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Research paper

Fish distributions in a tidal channel indicate the behavioural impact of a marine renewable energy installation

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ABSTRACT

In the dynamic environments targeted for marine renewable energy extraction, such as tidal channels, the natural distribution of fish and behavioural impacts of marine renewable energy installations (MREIs) are poorly understood. This study builds on recent methodological developments to reveal the behaviour of fish schools using data collected by a seabed-mounted echosounder deployed in extreme tidal flows and in the wake of a MREI (composed of the foundation of a full-scale tidal stream energy turbine). The results show a significant change ($p < 0.001$) in the vertical distribution of fish schools in the vicinity of a MREI compared to a nearby control location representative of the natural conditions. The MREI is associated with an overall increased rate of fish school observations (+74%), particularly at night (+163%) and in the MREI wake flow (+378%), related to the disruption of natural diurnal behavioural patterns in school characteristics (size, relative density, and distance from seabed). These results indicate an attraction effect of the MREI, and show that the aggregation and vertical distribution of fish in the modified flow conditions is dependent on tidal phase with evidence of avoidance of the MREI depth range during peak flow velocities. The behavioural responses observed in this study provide new information relevant to the environmental impact assessment of marine renewable energy developments and highlight priorities for further research.

1. Introduction

In recent years there have been rapid developments in the extraction of tidal stream energy with numerous marine renewable energy installations (MREIs), including full-scale tidal stream turbines, deployed around the world (Zhou et al., 2017). Energetic tidal channel environments are of high ecological importance (Benjamins et al., 2015), and the unknown effects of MREIs on marine animals are a major challenge for the development of the marine renewable energy industry (Copping et al., 2015; Fox et al., 2017). The potential behavioural impacts of MREIs could result from direct interaction of mobile animals with devices, or over larger scales due to the hydrodynamic consequences of changes to the natural flow structure with unknown ecological implications (Shields et al., 2011).

The potential for impacts on fish behaviour from MREIs may influence risks to larger predators and has been identified as a research gap (Roche et al., 2016). However, in the turbulent environments targeted for marine renewable energy extraction there is still a lack of baseline ecological data (Inger et al., 2009; Haslett et al., 2016). Recent field observations around marine renewable energy devices have focussed on fish interactions with turbine components at very fine scales using optical (Hammar et al., 2013; Broadhurst et al., 2014) and acoustic (Viehman and Zydlewski, 2015) cameras. However, only echosounder instruments with a sufficient range provide the practical means to investigate the behaviour of fish throughout the entire water column of a typical tidal channel. The functionality of echosounders in energetic environments has so far been limited due to the operational difficulties of data collection in such conditions and the intense interference caused by backscatter related to turbulence (Melvin and Cochrane, 2015). Consequently, previous field observations have been limited in the depth range or temporal coverage available, for example by excluding data from the upper part of the water column (Viehman et al., 2015) or during slack conditions (Shen et al., 2016).

Developments in data collection approaches (Williamson et al., 2015), data processing algorithms (Fraser et al., 2017a), and instrument integration techniques (Williamson et al., 2017) enable the first continuous observations of fish aggregations from nearly the entire water column around a MREI in a tidal channel. This study

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investigates the nature and significance of potential behavioural impacts of a MREI by comparing the vertical distribution of fish schools in a control location representative of the natural conditions with results from a location where a full-scale tidal stream energy turbine foundation is present.

2. Material and methods

2.1. Study site

This study considers the data collected during two instrument platform deployments at the Fall of Warness tidal test site (59°7′ to 59°11′N, 2°47′ to 2°50′W) in Orkney, Scotland. The conditions at the site are characterised by exceptionally strong semidiurnal tidal currents exceeding 3.5 m s^{-1}. The natural tidal flow in the site is approximately directionally-symmetric, with flow from the north-west to the south-east during the flood tidal phase, and from the south-east to the north-west during the ebb tidal phase. Previous surveys of the site indicate that the seabed is primarily composed of exposed swept bedrock with occasional boulders, cobbles, and patches of gravel and shelly sand (Aurora, 2005). Baseline environmental studies of the area (Aurora, 2005) indicated that the aggregating fish species likely to be present during data collection include: mackerel (*Scomber scombrus*), pollack (*Pollachius pollachius*), saithe (*Pollachius virens*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*), and sandeels (*Ammodytes spp.*).

2.2. Data collection

Data were collected by the seabed-mounted FLOWBEC platform during a field campaign at the European Marine Energy Centre (EMEC) in summer 2013 (Williamson et al., 2015). These platform deployments gathered multifrequency echosounder data using a Simrad EK60 scientific echosounder operating at 38, 120, and 200 kHz. The EK60 transducers were mounted on top of the platform, 0.9 m from the seabed, and were orientated directly upwards with overlapping 7° conical beams. All EK60 transducers were calibrated and pinged simultaneously at 1 Hz using a 1024 μs pulse length. Supporting data on the flow were provided by an acoustic Doppler velocimeter mounted on the platform and hydrodynamic model data for the site (Waggitt et al., 2016).

The first platform deployment was from June 3rd–15th and was positioned 15 m downstream (during flood) from the Atlantis AK-1000 seabed-mounted turbine foundation to provide the "MREI present" dataset. The turbine foundation lacked the nacelle and blades during data collection and was composed of a steel tripod base with a 10 m high central piling surrounded by three 4 m high concrete ballast blocks.

The second platform deployment was positioned in the same site 424 m away from the first deployment and recorded data out of the wake of any installations from June 18th–July 5th to provide the "control" dataset. Both deployments were during similar meteorological conditions and at locations approximately 35 m deep. Video footage from a remotely operated underwater vehicle during platform recoveries showed that comparable seabed characteristics were encountered in both deployment locations and confirmed the presence of aggregations of gadoid fish in the site. Maximum temporal comparability between the two deployments was achieved within logistical constraints by the shortest possible time gap between deployments (three days) and by coverage of the spring-neap cycle in each case. Similarly, spatial comparability was established by considering the bathymetry, natural hydrodynamics, and surrounding substrate at both deployment locations so that behavioural changes of marine animals could reasonably be attributed to the MREI.

2.3. Data processing and analysis

Information on the vertical distribution of fish aggregations was derived from the EK60 backscatter measurements following an adaptive processing method (Fraser et al., 2017a) developed to detect fish schools with high sensitivity throughout the dynamic conditions and intense acoustic interference encountered in tidal channel environments. Schools were validated by multi-frequency characteristics and by direct inspection of the data, and further supported by co-registration with observations from a synchronised multibeam echosounder also mounted on the platform (Williamson et al., 2017).

The vertical distribution of fish is characterised by calculating the distance to the centre of each school from the seabed. The local time (BST) at which each fish school is observed is used to find the proportion of observations during the daylight (approximately 04:00 to 22:00) and night. The diurnal phase for the time of each fish school observation is also computed, which varies between 0 and 1 through the 24 hour cycle so that 0 and 1 represent midnight and 0.5 represents noon. Similarly, flow velocity information from the hydrodynamic model is used to find the proportion of fish school observations during flow in the flood and ebb directions, and to compute the tidal phase for each observation. Tidal phase is defined between 0 and 1 through the approximately 12.5 hour flood-ebb cycle by flow velocity so that 0 to 0.5 represents flow in the flood direction and 0.5 to 1 represents flow in the ebb direction (i.e., peak flow velocities at approximately 0.25 and 0.75, and reduced flow velocities centred around slack conditions at 0, 0.5, and 1). The vertical distributions of fish schools for different deployments and flow directions are statistically compared using the non-parametric two-sample Kolmogorov–Smirnov test and considered significantly different if $p < 0.05$. The size of each school is characterised by the observed cross-sectional area, A. The relative density of each school is characterised by the mean volume backscattering strength measured at 200 kHz, $MVBS_{200}$, which is proportional to the number of fish in a given volume neglecting differences in target strength associated with species, orientation, and other effects.

3. Results

A total of 523 fish schools were observed in the presence of the MREI, and 396 fish schools observed in the control location representative of the natural conditions. The presence of fish schools is considered in terms of an occurrence rate by dividing the number of observed schools by the sampled time for a variety of cases (Table 1). The occurrence rate of fish schools increased overall from 1.10 schools $hour^{-1}$ in the control to 1.91 schools $hour^{-1}$ in the presence of the MREI. An increased occurrence rate is associated with the MREI presence in all cases considered, in particular at night and during the flood phase. The largest increase in fish school observations is associated with the lower part of the water column during flood flow (+378%), corresponding to observations in the wake of the MREI.

The overall vertical distribution of fish schools (Fig. 1) was significantly different ($p < 0.001$) between the two datasets, with a decreased mean distance from the seabed observed in the presence of the MREI (18.56 m) compared with the control (20.64 m). Control results show that most schools are recorded in the upper half of the water column, with increased mean distance from the seabed at night. In the presence of the MREI the day/night trend is reversed and a higher proportion of fish schools are recorded in the lower part of the water column. Flood and ebb results are similar in the control and not significantly different ($p = 0.89$); while a clear and significant ($p = 0.02$) difference between flood and ebb results is apparent in the presence of the MREI and dominated by the increase in fish school observations in the wake flow.