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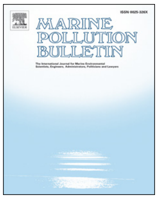

Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine

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ABSTRACT

There is global interest in marine renewable energy from underwater tidal turbines. Due to overlap in animal habitat with locations for tidal turbines, the potential for collisions has led to concern around strike risk. Using data from tagged harbor seals collected before construction and after operation of the SeaGen tidal turbine in Northern Ireland, this study quantifies risks of an operational turbine to harbor seals by taking into account turbine characteristics, tidal state, and seal behavior. We found 68% spatial avoidance (95% C.I., 37%, 83%) by harbor seals within 200 m of the turbine. When additionally accounting for variation in seal occupancy over depth and tidal flows, there is an overall reduction in collision risk from 1.29 to 0.125 seals per tidal cycle (90.3% reduction; (95% C.I., 83%, 98%)) compared to risk calculated under assumptions of uniform habitat use. This demonstrates the need to incorporate environmental conditions to properly assess strike risk.

1. Introduction

Many countries are developing marine renewable sources of energy to combat the effects of climate change, as well as to meet the need to acquire reliable, low carbon sources of energy. The industry worldwide is still in the early stages of development, deployment, and commercialization (Ernst and Young, 2013). Tidal in-stream energy conversion using underwater turbines offers a highly stable source of energy compared to other renewables, often with no visual impact. Tidal turbines come in many shapes and sizes (e.g., Wilson et al., 2014). They can spin horizontally or vertically, the number, size and shape of blades can vary, and the turbine can be shrouded or open. Irrespective of their design, a primary concern in permitting tidal turbine development is the concern for potential marine mammal collisions that cause injury or mortality. However, there is little behavioral response data from which to draw robust conclusions about strike risk (Wilson et al., 2014; Bald et al., 2015; Copping et al., 2016). There is a clear need to accurately quantify the marine mammal strike risk, especially as the industry moves from single demonstrator units to full commercial arrays.

Commercially viable tidal stream turbines require peak tidal currents faster than 2 to 2.5 m/s (Benelghali et al., 2007), which are commonly found where topographical features cause currents to accelerate such as in channels or passages, or around headlands. The predictable and strong tidal flows that are so useful for energy generation also provide valuable habitat for marine mammals. For example, tagged harbor seals (*Phoca vitulina*) in a narrow tidal channel concentrate around the narrowest point of the channel where tidal flows are strongest (Hastie et al., 2016), and have been shown to use these areas routinely for feeding (Thompson et al., 1991). These environments may also be used for other reasons such as corridors for travelling (using tidal assists), or for social interactions between conspecifics (Benjamins et al., 2016). The presence of subsurface structures associated with tidal turbines may also influence marine mammal habitat use (e.g., Russell et al., 2016). Subsurface structures would be expected to locally alter the hydrodynamics, altering the acoustic landscape and also potentially create ‘reef effects’. However, tidal energy generation impacts on marine mammals remain poorly understood (Inger et al., 2009; Benjamins et al., 2016), largely due to the complexity of tidal hydrodynamics, the significant technological difficulties of conducting research on mobile species in fast-moving water, and the

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lack of background information on how these habitats are typically used.

Marine mammal behavioral response to anthropogenic disturbance (such as new sound sources, or the introduction of a physical structure) remains poorly understood. Individual responses of the species found therein may include a range of behaviors such as increased vigilance, avoidance, attraction, startle response, and communication masking (Wilson et al., 2014). Response may also depend on intrinsic factors such as species, age, gender, current activity, experience, prior exposure, or motivation, as well as extrinsic factors such as precise features of the sound stimulus, geographic location and water depth (Wilson et al., 2014). Behavioral responses to disturbance are expected to be both complex and adaptive (Miksis-Olds et al., 2007; New et al., 2013).

Behaviors such as avoidance (defined here as an animal steering clear of the turbine region) and evasion (defined as near-field escape response to a turbine blade) are of particular interest as these would result in a reduction of animal density around the turbine, and therefore a reduction in collision or strike risk (Wilson et al., 2007). However, there is very little behavior information suitable for accurately estimating avoidance and evasion behavior around devices. Indeed, (Copping et al., 2016) comprehensively reviewed the literature and concluded “the lack of observations and measurements of animal movement around tidal turbines […] is the single biggest uncertainty of predictive strike risk models”.

As a consequence, there has been a great deal of speculation regarding the level of avoidance exhibited by marine mammals around turbines (Benjamins et al., 2015). Researchers and managers must currently use a wide range of plausible values for behavioral parameters in their strike risk models, and hence are left to deal with large uncertainties in decision-making (Scottish Natural Heritage, 2016). For this reason, reducing the uncertainty around risk estimates requires evidence-based predictions of avoidance and evasion behavior.

The central goal of this study is to study the response of a marine mammal to the introduction of a tidal turbine into a coastal area with strong tidal flows. Towards this end, we make use of a unique dataset of GPS/GSM-tagged harbor seals collected at the world's first commercial scale tidal turbine installation, the SeaGen tidal turbine, located in the Strangford Narrows, Northern Ireland. Seal tagging studies were carried out in 2006 prior to the installation of any turbine-related infrastructure, and were repeated in 2010 after the installation and deployment of the tidal turbine. Sparling et al. (2017) presented evidence that harbor seals demonstrated small scale avoidance responses to an operational turbine but did not examine the swimming behavior of the seals nor quantify the effect of this observed avoidance. This study assesses the nature and consequence of the turbine on seal behavior (water depth utilization, swimming behavior, and avoidance) with the aim to quantify the associated risk of collision. Our goal is to address the following questions: how do harbor seals use space in fast-moving tidal current areas, and how much overlap is there between the depth distribution of seals and the depth profile of an operational turbine? Similarly, do marine mammals react to the presence of operating turbines by either altering their dive profiles, their swim speeds or by altering their spatial distribution within the channel. And finally, if behavior is affected, does this reaction alter the risk posed by the turbine blades to the harbor seals population found in the Strangford Narrows?

2. Methods

2.1. Study location

The study area is located on the east coast of Northern Ireland (Fig. 1), in the Narrows that connect Strangford Lough to the Irish Sea. Strangford Lough is the largest inlet in the British Isles, covering 150 km^2. The large basin of the lough is connected to the Irish Sea via a narrow tidal inlet (the Narrows) that is 8 km long, 0.5 km wide at its narrowest, and on average 30 m deep. It is here that the construction of the SeaGen tidal turbine was initiated in 2008, becoming fully operational in 2010.

The tides in the open sea adjacent to Strangford Lough are dominated by the M2 tidal constituent (i.e., one cycle includes the twice daily lunar tide with period 12.42 h). The tidal constriction through the Narrows leads to extremely high water velocity with complex flow patterns due to submerged features and coastal geometry. Mean tidal speed is 3.5 m/s, and flows up to 4.8 m/s are observed (Kregting and Elsäßer, 2014).

Strangford Lough and Narrows are designated as a European Special Area of Conservation (SAC) under national legislation of the European Commission's Habitats Directive (Jackson and McLeod, 2000), with protection of the harbor seal population forming part of this designation. This legal protection means that any projects or developments within the Strangford SAC must not have a ‘Likely Significant Effect’ on the harbor seal population. Here, we focus on the potential effect of tidal turbine development on the harbor seal population, including assessment of behavioral changes and the potential for collision risk with the turbine.

In order to quantify the collision risk of harbor seals with the newly installed tidal turbines, a widely-used marine mammal strike risk model was used (Wilson et al., 2007, the Encounter Risk Model or ERM). There are four sources of measurements and observational data that provide the necessary inputs to the strike risk model: (i) measurements of the turbine setup including number of rotors, blade length and width, blade pitch angle; (ii) in-situ data on the rotational speed, tidal current speed and direction at the turbine location; (iii) an independent estimate of harbor seal density at the turbine location; and (iv) a 3-D movement dataset of tagged harbor seals that frequent the region of the turbine installation. Fig. 2 provides a conceptual diagram of the Encounter Risk Model and its inputs, with Table 1 providing a symbol key and definitions.

The emphasis is on comparing and contrasting seal behavior and strike risk for the pre-turbine and operational phases. Towards this end, data were collected both before the turbine was installed in 2006, as well as after it was installed and operational in 2010. Using these observations, we translated the estimated density of seals in Strangford Narrows to estimated number of seals at risk of being struck by the operational turbine. In the following sections, we describe how we processed the raw observed data into the input variables necessary to calculate collision risk (see Table 1, Fig. 2).

2.2. Turbine description and turbine data

Construction began on Marine Current Turbines Ltd.'s SeaGen tidal turbine (54.3687°N, 5.54582°W) in April 2008, with the first operation on July 2008. Between 2008 and 2010 the turbine operated intermittently, ramping up to near continuous operation by August 2010. The SeaGen turbine used two 8 m by 60 cm double-bladed rotors, $N_{rotors} = 2$, connected to a monopile foundation by a wing-shaped crossbeam, with each rotor producing up to 600 kW of power 18 to 20 h a day (https://en.wikipedia.org/wiki/SeaGen). The maximum rotational speed of the rotors was capped at $\Omega = 14.3$ rpm, which was reached at current speeds $v \geq 2.3$ m/s. The angle, γ, of each 8 m rotor blade, was 30° but could be pitched to maintain a constant rotational speed in currents above 2.3 m/s, as well as rotated through 180° allowing them to operate in both ebb and flow directions. The rotors were also designed to feather and stop rotation below current speeds of 1 m/s. The SeaGen turbine was located in water that is 24 m deep at the lowest tide, and as much as 29 m deep at high tide. The arc of the rotors were 5.5 m from the bottom, and at least 3 m below the water surface (i.e., at the lowest tide).

In-situ sensor instrument data for water currents, v, were available starting July 1, 2008. Sensors were located on each of the two rotors providing 5-minute averages for current speed and direction, as well as