Predicting the probability of encounter between fish species and tidal stream energy devices using acoustic telemetry

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I. INTRODUCTION

UNDERSTANDING the environmental effects of marine renewable energy devices is important for ensuring the responsible development of this new industry and is particularly relevant in ecologically sensitive regions. Minas Passage, Bay of Fundy, Canada, is a highly sought-after location for the development of tidal stream energy and is characterized by the world's highest tides (15-m range) and tidal flow speeds exceeding 5 m/s [1]. Efficient extraction of energy from these flows could produce over 2.5 GW of electricity each tidal cycle [2]. However, Minas Basin hosts at least 85 fish species, including diadromous and marine fishes for which Minas Passage serves as an important migratory corridor [3]. This includes species protected under Canada's Species at Risk Act, of cultural relevance to First Nations communities, and comprising important commercial and recreational fisheries.

Collision between marine species and rotating turbine blades is perceived to be the most direct environmental impact of tidal stream devices [4]. Risk of collision is typically framed as encounter risk, and is measured using models derived from predator-prey interactions that assess the probability of an animal entering the turbine's area of effect [5]. Globally, the majority of research focused on interactions between marine animals and tidal power devices has focused on marine mammals [6]. Direct observation of fish presence is difficult in extreme environments such as Minas Passage, particular given the need for species-specific information on potential encounter risk.

Acoustic telemetry, in which transmitters carried by fishes produce ultrasonic signals that can be detected by deployed receivers, can provide presence/absence data for the development of species-specific spatiotemporal distribution models and ultimately encounter rate models. Acoustic telemetry has become a standard method in fisheries and marine ecology studies, and collaborations with existing projects are possible through acoustic telemetry networks [7]. Acoustic tag detection locations can be matched in space and time with environmental data, which enables identification of associations between environmental conditions and species presence/absence and allows for predictive species distribution modelling [8]. Bangley et al. [9] combined the timing and detection location of acoustically tagged fish with oceanographic variables and used a boosted regression tree (BRT) modelling approach to develop a predictive species distribution model (SDM) for striped bass (*Morone saxatilis*) in Minas Passage the illustrated species presence probability at each tide stage.

A potential caveat of using acoustic telemetry in Minas Passage is that the extreme current velocities can have a significant effect on the detectability of acoustic signal, particularly from the 69-kHz transmitters used in that study [10]. Due to the longer time intervals typical of 69-kHz transmitters (usually 1-2 min), there may only be time for a single ping to reach the receiver while the tag is within detection range, and in some cases a tagged fish may be moved through the receiver's detection range before the next transmission is made. Here, we review the methods developed by Bangley et al. [9] and expand on this previous effort by incorporating data on tag detection efficiency to account for these environmental effects. This allows us to make conservative and realistic predictions of striped bass presence probability even in conditions where tag detectability is reduced. This is a crucial first step towards the development of statistically robust encounter rate models for quantifying the risk of tidal stream turbines to fish.

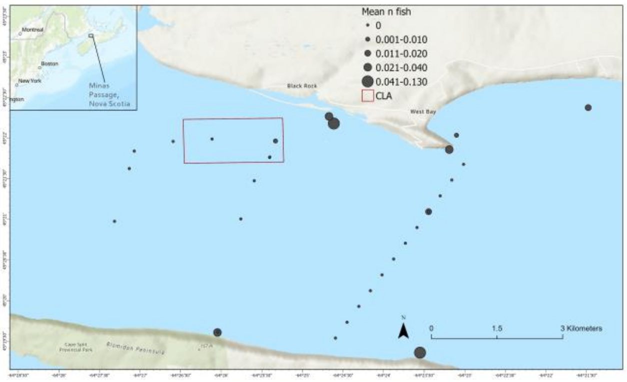
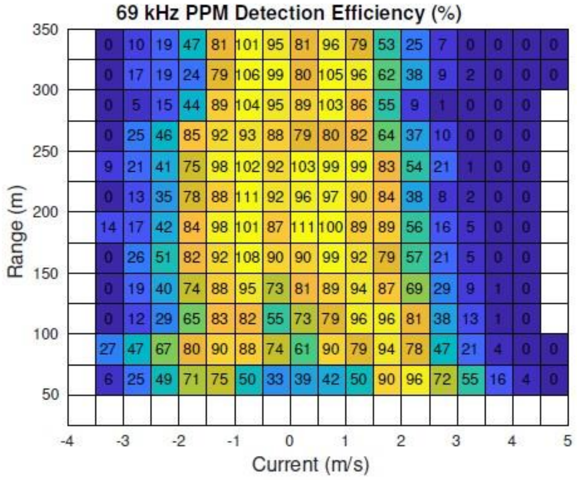


Fig. 1. Locations of acoustic receivers used to document striped bass presence/absence during 2017-2020 with mean number of unique individuals detected over that time period.



	0	10	19	47	81	101	95	81	96	79	53	25	7	0	0	0	0
	0	17	19	24	79	106	99	80	105	96	62	38	9	2	0	0	0
	0	5	15	44	89	104	95	89	103	86	55	9	1	0	0	0	
	0	25	46	85	92	93	88	79	80	82	64	37	10	0	0	0	
	9	21	41	75	98	102	92	103	99	99	83	54	21	1	0	0	
	0	13	35	78	88	111	92	96	97	90	84	38	8	2	0	0	
	14	17	42	84	98	101	87	111	100	89	89	56	16	5	0	0	
	0	26	51	82	92	108	90	90	99	92	79	57	21	5	0	0	
	0	19	40	74	88	95	73	81	89	94	87	69	29	9	1	0	
	0	12	29	65	83	82	55	73	79	96	96	81	38	13	1	0	
	27	47	67	80	90	88	74	61	90	79	94	78	47	21	4	0	0
	6	25	49	71	75	50	33	39	42	50	90	96	72	55	16	4	0

Fig.2. Matrix of detection efficiency (% of expected transmissions detected) over current velocity and distance from the receiver. Negative current velocity values represent outgoing tidal flow. Expected transmissions are based on the mean number of transmissions per 10 minutes, but transmissions are randomized so it is possible to detect greater than 100 % of expected transmissions.

II. METHODS

A. Acoustic telemetry and environmental data

Acoustic tag detections from striped bass originally tagged by researchers at Fisheries and Oceans Canada were used as records of presence and absence at receiver locations in Minas Passage (Fig. 1). The total deployment period of each receiver was summarized hourly and presence was defined as at lease on tagged fish being detected during that hour. These hourly records were matched in spatially and temporally with seven environmental variables that were summarized as the mean hourly value. The environmental variables were sea surface height, sea surface height gradient, divergence, vorticity, signed water current velocity, bathymetry standard deviation, and temperature. All variables except bathymetry standard deviation and temperature were derived from surface wave field data collected by two overlapping X-band radar installations in the vicinity of the Fundy Ocean Research Centre for Energy (FORCE) visitor's centre on the north shore of Minas Passage. Bathymetry standard deviation was taken from high-resolution (2-m) multibeam sonar bathymetry data in Minas Passage. Temperature data were taken from temperature sensors carried aboard Innovasea HR2 receivers deployed at various locations within Minas Passage.

B. Species Distribution Modeling

SDMs were generated using the BRT methodology described in Bangley et al. [9], which we briefly summarize here. Statistical procedures were conducted in R and BRT modelling used the package *gbm.auto* [11]. A form of regression tree modelling, BRT modelling divides the data at cut points in the range of each explanatory variable that reduce variance in the resulting branches. Tree splits typically occur at divisions between greater and lesser values of the response variable. Boosting repeats the regression tree process iteratively, using a stagewise machine learning process in which information from the previous tree is used to reduce the deviance within the next until there is no longer significant deviance between successive trees [12].

In this SDM, all environmental variables were used as the explanatory variables and hourly striped bass presence/absence was used as the response variable. The model used here had a tree complexity of 7 branches per split, a learning rate of 0.001, and 60% of the data were randomly selected to be used for cross-validation in each tree step. The relative influence of each variable was measured as the percentage of tree splits attributed to that variable [12]. This model was used to describe environmental associations with striped bass presence probability and predicted presence probability was mapped across a 150-m x 150-m resolution grid representing mean environmental conditions during a particular month and tide stage. In this demonstration we show results for grids based on environmental conditions in October 2019.

C. Incorporating Detection Efficiency

The effects of current velocity on detection efficiency were assessed using the initial range testing methods described in Bangley et al. [9]. Five receiver stations with Innovasea VR2W 69-kHz receivers were deployed within the FORCE tidal demonstration site with 50-m spacing between each station. 69-kHz sentinel tags were deployed 75 m from the each end of the receiver line. Detection efficiency was measured as the proportion of expected detections recorded on each receiver and was compared with distance from the transmitter and current velocity derived from the FVCOM model [13]. This range testing line was deployed over an entire tidal cycle from April 9th through May 11th, 2021. The data were used to interpolate a matrix of detection efficiency over distance from the receiver and current velocity for 69-kHz transmitters (Fig.2).

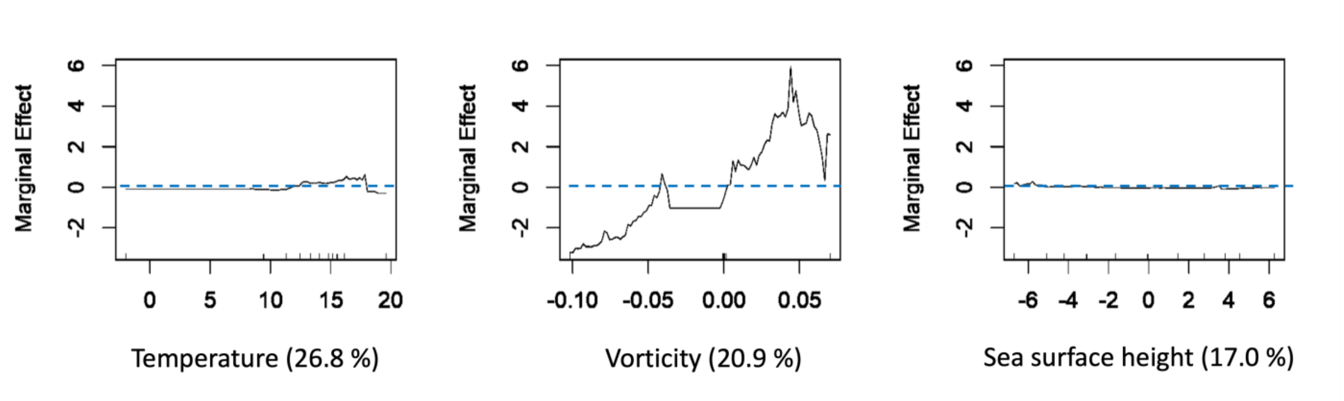


Fig. 1. Marginal effect plots showing the relative effect of the three most influential variables on striped bass presence probability in Minas Passage. The dashed blue line represents the line of zero effect.

We used this matrix of detection efficiency to develop a scaling function derived from a method originally developed to account for imperfect detection in visual surveys [14]. This function, summarized in (1) uses probability of presence (p) and probability of detection (d) to weight detections that were recorded in conditions associated with poor detection efficiency.

$$(p\ x\ (1-d))\ x\ (d(1-d)+(1-p)) \tag{1}$$

This scaling function was applied to mapped model results and used mean detection probability from the detection efficiency matrix (Fig. 2) up to 150 m from the receiver matched with the current velocity from the given cell of the environmental grid.

III. RESULTS

BRT results showed that striped bass were most positively associated with temperatures 12-17 °C, water with a moderate to strong vorticity, and sea surface heights typically occurring at lower tide stages (Fig. 3). Mapped scaled model results showed that elevated striped bass presence probability consistently occurred in the main channel of Minas Passage and to the west of the tidal demonstration site (Fig. 4). Overlap with the tidal demonstration site occurred during early and late ebb and late flood tide stages.

IV. DISCUSSION & CONCLUSION

Our results demonstrate that acoustic telemetry can be used to generate predictive species distribution models that can be used to assess overlap with potential tidal energy devices. We also demonstrate that applying a scaling function intended to mitigate the potential effects of current velocity on tag detection efficiency likely improves predictive performance and provides realistic results. While emerging tag technologies such as Innovasea HR transmitters show the potential to greatly improve detection efficiency [15], fish tagged with 69-kHz transmitters are highly likely be detected on receivers monitoring tidal power development sites in Minas Passage. These transmitters are suboptimal for use in high energy environments, but our methodology will allow for those detections to be used in assessing potential encounters with tidal energy devices with a more clear view of the potential variability involved than in previous studies.

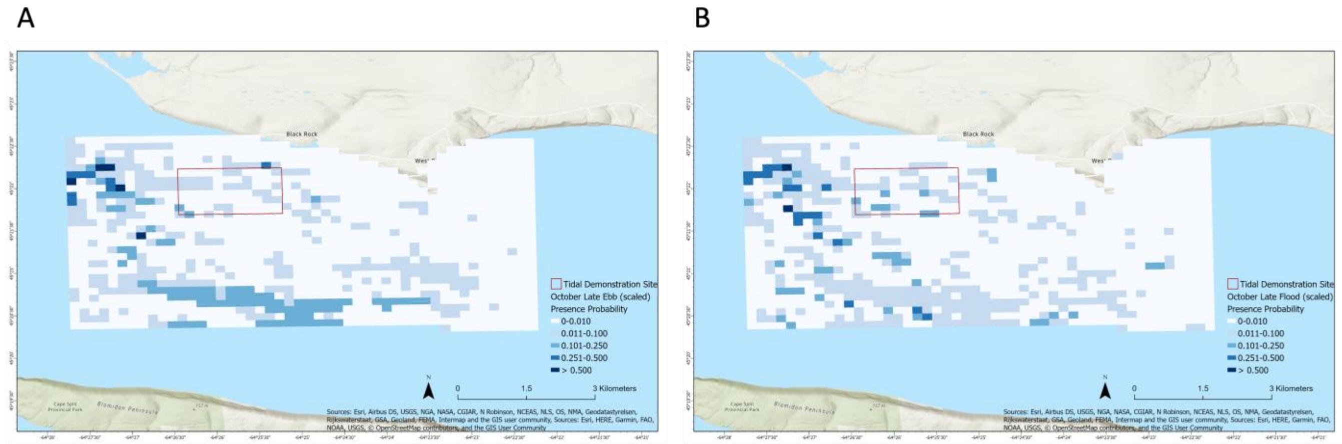


Fig. 2. Examples of mapped and scaled presence probability for striped bass in Minas Passage during A) late ebb and B) late flood tide stages.

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