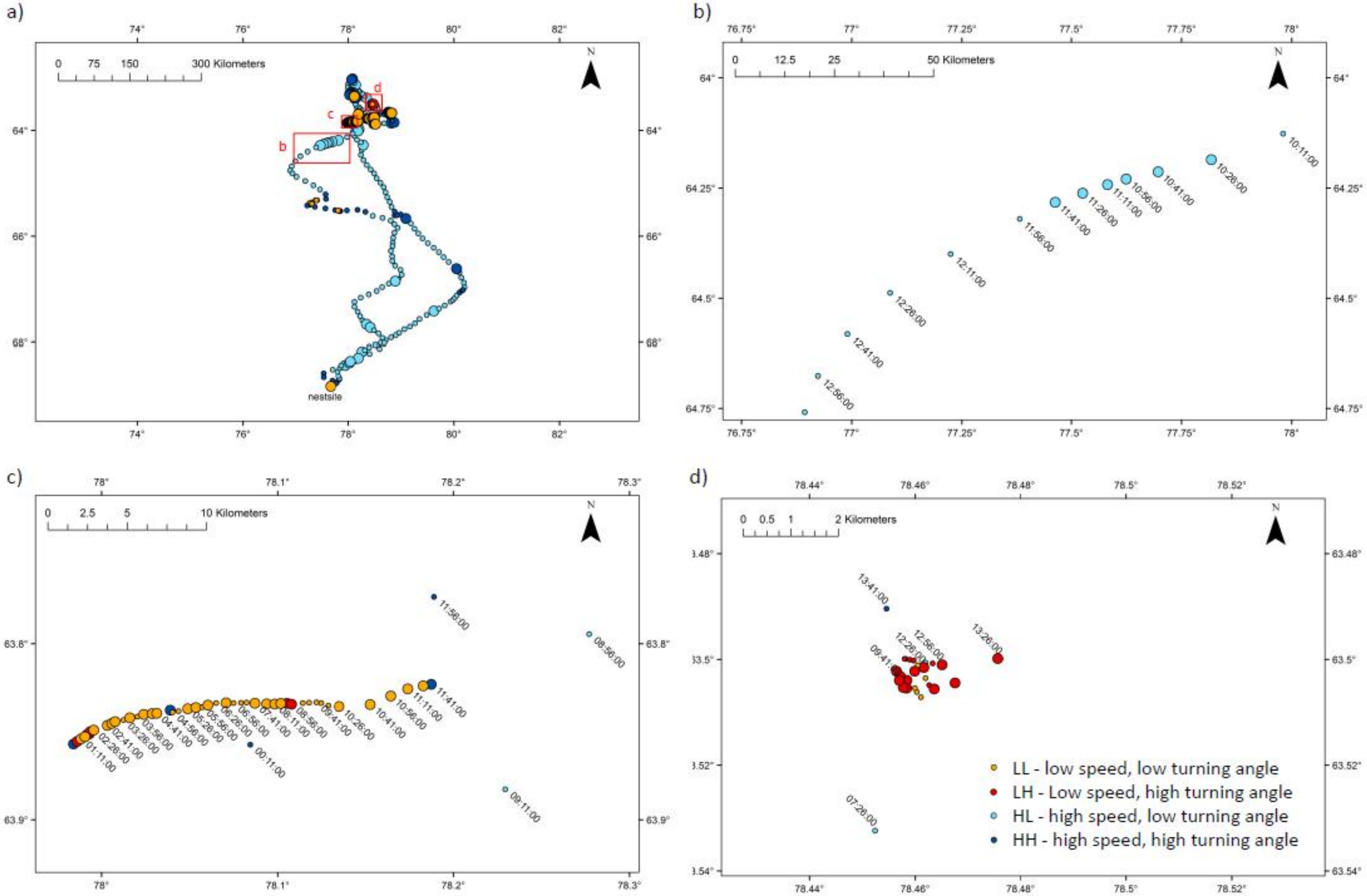


Figure S2.4. a) Example of an Antarctic petrel foraging trip during incubation and the assigned EMbC states (see colour legend). The size of dots indicates presence (large dots) or absence (small dots) of dive events. Red squares mark areas that are in shown in detail in b–d. b) and d) show apparent foraging activity (EMbC states LH and HH coinciding with dive events) followed by resting (EMbC states LL or LH). In c), one could have expected foraging behaviour based on EMbC state LH, but no dive event was recorded. Time stamps refer to UTC time.

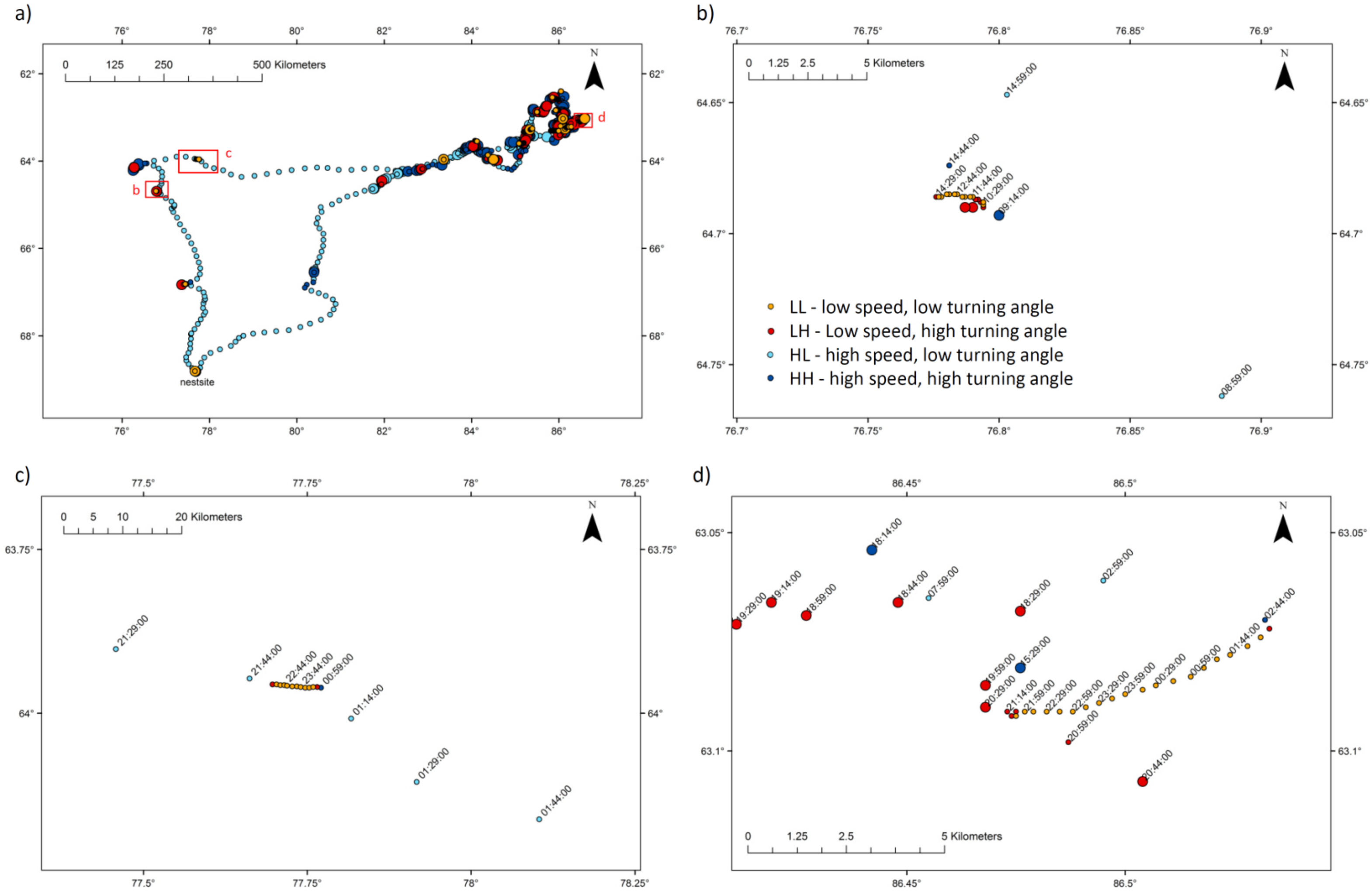
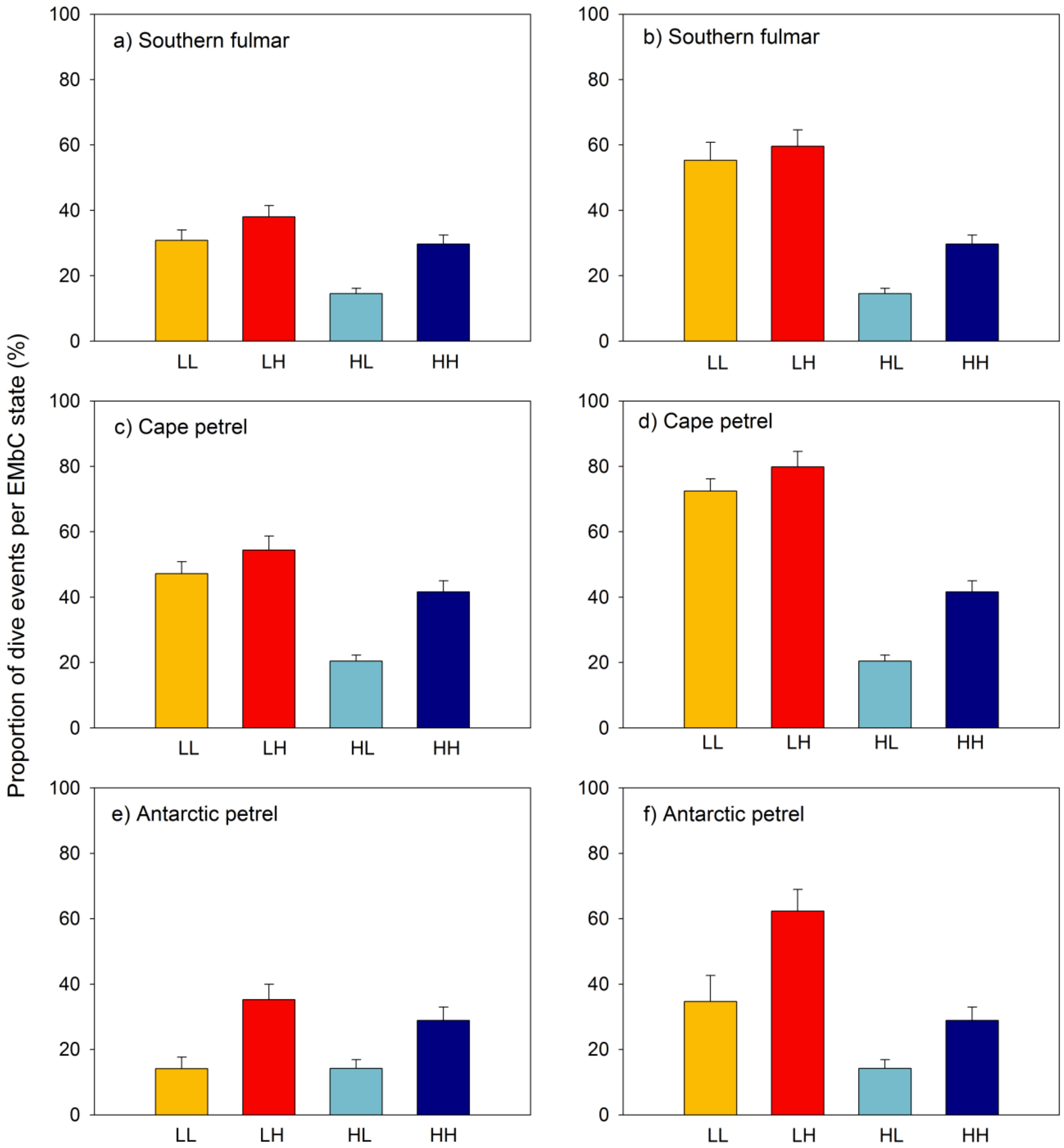


Figure S2.5. Correspondence between dive events and EMbC states for southern fulmars, Antarctic petrels and cape petrels. Plots on the left side were based on the entire dataset, plots on the right side on the dataset after removing post-dive resting periods (see text). The height of the bars refers to the proportion of dive events per EMbC state. For example, in southern fulmars, 31% of LL-assigned time-stamps coincided with diving events, while the remaining 69% did not. After removing the post-dive resting period, the figure of dive events coinciding with state LL in southern fulmars increased to 55%, while 45% of assigned LL states did not coincide with dive events. Error bars refer to S.E. based on individuals. For sample sizes, see Table 1 in the main manuscript.



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