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Fine-scale hydrodynamic metrics underlying predator occupancy patterns in tidal stream environments

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ABSTRACT

Whilst the development of the tidal stream industry will help meet marine renewable energy (MRE) targets, the potential impacts on mobile marine predators using these highly dynamic environments need consideration. Environmental impact assessments (EIAs) required for potential MRE sites generally involve site-specific animal density estimates obtained from lengthy and costly surveys. Recent studies indicate that whilst large-scale tidal forcing is predictable, local hydrodynamics are variable and often result in spatio-temporal patchiness of marine predators. Therefore, understanding how fine-scale hydrodynamics influence animal distribution patterns could inform the placing of devices to reduce collision and displacement risks. Quantifying distributions requires animal at-sea locations and the concurrent collection of high-resolution hydrodynamic measurements. As the latter are routinely collected during tidal resource characterization at potential MRE sites, there is an untapped opportunity to efficiently collect information on the former to improve EIAs. Here we describe a survey approach that uses vessel-mounted ADCP (Acoustic Doppler current profiler) transects in combination with marine mammal surveys to collect high-resolution and concurrent hydrodynamic data in relation to pinniped (harbour seals *Phoca vitulina*, grey seals *Halichoerus grypus*) at-sea occupancy patterns within an energetic tidal channel (peak current magnitudes > $4.5\,ms^{-1}$). We identified novel ADCP-derived fine-scale hydrodynamic metrics that could have ecological relevance for seals using these habitats. We show that our local acoustic backscattering strength metric (an indicator for macro-turbulence) had the highest influence on seal encounters. During peak flows, pinnipeds avoided the mid-channel characterized by extreme backscatter. At-sea occupancy further corresponded with the increased shear and eddies that are strong relative to the mean flows found at the edges of the channel. Our approach, providing oceanographic context to animal habitat use through combined survey methodologies, enhances environmental management of potential MRE sites. The cost-effective collection of such data and the application of our metrics could streamline the EIA process in the early stages of the consenting process.

1. Introduction

The global drive towards marine renewable energy (MRE) extraction has led to a rapid increase in planned tidal turbine installations in coastal areas experiencing high (> $2\,ms^{-1}$) current speeds (Fraenkel, 2004). Whilst the exploitation of tidal stream energy will help reach renewable energy targets, the potential impacts on animals using these habitats must be considered in recognition of marine licensing and legislation. A variety of mobile marine predators (cetaceans, pinnipeds, seabirds) exploit tidally energetic environments for foraging opportunities (Benjamins et al., 2015a). However, there is still a large degree of uncertainty surrounding interactions between predators and tidal devices. A range of potential impacts have been identified including collisions with moving components, displacement from foraging areas and changes in foraging efficiency and locomotive costs due to possible alteration of flow fields around array installations (Shields et al., 2011; Fox et al., 2017). To protect against these risks, environmental impact assessments (EIA) are generally required in the consenting process, where potential risks are identified, and mitigation measures established before developments commence. In many parts of the world, developers are tasked by regulators to undertake marine mammal site characterizations (e.g. boat-, plane- or shore-based surveys) as part of EIAs (Wilson et al., 2007; Savidge et al., 2014). These surveys are aimed at generating baseline data of marine mammal presence to eventually

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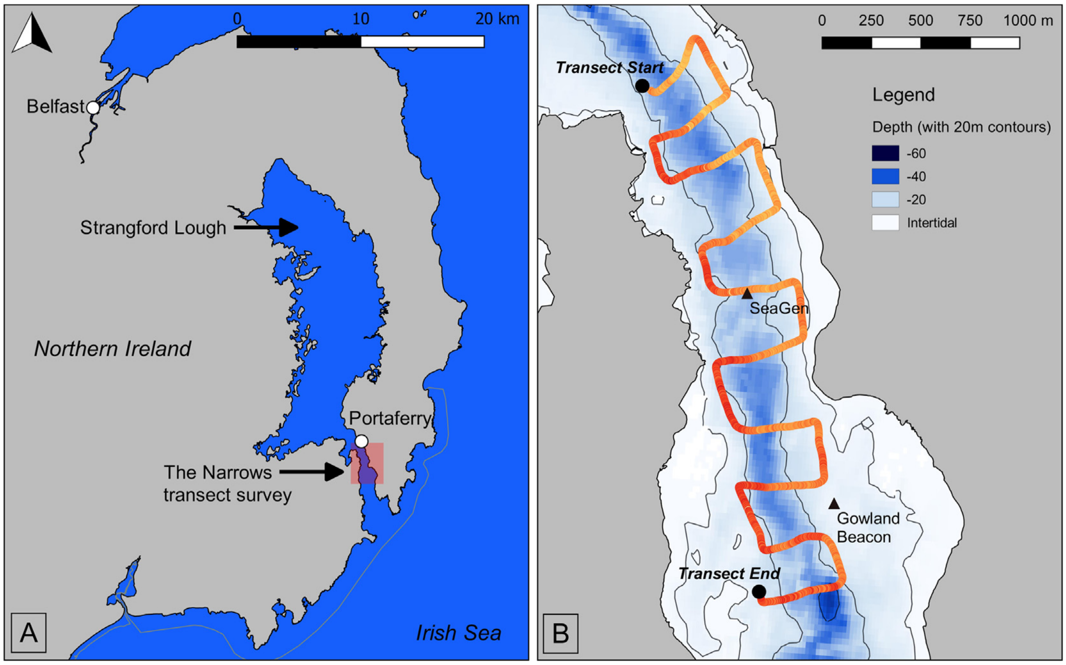

Fig. 1. (A) Map showing the study area within the Narrows, a tidal channel located in Strangford Lough, Northern Ireland, UK, highlighted by a red box. (B) Path of a representative vessel-mounted ADCP transect (Transect 1, 20 October 2016) performed within the Narrows colored by ADCP-derived sea surface temperature (°C). Note, small cross-channel variation in temperatures (min = 13.18 °C, yellow; max = 13.98 °C, red) are visible due to different rates of advection and vertical mixing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

derive site-specific absolute abundance or density estimates (Benjamins et al., 2015b). However, despite the high cost and time involved in these surveys, the density estimates generally have high levels of uncertainty due to the complexity of ecological systems (Harwood and Stokes, 2003).

A different approach is to understand how animals use these energetic tidal environments in relation to hydrodynamic forcing and fine-scale variations in vertical profiles. Flow regimes are not homogenous in tidal environments and vary owing to the occurrence of fine-scale, tidally-driven or bathymetry-induced physical processes, including shear boundaries, eddies and boils (Nimmo-Smith et al., 1999; Evans et al., 2013; Jones et al., 2014; Kregting et al., 2016). This heterogeneity creates spatial and temporal variation in the distribution of species, with marine predators regularly associated with certain tidal velocities and physical processes (Johnston et al., 2005; Embling et al., 2012; Jones et al., 2014; Waggitt et al., 2016a; Waggitt et al., 2016b; Benjamins et al., 2016; Benjamins et al., 2017). Therefore, quantifying spatio-temporal variation in animal site usage in relation to hydrodynamic features may help to identify which and when areas may be used (Zamon, 2001; Waggitt and Scott, 2014; Benjamins et al., 2015b; Hastie et al., 2016; Waggitt et al., 2017a). This can provide developers with valuable information prior to array installation to reduce the risk of collision and displacement. This information can also predict changes in distributions caused by potential alterations in the hydrodynamic regime around installations (Shields et al., 2011).

Tidal resource characterization generally marks the early stages of an MRE project to quantify the physical properties of the site, estimate potential energy generation and evaluate the placing of devices (Polagye and Thomson, 2013). Acoustic Doppler current profilers (ADCPs) are instruments designed to measure current velocities (speed and direction) and flow structures throughout the water column and are widely used during MRE resource characterization to capture the local flow dynamics over a range of spatial and temporal scales (Evans et al., 2013). ADCPs can either be bottom-mounted to measure a flow's temporal variation at a specific location (Lu and Lueck, 1999), or vessel-mounted to infer spatial variation in velocities across a site (Simpson et al., 1990). To capture fine-scale spatial heterogeneity, it has been demonstrated that vessel-mounted ADCP surveys can provide valuable means to characterize tidal energy sites, overcoming the need to deploy high-resolution grids of moored ADCPs across a site (Fong and Monismith, 2004; Epler et al., 2010; Evans et al., 2013; Goddijn-Murphy et al., 2013; Savidge et al., 2014).

With extensive resources allocated towards MRE resource characterization, there currently appears to be an untapped resource for combined survey methodologies that could be adapted for EIAs to assess risks to marine mammals. Specifically, vessel-mounted ADCP surveys could provide a platform to collect fine-scale data on marine mammal at-sea distribution patterns in relation to concurrently measured tidally-induced physical features.

In this study, we aimed to combine surveys of at-sea occupancy patterns of two pinniped species known to exhibit tidal patterns in their distributions (harbour seals *Phoca vitulina* and grey seals *Halichoerus grypus*) in relation to concurrently collected, high-resolution hydrodynamic data. The study was performed in a highly dynamic, restricted tidal channel located in Strangford Lough, Northern Ireland. Characterized by depth-averaged current magnitudes exceeding 4 ms^{-1} during spring tides, the channel is frequently exploited as a tidal turbine test site (Jeffcoate et al., 2016).

Using vessel-mounted ADCP transects, data were collected during a spring and neap tidal cycle to fulfil two main objectives. Firstly, we sought to measure high-resolution spatial and temporal variations in hydrodynamic conditions to visualize and quantify novel fine-scale metrics of physical processes to provide oceanographic context to animal site usage (macro-turbulence, eddies and shear). Secondly, to test the ecological relevance of these metrics by comparing their explanatory power to inform at-sea pinniped distributions to that of more commonly-used measurements in tidal stream environments (current magnitude, depth and time to high water).