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Seabird movement reveals the ecological footprint of fishing vessels

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Exploitation of the seas is currently unsustainable, with increasing demand for marine resources placing intense pressure on the Earth's largest ecosystem [1]. The scale of anthropogenic effects varies from local to entire ocean basins [1–3]. For example, discards of commercial capture fisheries can have both positive and negative impacts on scavengers at the population and community- level [2–6], although this is driven by individual foraging behaviour [3,7]. Currently, we have little understanding of the scale at which individual animals initiate such behaviours. We use the known interaction between fisheries and a wide-ranging seabird, the Northern gannet *Morus bassanus* [3], to investigate how fishing vessels affect individual birds' behaviours in near real-time. We document the footprint of fishing vessels' (≥15 m length) influence on foraging decisions (≤11 km), and a potential underlying behavioural mechanism, by revealing how birds respond differently to vessels depending on gear type and activity. Such influences have important implications for fisheries, including the proposed discard ban [8]), and wider marine management.

Understanding the spatial influence of fisheries is critical to marine planning and policy [1,4,8]. The issue of scale is particularly important to the ecology and conservation of a suite of wide- ranging marine predators, where studies of scale-dependent foraging strategies [2,3,5] have yet to resolve mechanisms used to locate patchy prey, and where spatial planning lacks a landscape scale. To address this knowledge gap we analysed high resolution GPS tracking data from 74 chick-rearing gannets contemporaneously tracked from six breeding colonies during June to July 2011 (Supplemental information); and combined these with anonymised fisheries data from the Vessel Monitoring System (VMS) within the Irish Exclusive Economic Zone (EEZ). We are thus able to characterize the impact of fishing vessels on seabird behavior at a range of colony sizes with varying degrees of intraspecific competition and environmental conditions [3,7], and throughout a national management unit [8]. Using an ethoinformatics approach based on flight speed and tortuosity, gannet GPS locations were assigned one of two behavioural states: 'foraging' or 'commuting' [7] (Supplemental information). The distance to nearest vessel, vessel type (comprising trawlers and non-trawlers due to differences in discard opportunities; Supplemental information) and vessel activity ('drifting', 'fishing' or 'steaming', based on instantaneous vessel speed and gear- specific fishing speeds; Supplemental information) were appended to every gannet location. We used multi-state Markov models to examine the influence of vessel distance, type and activity on the transition probabilities between the behavioural states of individual birds during foraging trips (Supplemental information).

Our models reveal that gannet behavior is influenced by fishing vessels at distances up to 11 km, with significant deviation from the null transition probability between states first detected at this range (Figure 1A; after controlling for significant effects of both sex and colony; Supplemental information). This is the first estimate of the size of the ecological footprint of a fishing vessel, and suggests how individual behavioural decisions can underlie broad-scale correlations between fisheries and seabird distributions [2,5].

While the presence of fishing vessels alone has a significant impact on seabird behaviour, there is a small possibility that the relationship exists because both humans and birds are exploiting the same productive fishing areas [5]. Thus we further investigated bird–boat interactions based on vessel type and activity, limiting bird locations to those within the 11 km response threshold. Distance to vessel remained an important predictor of behavioral switching with birds becoming increasingly likely to switch to foraging and less likely to switch to commuting with increasing proximity to a vessel (11.1% per km and 4.7% per km, respectively). More importantly, there was a strong interaction between the effects of vessel type and vessel activity on bird behavioural transition probabilities. Gannets were significantly more likely to switch to foraging, and significantly less likely to switch to commuting behavior when vessels were fishing; and significantly more likely to switch to commuting when trawlers were steaming or drifting (Figure 1B,C). Effects were different for non-trawlers where discard opportunities differ - birds were more likely to switch to foraging, and less likely to switch to commuting when non-trawlers were drifting compared to fishing, likely reflecting the processing of catch on these vessels (Figure 1B,C). It thus appears that individual gannets are able to reliably differentiate between both vessel types and vessel activity and adjust their behavior accordingly [9]. Attraction to boats can be enhanced by the presence of con- or hetero-specifics already in attendance [9,10], and may strengthen depending on species and time of year [5,6,9]. Birds may therefore be particularly attuned to identifying specific behaviours or characteristic cues, and are capable of applying these to human fishers, triggering similar behavioural responses [9].

In the marine environment, vessels alone can significantly affect the distribution or behavior of many species through disturbance and attraction [1,5,10]. At a fundamental level, the response of individual birds to the presence of humans as top predators [2,9,10] can have important effects on population processes [4,6]. From an

applied perspective, understanding these local-scale processes, and the way in which they influence broader patterns across national territorial waters, is vital for effective marine planning and fisheries management, particularly in light of proposed fisheries reform [8]. Our results suggest that each vessel can significantly influence the distribution and foraging patterns of wide-ranging marine predators.

Supplemental Information

Supplemental Information including experimental procedures, two tables and one figure can be found with this article online at http://dx.doi.org/10.1016/j.cub.2014.04.041.

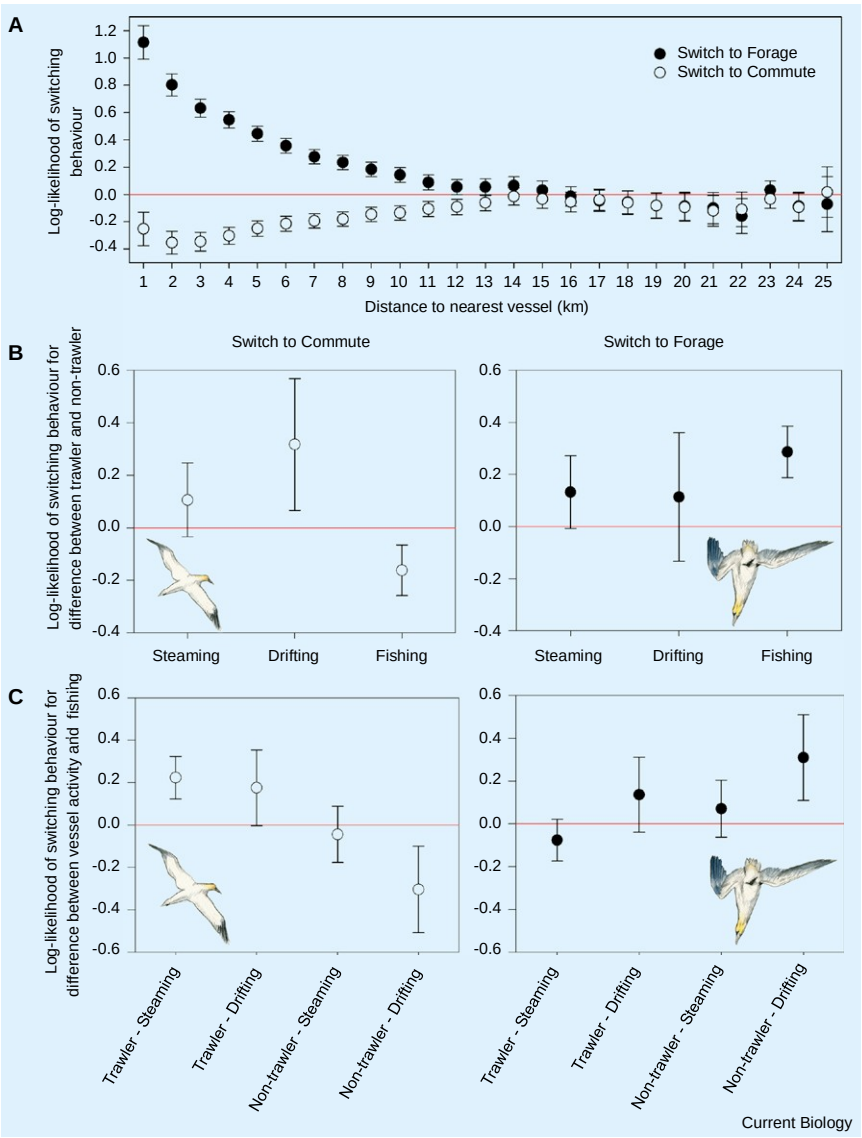

Figure 1. Influence of fishing vessels on seabird behavior.95% CIs passing through zero (red line) indicate no significant effect on transition probabilities.

(A) Influence of vessel proximity on the log-likelihood of gannets switching between behavioural states (commute to forage: filled circles; forage to commute: open circles). At distances ≤11 km, gannets are significantly less likely to switch from foraging to commuting and also significantly more likely to switch to foraging behavior. (B) Effect of closest vessel type across different fishing activities on gannet behavioural transition rates (log-likelihood ± 95% CIs). Values compare between trawlers and non-trawlers for each behavioural switch, with those passing through zero indicating no significant difference between vessel types. When vessels travel at fishing speeds, gannets are more likely to switch to foraging, and less likely to switch to commuting, when vessels are trawlers as opposed to non-trawlers. Birds are also more likely to switch to commuting when trawlers are drifting. (C) Effect of closest vessel activity within vessel types on gannet behavioural transition rates (log-likelihood ± 95% CIs). Values compare activities to the baseline that each vessel type is fishing for each behavioural switch. Gannets are more likely to switch to commuting when trawlers are steaming compared to fishing. Birds are less likely to

switch to commuting, and more likely to switch to foraging, when non-trawlers are drifting compared to fishing. These differences likely reflect contrasting discard availabilities between vessel types.

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