Seabirds and marine renewables:
are we asking the right questions about indirect effects?

BETH E. SCOTT

University of Aberdeen, School of Biological Sciences, Institute of Biological and Environmental Sciences (IBES), UK
Email: b.e.scott@abdn.ac.uk

The marine environment is actually much less variable and more predictable than the terrestrial environment (Steele 1991) and most marine species rely on the predictability of daily, biweekly and seasonal currents to drive their foraging and migratory behaviours. In shallow sea regions such as the North Sea, which are physically driven by seasonal weather and tidal forces, at any given season and location, the direction and strength of residual currents and level of stratification can be predicted with great accuracy. Counter to public assumption these values can be predicted much more accurately for oceans than can a similar prediction of wind direction and ground temperature done on land. The assumptions that the oceans are more variable than terrestrial systems most likely comes from the fact that hourly, daily and biweekly tidal motions, which rotate patches of water in ellipses, ensure that planktonic organisms, or any other organisms choosing to move with the tide, will not be in the same place of sampling even in a short space of time. The speed of tidal currents can also be calculated anywhere in space and time and therefore predictions can be made of the location of important physical and biological features such as frontal areas, and the location where the level of vertical mixing changes (from changes in either depth or tidal speeds) from mixed to stratified water masses (Sharples & Simpson 2012). The use of satellite information has also been used to locate, almost in real time, locations of the thermal surface fronts (Miller 2009). The predictability of this spatial and temporal information is important in the study of the impact of renewable energy developments on seabird populations because seabird foraging is most likely tied to predicable temporal variations such as daily and biweekly tidal schedules and the evidence is mounting that foraging also only occurs at specific locations linked to level of tidal mixing (Scott *et al.* 2010, Embling *et al.* 2012) that ultimately must be related to prey availability.

However, the marine environment is going to change. As we start putting in hundreds and then thousands of marine renewable devices (i.e. tidal and wave devices extracting energy) in large arrays of areas of 10s of km², or allow levels of CO_2 to rise such that the variance in wind speeds and sea levels will also rise, we will start to change physical aspects that are fundamental to the predictability of the marine environment. At large spatial scales (whole North Sea scale) what will change is the location of amphordrotic points (also known as tidal nodes) and therefore at local scales (<100 km) this will change the level of vertical tidal physical mixing (Wolf *et al.* 2009). Local level of tidal mixing drives plankton dynamics (Simpson & Sharples 2012) and therefore the indirect effects of changes in mixing will influence the amount, species types and locations of elevated primary production (frontal and subsurface productive locations). This of course will influence the range and behaviour of pelagic fish species which choose to feed within these areas and which are the prey of most seabirds. Therefore, to truly understand the indirect effects of marine renewable developments we must shift the focus of research onto a more fundamentally mechanistic understanding of the use of ocean habitat for foraging and the choice of prey by seabird species. Research on potential environmental interactions between marine renewables and seabirds needs a much clearer ecological focus that incorporates hypothesis testing as to what is driving foraging distributions rather than just the production of distributional abundance maps. Indeed, recent work has shown that the current focus on accurate abundance estimates from at-sea distributional data is fundamentally flawed (Maclean *et al.* 2013) due in no small part to the perceived level of variance of at-sea sampling by possibly not taking into account temporal differences such as tidal speeds and direction (Cox *et al.* 2013).
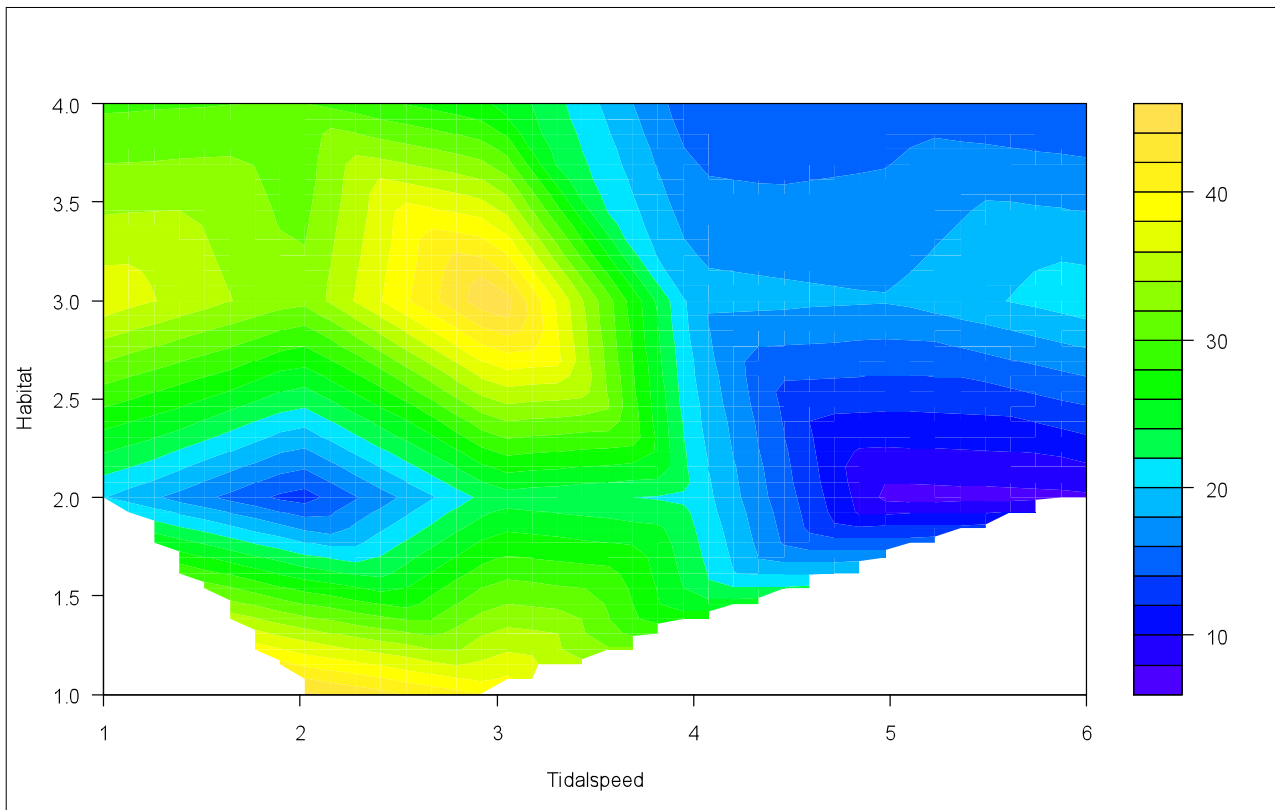
Figure 1   Arctic Tern *Sterna paradisaea*: the mean number of actively foraging Arctic Terns per observation period at different tidal speeds and within different habitat types. The tidal speeds respectively represent 1 = increasing ebb (tidal speeds <85% of the daily maxim speed during the increasing phase of the ebb tide), 2 = maximum ebb (tidal speeds >85% of the daily maxim speed during ebb), 3 = decreasing ebb (tidal speeds <85% of the daily maxim speed during the decreasing phase of the ebb tide), 4 = increasing flood (tidal speeds <85% of the daily maxim speed during the increasing phase of the flood tide), 5 = maximum flood (tidal speeds >85% of the daily maxim speed during flood), 6 = decreasing flood (tidal speeds <85% of the daily maxim speed during the decreasing phase of the flood tide). The habitats respectively represent, 1 = shear, 2 = fast flow with little or no surface turbulence signal, 3 = turbulent boils, 4 = up/downstream of region with turbulent boils.

This extended abstract suggests a range of at-sea and onshore environmental variables and sampling methodologies that attempt to test hypothesises that seabird species are actively targeting specific levels and types of vertical and horizontal mixing as foraging habitats. Over the last decade there has been an encouraging increase in multi-disciplinary work that brings together physical oceanographers, seabird and fish experts that are looking to identify important environmental variables (the latest being a special issue of *Biological Conservation* 2012). We suggest that the variables of interest across spatial scales are rapid changes in topography and high levels of patchy chlorophyll biomass and with temporal variables, the state of tidal currents, daily and monthly (spring vs. neap). Within shallow seas (<200 m) a variable that can encompass both the spatial and the combined spatial–temporal variance of the effects of tidal mixing is captured in one variable: a ratio, $\log_{10}(h/u^3)$, where h is the depth of the water column and u^3 is the speed of the tide, cubed. The value of 2.9 (m^{-2}s^3) is the prediction of where frontal areas occur (Simpson & Sharples 2012) and ranges of mean monthly values may be a good indicator of larger scale habitat use for seabirds with values <3.65 possibly being the habitat boundary between the more coastal, less stratified areas which are heavily used by a range of seabird species for foraging and the more offshore regions with only very few

species utilizing areas with values >3.65 (Scott *et al.* 2010). Pelagic fish and zooplankton species distributions are also shown to be significantly influenced by spatial levels of tidal mixing (Cox *et al.* 2013). These relationships between tidal mixing levels and foraging habitats should be investigated with a wide range of distributional data and should also be considered when creating stratified survey designs.

At smaller spatial scale (1–10 km) the influence of the daily and bi-monthly changes in tidal speeds needs to be considered as a factor affecting the temporal existence and location of foraging habitat. We have tested the methods that take into account the speed of tide while sampling at sea (Embling *et al.* 2012) and transferred them to onshore survey methods in areas of high tidal energy where different habitat types, e.g. areas of shear, turbulent boils and slower flows, are obvious to the observer. Preliminary results of specific sites in Orkney, Scotland, show clear species-specific use of different physicals types of habitats and indicate possible specialized prey catching techniques and niche separation (Figs 1 and 2). These type of studies need to be followed up with simultaneous collections of water current characteristics and prey distributions (via acoustic sonar) to be able to quantify the physical habitat being used for foraging (see more in Scott *et al.* 2013).
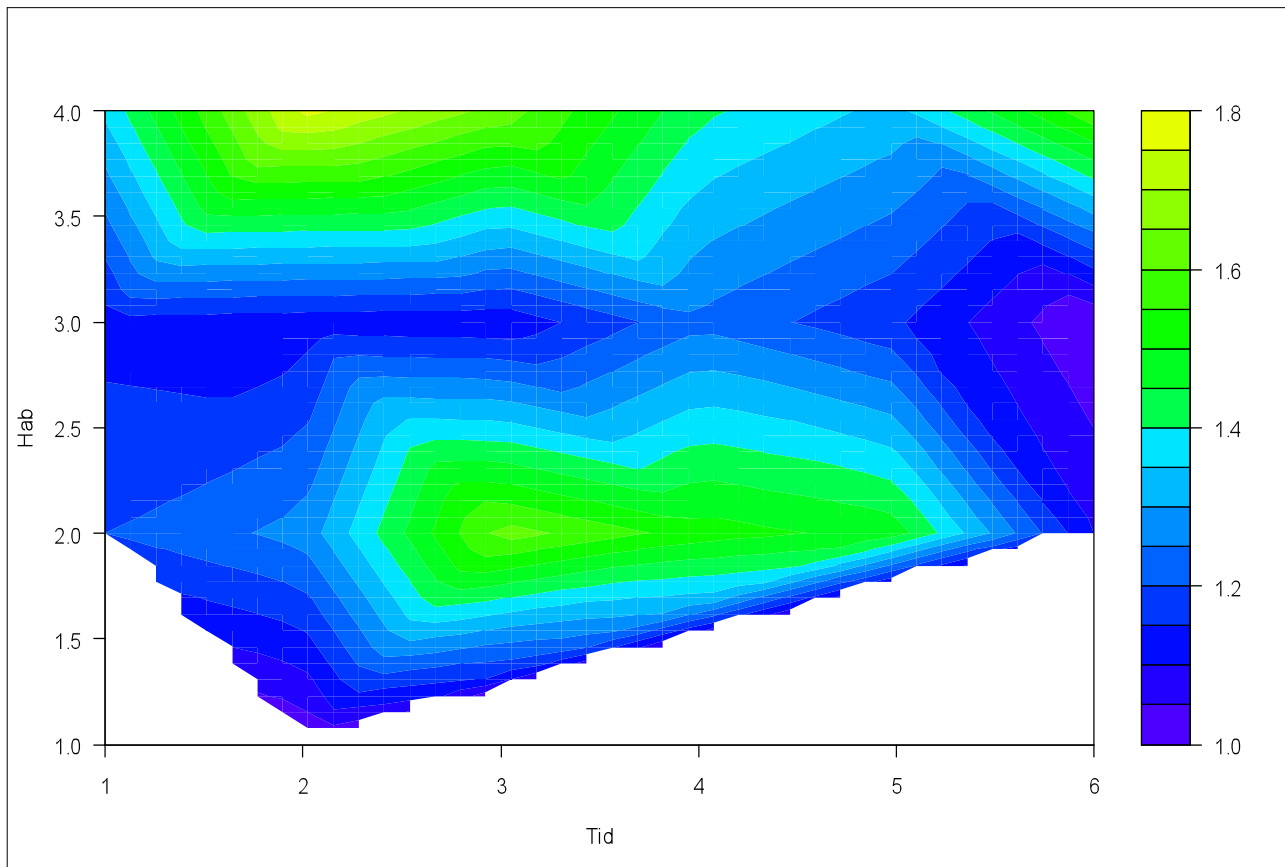

Figure 2   Black Guillemot *Cephus grylle*: the mean number of actively foraging Black Guillemots per observation period at different tidal speeds and within different habitat types. The speeds and habitats are the same as for Figure 1.

In summary we have to better understand, via mechanistic processes, what constitutes important biological and/or physical variables that lead to increased prey availability that will define seabird foraging habitat in our oceans. We suggest that these

are the sort of approaches the research community needs to tackle if we are to understand what the future marine environment has in store for seabird foraging whether via the indirect effects of large, multiple renewable developments or climate change.

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