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Fish interactions with marine renewable devices: lessons learned, from ecological design to improving cost-effectiveness

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ABSTRACT
We are studying fishes associated with a tidal-stream energy project in Cobscook Bay, the north eastern-most bay of the United States, at the entrance to the Bay of Fundy. Tidal energy devices under consideration are Ocean Renewable Power Company's (ORPC) TidGen® and OCGen® systems. Our research was initiated in 2009 to determine the 'natural' vertical distribution and density of fishes. Baseline data enabled the detection of turbine effects, and will be used to estimate the likelihood that fish encounter a tidal turbine once installed at a fixed height in the water column. Since then, we have built on this research, adding studies of fish behaviour in response to a tidal energy device in the near-field (within 3 m) and mid-field (up to 200 m away). Approaches at multiple spatial and temporal scales are proving useful in deciphering the previously unknown behaviours of fish in response to marine hydrokinetic (MHK) devices and enabling more focused methods for future monitoring.

INTRODUCTION

Interactions between fish and proposed energy extraction devices are not well characterised, yet are certain to occur. A basic understanding of the annual, seasonal, diel, tidal, and spatial variability of fish presence in a tidally dynamic area targeted for energy extraction is required before the impacts of MHK devices can be determined.

Behavioural responses of fishes to MHK devices are likely to include avoidance and attraction, depending on the individual. While there have been several studies of fish survival through down-scaled MHK turbines in laboratory flumes,[1,2] there is only one field study published to date.[3] That study assessed the behavioural responses of fish within 3 m of an MHK device. Behaviours observed included passing by (never interacting), avoiding, entering or exiting, and milling behind the device.

Such behavioural responses can result in changes in fish depth distributions in the area of an MHK device. We hypothesize that the overall density and vertical distribution of fishes at an MHK project site will change when a device is installed. For example, there may be (1) an overall reduced fish density at a project site; or (2) a detectable change in vertical distribution of fish in the water column after device installation. Answering such questions requires baseline assessments documenting seasonal, diel, and tidal variation of fish density and vertical distributions at project and control sites over multiple years.

Behavioural responses to an MHK device are likely to occur at a distance greater than 3 m, which is the extent that has been studied to date.[3] We expect that responses may be influenced by changes to the hydrodynamic environment produced by the device. The hydrodynamic influence has been estimated to extend as far as 200 m upstream of the device.[4] Therefore, behavioural responses should be examined at a range of distances on either side of an MHK device.

We have implemented three studies at varying spatial and temporal scales to provide a more holistic view of fish-device interactions.

METHODOLOGY

(1) In September 2010, we used two DIDSON acoustic cameras to view the near-field (within 3 m) of a commercial-scale test device (ORPC's beta turbine generator unit) suspended below a research platform in outer Cobscook Bay.[5] With data collected over 24 hours, we classified and quantified fish responses to the device and explored the effects of diel condition (day or night), turbine motion (rotating or not), and fish size (small, $\leq$ 10 cm; or large, > 10 cm) on those responses.

(2) Since 2010, twenty-two stationary hydroacoustic surveys have been conducted using a down-looking single beam echosounder (Table 1). Three of the project site surveys took place while the ORPC TidGen® was deployed. Surveys spanned 24 hours and were carried out at the project site (within 50 m of the device, when deployed) and a control site (1 km away from the project site).

These data allowed us to establish baseline information on fish density and vertical distribution, examine variation with respect to seasonal, diel, and tidal cycles, and test for effects of the device on these parameters.[5] We will model the likelihood for fish to encounter the turbine and static portions of the device based on their vertical distribution pre- and during- device deployment.

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Table 1. 2010-2013 down-looking hydroacoustic surveys. 1 = project site (a = beside device, b = in-line with device); 2 = control site. White = pre-deployment; light grey = TidGen® bottom frame deployed; dark grey = TidGen® turbine deployed (complete device).

Month	Year			
	2010	2011	2012	2013
Jan			1, 2	
Feb				
Mar		1, 2	1, 2	1a, 1b, 2
April				
May	1, 2	1, 2	1a, 1b, 2	2
June		1,2	2	2
July				
Aug	1, 2	1, 2	1a, 1b, 2	2
Sept	1, 2	1, 2	1a, 1b, 2	2
Oct	1, 2			
Nov	1, 2	1, 2		
Dec				

(3) Preliminary mobile surveys using a down-looking split-beam echosounder have been initiated, with transects spanning 200 m up- and down-stream of the ORPC TidGen® device. Future mobile surveys will be conducted over and around the OCGen® device. Fish will be tracked in 3D as they approach the device, and their behaviour will be examined as a function of fish size and hydrodynamics. This approach will allow the analysis of fish behaviour from 3 to 200 m away from the OCGen®. Replicate transects will be conducted over a tidal cycle, enabling assessment of fish behaviour during an entire cycle.

From 2011-2013, benthic and pelagic trawls were conducted to characterise species composition of the area and verify acoustic targets. The data are not presented here.

OBSERVATIONS

During all survey periods, fish of various (unknown) sizes and species were present in the water column, regardless of tidal stage or diel period.

(1) For those fish observed within 3 m of the beta turbine generator unit, movement was in the same direction as the water current. Most fish observed were small (≤10 cm). Approximately 50% of individual fish and 67% of schools did not interact with the turbine, passing by either above or below it. Less than 1% of individuals and 15% of schools showed avoidance behaviour, and 35% of individuals and 14% of schools entered or exited the turbine. Turbine rotation reduced the probability of entering the turbine by 35% and increased the probability of avoiding and passing by 120% and 97%, respectively. Schools avoided the turbine from farther away than individuals (on average 2.5 m versus 1.7 m).[3] We suspect many individual fish initiated avoidance manoeuvres upstream of the viewing window, as roughly half were already above or below the turbine upon entering the view.

(2) A seasonal pattern in fish density was apparent in all years of baseline data collection, with maxima occurring in spring and late fall.[5] Density was generally greatest near the sea floor. Fish were more evenly distributed in the water column at night than during the day, but changes in vertical distribution related to tidal cycles were inconsistent. Patterns in fish density and vertical distribution were similar at the project and control sites (Figure 1), demonstrating that the control site provides a useful reference for identifying effects of the tidal device on fish.

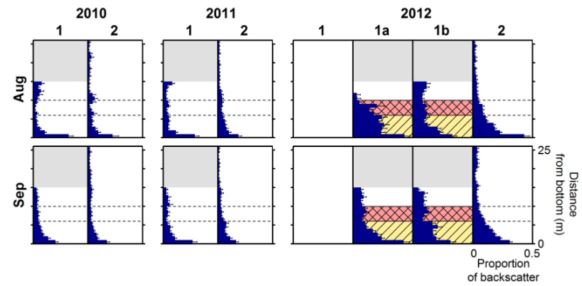

Figure 1. Examples of fish vertical distribution. 1 = project site (a = beside device, b = in-line with device); 2 = control site. Bars = proportion of area backscatter; whiskers = standard error. Dashed lines = turbine depth. Yellow hatch = bottom support frame deployed; red crosshatch = TidGen® turbine deployed (complete device). Grey areas = no data (control site deeper than project site).

(3) Experimental mobile transects were made over the TidGen® in Mar 2013. Preliminary analyses of the data indicated that we will be able to characterise fish presence and responses to the device (Figure 2).

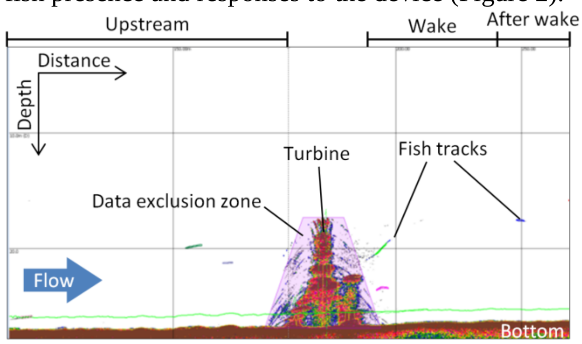

Figure 2. Sample echogram from a preliminary transect over the TidGen® device. Each fish track is a single fish moving through time and space.

CONCLUSIONS

(1) Near-field observation using DIDSON acoustic cameras provided valuable information on the behaviour of fish within 3 m of a tidal energy device, and how they interacted with the turbine. The DIDSON was effective during the day and night. This is important because fish were present during both periods, and down-looking hydroacoustic surveys indicated they occupy more of the water column at night (and may therefore be more likely to interact with a mid-water-column turbine). However, this approach was limited by the DIDSON's resolution and sampling volume, the

large amount of data produced, and the time required for data processing.[3]

(2) The collection of baseline vertical distribution data at project and control sites in 24-hr spans during multiple seasons and years has provided necessary information on fish presence and vertical distribution on multiple temporal scales in this highly dynamic tidal region, none of which existed previously. The project site has proven to vary with the control site, and continued surveys at both sites should allow turbine effects to be discriminated from natural variation.[5] Temporal resolution within each survey was high (2 Hz) and will allow fine-scale examination of patterns in vertical distribution and density occurring over 24 hour time spans. The single beam echosounder provided sufficient data to meet permitting requirements and is therefore a low-cost option for initial site assessments for offshore energy development (compared to split- or multi-beam systems, for example).

Challenges of this approach included limited temporal resolution over the long-term (24 h surveys were temporally separated throughout the year), sampling close enough to the device to document effects, and inability to discriminate to the species level or to generate size estimates (mostly due to use of wide-angle, single beam echosounder).

(3) Mobile transects provide better spatial coverage than the other two approaches, filling the physical gap between stationary down-looking surveys and the DIDSON study. However, limitations of this approach include low long-term temporal resolution due to restricted sampling time and the inability to discriminate species (though the split-beam echosounder can provide some information on fish size).

Integration of these three approaches, each of which addresses a different spatial or temporal scale (Figure 3), will (a) generate a more complete understanding of fish interactions with tidal-stream energy devices, (b) decrease uncertainty of the effects devices have on fishes, and (c) better determine the best approaches for assessing effects.

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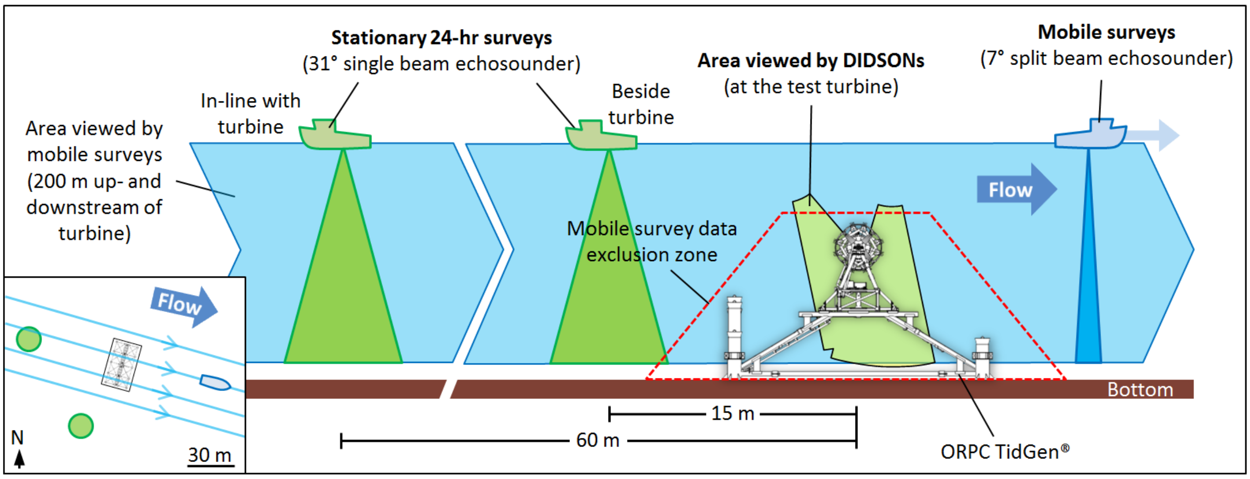

Figure 3. Conceptual schematic of combined study scales, with ORPC TidGen® device as reference.