Marine mammals trace anthropogenic structures at sea

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In the terrestrial environment, there are examples from all trophic levels of species that have adapted to fill vacant niches in environments heavily modified by humans (e.g. [1]). In the marine environment, ocean infrastructure has led to artificial reefs resulting in localized increases in fish and crustacean densities [2]. Whether marine apex predators exhibit behavioural adaptations to utilise such scattered resources is unknown, primarily because collecting individual-based fine-scale behavioural data is challenging. With high resolution GPS data we show how infrastructure, including wind turbines and pipelines, shapes the individual movements of two seal species (*Phoca vitulina* and *Halichoerus grypus*). Using state-space models, we infer that these individuals are using structures to forage. As we are entering a period of unprecedented changes in marine infrastructure, we note that the ecological consequences of such behaviours by apex predators are likely to be complex and may not necessarily be positive.

Evidence for use of marine structures by apex predators is limited and based on non-individualised presence data from acoustic or visual studies at single structures or complexes [3]. To understand whether marine predators make preferential use of anthropogenic structures themselves, we need information at sufficiently high resolution to describe fine scale movement and activity patterns of individual animals in relation to both point (e.g. wind turbines) and linear structures (e.g. exposed pipelines). Such information is now available from animal-borne GPS tracking devices (GPS/GSM tags, Sea Mammal Research Unit). Such tags were deployed on harbour and grey seals on the British and Dutch coasts of the North Sea. Both species alternate foraging trips at-sea, lasting from a few days to a month, with visits to land to haul-out.

We recorded harbour seals within two active wind farms: Alpha Ventus, Germany and Sheringham Shoal, south-east UK. In the north-east Netherlands, four of 96 individuals tagged in 2010 and 2011 (tag duration: 25-161 days) entered Alpha Ventus. Two of these individuals showed a striking grid-like pattern of movements as they concentrated their activity at individual turbines and showed directed movements between them (Figure 1). In 2012, while some turbines were operational, seven of 22 individuals tagged in south-east England entered Sheringham Shoal. One did so on each of its 13 trips and showed similar grid-like movement patterns (see Movie S1).

Both grey and harbour seals also associated with linear structures, subsea pipelines (Supplemental information). In 2008, of ten grey and six harbor seals tagged in south-east Scotland, one of each species associated with pipelines. Of 138 harbor seals tagged in the north-east Netherlands (2009-2011), two encountered a 60 km section of pipeline and followed it on multiple trips for up to ten days at a time (see Figure S1). In addition, two of 22 seals tagged elsewhere in the Netherlands were also recorded following pipelines.

The data strongly suggest that these structures were used for foraging and the directed movements show that animals could effectively navigate to and between structures. Area restricted searching, characterized by high sinuosity and reduced horizontal speed, has been used to identify likely foraging in seals [4]. Using state space models [4], we found that the three animals that showed a grid-like movement pattern concentrated their foraging effort in wind farms. Furthermore, within the wind farms, given presence the probability of

foraging significantly increased towards these individual structures for the two seals that spent the majority of their time near the turbines (Figure 1). When closely following linear structures, high sinuosity associated with area restricted searching should not be expected by default. However, within 100m of the pipelines, the distribution of speeds was similar to that of foraging estimated in the state-space models and were skewed to the lower end of the distribution of speeds for entire trips including both foraging and travelling (see Figure S1).

The finding that some seals adjust their behavior to make use of anthropogenic structures raises questions regarding adaptive advantages, population level effects and the wider ecological consequences. For the individuals that have consistently adopted this strategy, it appears to be a successful behavioral adaptation in terms of foraging success. Although other study individuals encountered pipelines and may have briefly used them, clearly only a small proportion of individuals make sustained use of anthropogenic structures for foraging. Nevertheless, this is likely to reflect a large number of individuals given that the population of harbor seals in the North Sea exceeds 35,000 [5, 6] and 65,000 grey seals are estimated to haul-out on the British coast of the North Sea alone [7]. Furthermore, the proportion of animals encountering and utilizing such structures is likely to increase with the planned development of marine renewable energy generation.

These findings have implications for both the understanding and management of the relationship between anthropogenic structures and top predators. Some individuals clearly perceived the benefits of spending time in an operational wind farm outweigh any potential

negative effects of exposure to audible turbine noise [8]. Further studies are needed to identify the effects this might have on the auditory system of seals. Furthermore, if reef effects persist once pipelines are inactive, the burial or removal of such pipelines as often conducted during decommissioning would eliminate these foraging opportunities. The three study animals that concentrated their foraging within wind farms also foraged outside the wind farm, suggesting that these individuals are not completely dependent on anthropogenic structures. The ecological consequences of the utilization of artificial reefs by top predators may be multi-faceted. It is unclear whether artificial reefs constitute an increase or just a concentration of overall biomass (The Production versus Attraction debate [2]). Given that we are entering a period of unprecedented development of the marine renewables industry and, in some places, decommissioning of oil and gas infrastructure this uncertainty needs to be resolved to assess whether anthropogenic structures should be designed and managed to reduce the overall ecological footprint (if they concentrate biomass and thereby make prey populations more vulnerable) or to maximize any potential ecological benefits (e.g. foraging opportunities for top predators)[9].

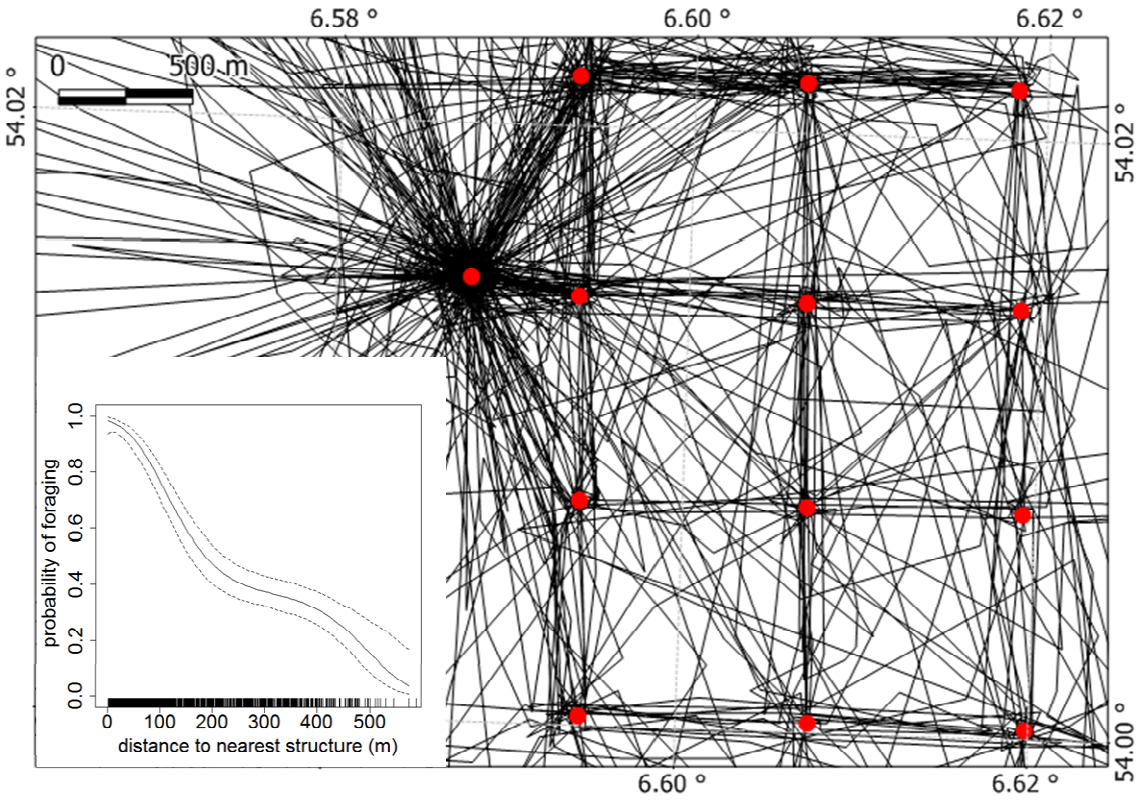

Figure 1. The tracks of an individual around Alpha Ventus. Points show structures including turbines and the meteorological mast. Also shown is that within the wind farm the probability of foraging increases significantly with decreasing distance to a structure; the dashed lines indicate the 95% confidence intervals.

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