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Using a spatial overlap approach to estimate the risk of collisions between deep diving seabirds and tidal stream turbines: A review of potential methods and approaches ☆

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ABSTRACT

It is likely that there will be a substantial increase in the number of tidal stream turbines within the UK over the next decade. However, the ecological impacts upon marine top-predators, including seabirds, remain largely unknown. Although tidal stream turbines could have many direct and indirect impacts upon seabird populations, it is the risk of direct collisions between individuals and moving components that currently causes the most concern. Species such as Auks *Alcidae* sp., Cormorants *Phalacrocorax* sp. and Divers *Gavia* sp. almost certainly face higher risks than others. However, it is likely that they are not equally vulnerable. Part of predicting which are most vulnerable involves the estimation of spatial overlap between their foraging distributions and the location of tidal stream turbines. This paper reviews potential methods and approaches that should help to predict whether a population would: (1) exploit areas suitable for tidal stream turbines, (2) dive near tidal stream turbines within these areas, or (3) dive to depths where moving components are found? Answering these questions in a hierarchical manner (from 1 to 3) could help to predict the extent of spatial overlap for vulnerable populations. These approaches require a fundamental understanding of the mechanistic links between physical conditions, prey characteristics and foraging opportunities. Therefore, multi-disciplinary approaches incorporating methods usually associated with oceanographic and fisheries studies are needed to document physical conditions and prey characteristics over large and small spatial scales. Answering these questions also requires collaborative efforts and a strategic governance approach to collating the wide range of distributional, prey and physical datasets currently being collected.

1. Introduction

The UK government has set targets to supply 20% of its energy requirements from renewable sources by 2020 (European Commission's Renewable Energy Directive (2009/28/EC)). However, it is recognised that land based energy resources including solar, wind and biomass often create conflicts over land use and ownership [1]. Therefore, alternative solutions are desirable. Fortunately the UK has large and exploitable offshore energy resources including wind, wave and tidal currents [2] and an increase in their use could go some way towards reaching these government targets. Currently the UK's marine renewable energy installations are dominated by wind turbines although it is acknowledged that diversification is necessary [3]. As a result, there is an interest in the development of installations to exploit tidal current energies, and it is likely that there will be a substantial increase in the number of tidal stream turbine installations within UK waters over the next decade [1].

The UK holds internationally important numbers of seabirds [4] and there is a legal obligation to consider the effects from tidal stream turbines upon these populations (The European Birds Directive; 2009/147/EC). Although the potential impacts on UK seabird populations are diverse in their nature and severity [5,6], it is the possibility of mortalities from collisions with moving components that often cause the most concern [7]. In this respect, tidal stream turbines differ from other marine renewable installations in that their moving components occur beneath the water surface. Therefore, only species that can dive to depths where moving components are found face collision risks. The depth at which moving components are found varies among currently active devices, although most are between 10 and 40 m from the water surface [5]. These depths are well within the maximum recorded diving ranges of several abundant species within the UK [5]. However, it is believed that Auks *Alcidae sp*, Cormorants *Phalacrocorax sp.* and Divers *Gavia sp.* are most vulnerable to collisions due to their tendency to consistently dive to depths where moving components are found, and also to exploit habitats suitable for tidal stream turbine installations [8]. Despite this it

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remains unknown whether direct collisions represent real and serious threats to these populations.

An important part of assessing collision risks may be estimating spatial overlap between the foraging distribution of vulnerable species and the locations of tidal stream turbines. Due to the diverse and synergistic manner of processes governing species foraging distribution [9–11], quantifying spatial overlap offers challenges. Therefore, pragmatic approaches are necessary. One approach is to divide the process of estimating spatial overlap into three different stages and spatial scales by asking whether a population would (1) exploit areas suitable for tidal stream turbines, (2) dive near tidal stream turbines within these areas, or (3) dive to depths where moving components are found? Answering these questions in a hierarchical manner (from 1 to 3) could help to predict the extent of spatial overlap for a range of species and identify those most vulnerable to collisions.

This paper reviews potential methods and approaches that should answer these three questions. It focuses exclusively on the species that are considered most vulnerable to collisions in the UK; they were Common Guillemots *Uria algaa,* Razorbills *Alca torda,* Atlantic Puffins *Fratercula arctica,* Black Guillemots *Cepphus grylle*, European Shags *Phalacrocorax aristotelis* and Great Cormorants *Phalacrocorax carbo.* Although Red Throated Divers *Gavia stellate*, Black Throated Divers *Gavia arctica* and Great Northern Divers *Gavia immer* are also considered vulnerable, there is little information on the foraging behaviour of these species. They were therefore omitted from any discussions, although many of the methods and approaches outlined here may well be applicable for these species. Throughout this paper, populations were considered to be groups of conspecifics that are present within a geographical region where tidal stream turbine installations are present or planned (~100 km). Areas within the regions where installations are present or planned are referred to as 'habitats' (1–10 km) and those immediately around tidal stream turbines as 'micro-habitats' (100 m).

2. Will populations exploit habitats suitable for tidal stream turbines (1–10 km)?

2.1. Tidal stream habitat and seabirds (1–10 km)

Tidal stream turbines require quite specific conditions. Mean spring peak tidal currents faster than 4–5 knots (2–2.5 ms^{-1}) and energy levels greater than 1 Nm^2 are needed for economically viable large scale (> 10 MW) projects [1]. These conditions are usually found in tidal passes between land masses and around headlands where topographical features cause currents to accelerate, providing the speeds and energy levels needed for sufficient energy returns [1]. In North America, large numbers of Auks and Cormorants have been recorded foraging within these habitats [11–14]. Within the UK, these habitats are limited in their spatial extent [15] and quantity, with only around 30 sites having the potential to provide economically efficient energy returns [16]. However, it cannot be assumed that they are not important foraging habitats on this basis alone. For example, most tidal resources are found in northern Scotland, Orkney and Shetland; the three regions that support the vast majority of breeding seabirds in the UK [4]. Moreover, seabird distribution maps based upon several decades of vessel surveys reveal high numbers of Auks and Cormorants within the regions where tidal passes are found [17]. Therefore, determining which of these populations exploit tidal passes is the first stage of predicting spatial overlap. However, it is also important to quantify what proportions of these populations may exploit these habitats. Seabirds are long-lived species with delayed maturity and low fecundity rates. As such, adult mortality rates have a significant influence on population dynamics [18] and predicting impacts depends upon estimating the number of potential mortalities among vulnerable species.

2.2. Seabird distributions (1–10 km)

At the habitat scale, strong and positive spatial relationships are often seen between a populations' foraging distribution and that of their preferred prey items [19–21]. High abundances of prey items are found in habitats characterised by high levels of primary production and/or accumulation of biological biomass and, as such, many foraging seabirds are also found within these habitats [11,22]. However, foraging distributions differ among populations, perhaps reflecting differences in their prey choice [23] and/or behaviours [24,25]. For example, Black guillemots and Cormorants usually exploit benthic prey [26,27] and could favour coastal habitats where the seabed is more accessible. For Cormorants, a need to dry out their wettable plumage between dives means that habitats also need to be near suitable roosting sites [28]. Atlantic Puffins, Common Guillemots and Razorbills usually exploit pelagic prey and may favour habitats where physical conditions help to accumulate zooplankton or fish, for example [11,24]. It must also be acknowledged that a populations' foraging distribution changes over time. This is sometimes explained by annual [29,30] or seasonal [31] changes in their preys' distribution or abundance. However, the main mechanisms are reproductive duties. During summer months seabirds must repeatedly commute between foraging habitats and terrestrial breeding colonies [32,33]. As a result, a populations' foraging distribution tends to be centred on the location of breeding colonies within the region [34].

2.3. Estimating spatial overlap (1–10 km)

Spatial overlap at the habitat scale most likely varies among populations and within populations over time. One way to estimate spatial overlap is to directly record foraging distributions over multiple years and seasons. However, even with large quantities of distributional data, robust estimates are difficult from these sources alone [35]. Moreover, the irregular changes in foraging distributions that are seen among seasons and years mean that future levels of spatial overlap cannot be accurately predicted from the past records. Therefore, there is a need to understand precisely how a populations' foraging distribution is shaped by the ecological and physical factors. This would allow predictions as to what scenarios (e.g. seasons, prey characteristics) could increase or decrease a populations' use of tidal passes.

One solution lies in spatial modelling approaches. Although encompassing a broad range of methods, most approaches are based upon resource selection functions (RSFs) [36]. RSF first uses statistical models to establish relationships between the presence or abundance of foraging individuals and a range of habitat characteristics. They then use these relationships to predict the chances of the presence (or the abundance) of foraging individuals within a habitat given its characteristics [36–38]. In addition to habitat characteristics, however, models must also consider ecological factors such as prey characteristics and the location of breeding colonies [39–41]. Thankfully, as RSF is based upon conventional statistics, they can accommodate multiple explanatory factors and also non-linear relationships such as functional responses [42,43]. By using spatial modelling approaches to understand relationships between foraging distributions and habitat characteristics, it is possible to start predicting which, and when, populations have the most spatial overlap at the habitat scale.