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Interactions of aquatic animals with the ORPC OCGen® in Cobscook Bay, Maine: Monitoring behavior change and assessing the probability of encounter with a deployed MHK device

USDOE Award Number: DE-EE0006384

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Executive Summary

Commercial viability of the marine hydrokinetic (MHK) energy industry is contingent on numerous and diverse factors. A major factor is the effects deployed devices have on animals. This factor is multi-faceted since it is dependent on the availability of appropriate scientific approaches to detect these effects. One of the animal groups with overlapping distributions of MHK devices are fishes. As such, individual fish behavior is likely to be influenced by the presence and operation of MHK devices. Depending on the scale of deployment there are implications for changes to essential fish habitat and effects that can be explored during deployment of a single device yet most changes are likely to be realized when multiple devices are deployed over large areas. It is not only important to document these effects and examine the need for mitigation, but also determine whether the methods involved can be used within the economic constraints of this nascent industry. The results presented in this report benefit the MHK industry by providing transferrable environmental monitoring approaches for MHK projects, specifically related to the interactions between static and dynamic tidal turbines and fish. In addition, some of the data can be used to generalize conditions (e.g., the temporal periodicity of fish presence in tidal regions and probability of fish encountering a device) at other MHK sites with similar physical conditions and fish assemblages.

Ocean Renewable Power Company, LLC (ORPC) deployed and tested a prototype OCGen® tidal module in Cobscook Bay, Maine, in the summer of 2014. University of Maine researchers proposed an approach to inform other researchers, regulators, and industry members of the effects of this deployment on fish. While the approach was specifically applied to the OCGen® module, results are applicable to other pilot projects and inform future array deployments. Research funded under this grant allowed us to quantify fish presence as well as individual and group-level behavior changes in the presence of the deployed OCGen® module along with a bottom support frame from a previously deployed device (TidGen®). Specific objectives associated with fish behavior changes were (1) continuation of two long-term datasets: (a) stationary down-looking hydroacoustic dataset near an MHK device (group-level) and (b) stationary side-looking hydroacoustics near the bottom-support frame of a previously deployed MHK device (individual-level); (2) application of new processing methods to down-looking hydroacoustic datasets to improve fish species identification (group-level); and (3) development of an encounter probability model using data on fish abundance, vertical distribution, and behavior.

Objectives

Objective 1a: Continuation of a long-term, down-looking hydroacoustic dataset, was an extension from previous funding used to collect fish vertical distribution and overall abundance around ORPC's TidGen® tidal power system from 2010-13. This multi-year dataset enabled the construction of seasonal trends in fish abundance that was used by regulators to make decisions about the deployment of the OCGen® module. Data collected during this award (2014-15) at the module deployment site revealed similar seasonal trends as those reported from 2010-2013 (Viehman et al. 2015 and unpublished data). Generally, relative densities of fish were lower in winter and higher in early spring and later fall. There were some differences in relative fish density and fish vertical distributions among sites. However, these differences lacked consistency and could not be attributed to only the operations of the turbine because the OCGen® module operation varied throughout the study period. During the first of three surveys when the OCGen® module was present, the module's turbine was rotating, and in the second and third the turbine was present but not rotating. There was a significant interaction was observed in August when the device was static and industry activity was high, leading us to believe that the amount of on- and in-water industry activity may be a driver to decreases in fish density at the impact site.

Objective 1b: The behavior of individual fish in a region of interest for MHK device deployment was explored using a bottom-mounted, side-looking, transducer. This had been stationed near the TidGen® Power System during (2012) and after (2013 – 2015) its deployment. Individual fish movement through the acoustic beam was compared between times when the device was present but static (2012) and when the device was absent (and only the bottom-support frame remained, 2013-2015). Linear models revealed that turbine presence had no significant effect on individual fishes' horizontal deflection from the direction of water flow, indicating minimal behavioral response to the turbine presence, at the ranges sampled (approximately 8-23 m from the turbine face). The same echosounder was used to observe fish abundance at the TidGen® Power System site for a year after its removal. Cyclical patterns related to tidal, diel, and seasonal cycles were found. These temporal patterns were used to develop an optimum sampling design for long-term monitoring of MHK sites with similar physical conditions and fish assemblages. The design reduces variation in results by timing surveys with these natural cycles. For example, 24-hour surveys would encompass short-term variations and when they are carried out at the same stage in the spring-neap tidal cycle throughout the year even more natural variation can be captured. This monitoring approach could be used to maximize the accuracy of survey results while minimizing the necessary number of surveys (and cost) at this and similar tidal energy sites.

Objective 2: "Delta mean volume backscattering strength (ΔMVBS)" or "dB differencing" methods were used to improve fish species identification in previously available hydroacoustic datasets, based on differing backscattering properties. Our goal was to apply this technique to isolate fish with swimbladders, which scatter more sound, from mackerel, which lack swimbladders and scatter less sound. However, closer scrutiny of the dataset revealed that the species with and without swimbladders were present in mixed schools. Unfortunately, in order to separate species using dB differencing the species must also be separated in space. Ultimately, we were able to apply dB differencing to isolate zooplankton from all fish (e.g. those with and without swimbladders), which improved the accuracy of relative fish density estimates obtained from the long-term, down-looking hydroacoustic dataset (Objective 1).

Objective 3: A model was developed to examine the probability of fish encountering an MHK device in Cobscook Bay. Data used in the model included stationary and mobile down-looking hydroacoustic data collected with this and previous DOE funding. The model was composed of three probabilities: (i) the probability of fish being at the device depth when the device was absent; (ii) the probability of fish behavior changing to avoid the device before being detected by stationary sampling near the device (~ 50 m from the device); and (iii) the probability of fish behavior changing to avoid the device between 140 and 10 m from the device. According to the model, in total, the probability of fish encountering the entire TidGen® device was 43.2% (95% CI: 30.5, 55.3), which included the bottom support frame as well as the turbine, and 5.8% (95% CI: 4.3, 7.3) of fish would be at the depth of the dynamic portion of the device (the rotating foils). Understanding where fish are in the water column relative to a deployed tidal energy device provides important baseline metrics for regulators responsible for permitting MHK devices.

Accomplishments

Project Goal: The goal of this project was to quantify aquatic animal behavior changes associated with the presence of a deployed marine hydrokinetic (MHK) device.

Project Objectives: Specific objectives included: (i) continuation of long-term, seasonal hydroacoustic datasets near an MHK device; (ii) application of new processing methods to hydroacoustic datasets to improve species identification; and (iii) development of an encounter probability model using data on fish abundance, vertical distribution, and behavior collected near an MHK device.

DE-EE0006384: Project tasks and milestones.

Task #	Task Description	Associated Milestones	Associated Objectives
1	Development of a detailed work plan, including timing, length, and methodological details for each proposed task	1,2,3,4	i
2	Develop dB differencing methods for down-looking hydroacoustic data	5, 6, 7	ii
3	Develop probability of encounter model	8, 9, 10	iii
4	Collect down-looking hydroacoustic data at control site in March	11	i
5	Collect down-looking hydroacoustic data at a control site (May, Aug, and Nov) and at the OCGen® site and the control site for four weeks while the device was deployed; and 5 benthic and pelagic trawl sampling events in May (1), Aug (3), and Sep (1)	12, 13, 14	i
6	Collect side-looking hydroacoustic data at TidGen®	15, 16, 17	i
7	Side-looking hydroacoustic data analysis	18, 19	i
8	Down-looking hydroacoustic data analysis (of 2014 data)	20	i
9	Finalize dB differencing- incorporating 2014 data with baseline data (2011-2013)	21, 22	ii
10	Finalize probability of encounter model	23, 24	iii
11	Finalize side-looking hydroacoustic data assessment	25	i
12	Final Report	26	i, ii, iii

Summary

Introduction

Recent awareness of the urgent nature of climate change has led to reestablished interest in renewable energy sources. The potential to harness tidal currents is viable in particular geographical locations (http://energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization#Tidal_Streams_Resource_Assessment; accessed Mar 28, 2016), and while it is not as established an industry as wind and solar, tidal resources have the distinct advantage of being predictable. There is a nascent industry developing to harness the energy from tidal currents using novel marine hydrokinetic (MHK) turbine designs, but there have been few opportunities to evaluate the effects of these new energy devices on marine animals. There have been a limited number of deployed devices and the challenges of testing these are exacerbated by the difficulty of collecting data in such high-energy locations (Viehman, et al. 2015; Broadhurst et al. 2014). Although the scientific literature is growing in relation to potential animal interactions with these devices (Staines et al. 2015; Viehman and Zydlewski 2015; Hammar et al. 2014; Broadhurst et al. 2014), there is still much work to be done to properly inform policy makers. Uncertainty in this area is seen as a major regulatory barrier.

The uncertainty of interactions between fish and tidal energy devices was the foundation of this research. Concerns about interactions cover several scenarios, from direct strike and mortality occurring at the turbine foils to far-field effects on behavior due to avoidance reactions which may have implications for foraging and reproductive behavior, influencing long-term survival. Theoretical papers and laboratory experiments have been conducted to provide insight to fish interactions with MHK tidal devices (Amaral et al. 2015; Čada and Bevelhimer 2011; Castro-Santos and Haro 2015; Hammar et al. 2015; Romero-Gomez and Richmond 2014). However, actual deployed devices with associated empirical fish interaction data are limited (Broadhurst et al. 2014, Hammar et al. 2014, Viehman et al. 2015, Staines et al. 2015, Viehman and Zydlewski 2015a, Viehman and Zydlewski 2015b). This report adds to the current understanding of fish behavior near, and interactions with, a single deployed MHK tidal device. Based on successful research in Cobscook Bay (Viehman et al. 2015) with the previously deployed TidGen® Power System, we chose hydroacoustics to collect information on fish at this tidal energy site.

The TidGen® device was removed in July 2013, with the bottom support frame left in place on the seafloor. ORPC followed up with the deployment of a model version of a prototype OCGen® module attached to the seafloor by a gravity anchor mooring system. The impetus for this deployment was to test the gravity anchor mooring system and allow marine animal monitoring during the testing phase, which lasted 2.5 months.

The goal of this project was to quantify aquatic animal (primarily fish) behavior changes associated with the presence of a deployed MHK energy device. Three objectives were used to reach this goal:

- *Objective 1*: continuation of long-term hydroacoustic datasets near an MHK energy device.

  Questions:

  1. Was *fish density* different during times when the OCGen® module was present and absent?
  2. Was *fish vertical distribution* different during times when the OCGen® module was present and absent?
  3. What were *individual fish behaviors* in front of and in the wake of the TidGen® module?
  4. Can a long-term hydroacoustic record of *fish abundance* be used to determine an ideal sampling strategy at this and similar tidal energy sites?

- *Objective 2*: application of new processing methods to hydroacoustic datasets to improve species identification.
  Question: Can acoustically detected mackerel (a seasonally abundant species in Cobscook Bay) be separated from other species using frequency response differences between 38 and 200 kHz?

- *Objective 3*: development of an encounter probability model using data on fish abundance, vertical distribution, and behavior collected near an MHK energy device.
  Question: What were the probabilities of fish encountering an MHK device based on fish vertical distribution, diel and tidal cycles, and behavior near the device?

The study site was the area around the ORPC OCGen® module deployment (44° 54.603 N / 67° 02.754 W) located in the outer bay of Cobscook Bay near the city of Eastport, Maine (Figure 1). Water depth at the device location was approximately 24 m at low tide and 33 m at high tide. Tidal current speeds in the area varied from 0-2 $m \cdot s^{-1}$, depending on time of tide and lunar cycle. Major commercial fisheries in the area were lobster, scallops, and sea urchins. Boat traffic was minimal with only fishing and recreational boats utilizing the nearby waters and no shipping traffic at the deployment location. The site was easily accessible via a pier at the Eastport Boat School, approximately 2.4 km away.

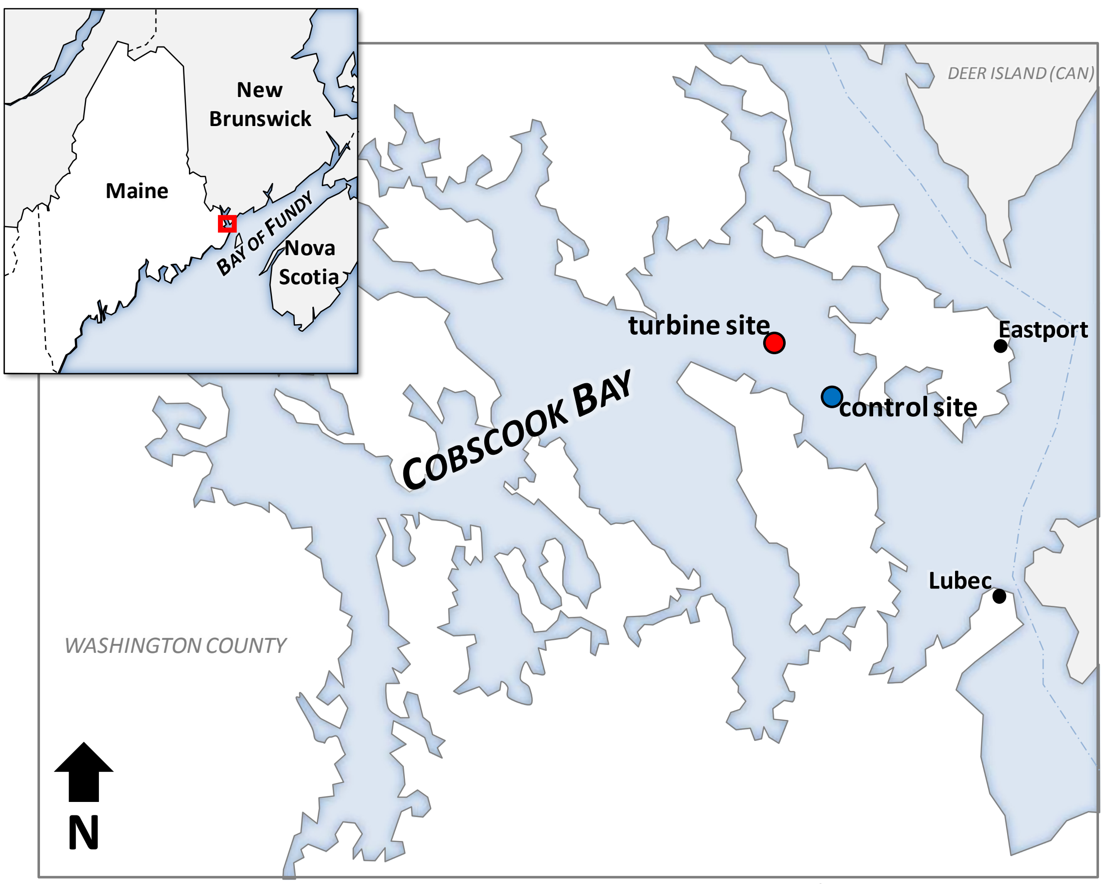

Figure 1. Study area and location of the MHK deployment sites (ORPC's TidGen® device bottom support frame and OCGen® module) and the control site, approximately 1.6 km away.

Results and Discussion

Objective 1

The continuation of two long-term hydroacoustic datasets: (a) discrete 24-h stationary, down-looking hydroacoustic surveys and (b) continuous stationary, side-looking hydroacoustic data collection.

a) Stationary down-looking hydroacoustics

The original down-looking dataset that was collected in Cobscook Bay began in May 2010, as the first step in a before-after-control-impact (BACI) study of relative fish density at this site. Data collected from March through November 2014 were funded by this DOE award. All data (2010 – 2014) were collected using a Simrad ES60 echosounder with a 38/200 Combi W transducer that was mounted on the side of a moored vessel. Similarly to the previous long-term dataset (Viehman et al. 2015), 24-hour surveys were carried out at the turbine site beside (CB1a) and in-line with (CB1b) the OCGen® module, as well as at the control site (CB2) approximately 1.6 km seaward. Data processing included the dB differencing methods (Objective 2) which removed most zooplankton from relative fish density estimates. The 2014 dataset is summarized in Table 1.

Table 1. Months of 24-h down-looking hydroacoustic surveys in 2014. The sampling sites were CB1a (beside), CB1b (in-line), and CB2 (control). Each site was sampled for 24 h. The OCGen® module was present only for Aug surveys. The turbine was rotating for Aug(1) (light gray) and static for Aug(2) and Aug(3) (dark gray) surveys.

Mar	Apr	May	Jun	Jul	Aug(1)	Aug(2)	Aug(3)	Sep	Oct	Nov
CB2		CB2			CB1a CB1b CB2	CB1a CB1b CB2	CB1a CB1b CB2	CB1a CB1b CB2		CB2

To examine the difference in fish density with and without the OCGen® module, fish density was quantified using volume backscattering strength (S_v). S_v is a measure of the sound scattered by a unit volume of water and is assumed proportional to fish density. S_v is expressed in the logarithmic domain as decibels, dB re 1 m^{-3}. Relative fish density was lowest in March and highest in May at the control site (Figure 3). This was typical of other years in the long-term hydroacoustic dataset (Viehman et al. 2015). There were significant differences between the turbine in-line (CB1b) and control (CB2) sites within the Aug(3) survey and between the turbine beside (CB1a) and control sites for the Sep survey (Figure 3). The differences between sites within surveys showed higher fish densities at the sites near the OCGen® module than at the control site, where there was no device. As such, these results do not seem to indicate that the OCGen® module had an effect on the density of fish. There was also a significant difference among surveys at the control site (CB2) between the Aug(1) and Sep surveys (not shown in figure). As this single difference among surveys for a single site was at the control site, it is likely due to a seasonal difference from early August to mid-September.

For detailed processing, analysis, and discussion, see Staines et al. (submitted), Appendix 3b.

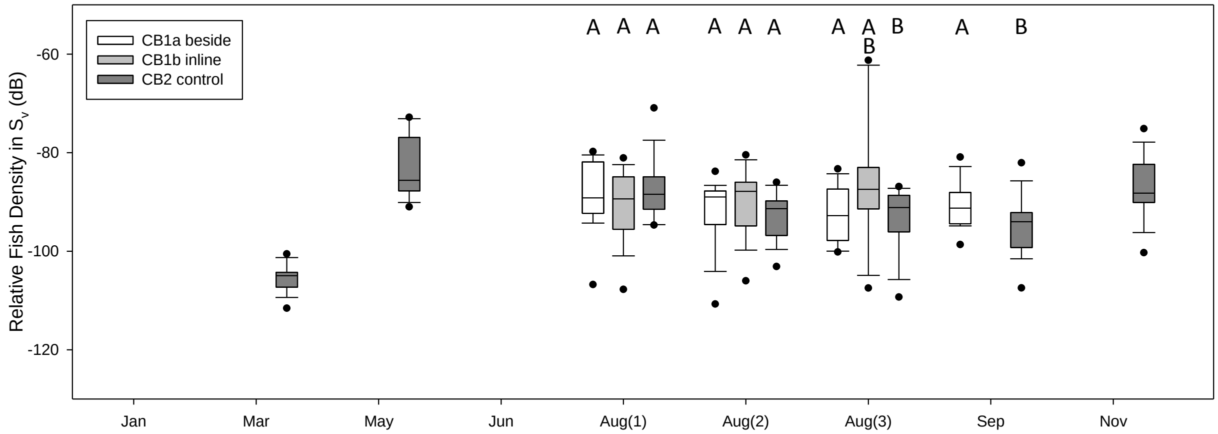

Figure 3. Relative fish density for each stationary down-looking hydroacoustic survey in 2014. The y-axis is relative fish density as mean volume backscatter strength (S_v) from 0-15 m above the sea floor. Boxes represent the median and 25th and 75th percentiles. The whiskers represent the 10th and 90th percentiles, while the dots represent the 5th and 95th percentiles. Statistically significant differences among sites for a single survey (i.e. CB1a, CB1b, and CB2 in Aug(1)) are represented by different letters above each site. The relative fish density estimates were from ebb tides only. Data collected during flood tides were removed due to acoustic interference from the bottom support frame from the previously deployed TidGen® device. The Sep CB1b survey was not included due to contamination of the data by a buoy line.

To examine the difference in fish vertical distribution with and without the OCGen® module the vertical distribution of fish throughout the water column was quantified using area backscatter coefficient, s_a. This is the summation of volume backscatter over a given depth range and is also proportional to fish density. s_a is expressed in the linear domain with units of $m^2 \cdot m^{-2}$ and is additive. Vertical distributions of fish were constructed using the proportion of area backscatter coefficients, s_a, contained within each 1-m depth layer, measured upward from the seafloor. Typically, fish density was highest near the bottom (seafloor) at most sites, with a few exceptions (Figure 4). Within single surveys there were significant differences between the beside and control sites for Aug(2). This result was due to almost half of the area backscatter at the beside site being in the bottom 1 m of the water column. For tests among survey dates for a single site, Aug(1) was significantly different from Aug(3) and Sep at the beside turbine site; Aug(2) was significantly different from Aug(1) and Aug(3) at the in-line with the turbine site; and Aug(1) was significantly different from Aug(2), Aug(3) and Sep for the control site (Figure 4). *Aug(1) was the only survey when the foils were rotating.* Vertical distribution of fishes on that date was significantly different for several comparisons, suggesting a possible effect of the dynamic tidal energy device on fish use of the water column nearby. Differences among comparisons were not consistent, possibly indicating that the differences were caused by the inconsistency of device operation.

For detailed processing, analysis, and discussion, see Staines et al. 2015 in Appendix 1 and Staines et al. submitted Appendix 3b.

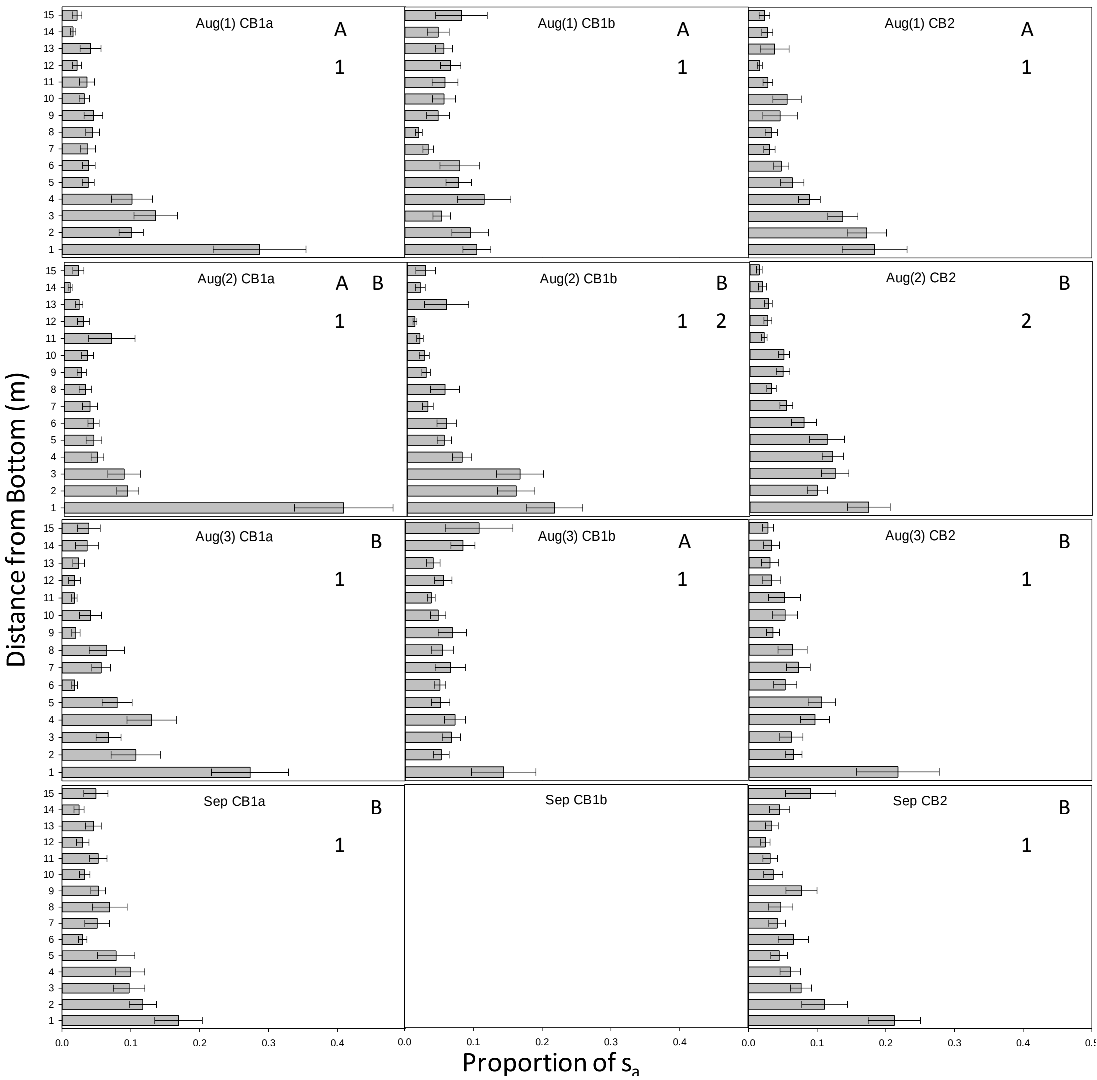

Figure 4. Vertical distribution of fish at each site for Aug(1), Aug(2), Aug(3), and Sep surveys. Horizontal bars represent the proportion of s_a (proportional to fish density) within each 1 m depth bin, from 0-15 m above the seafloor. Whiskers are one standard error. The OCGen® module was deployed for all Aug surveys but not Sep. The Aug(1) survey was the only survey during which the foils were rotating. Data used were from ebb tides only due to acoustic interference from the TidGen® support frame during flood tides. Statistical testing among sites for a single survey are shown left to right, i.e. Aug(1) for CB1a, CB1b, and CB2, with significant differences indicated by different numbers. Statistical testing among surveys for a single site are shown top to bottom, i.e. CB1a for Aug(1), Aug(2), Aug(3), and Sep with significant differences indicated by different letters. The Sep CB1b survey was not included due to contamination of the data by a buoy line.

Trawl samples were taken during each down-looking hydroacoustic survey at the control site in 2014 to examine seasonal patterns in fish presence. Samples were conducted during day and night slack tides. Midwater and benthic trawls were used. All trawls were standardized by boat speed and time. As such, numbers presented can be directly compared. The bathymetry near the control site was not conducive to safe trawling, so each trawling event took place 2.75 km away. Winter flounder (*Pseudopleuronectes americanus*) and longhorn sculpin (*Myoxocephalus octodecimspinosus*) dominated the catches. There was a major influx of Atlantic mackerel (*Scomber scombrus*) to Cobscook Bay starting in July, and though trawl speeds were not sufficient to capture them, mackerel were often caught on hook-and-line during slack tides of the down-looking hydroacoustic surveys. The total trawl catch for 2014 is shown in Table 2.

Table 2. Numbers of each species collected via trawling during down-looking hydroacoustic surveys. Totals are shown for sampling events that occurred before OCGen® module deployment (May 2014), during deployment (Aug 2014), and immediately after deployment (Sep 2014).

Common name	Before Deployment	During Deployment	After Deployment
Winter flounder	1108	559	168
Longhorn sculpin	218	48	42
Red hake	68	30	0
Atlantic herring	24	21	0
Silver hake	14	68	5
Atlantic cod	8	2	0
Shorthorn sculpin	6	19	10
Grubby sculpin	5	24	0
Threespine stickleback	3	0	0
Atlantic halibut	2	3	0
Haddock	2	92	21
Atlantic tomcod	2	0	0
Winter skate	1	0	0
Alewife	1	0	0
Ocean pout	1	0	0
Greenland halibut	1	0	0
Rainbow smelt	1	2	2
White hake	0	66	6
Little skate	0	1	0
Lumpfish	0	1	0
Rock gunnel	0	2	0
Sea raven	0	1	1
Cusk	0	1	0
Pollock	0	2	0
Butterfish	0	1	1
Spotted hake	0	0	1
Lanternfish	0	0	1

b) Side-looking hydroacoustics

The second long-term hydroacoustic dataset was stationary, side-looking hydroacoustic data collection that began in August 2012, when ORPC installed a Simrad EK60 echosounder with an ES200-7C split-beam transducer near the TidGen® Power System. The transducer was mounted on a pile 45 m to the side of the TidGen® Power System. The acoustic beam sampled a conical volume of water spanning 8.1 m - 13.8 m from the turbine face at its near end, and 13.5 m - 23.1 m from the turbine face at its far end (Figure 5). The beam was sampled 5 times per second as continuously as possible from August 2012 to July 2015. Whenever the TidGen® device was generating power, prior to April 2013, data were only collected at slack tides (when the turbine was not rotating) because of electrical interference of power generation on the hydroacoustic electronic equipment during running tides. This report focuses on data collected from April 2013 to July 2013, when the TidGen® turbine was still present but the brake was applied (and it was therefore not rotating); and on data collected from July 2013 to July 2015, when only the TidGen® bottom support frame was present (no turbine).

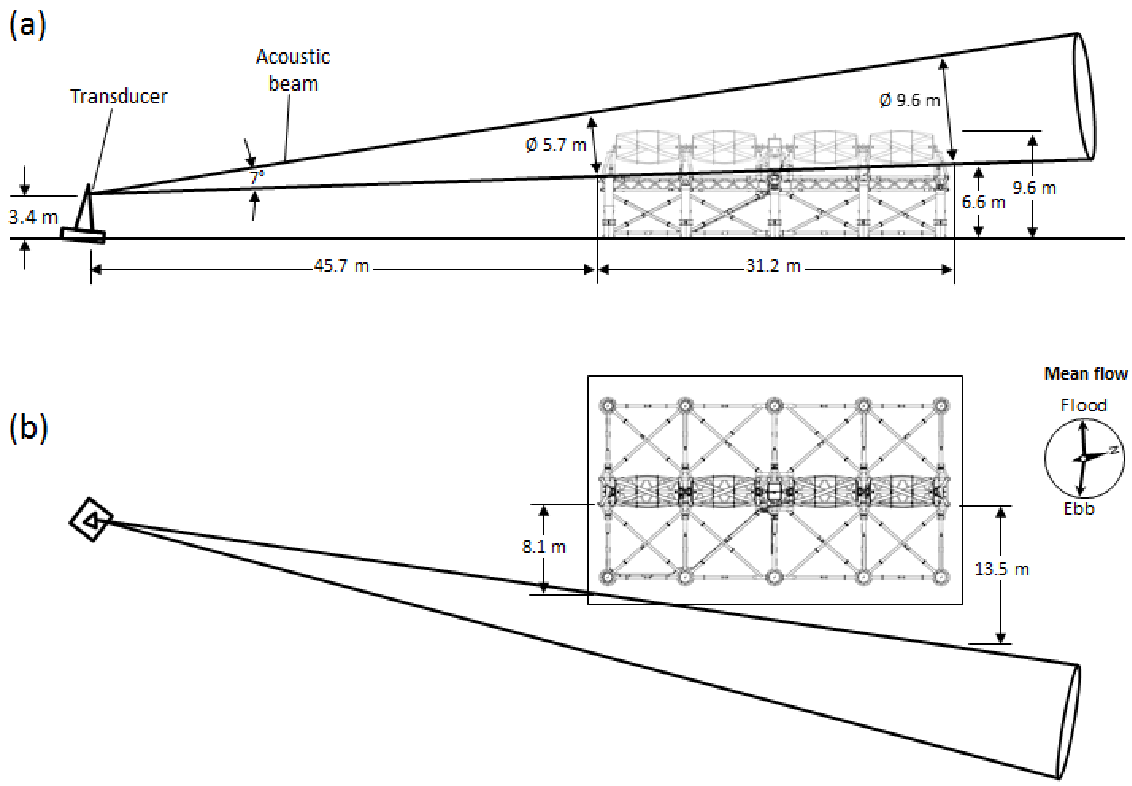

Figure 5. Side-looking hydroacoustic setup for monitoring individual fish behavior near the ORPC TidGen® device and subsequently the bottom support frame after turbine removal in July 2013. The tidal rose represents the mean tidal flow direction relative to north.

To examine individual fish behaviors in front of and in the wake of the TidGen® tidal energy device fish tracks were extracted from the side-looking hydroacoustic dataset during times when the turbine was present (though the brake was applied) and during times when it was absent (and only the TidGen® bottom support frame was present; Table 3). The heading of each fish relative to water flow was used to evaluate device effects on fish behavior.

Table 3. Summary of hydroacoustic data analyzed for this study.

Turbine state	Year	Dates of continuous data collection	Total time in dataset	Total fish detected
TidGen® present, brake applied	2013	4/25 - 5/02 5/07 - 5/14 5/24 - 6/04 6/26 - 7/05	38 days	5,227
TidGen® absent (bottom support frame present)	2014	4/24 - 5/27 6/04 - 6/26 6/30 - 7/05	63 days	5,749

Most tracked fish targets were moving in the same direction as the tidal current, with varying degrees of deflection from the median direction. For each tidal stage (flood, when fish were approaching the turbine; and ebb, when fish were departing from the turbine), a linear model was used to test for effects of turbine state (present or absent), zone (beside the turbine or in-line with the turbine), diel condition (day or night), and fish size (TS) on deflection from the median movement direction. The linear model was statistically significant (likely due to the large sample size) but the fit was poor for both the ebb and flood tide (adjusted R^2 of 0.008 and 0.037, respectively), meaning the factors examined did not have strong enough effects on fish movement to be biologically relevant. The absence of biologically significant factor effects on fish deflection (particularly effects of zone and turbine state) indicated that the turbine did not have a noticeable effect on individual fish movement at the ranges observed in this study (8-23 m), during either fish approach or departure from the device.

For detailed processing, analysis, and discussion, see Viehman and Zydlewski (submitted) in Appendix 3a.

While the above analysis utilized a small portion of the full side-looking hydroacoustic dataset, temporal analyses with Fourier and wavelet transforms were performed on a full year of side-looking fish detections (Table 4) to answer the fourth research question associated with this objective: *can a long-term hydroacoustic record of fish abundance be used to determine an ideal sampling strategy at this and similar tidal energy sites?* During the year of data collection, only the bottom support frame of the TidGen® device was present, and was assumed to have negligible effects on fish abundance in the sampled volume.

Table 4. Summary of side-looking hydroacoustic data collected at TidGen® site in 2014.

Start date	End date	Data collection	Time spanned
12/01/13	01/02/14	No data.	31 d, 18.4 hr
01/02/14	02/23/14	Data collected continuously.	51 d, 9.4 hr
02/23/14	02/24/14	No data.	1 d, 9 hr
02/24/14	04/15/14	Data collected continuously.	49 d, 16.5 hr
04/15/14	04/18/14	No data.	3 d, 6.9 hr
04/18/14	05/27/14	Data collected continuously.	39 d, 5.8 hr
05/27/14	06/04/14	No data.	7 d, 20.5 hr
06/04/14	06/26/14	Data collected continuously.	21 d, 21 hr
06/26/14	06/30/14	No data.	4 d, 9.8 hr
06/30/14	07/05/14	Data collected continuously.	4 d, 9.5 hr
07/05/14	07/14/14	No data.	9 d, 5.1 hr
07/14/14	07/20/14	Data collected continuously.	6 d, 8.8 hr
07/20/14	07/21/14	No data.	0 d, 13.2 hr
07/21/14	08/03/14	Data collected continuously.	13 d, 2.8 hr
08/03/14	08/04/14	No data.	0 d, 20.7 hr
08/04/14	08/27/14	Data collected continuously.	23 d, 4 hr
08/27/14	09/05/14	No data.	8 d, 22 hr
09/05/14	11/01/14	Data collected continuously.	57 d, 6 hr
11/01/14	11/06/14	No data.	4 d, 20.4 hr
11/06/14	11/07/14	Data collected continuously.	1 d, 8.1 hr
11/07/14	11/10/14	No data.	2 d, 19.1 hr
11/10/14	12/27/14	Data collected continuously.	46 d, 22.6 hr
12/27/14	01/05/15	No data.	9 d, 0 hr

The Fourier transform revealed cyclical patterns in fish abundance related to tidal and diel cycles, with periodicities of 6.2, 12.4, and 24 hours, as well as a cycle lasting approximately 60 days (Figure 6).

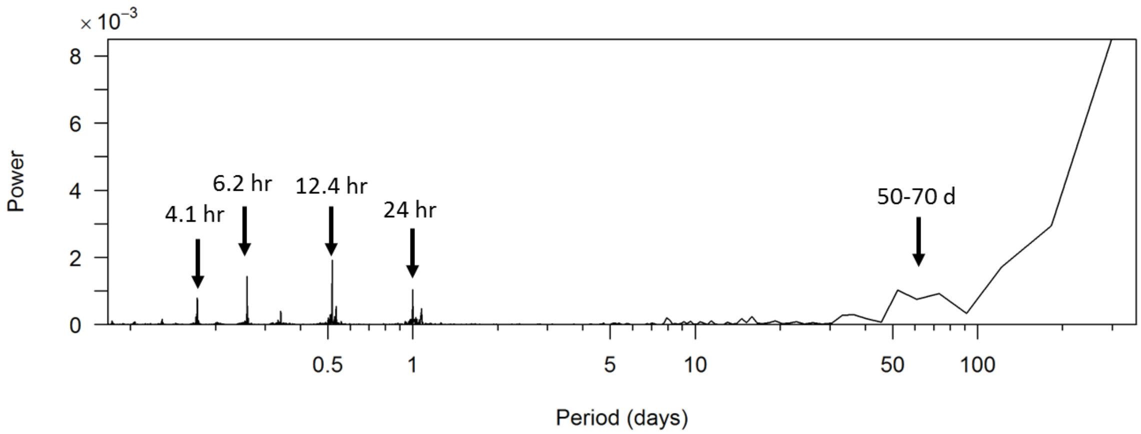

Figure 6. Power spectrum from Fourier transform of time series of fish abundance in the sampled volume of side-looking hydroacoustics data collected at the TidGen® site in 2014. Principal periodicities in the time series are indicated by arrows.

The wavelet transform revealed that the patterns identified by the Fourier transform were present throughout the year, but varied over time (Figure 7). The 12.4-hr tidal periodicity was present throughout most of the year, indicating one tidal stage may have more fish than the others. The diel pattern became important in the summer, perhaps due to seasonal changes in the local fish community. While the diel pattern was present, more fish were detected at night than during the day. A 15-day periodicity starting in July was also apparent in the wavelet transform, indicating a potential influence of the spring-neap tidal cycle (i.e., lunar phase) on fish abundance.

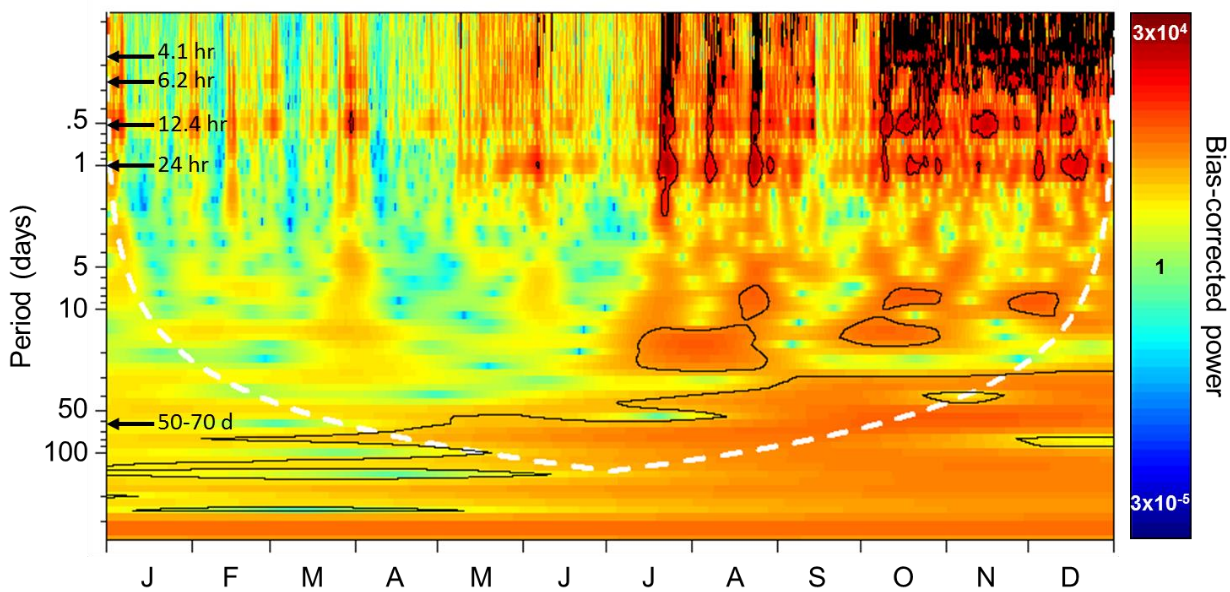

Figure 7. Wavelet spectrum of fish abundance time series collected with side-looking hydroacoustics at the TidGen® site. Color indicates the magnitude of the bias-corrected wavelet power, with red indicating higher power and blue indicating lower power. Black contours enclose areas of significance at the 0.95 level. Arrows correspond to the periodicities indicated in Figure 4. The dashed white line indicates the cone of influence, below which power values may be reduced by edge effects.

This variation over the course of a year has implications for long-term monitoring of fish abundance at this and other tidal power sites. To explore the effects of survey timing on the observed long-term trends in fish abundance, four different survey designs were simulated by subsampling the 1-year dataset: 1) six

1-hour surveys per year on random days; 2) six 24-hour surveys per year on random days; 3) one 24-hour survey per month in Mar, May, Jun, Aug, Sep, and Nov, timed to hold lunar phase constant (i.e. spring or neap tides); and 4) one 24-hour survey every 60 days (first day chosen randomly) (Figure 8). 24-hour surveys were best at reducing the effects of short-term variation (e.g. tidal and diel cycles) on observed trends, and the most consistent and accurate observations were achieved using designs which timed surveys based on existing patterns in fish abundance (designs c and d; Figure 8).

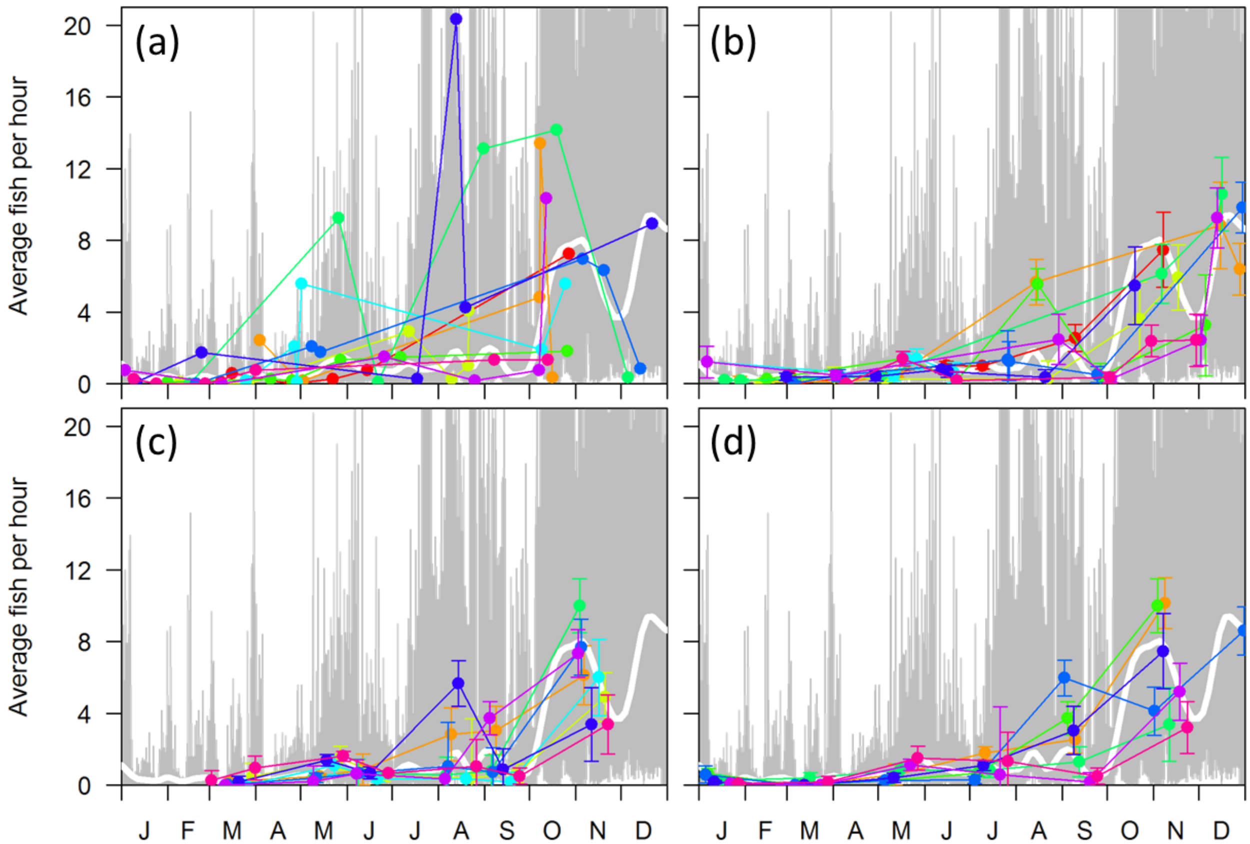

Figure 8. Influence of survey timing and duration on apparent trends in fish abundance (average number of fish per hour). Grey line is the fish abundance time series. Thick white line is the Lowess-smoothed abundance time series. Sampling schemes shown are: (a) 6 randomly spaced 1-hour surveys; (b) 6 randomly spaced 24-hour surveys; (c) 24-hour surveys carried out in March, May, June, August, September, and November, with lunar stage held constant; (d) 24-hour surveys spaced 60 days apart. Each colored line is the result of one iteration of the sampling scheme (n = 10). For 24-hour surveys, points are medians of data included in a given survey, and error bars represent one standard error.

For detailed processing, analysis, and discussion of a 3-month data subset see Viehman and Zydlewski 2015 in Appendix 1. For details on entire year of data, see Viehman et al. submitted Appendix 3d.

Conclusions

- ***Stationary down-looking hydroacoustics***
  - Fish density was highest in May.
  - Fish density tended to be higher near the sea bottom.
  - There were some significant differences in fish density and vertical distribution when testing between sites within surveys and between surveys within sites but they were inconsistently related to turbine presence and operation.
- ***Side-looking hydroacoustics***

- The presence of the static turbine did not significantly affect fish movement relative to the bulk water currents at the site.
- There were distinct cyclical patterns of fish abundance at the site of the TidGen® that coincided with tidal and diel cycles.
- Survey timing can affect how long-term trends in fish abundance are observed and documented at a tidal energy site. Survey timing can be adjusted to account for these natural cycles, reduce variation in observed fish abundance, and minimize cost of surveys.

Objective 2

A major limitation of hydroacoustic data used in fisheries applications is the inability to separate fish density by species. New processing approaches to improve species identification were attempted on the long-term, down-looking hydroacoustic dataset. We used a method known as dB differencing (Kang et al. 2002, Madureira et al. 1993). This method compares backscatter data collected at two or more frequencies to identify differences specific to particular species. We used our existing down-looking hydroacoustic data collected with 38 and 200 kHz in Cobscook Bay from 2011-2013 to test if dB differencing could be used to separate fish species with swimbladders (e.g. Atlantic herring) from those without (e.g. Atlantic mackerel).

The backscatter from 200 kHz was subtracted from 38 kHz backscatter to provide a metric called the frequency response, r(f). The r(f) was used to categorize groups of backscatter. The following r(f) ranges were used for our backscatter type classifications based on peer reviewed literature (Korneliussen and Ona 2002):

- r(f) < 2 dB = fish with swimbladder
- 2 dB < r(f) < 6 dB = mackerel
- r(f) > 6 dB = zooplankton

This information along with knowledge that mackerel were absent in Cobscook Bay until July each year led us to propose that the r(f) of swimbladdered fish and zooplankton would be observed in all sampled months while the r(f) of mackerel would only be present from July onward. However, we observed the mackerel r(f) in all sampled months and amounts of related backscatter varied little. In other words, based on the hydroacoustics, mackerel were present during all sampled months (Figure 9), although they could not have been based on knowledge of their physical absence in certain months (e.g., May and June).

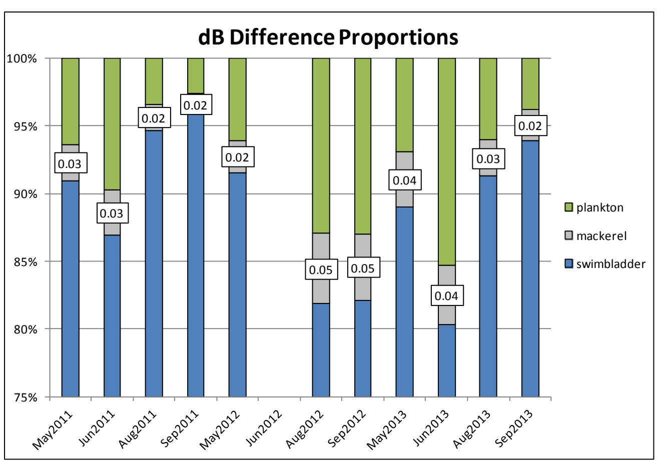

Figure 9. Proportions of the three categories of backscatter from dB differencing methods using control site (CB2) data. Note that the proportion of mackerel was similar for all months when it should be low or absent in May and June and higher in August and September.

For dB differencing methods to separate species by r(f) they must be separated by range if they are ensonified in the same sampling volume (ping), or separated by time if they are ensonified in different sampling volumes. In Cobscook Bay, fish of differing species shoal together (e.g. herring and mackerel). A major food source for herring and mackerel in the bay is zooplankton. So groups of backscatter could possibly be composed of two or more of our backscatter type classifications. This leads to a mixed r(f) that could be misleading. For instance, a mixed shoal of herring and krill (zooplankton) could lead to an r(f) that was representative of neither but resemble that of mackerel. This is a possible scenario for sampled months of May and June when we know mackerel to be absent but still observe their r(f) signature.

While this mixed signal made it challenging to separate mackerel from other scatterers, we have confidence in our estimation of fish with swimbladders, i.e., separating them from zooplankton. The r(f) signal that was representative of mackerel acts as a buffer between the r(f) signal of fish with swimbladders and the r(f) signal of zooplankton. Within the full spectrum of r(f) signals that we encounter, there were two major thresholds; one that separated fish with swimbladders and mackerel (-2 dB), and one that separated mackerel and zooplankton (6 dB) (Figure 6). We can therefore provide an overall estimate of fish (swimbladder and mackerel), excluding zooplankton. Using the 2 dB threshold does not affect our overall fish estimate but the 6 dB threshold does not provide a distinctive cutoff between mackerel and zooplankton. At the 6 dB threshold, depending on the mixture of r(f) signals, we were confidently estimating fish with swimbladders and mackerel, with the possibility of including a small amount of zooplankton in the estimate or excluding a small amount of mackerel. Our confidence in the estimation of fish with swimbladders was further strengthened by the fact that they will always contribute more to overall backscatter and thus be better represented in the S_v metric. These methods were incorporated for all stationary, down-looking hydroacoustic data from Objective 1.

For detailed processing steps see Staines et al. (in progress) in Appendix 2.

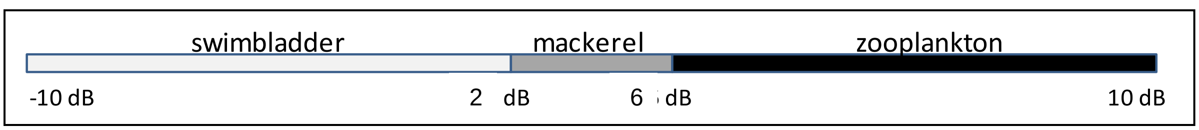

Figure 10. The frequency response, r(f), value line for dB differencing methods. Note that the mackerel r(f) is between the swimbladder and zooplankton r(f)s.

Conclusions

- Using dB differencing methods, the frequency response, r(f), of mackerel was observed in the data during months when they were known to be physically absent, leading to the conclusion that other factors were contributing to the r(f) observed.
- Mackerel, herring, and zooplankton (e.g. krill) reside in Cobscook Bay in mixed shoals, which confounded the frequency response metric, r(f), used to separate mackerel from other species.
- While we were unable to separate mackerel from other fish species, there was improved confidence in using dB differencing methods to remove zooplankton from relative fish density estimates.

Objective 3

To develop an encounter probability model, we used empirical data on fish abundance, vertical distribution, and behavior collected near two MHK energy devices. Two separate datasets were used for this objective. The first was the dataset presented in Objective 2, collected from 2011 – 2013 using this and other DOE awards. The second dataset was collected under a different funding source and used mobile, down-looking hydroacoustic data. These data were collected with a Simrad EK60 echosounder with an ES200-7C split-beam transducer. The transducer was attached to a vessel and repeated transects were conducted over and beside (control) the deployed OCGen® module by drifting with the tidal current. We used three proportional fish density values for a probability of encounter model, $P = p_1 * (1 - p_2) * (1 - p_3)$. The first was p_1, the proportion of fish at the depth of the device when the device was absent; the second was p_2, the proportion of fish avoiding the device prior to detection in our down-looking hydroacoustic data collected near the device. The first two proportions used the first dataset of stationary, down-looking hydroacoustics. The third proportion was p_3, the proportion of fish avoiding the device between being detected in our down-looking hydroacoustic surveys near the device and actually encountering the device; this proportion was derived from mobile, down-looking hydroacoustic surveys.

The first proportion, p_1, was estimated using a Bayesian Generalized Linear Model (BGLM) with stationary down-looking data from 2011-2013 and took into account potential effects related to month, diel, and tidal variation. This proportion was also separated by those depths that include the entire TidGen® Power System (0.5 - 9.5 m) and just the dynamic parts (foils) of the device (6.5 - 9.5 m) above the sea floor. The overall mean probability for the depths of the entire device ranged from 0.658 - 0.689, and the overall mean probability for the depth of the foils ranged from 0.079 - 0.093.

The second proportion, p_2, was determined by testing for differences in the vertical fish distributions between the project and control sites before and after the installation of the TidGen® device (Figure 11). There were no significant differences for any comparisons. This resulted in the value for $p_2 = 0$.

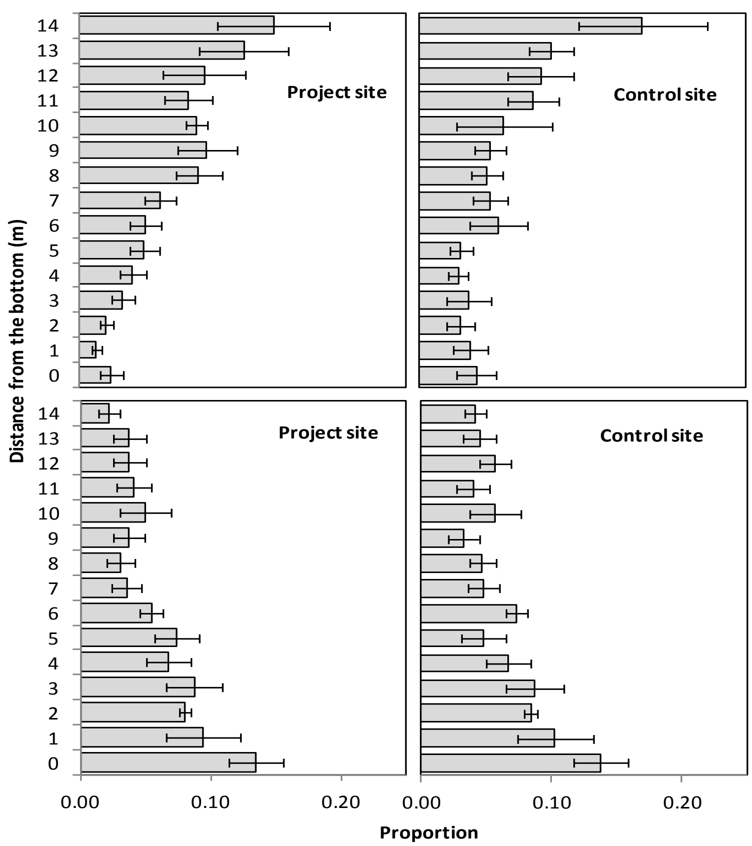

Figure 11. Vertical distribution of fish during ebb tide in May (upper panels) and September (lower panels) 2012 surveys at project and control sites. Vertical axis is distance above bottom (m). Each horizontal bar represents the proportion of area backscatter (s_a) within each 1 m water column layer. Whiskers denote one standard error.

Proportion three, p_3, was determined using mobile, down-looking hydroacoustic transects. Transects started 200 m upstream of the OCGen® module. The number of fish detected decreased as the vessel approached the OCGen® module. A linear regression was fitted to the data (R^2 = 0.86), and it was determined that a 37.2% mean decrease in the number of fish occurred from 140 m to 10 m upstream of the device (Figure 12), so p_3 = 0.372. Control transects (those not traveling over the device) showed no such decrease in fish numbers.

For detailed processing, analysis, and discussion, see Shen et al. 2015 in Appendix 1 and Shen et al. (2016) in Appendix 3a.

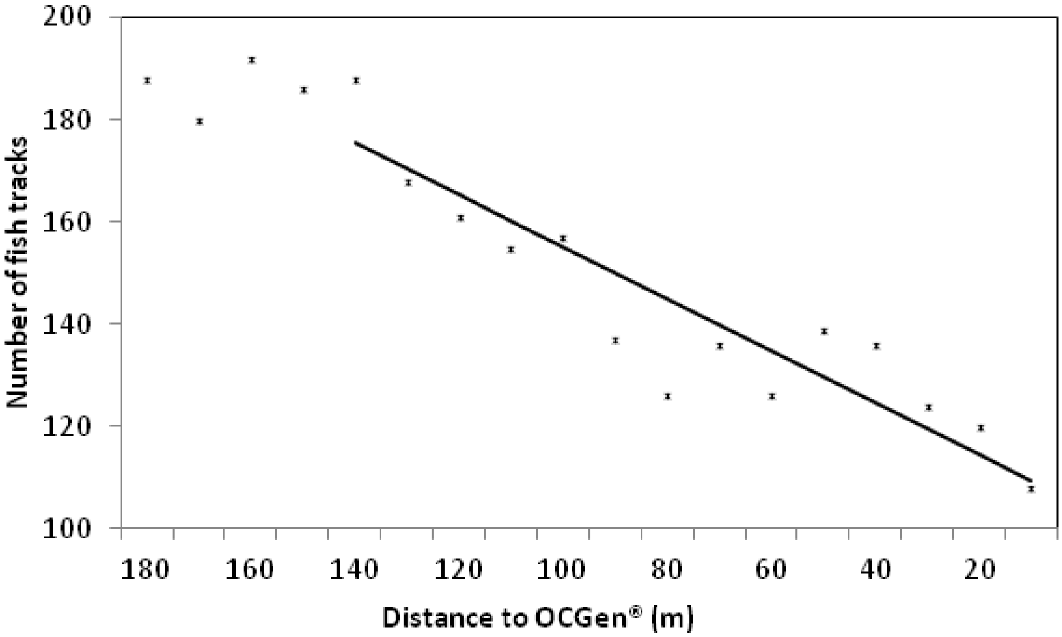

Figure 12. Number of fish tracks upstream of the OCGen® module from transects over the device. Note that the number of tracks begin decreasing at approximately 140 m from the device.

Conclusions

- Modeled maximum probability of fish encountering the whole TidGen® Power System (including bottom support frame) was 0.432 (95% CI: 30.5, 55.3), and the probability of fish encountering only the device foils was 0.058 (95% CI: 4.3, 7.3).
- The third proportion, p_3, had the highest value of the three model components and represented the closest proximity to a deployed device.
    - This was evidence that individual fish avoidance can occur as far away as 140 m.
    - In combination with evidence from Objective 1, behavioral changes can occur between 140 and 10 m from a device.

Problems Encountered

The originally proposed project was to examine the installation and redeployment of ORPC's TidGen® device. Technical issues arose and its installation was postponed. The OCGen® module mooring test installation was planned for a similar time and this device replaced the originally planned TidGen® for proposed research. The goal and objectives of the research did not change but addressed animal interactions with the OCGen® module instead. Additionally, the OCGen® module was deployed in a location close to the proposed TidGen® location and was also located at a similar depth in the water column, making processing, analysis, and interpretation of data comparable between the two devices.

There were three down-looking hydroacoustic surveys in August during the OCGen® deployment. During the first survey all components of the device were intact and operating according to plan. The second and third surveys occurred during times when the turbine foils were static for unknown reasons (see ORPC final technical report to USDOE: *OCGen®Module Mooring Project DE-EE0002650* for further details).

The OCGen® module was deployed close to the TidGen® bottom support frame (BSF). An attempt was made to place survey moorings in positions that would prevent the survey vessel from being located over the TidGen® BSF during flood tides, but the scope of the mooring lines still placed the transducer over the BSF. The combined size of the acoustic beam and space between the BSF and OCGen® module did not enable positioning to avoid the BSF contaminating the acoustic data from 0-5 m above the seafloor during flood tides. As such, those data were unusable for the proposed analyses. So, we processed data with and without the 0-5 m in both tidal stages and relative fish density estimates from both processing methods, including seasonal trends, were not different. From previous research, we knew that fish densities were higher near the seafloor, so we decided the best solution was to exclude flood tide data (contaminated by the BSF), in order to include the bottom 5 m of the water column.

During the September CB1a (beside) survey, there was an object in the water column that contaminated the data to the point of being unusable for the proposed analyses. The object was most likely a buoy and associated line from a lobster pot. We removed this survey from processing (Figures 3 and 4).

Recommendations

The continuation and development of the MHK industry will depend on determining effects of operational devices on fishes. Methods for monitoring will require further research, and refinement will help reduce the regulatory barrier for industry to progress toward commercial viability. The research summarized in this report represents viable approaches that could be used at other MHK tidal power sites with similar physical dynamics and fish assemblages, e.g., Canada and Europe.

Stationary, down-looking hydroacoustic approaches provided data that revealed seasonal differences at our Northwest Atlantic study site. The same data were processed to quantify fish vertical distribution and relative density at both the turbine site and a nearby control site. Collecting data at both a turbine and control site allowed meaningful comparisons for examining effects on fishes in the area. While we do recommend stationary, down-looking hydroacoustics as a valid means of environmental assessment for fishes near MHK tidal device deployments, certain details must be considered: (1) transducer type (balance between cost and detailed behavior); and (2) stationary approach (feasibility in extreme flows).

(1) To minimize monitoring costs, we used a single-beam transducer (~$10,000 US). A split-beam transducer (~$50,000) would have enabled collection of target strength data, which can be used to approximate fish size. It would also provide fish position within the beam, which can provide individual behavior (see Objective 1: Side-looking hydroacoustics).

(2) Sites that are deeper and have stronger tidal currents may not be suitable for stationary hydroacoustics methods. The tidal current speeds in our study area rarely exceeded 2 $m \cdot s^{-1}$, and the maximum depth was less than 50 m. Other locations, such as Minas Passage in Nova Scotia, could be too deep with currents too swift to allow stationary surveys from a moored vessel. Such locations would warrant the use of mobile, down-looking hydroacoustic surveys similar to those in Objective 3, though processing and analyses of these data would be similar to stationary surveys. The same limitations posed by current speed and depth on stationary, down-looking hydroacoustic surveys would apply to stationary, bottom-mounted applications similar to the side-looking echosounder in Cobscook Bay at the TidGen®. Installation and maintenance of a side-looking echosounder would be challenging and expensive, but not impossible.

Results from side-looking hydroacoustics data collection near a static turbine (Objective 1, Research Question 3) suggest the need for data collection closer to a device if the goal is to observe distinct behavior changes related to turbine evasion. In previous research (Viehman and Zydlewski 2015a), data collected within 0-3 m of a turbine allowed the assessment of individual-level responses of fish interacting with a device. Data collected under Objective 3, however, also suggest a need to examine responses as far away as 140 m, though individual-level responses at these ranges may not be as abrupt or obvious as those observed in the immediate vicinity of the device. *The spatial distance of observation must therefore be chosen based on the question asked*; e.g., what does a fish do when it physically encounters a device, vs. at what distance do fish respond to devices? Both questions are important for various species, and results will be dependent on fish species and size (Viehman and Zydlewski 2015; Hammar et al. 2014). So, while probability of encounter estimates incorporating far-field fish behavior are informative, particularly during initial monitoring, documenting near-field events such as fish strike occurrence and the fate of those fish remains important, as well. Collecting meaningful data on the direct interactions of fish with turbine foils in these high-energy and often turbid environments will continue to be a challenge. Multi-beam echosounders, acoustic cameras, and optical cameras are all viable methods but create large amounts of data and require time-consuming processing. Such methods will aid in determining fish interactions with individual turbines, but medium- and large-scale approaches will be required if we wish to document effects of arrays of tidal energy devices.

Sampling to control for the influence of seasonal, daily, and tidal cycles at different tidal power sites will improve study consistency across sites, streamlining the monitoring process and allowing comparisons between sites. Results from Objective 1, Research Question 4, indicate that cyclical temporal patterns in fish abundance can be used to design long-term monitoring schedules to yield accurate longer-term trends of fish abundance at tidal power development sites. Results indicated that surveys should be 24 hours long to capture tidal and diel variation in fish abundance, and should take place at the same point in the neap/spring tidal cycle. Monthly or semi-monthly surveys would likely capture seasonal changes such as emigration and immigration of different species, but analysis of a longer dataset (Viehman and Zydlewski submitted, Appendix 3) will allow us to determine the minimum number of surveys needed per year.

Multi-frequency methods should be used to improve quantitative hydroacoustic fish metrics. Dual frequency single beam hydroacoustics can be used to remove the majority of zooplankton from relative fish density estimates using dB differencing methods. This enables more appropriate measures of relative fish density than considering the return signal from just a single frequency. Determining the species of fish sampled with hydroacoustic gear remains an area of intense research in fisheries science. The traditional means of estimating species sampled is through physical capture (MacLennan and Simmonds 2008; Simmonds and MacLennan 2005). Numerous studies have shown that certain targets (e.g. fish and zooplankton) scatter sound differently depending on acoustic frequency (Kang et al. 2002; Madureira et al. 1993). We used dB differencing methods to attempt to separate Atlantic mackerel from swimbladdered fish in Cobscook Bay but were challenged by the mixed shoals of species (i.e. mackerel and herring). While differentiating fish species using only hydroacoustic data eluded us, we were able to confidently remove the majority of zooplankton from our relative fish density estimates using dB differencing methods. We stress that these methods will require the use of at least two frequencies, which could increase survey equipment costs.

As potential tidal power sites are proposed, it will be important to provide baseline data for regulators to consider potential effects of tidal power devices on fishes. The probability of encounter model produced from this research was a prime example of the utility of such baseline information. Collecting data on fish location in the water column, combined with the knowledge of depths spanned by a proposed device, and concurrently-collected data at a control site allowed us to determine the first probability component of the encounter model. Collecting data after device installation allowed us to resolve the second and third model components. The probability of encounter model was an important first step toward determining the overall effects of a tidal turbine on nearby fishes.

The early stages of this industry have provided pilot project deployments where empirical data on fish have been collected. While this begins to answer questions about small-scale turbine effects, the future of the industry involves multiple-device arrays, which has implications at a larger scale. Determining effects on fish in these scenarios could prove more challenging with confounding spatial variation of the larger geographical coverage.

Capturing fish behavior and movement around arrays will be necessary to determine array-level effects. Mobile, down-looking hydroacoustics from a vessel would likely be the most ideal method. Collecting data in the area planned for array deployment both before and after device installations along with surveys at one or more control sites would allow for a Before-After-Control-Impact (BACI) study design. A BACI design has the advantage of compensating for variation that may be spatially or temporally specific (i.e. annual variation and site specific variation). A BACI design that uses metrics similar to those used to address research questions 1 and 2 of Objective 1 of this study and the survey timing suggested in Objective 1, question 3, would provide useful results by showing changes in water column use and overall fish density in the area of the array while minimizing effects of natural cycles in abundance. We also will likely need to develop new approaches to produce meaningful results at multiple spatial scales.

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Viehman, H., G. B. Zydlewski, J. D. McCleave, G. J. Staines. 2015. Using hydroacoustics to understand fish presence and vertical distribution in a tidally dynamic region targeted for energy extraction. *Estuaries and Coasts* 38(Suppl. 1): S215-S226.

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Viehman, H., G. B. Zydlewski. 2015b. Using temporal analysis techniques to optimize hydroacoustic surveys of fish at MHK devices. *Proceedings of the 11th European Wave and Tidal Energy Conference.* 6-11 September. Nantes, France.

Appendix 1

Publications
Viehman, H.A., G.B. Zydlewski TO BE SUBMITTED. High-resolution, long-term observation of fish passage at a tidal energy site: Predictable patterns on multiple temporal scales. *PLOS One.*

Viehman, H.A., G.B. Zydlewski, W. Halteman, D. Degan. *Submitted*. Fish behavior near a static tidal energy device. *PLOS One*.

Staines, G., G.B. Zydlewski, H. A. Viehman. *submitted*. Changes in relative fish density around a deployed marine hydrokinetic (MHK) device in Cobscook Bay, Maine. International Journal of Marine Energy.

Shen, H., G.B. Zydlewski, H. A. Viehman, G. Staines. 2016. Estimating the probability of fish encountering a marine hydrokinetic device. Renewable Energy 97: 746-756.

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Appendix 2

Conference/Presentation List

Zydlewski, G.B., G. Staines, H. Viehman, H. Shen. 2016. Fish Behavior, Presence, and Distribution in a Tidally Dynamic Region, with and without a Tidal Energy Device. Poster presentation to Ocean Sciences annual meeting. New Orleans, LA. 26 February.

Viehman, H., G. B. Zydlewski, G. Staines, H. Shen. 2015. What about the fish? Studying effects of tidal power turbines in the USA. Oral presentation to zoology faculty and graduate students at the University of Aberdeen. Aberdeen, Scotland. 17 September.

Viehman, H., G. B. Zydlewski. 2015. Using temporal analysis techniques to optimize hydroacoustic surveys of fish at MHK devices. Oral presentation at the European Wave and Tidal Energy Conference. Nantes, France. 6-11 September.

Staines, G., G. B. Zydlewski, H. Viehman, H. Shen, J. McCleave. 2015. Changes in vertical fish distributions near a hydrokinetic device in Cobscook Bay, Maine, USA. Oral presentation at the European Wave and Tidal Energy Conference. Nantes, France. 6-11 September.

Viehman, H., G. B. Zydlewski. 2015. Altered fish behavior near a static hydrokinetic turbine. Oral presentation at the 145th meeting of the American Fisheries Society. Portland, OR. 16-20 August.

Zydlewski, G.B. 2015. State of the Science on MHK monitoring technology. At the 2015 NOAA National Hydropower Meeting. Greater Atlantic Regional Fisheries Office, Gloucester, MA. 9 July.

Shen, H., Zydlewski, G.B., Viehman, H., Staines, G. 2015. Estimating the probability of fish encountering a marine hydrokinetic device. Oral Presentation at the 3rd Marine Energy Technology Symposium, Washington, DC. 28 April.

Shen, H., G. B. Zydlewski, H. Viehman, G. Staines. 2015. Estimating the probability of fish encountering a marine hydrokinetic device. Oral presentation at the Marine Energy Technology Symposium. Washington, D.C. 27-29 April.

Viehman, H., G. B. Zydlewski. 2015. A unique approach to developing alternative energy from the ocean. Oral presentation to University administrators, engineering and biology faculty at Hirosaki University. Hirosaki, Japan. 7 January.

Viehman, H**.** 2014. Do tidal turbines affect fish? Poster presentation at the International Network on Offshore Renewable Energy North American Symposium. Halifax, Canada. 2 November.

Zydlewski, G.B. 2014. Effects monitoring of fish at/near an ORPC turbine. Given by Webinar at the Environmental Monitoring, Regulatory Needs & Scientific Capabilities workshop in Wolfville, Nova Scotia, Canada, sponsored by Annex IV, Acadia University and NS Energy. 1 November.

Shen, H., Zydlewski, G.B., Staines, G.S, Viehman, H. 2014. Modeling the Probability of Fish Encounter with a Tidal Energy Turbine. 144th meeting of the American Fisheries Society in Quebec, Canada. Given in the Symposium: Understanding Fish and their Ecosystems in Challenging Environments. 20 August.

Viehman, H., Zydlewski, G.B. 2014. Optimizing Sampling Based on Temporal Variation in Fish Abundance at a Tidal Energy Site in Cobscook Bay, Maine. 144th meeting of the American Fisheries

Society in Quebec, Canada. Given in the Symposium: Understanding Fish and their Ecosystems in Challenging Environments. 20 August.

Zydlewski, G.B., Viehman, H., Staines, G., Shen, H., McCleave, J.D., Vieser, J. 2014. Decreasing uncertainty concerning fish and marine hydrokinetic devices in tidally energetic regions. Invited presentation at the Nova Scotia Offshore Energy Research Association 2014 Research and Development conference. Halifax, NS, Canada. 21 May.

Zydlewski, G.B., Viehman, H., Staines, G., Shen, H., McCleave, J.D., Vieser, J. 2014. Fish interactions with marine renewable devices: Lessons learned, from ecological design to cost-effectiveness. Invited presentation at the 2nd Environmental Interactions of Marine Renewable Energy Technologies Conference. Stornoway, Scotland. 30 April.

Viehman, H., G. B. Zydlewski, James D. McCleave. 2014. Assessing effects of tidal turbines on fishes. Poster presentation at the Maine Sea Grant annual symposium. Orono, ME. 3 April.

Appendix 3:

Submitted Manuscripts

a. Shen et al. 2015. *Renewable Energy*
b. Staines, G.J., Zydlewski, G.B., Viehman, H.A. submitted to the *International Journal of Marine Energy*
c. Viehman , H.A., Zydlewski, G.B., Halteman, W., Degan, D. submitted to *PLoSOne*
d. Viehman, H.A., Zydlewski, G.B. submitted to *PLoSOne*