finding food

Main foraging strategies by odour cues

The **Procellariforms** is an order of **pelagic seabirds.** They live in the ocean –only reaching land in order to breed. All Procellariforms species **feed at sea** having a wide repertoire of prey such as fish, crustaceans or cephalopods. Because their diet is conditioned by prey-distribution area, the climate and prey availability, they **need to migrate large distances**. All species have a **well-developed olfactory system**, which helps to: (i) **select** the **highest availability prey-areas**; (ii) **locate** and **recognize its nest** from the rest of the colony; (iii) **recognize their partner** by their smell [1].

Objectives

This poster focus on **the smell** as a main **sensorial mechanism** for seabirds air **navigation**, addressing the **foraging movement strategies** that seabirds use and the elaboration of **olfactory maps** that allow them to navigate. The seabird's **olfactory system** is described to understand the role in their orientation by the open sea.

I have done an extensive search using *SCOPUS*, *ProQuest*, *CSIC*, *Web of Science*, *REDIB* and *PubMed*. 33 articles were reviewed and also video conferences (1) and professional websites (2).

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Major orientation mechanism

How pelagic birds can orient through oceans is a mystery that has motived to investigate about what mechanisms they use in order to orient on their trips. Several mechanisms have been proposed, for instance, the magnetism[2]. However, magnetically disturbed experiments have been demonstrated that geomagnetic cues seem to have little relevance on their orientation. Nevertheless, **orientation by olfaction** suggests that would be an efficient mechanism, based on olfactory cues, which might be particularly suitable in featureless ocean environments [2].

Odours may be transported by winds and water currents far from their source forming a gradient that **mark a route**[2] (*Fig.1*). These olfactory cues, in association with other visual cues, could form a set of **seamarks** which could be learned by birds and used [5], so it is speculated that seabirds may **build up a map** of these features over time [3], [4].

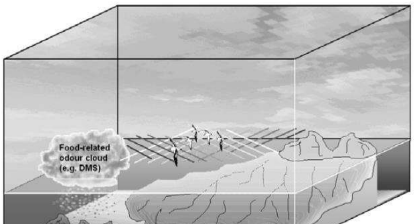

Figure 1. Hypothetical sketch of an olfactory landscape [2].

Odours as a cue trace

Seabirds are sensitive to a variety of scented compounds associated with their potential preys. The most studied traces are krill-related odours and phytoplankton associated odours as dimethyl sulphide (DMS). In the atmosphere, these odours might provide cues orientation from gradients [8], indicating foraging areas [6].

Antarctic prions (*Pachiptila desolata*) respond to and naturally associate with DMS. An investigation performed in the Kerguelen Archipelago (2005) demonstrated two main facts: (i) prions are DMS-odour responsive (tested recording heat rate increases after DMS exposition); (ii) prions attracted by DMS-cues in a non-forage scenario (tested by Y-mazes) [8].

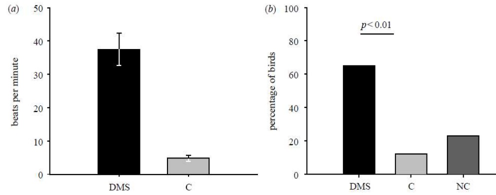

Figure 6. (A) Physiological response to DMS molecule. Mean change in heart rate (beats·min^{-1}) in 10 individuals tested in response to DMS or control stimulus; (B) Orientation to DMS in a Y-maze experiment. The graph shows the bird percentage that chose DMS, control (C) or did not chose (NC) in Y-maze tests[8].

Foraging strategies

The **spatial scale** is important to consider in heterogeneous environments. To navigate, seabirds have adopted specific movement patterns and behaviours, as a result of a strong selection[5]. First, they employ **large-scale foraging strategies** to locate prey-source patches. Then, they shift to a **smaller scale** to pinpoint accessible prey patches [6] (*Fig. 2*), triggering them to begin an **area-restricted search** (ARS) [6].

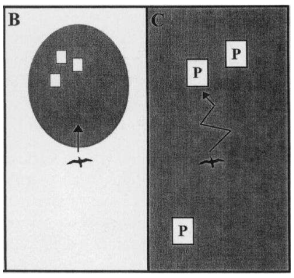

Figure 2. The image shows (B) A large-scale odour signature that indicate a productive ocean area where prey is probably be found; (C) once in a productive area, birds may track prey using smell. For both diagram, odour features are indicated in grey and white empty squares or P white squares depict prey patches [6].

Olfactory role in foraging trips and homing

A study on shearwaters performed at the Tuscan Archipelago tested if **topographical cues** may provide an **alternative navigational mechanism** for homing in *magnet* (*"M"*), *anosmic* (*"A"*) and *control* (*"C"*) GPS-tracked seabirds after their releasement (400km far from the colony). *"A"* birds oriented in a significantly different direction from home than *"M"* and *"C"* birds[1] (*Fig.4*). However, the previous hypothesis only analysed homing flights instead of the entire trips. A recent study performed in Menorca (Balearic Islands), worked on this. Birds treated (*"M"*, *"A"* and *"C"*) were tracked closely to their nests. All manipulated birds started a foraging trip but in homing phase, **smell-deprived birds were notably impaired in their orientation** towards the colony unlike the trajectories of *"C"* and *"M"* disturbed individuals but coastal navigation was not affected (*Fig.5*). Hence, it is strongly suggested that **seabirds consult an olfactory map to guide them** through marine environments[7].

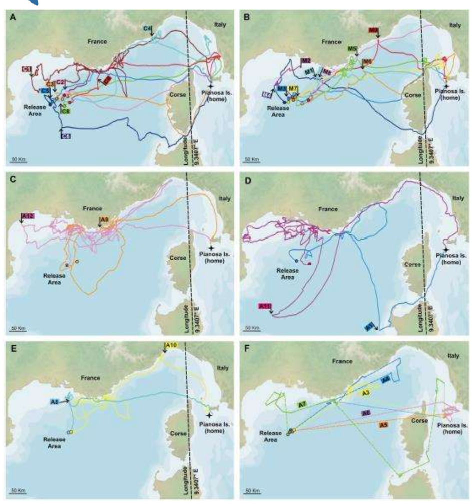

Figure 4. Homing flights of shearwaters to the colony. The panels report the GPS tracks, circles represent the release point and arrows at the basis flag represent the decision orientation point. Panels: (A) Control GPS tracks; (B) Magnetic GPS tracks; (C-E) Anosmic GPS tracks; (F) Anosmic PTT tracks [1].

Movement patterns

Seabirds use 3 navigational model movements (*Fig. 3*) in foraging trips: (i) **correlated random walks**; (ii) **commuting movements**; (iii) **looping movements**. The former, are rarely observed in this type of trip. Commuting type is the most used by seabird populations. The latter, has a loop or a figure eight shape [5] (*Fig. 3*). While commuting trips suggests that the individual guess where to find prey, the looping course suggests that the animal is searching deliberately, and stopping only when it encounters its target [5].

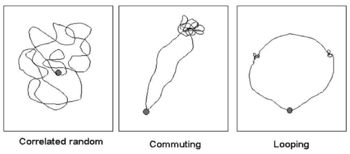

Figure 3. The three types of movement that could be used and alternate during a foraging trip: Correlated random (left image), Commuting (core image), Looping (right image). Grey circles indicate the colony position [5].

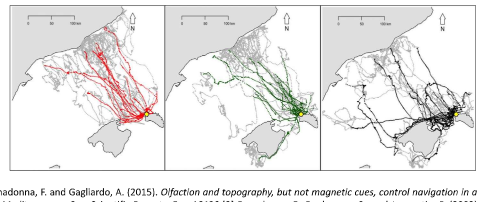

Figure 5. Control GPS tracks (left), magnetic (core) and anosmic (right). All tracks are represented in grey except de homing part that appear in red, green and black, respectively. Yellow stars show the position of the colony [7].

Conclusions

The identification of **DMS as a biogenic odour** that Procellariforms can detect provides an important advance in our ability to start comprehending how **olfactory information** might be used as an **orientation tool** at large spatial scales in seabirds [8]. Investigators suggest that different ocean areas are remembered by seabirds on the basis of their olfactory features, so as to **build up a cognitive map** on the basis of **olfactory cues**. Furthermore, **pelagic birds can use scents** not only for foraging or homing, but also within **social and familiar interactions**, such as burrow recognition, and for both chick and partner recognition [3], [9]. So, from that preliminary review, it seems logical to conclude that olfaction plays a substantial role in the Procellariforms' schedule ecology and species viability.

References

[1] Pollonara, E., Luschi, P., Guilford, T., Wikelski, M., Bonadonna, F. and Gagliardo, A. (2015). *Olfaction and topography, but not magnetic cues, control navigation in a pelagic seabird: displacements with shearwaters in the Mediterranean Sea*. Scientific Reports, 5, p.16486;[2] Bonadonna, F., Benhamou, S., and Jouventin, P. (2003) *Orientation in "Featureless" environments: the extreme case of pelagic birds*. Avian Migration, Springer-Verlag Berlin Heidelberg;[3] Nevitt, G. (2008). *Sensory ecology on the high seas: the odor world of the procellariiform seabirds*. Journal of Experimental Biology, 211(11), pp.1706-1713;[4] Reynolds, A., Cecere, J., Paiva, V., Ramos, J. and Focardi, S. (2015). *Pelagic seabird flight patterns are consistent with a reliance on olfactory maps for oceanic navigation.* Proceedings of the Royal Society B: Biological Sciences, 282(1811), p.20150468;[5] Weimerskirch, H. (2007). *Are seabirds foraging for unpredictable resources?*. Deep Sea Research Part II: Topical Studies in Oceanography, 54(3-4), pp.211-223;[6] Nevitt, G. (2000). *Olfactory foraging by Antarctic procellariiform seabirds: life at high Reynolds numbers*. The Biological Bulletin, 198(2), pp.245-253;[7] Padget, O., Dell'Ariccia, G., Gagliardo, A., Gonzalez-Solis, J & Guilford, T. (2017). *The effect of zinc sulphate and neodymium magnet treatments on a free-ranging, pelagic seabird*. Unpublished;[8] Nevitt, G. and Bonadonna, F. (2005). *Sensitivity to dimethyl sulphide suggests a mechanism for olfactory navigation by seabirds*. Biology Letters, 1(3), pp.303-305;[9] Bonadonna, F. (2017). *'The Lords of the perfumes'*. 6th International Albatross and Petrel Conference. Universitat de Barcelona; [10] Image: Diego Delso (CC BY-SA 3.0).