GPS tracking of great skuas *Stercorarius skua* to investigate interactions with fisheries and marine renewable energy developments

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Summary
We used GPS technology to improve our understanding of how a declining breeding population of a scarce endemic seabird, the great skua (*Stercorarius skua)*, uses the marine environment by tracking the movements and behaviour of breeding adults from two Scottish special protection areas on the Orkney and Shetland Islands. We assessed spatial overlap with a long-term human activity (fishing) and a relatively recent human activity (marine renewable energy generation) to improve our understanding of this species' response to current and future pressures. These pressures include the increasing development of the marine environment for renewable energy generation and changes to fisheries discard policies. Increasing our understanding of seabird movements at sea in relation to human activities will support marine spatial planning (MSP) by informing the management of sustainable marine activities, the sensitive designation of sites for marine renewable energy development and the implementation of marine protected areas.

Introduction
Globally we are witnessing an increase in human activities in inshore and offshore marine environments. This is coupled with increasing awareness of the need to manage marine ecosystems sustainably for human benefit but also to ensure the conservation of the marine environment. Many seabird species are apex predators and can be good indicators of the health of marine ecosystems. In the North Atlantic, many populations of seabirds are in decline, indicating that they are under pressure. Understanding the mechanisms driving these declines is vital to ensure the conservation of seabirds and to predict potential effects of increasing or additional human activities at sea. We investigate the movements at sea of a scarce endemic seabird, the great skua (*Stercorarius skua)*, to identify interactions with existing and proposed human activities in the marine environment to support informed MSP.

Materials and Methods
We used the recently developed UvA Bird Tracking System (UvA-BiTS, University of Amsterdam) to collect movement data from great skuas. GPS data loggers were fitted to 17 breeding individuals: 7 from a colony on Hoy, Orkney (58°52'N, 3°24'W) and 10 from Foula, Shetland (60°8'N, 2°5'W). The loggers were solar powered and wirelessly transmitted data to a base-station in the colony. Loggers were attached using a backpack harness of Teflon ribbon. The harness and tracking device weighed ca.25g - less than 3% of the body mass of tracked birds. GPS fixes were recorded at intervals ranging between 1-30mins throughout the breeding season until birds left the area on migration. We identified core foraging areas of each bird using the 50% utilization distribution (UD) of foraging trips, which excluded foraging trips that also incorporated non-foraging behaviour such as bathing. To eliminate bias in calculating the UD, all tracks were linearly interpolated to establish regular 10 minute time intervals between trip locations. In all cases the UD was calculated using a smoothing parameter of 10km and a grid size of 1km^2. The smoothing parameter was identified through successive trials where the UD was calculated using a range of bandwidths. The overlap of UDs with demersal (mobile

gear) fishing activity was visually assessed. Intensity of fishing activity for 2007-2011 was derived from vessel monitoring system (VMS) and landings data from all UK fishing vessels ≥15m in length landing into UK ports (A.Kafas, Marine Scotland Science). The proportion of overlap of the 50% UD of each bird was calculated for existing, proposed and search areas for future marine renewable energy developments. Data were analysed using ArcGIS (ArcMap ver.10. ESRI, USA) and the packages 'adehabitatHR' and 'adehabitatLT' (Calenge, 2013) in R ver.3.0.1 (R Core Team, 2013).

Results and Discussion

During foraging, twelve of the seventeen birds overlapped with large areas of high intensity demersal (mobile gear) fishing activity (Fig. 1A). Great skuas are known to interact with fisheries to access food in the form of discards (Votier *et al.* 2004). By investigating the extent of this relationship we can improve predictions of how changes to fisheries discard policies may affect this scarce seabird.

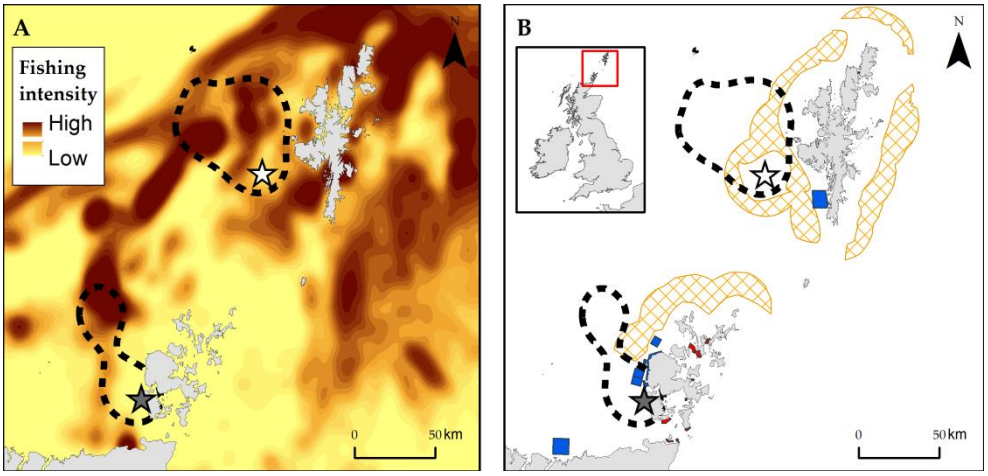

Figure 1. Overlap of core foraging areas (50% utilization distribution, black dashed line) of two breeding great skuas from colonies on Hoy, Orkney (grey star) and Foula, Shetland (white star) with: (A) Demersal (mobile gear) fishing intensity 2007-2011; (B) Proposed and existing wave (blue polygons) and tidal-stream (red polygons) renewable energy development sites, and search areas for future offshore wind options (orange cross-hatched polygons).

None of the UDs of birds tracked from Foula overlapped with existing or proposed marine renewable energy development sites. Six of the seven birds tracked from Hoy overlapped with at least one proposed or existing wave energy development site, with one bird overlapping with five wave development sites. These overlaps represented only a small proportion of the core foraging area of each bird (mean = 1.0% +/- 1.9 s.d.). None of the UDs overlapped with existing or proposed offshore wind farm sites. However, ten birds overlapped with search areas for future offshore wind options (For all birds tracked: mean = 13.0% +/- 13.9 s.d.) (Fig. 1B). Given the Scottish government's target of generating 100% of electricity demand from renewable sources it is likely that some of these areas will be proposed for offshore wind developments in the future. This is relevant because whilst great skuas appear to be at low risk of negative effects from wave energy developments (Furness *et al.* 2013), they are likely to be more vulnerable to offshore wind installations (Furness *et al.* 2012).

References

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