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Environmental monitoring at the Fundy Ocean Research Center for Energy (FORCE)

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Abstract—**The Fundy Ocean Research Center for Energy (FORCE) is Canada's leading centre for the demonstration and evaluation of in-stream tidal energy technology. Located in the Minas Passage of the Bay of Fundy, Nova Scotia, Canada, FORCE supports evaluation of in-stream tidal energy devices at its test site. Beyond providing infrastructure support for testing tidal turbine technologies, FORCE also serves a stewardship role through environmental monitoring activities. FORCE has been conducting environmental monitoring at its test site since 2009, with current monitoring projects focused on lobster, fish, seabirds, marine mammals, and profiling turbine-generated sound. This paper overviews the elements of these monitoring projects, including objectives, methodologies and major findings of the studies conducted to date. Because operational turbines have only been deployed at FORCE for brief periods, much of the monitoring data collected to date has contributed towards characterizing baselines. Monitoring projects have revealed a relatively high population density of lobster at the FORCE site, seasonal variability in fish densities that reflect migratory periods for anadromous and marine fishes in the Bay of Fundy, temporary avoidance of the FORCE test site by harbour porpoise during turbine installation, relatively low seabird species diversity and abundance, and minimal impacts of turbine generated sound on fish and harbour porpoise. Results of FORCE's monitoring activities are broadly consistent with the growing body of international research that has documented few negative impacts of in-stream tidal turbines on marine life to date. However, additional monitoring during extended periods of turbine deployment are required to fully characterize impacts.**

Keywords—**FORCE, Bay of Fundy, Canada, environmental monitoring**

I. Introduction

THE Fundy Ocean Research Center for Energy (FORCE) is Canada's leading site for research, testing, and evaluation of in-stream tidal energy devices.

Fig. 1. Map of Atlantic Canada showing the Bay of Fundy and the location of the FORCE test site in Minas Passage.

FORCE is located in what is considered to be one of the strongest tidal energy resources in the world – the Minas Passage of the Bay of Fundy, Nova Scotia, Canada (Figure 1– estimated to contain more than 2,500 megawatts (MW) of extractable power [1].

As 'host' to technology development, FORCE provides five undersea 'berths' for turbine generator testing. Four of these berths have access to subsea power cables that will connect turbines to land-based infrastructure, an onshore substation and power lines connected to the local transmission system. In addition, FORCE also hosts a visitors/operations center that has welcomed more than 30,000 visitors since opening in 2011.

Another key role for FORCE is to conduct, facilitate, and promote the collection of environmental data – something it and its partners have been doing for nearly ten years. Since 2009, FORCE has been conducting or facilitating environmental data collection at its test site in consideration of a number of variables, including geology, bathymetry, current flows, various marine species, traditional knowledge, sedimentation, and more. Since its latest monitoring effort began in spring 2016, FORCE has

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focused its monitoring efforts on lobster, fish, marine mammals, seabirds, and the profiling of turbine-generated sound.

The purpose of this paper is to provide a broad overview of the environmental monitoring that FORCE conducts in the Minas Passage to aid environmentally responsible and sustainable energy extraction from the Bay of Fundy.

II. Overview of Monitoring Programs

Environmental monitoring of marine renewable energy devices is a critical component to ensuring that this sector continues to advance in a responsible and sustainable manner. This includes collecting baseline and effects monitoring data to test predictions related to the potential impacts of tidal turbines on ecosystem components. FORCE presently collects baseline and effects monitoring data for lobster, fish, marine mammals, seabirds and marine sound at its test site in the Minas Passage. Here, we overview the objective, methodology, and major findings of the studies conducted to date for each of these monitoring programs.

A. Lobster monitoring

The Nova Scotia commercial American lobster (*Homarus americanus*) fishery is a lucrative industry and includes commercial harvest in the Bay of Fundy. As such, FORCE's present monitoring program focuses on understanding the impacts of turbines on commercial lobster harvest. In fall 2017, FORCE and its partner NEXUS Coastal Resource Management Ltd. conducted a baseline lobster catchability study using baited commercial lobster traps deployed following a modified Bayley design [2]. This baseline study design consisted of two concentric rings, each 50 metres wide, that were centred around the future site of turbine deployment (Figure 2). Each ring contained eight randomized fixed stations where traps were deployed and retrieved after a 24-hr soak period. Trap deployment and retrievals were repeated three times. Captured lobsters were assessed for carapace length, weight, shell condition, sex and reproductive stage (i.e., male, female, and berried female), and then returned to the water. Data were recorded on a per trap basis and were reported as catch-per-unit-effort (CPUE) – a proxy measure for population density.

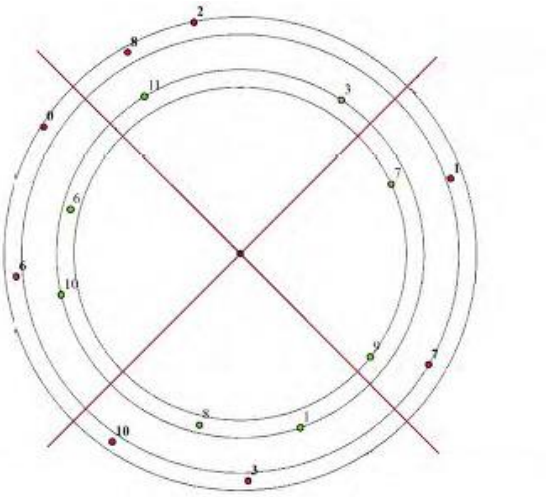

Fig. 2. The modified Bayley survey design [2] used in FORCE's lobster catchability study. Baited commercial lobster traps are deployed in eight randomized fixed stations in two concentric rings (outer and inner) that are divided into quadrants.

Analyses by NEXUS Coastal Resource Management Ltd. revealed a high population density of lobsters (i.e., >2.7 kg/trap) at the FORCE test site during the study period. The data suggest a uniformly high population density across the FORCE site, as analyses failed to detect any significant differences in the number of lobsters captured between rings or quadrants. However, a decline in catch rates was observed over the course of the study that was consistent with increasing tidal amplitude (i.e., there was a statistically significant negative relationship between catch rates and maximum tidal range); suggesting limited movement of lobster during periods of high tidal velocity. Whereas a preliminary evaluation suggested low lobster population density at the FORCE site due to the presence of scoured bedrock as the primary benthic habitat, initial results of the catchability study suggest that the impacts of tidal turbines on lobster may be greater than anticipated. However, data collection in the presence of an operational turbine is needed to compare to the 2017 baseline dataset to test this supposition.

B. Fish monitoring

Since May 2016, FORCE has been conducting mobile hydroacoustic fish surveys using a downward facing split-beam echosounder (i.e., a Simrad EK80 mounted to a modified fishing vessel) to test for indirect effects of tidal turbines on fish density and vertical distribution in the water column, and to estimate the probability of fish encountering a turbine based on any 'co-occurrence' relative to turbine depth. The mobile survey is based on a BACI (Before-After Control-Impact) study design and includes a series of transects over the FORCE test site and a nearby reference (control) site (Figure 3). These surveys occur on a near-monthly basis and take place over a 24-hr period to quantify fish distribution and density over two tidal cycles during both day and night conditions. These surveys have occurred prior to turbine installation and after installation at the FORCE site. The data are provided to FORCE's colleagues at the University of Maine who use a two-stage generalized linear model to quantify variation in fish density.

Analyses of hydroacoustic fish survey data collected during baseline studies in 2011 and 2012 [3] and those during the May 2016 – August 2017 [4] revealed similar fish densities between the FORCE test site and the reference site and demonstrated similar patterns of seasonal change. Survey data collected during the November 2016 – June 2017 deployment of the 2.0 MW

OpenHydro turbine at the FORCE site revealed a strong seasonal effect on fish density, with the highest densities observed during May, November and January; consistent with seasonal migrations of anadromous and marine fishes in the Bay of Fundy. These data also revealed that fish density at the height of the OpenHydro turbine was highly variable across tidal stage (ebb/flood), diel stage (day/night), time of year, and even within the FORCE test

Fig. 3. Transects over the FORCE test site and a reference site used in the BACI design of FORCE's fish monitoring program.

site itself. However, relative to the reference site, the data did not show a significant effect of the OpenHydro turbine on relative fish density or vertical distribution in the water column, suggesting minimal effects of this tidal turbine design on marine and anadromous fishes at the FORCE site. Additional data are required to confirm the effects of other types of turbine designs on fish density and distribution in the Minas Passage.

C. *Marine mammal monitoring*

FORCE's marine mammal monitoring program is conducted in partnership with Sea Mammal Research Unit Canada Ltd. and involves the use of passive acoustic monitoring (PAM) marine mammal detectors (i.e., C-PODs), that record the vocalizations of toothed whales, porpoises, and dolphins. Five C-PODs are deployed on SUBS (Streamlined Underwater Buoyance System) packages that are anchored to the seabed within the FORCE site and the surrounding area (Figure 4). The program focuses on the harbour porpoise (*Phocoena phocoena*) – the primary marine mammal species found in the Minas Passage and is known to have a small population that inhabits the inner Bay of Fundy [5]. The overall goal of this program is to understand if there is a change in marine mammal presence in proximity to deployed tidal turbines and builds upon baseline C-POD data collected within the Minas Passage since 2011.

During 2011 – 2018, more than 4,650 'C-POD days' worth of data were collected at the FORCE site and the surrounding area. Over this period, it was found that harbour porpoise spatiotemporal movements varied over longer (i.e., seasonal peaks and lunar cycles) and shorter (i.e., nocturnal preference and tidal stage) time scales. Analyses of the data collected during the November 2016 – June 2017 deployment of the OpenHydro turbine suggested some avoidance of the region near the turbine [6]. Specifically, C-PODs in closest proximity to the turbine (i.e., 230 metres and 210 metres distance) demonstrated decreased marine mammal detections relative to those

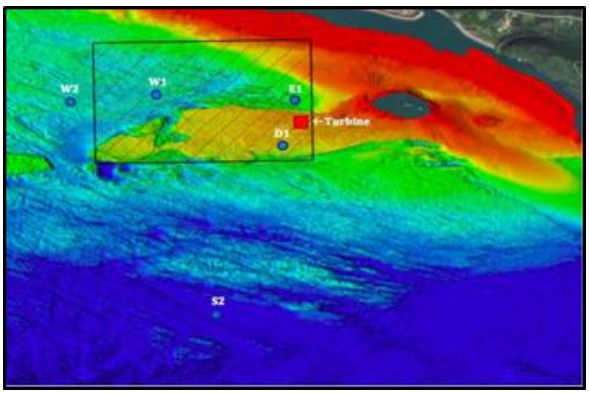

Fig. 4. Location of the five C-PODs (W1, W2, E1, D1, and S2) deployed within the FORCE test site and surrounding area used for monitoring harbour porpoise.

located further away. There was no evidence for avoidance of regions farther afield during the operation of the OpenHydro turbine. The most recent results demonstrated a temporary decrease in detections during turbine installation activities, consistent with previous findings [6], but this will require additional data collected during turbine operations to permit a proper assessment.

D. *Seabird monitoring*

The main objective of the seabird monitoring program is to collect species composition, abundance and spatial distribution data from the FORCE test site and surrounding area to determine whether turbine operations cause displacement of seabirds from their habitual waters. FORCE works with Envirosphere Consultants Ltd. to conduct monthly observational seabird surveys (6-hr periods coinciding with the ebb tide) using a geographical grid system (Figure 5) to record observations from the FORCE site and surrounding area. A series of summary statistics including i) total and average number of species observed per survey and ii) average abundance of each species per survey, provide valuable information about species presence, behaviour and seasonality throughout the FORCE test site and Minas Passage [7]. Whereas there has been limited opportunity to determine the potential

effects of tidal turbines on seabirds due to the short period during which an operational turbine has been present at the FORCE site, baseline data collected to date have revealed the presence of 36 different seabird species at the FORCE site, with greater black-backed (*Larus marinus*) and herring gull (*L. argentatus*) observed most frequently. Baseline data indicated moderate and approximately equal use of survey sub-areas, but also revealed that the abundance of seabirds at the FORCE site is low relative to other coastal areas in the Bay of Fundy and Atlantic Canada. However, seasonal peaks in abundance correspond with migratory movements through the region.

FORCE has recently partnered with Acadia University and Envirosphere Consultants Ltd. to synthesize multiple years of baseline data and to integrate it with data from radar-based monitoring at the FORCE site. Similar to observational studies, radar analysis revealed a seasonal pattern of activity with very few birds present in the winter and peaks during spring and fall migrations [8].

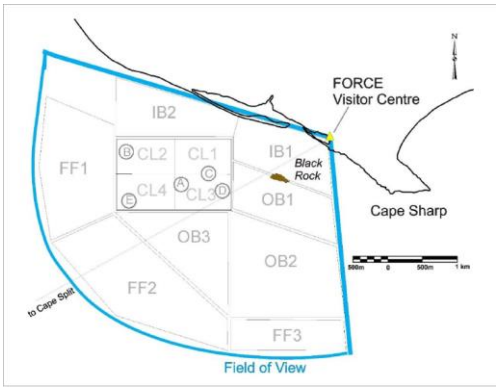

Fig. 5. Geographical grid system used in FORCE's observation-based seabird monitoring program.

E. *Marine sound monitoring*

The objective of FORCE's marine sound monitoring effort is to collect ambient sound measurements to characterize the soundscape of the FORCE test site and to understand the operational sounds produced from operating tidal turbines. Data collected from these efforts are used to test the prediction that operational sounds produced from tidal turbines are unlikely to cause mortality, physical injury or hearing impairment to marine animals.

JASCO Applied Sciences conducted a comparative integrated analysis of sound data collected during the 2016-2017 deployment of the OpenHydro turbine. Data collected using a series of different hydrophone configurations (i.e., surface-drifting icListen hydrophones, turbine-mounted icListen hydrophones, and an Autonomous Multichannel Acoustic Recorder (AMAR)), revealed that sound levels increased with current speed in the Minas Passage, and were higher during flood tide than ebb tide [9]. Regardless of the operational status of the OpenHydro turbine (i.e., generating power of 'free-spinning'), current speed influenced sound levels, but current direction did not. This was evidenced by an increase in marine sound by 20-30 decibels (dB) in both the generating and 'free-spinning' states as current speed increased. Similarly, the OpenHydro turbine was found to emit a band of sound in the 3150 – 4000 Hertz (Hz) range while generating power, with sound levels increasing by ~10 dB as the current speed increased.

Results indicated that turbine-generated sound only exceeded the threshold for behavioural disturbance to fish at short ranges (<500 metres) and only at the highest current speeds on the flood tide. Whereas the OpenHydro turbine may have been audible to herring (or mask sounds a herring could hear) up to 1,000 metres, it was typically < 500 metres. Analyses also suggested that sound emitted from the OpenHydro turbine while generating power could be detected by harbour porpoise up to 800 metres but would only influence their behaviour at ranges <300 metres. In the 'free-spinning' state, the OpenHydro turbine did not generate sound levels in the harbour porpoise hearing frequency band that were measurable above ambient sediment noise. Interestingly, at most frequencies the OpenHydro turbine emitted a lower source level for sound than vessels that might typically be in the Minas Passage.

F. *FAST program*

In 2012, FORCE created the Fundy Advanced Sensor Technology (FAST) Program to enhance site characterization, environmental monitoring, and marine operations capabilities in the high-flows of the Minas Passage. The FAST program consists of a series of onshore equipment and subsea (autonomous and cabled platforms) monitoring equipment that can be integrated to address specific research project requirements. Presently, FAST projects focus on turbulence and wake characterization, fish distribution monitoring, and target identification. The program provides the capacity required to support continued improvement in data acquisition, research and environmental monitoring at the FORCE site.

III. DISCUSSION

Environmental monitoring and research efforts at the FORCE site over the last several years have contributed to the growing body of knowledge about the ecology and physical environment of the Minas Passage. Though there have been limited periods of turbine operation at the FORCE site, initial findings are enhancing our collective understanding of the potential risks that in-stream tidal energy devices pose to marine life and the marine environment within the Bay of Fundy.

With respect to mid-field monitoring at the FORCE site, no substantive changes have been observed in the distribution and behaviour of fish [4], seabirds [7], or marine mammals [6] in relation to the deployment of the

OpenHydro turbine in 2016 – 2017. This is consistent with studies elsewhere that have documented no changes in behaviour of fish in the vicinity of an operational turbine [10], but will require further testing and analysis to improve certainty in these conclusions.

FORCE's mid-field monitoring efforts revealed temporary declines in the presence of harbour porpoise during installation of the OpenHydro turbine in November 2016 that are likely attributable to increased vessel activity associated with the installation. These observations are consistent with the temporary displacement of harbour porpoise detected during the installation of the SeaGen project in Strangford Slough, N. Ireland [11]. Similar observations have been made regarding the temporary displacement of seabirds during turbine installation activities [11, 12].

Marine mammals are known to be impacted by anthropogenic sounds, including those emitted by underwater construction and associated vessels, that can lead to injury or changes in behaviour and distribution [13]. Whereas sound generated from the OpenHydro turbine deployed at the FORCE site was audible to fish and harbour porpoise in the 500 m – 800 m range [9], analysis of these data suggest that it is unlikely this sound level caused injury [6].

IV. Conclusion

Results of FORCE's mid-field monitoring activities are broadly consistent with the growing body of international research focused on resolving the environmental effects of tidal energy technology that have documented few negative impacts of in-stream tidal turbines on marine life [14, 15]. For instance, research has shown that fish generally avoid operating turbines [14] by exhibiting fine-scale behavioural adjustments in response to these devices. Whereas additional study is required, initial findings from the FORCE test site and from international monitoring efforts provide an early picture of turbine-marine life interactions. These efforts also provide an opportunity to employ the principles of adaptive management in refining existing monitoring activities and in developing additional technologies, tools, methodologies and protocols that will be required to monitor tidal energy turbines in the future. For instance, initiatives like the FAST Program have facilitated the continued development and enhancement of standard operating procedures for environmental monitoring at FORCE.

Much of the environmental monitoring at FORCE has focused on collecting baseline data and understanding the mid-field effects of turbines on ecological components of Minas Passage and the Bay of Fundy. However, the OpenHydro turbine was only deployed at FORCE for a relatively short period (i.e., November 2016 – June 2017), and lengthier deployment periods are required to understand the near-field effects on fish, marine mammals and seabirds at FORCE.

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References

[1] R. Karsten, D. Greenberg, M. Tarbotton, J. Culina, A. Swan, M. O'Flaherty-Sproul, and A. Corkum, "Assessment of the potential of tidal power from Minas Passage and Minas Basin", Acadia University, Bedford Institute of Oceanography, Fisheries and Oceans Canada, Offshore Energy Environmental Research Association (OEER), and Triton Environmental Consultants Ltd., Document 300-170-09-11, 20 Nov. 2011.

[2] CEF Consultants Ltd., "Fundy tidal energy demonstration project – lobster catch monitoring: summary of results from three surveys with recommendations for a revised survey design – final report", 01 Feb. 2011.

[3] G.D. Melvin and N.A. Cochrane, "Multibeam acoustic detection of fish and water column targets at high-flow sites", *Estuaries and Coasts*, vol. 38, no. 1, pp. 227-240, 2014.

[4] A. Daroux and G Zydlewski, "Fish monitoring to assess effects of a turbine in a tidal energy development site', In Proc. 12th European Wave and Tidal Energy Conference, 2017, pp.1166-1 – 1166-6.

[5] D.E. Gaskin, "Status of the harbour porpoise, *Phocoena phocoena*, in Canada", *Canadian Field-Naturalist*, vol. 106, no. 1, pp. 36-54, 1992.

[6] R. Joy, J.D. Wood, C.E. Sparling, D.J. Tollit, A.E. Copping, and B.J. McConnell, "Empirical measures of harbor seal behaviour and avoidance of an operational tidal turbine", *Marine Pollution Bulletin*, vol. 136, pp. 92-106, 2018.

[7] Envirosphere Consultants Ltd., "Marine seabirds monitoring program – tidal energy demonstration site-Minas Passage, 2016-2017", 22 Dec 2017.

[8] J. Walker and P. Taylor, "Using radar data to evaluate seabird abundance and habitat use at the Fundy Ocean Research Center for Energy site near

Parrsboro, NS", Acadia University, Project Report. 300-223, 28 Sep. 2018.

[9] B. Martin, C. Whitt, and L. Horwich, "Acoustic data analysis of the OpenHydro opencentre turbine at FORCE: Final Report", JASCO Applied Sciences, Dartmouth, Nova Scotia, Canada, Tech. Report. 01588 v. 3.0b, 28 Jun 2018.

[10] M.S. Bevelhimer, C. Scherelis, J. Colby, C. Tomichek, and M.A. Adonizio, "Fish behavioural response during hydrokinetic turbine encounters based on multi-beam hydroacoustic results", In Proc. 3rd Marine Energy Technology Symposium, 2015, pp. 1-4.

[11] G. Keenan, C. Sparling, H. Williams, F. Fortune, and A. Davison, "SeaGen environmental monitoring programme: Final Report", Royal Haskoning, Edinburgh, UK, Tech. Report. 9S8562/R/3037129/Edin, 16 Jan. 2011.

[12] C. Long, "Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems", Scottish Natural Heritage Commissioned Report No. 947, 2017.

[13] T. Gotz, G. Hastie, L.T. Hatch, O. Raustein, B. Southall, M.Tasker, and F. Thomsen, "Overview of the impacts of anthropogenic underwater sound in the marine environment", OSPAR Commission, London, UK, 2009.

[14] A. Copping, N. Sather, L. Hanna, J. Whiting, G. Zydlewski, G. Staines, A. Gill, I. Hutchison, A. O'Hagan, T. Simas, J. Bald, C. Sparling, J. Wood, and E. Masdsen, "ANNEX IV 2016 State of the Science Report: Environmental effects of marine renewable energy development around the world", 2016.

[15] A. Copping, "The state of knowledge for environmental effects: driving consenting/permitting for the marine renewable energy industry", Pacific Northwest National Laboratory, Seattle, USA, Jan. 2018.