Environmental Effects Monitoring Program

Quarterly Report: April-June 2022

July 5, 2022

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What's New?

SUSTAINABLE MARINE CONNECTS TO THE GRID

On May 11th, 2022 Sustainable Marine announced it has successfully delivered the first floating tidal stream energy power to Nova Scotia's power grid through their PLAT-I system in Grand Passage. read more

PRECAUTIONARY PRINCIPLE WORKSHOP

On April 7th, 2022 FORCE hosted a half-day workshop in Halifax focused on advancing understanding of the precautionary principle as it applies to the regulation of the marine renewable energy sector. The purpose of this workshop is to bring together stakeholders, rights holders and regulators to better understand the precautionary principle and the benefits and challenges it brings to regulating and advancing tidal development. read more

FORCE SCIENCE DIRECTOR CHAIRS SESSION AT PAMEC

Dr. Dan Hasselman chaired a session at the Pan American Marine Energy Conference in Ensenada, Mexico entitled 'The role of MRE test centers in facilitating MRE development'. read more

NEW REPORT ON CHALLENGES OF USING UPDWARD FACING ECHOSOUNDERS IN DYNAMIC MARINE ENVIRONMENTS

Viehman et al. 2022 recently published a study examining entrained air contamination in echosounder data collected from the FORCE test site. The report is available in Appendix II of this report. read more

FISH SYNTHESIS PROJECT

Graham Daborn of Acadia University is leading a fish synthesis project that will bring together existing knowledge of fish distribution, abundance, and use of the Minas Passage using existing literature from stock assessments, prior hydroacoustic surveys, acoustic telemetry-based surveys, as well as other relevant sources of information. read more

ADCP PLATFORM RECOVERED

Two ADCP platforms were deployed in January to collect current flow data that will be used concurrently with a high-resolution radar network to create the first spatiotemporal flow atlas of the Minas Passage to

help understand its turbulent hydrodynamic features. One of the ADCP's was recovered on May 4th.
read more

RAP 2022 FISH TAGGING UNDERWAY

The 2022 fish tagging under the Risk Assessment Program (RAP) is well underway in collaboration with our partners at the Mi'kmaw Conservation Group (MCG) and DFO Science. read more

RAP ACOUSTIC RECIEVER ARRAY DEPLOYED

There was a delay in redeploying the RAP acoustic receiver array due equipment repairs being required. This time was used to reassess the positioning of acoustic receivers on the mooring/SUBs packages and develop a more streamlined design to alleviate extensive drag and reduce damage. The line was redeployed in early May. read more

VITALITY PLATFORM SUCCESSFULLY DEPLOYED

On May 25th, 2022 the VITALITY platform was successfully deployed in the Minas Passage. The platform is currently streaming live data back to the FORCE visitor centre and work is underway to make those data sets accessible to CIOOS. read more

Executive Summary

Tidal stream energy devices are an emerging renewable energy technology that use the ebb and flow of the tides to generate electricity. These devices are in various stages of research, development, operation and testing in countries around the world.

FORCE was established in 2009 after undergoing a joint federal-provincial environmental assessment with the mandate to enable the testing and demonstration of tidal stream devices. Since that time, more than 100 related research studies have been completed or are underway with funding from FORCE, Net Zero Atlantic (formally the Offshore Energy Research Association (OERA)), and others. These studies have considered physical, biological, socioeconomic, and other research areas.

The current suite of monitoring programs implemented by FORCE build off those initiated during 2016-2020 that were conducted in anticipation of tidal stream energy device deployments at FORCE's tidal demonstration site. These efforts are divided into two components: FORCE monitoring activities (>100 metres from a device), and developer or 'device-specific' monitoring led by project developers (≤100 metres from a device) at the FORCE site. All plans are reviewed by FORCE's independent Environmental Monitoring Advisory Committee (EMAC) and federal and provincial regulators prior to implementation.

FORCE monitoring presently consists of monitoring for fish, marine mammals, seabirds, lobster, and marine sound. During monitoring from 2016 through 2020, FORCE completed:

- ~564 hours of hydroacoustic fish surveys;
- more than 5,083'C-POD' marine mammal monitoring days;
- bi-weekly shoreline observations;
- 49 observational seabird surveys;
- four drifting marine sound surveys and additional sound monitoring; and
- 11 days of lobster surveys

FORCE submitted its 2021-2023 proposed EEMP to regulators in early 2021 and is awaiting feedback. The 2021-2023 EEMP is designed to prepare for effects testing with the deployment of operational tidal stream energy devices and adheres to the principles of adaptive management by evaluating existing datasets to ensure appropriate monitoring approaches are being implemented. Moreover, the plan adopts internationally accepted standards for monitoring where possible, including feasibility assessments for new monitoring approaches that are planned to be implemented. The 2021-2023 EEMP has been implemented as designed and reviewed by FORCE's environmental monitoring advisory committee (EMAC)

Since the beginning of the 2021-2023 EEMP, FORCE has completed;

- 8 days of lobster surveys; and
- bi-weekly shoreline observations

FORCE is working with academic and Indigenous partner organizations to advance the Risk Assessment Program (RAP) for tidal stream energy. This program seeks to develop credible and statistically robust encounter rate models for migratory and resident fish species in Minas Passage with tidal stream energy devices. This will be accomplished by combining physical oceanographic data related to flow and turbulence in the Minas Passage with hydroacoustic

tagging information for various fish species in the region curated by the Ocean Tracking Network at Dalhousie University. Since the start of the project, FORCE has established a high-resolution radar network in Minas Passage and has started to quantify hydrodynamic features in the region and build the tidal flow atlas required for the program. FORCE has also started modelling the spatiotemporal distributions for the nine species for which sufficient acoustic tracking data is available and is developing species distribution maps for each species. In partnership with FORCE, the Mi'kmaw Conservation Group (MCG) has commenced the fish tagging component of the program that is required for encounter rate model validation which will continue into 2022. To share the results of the modelling work, FORCE is currently exploring the development of a user-friendly graphical user interface as a science-based decision support tool that would be accessible by regulators, rights holders, stakeholders, industry, and academia. Ultimately, this work will contribute towards understanding the risk of tidal stream energy development for fishes in the Bay of Fundy and will assist in the development of future environmental effects monitoring programs.

This report provides a summary of monitoring activities and data analyses completed at the FORCE site up to the end of the second quarter of 2022. In addition, it also highlights findings from international research efforts, previous data collection periods at the FORCE site, and additional research work that is being conducted by FORCE and its partners. This includes supporting fish tagging efforts with Acadia University and the Ocean Tracking Network, radar research projects, and subsea instrumentation platform deployments through the Fundy Advanced Sensor Technology (FAST) Program. Finally, the report presents details regarding future research and monitoring efforts at the FORCE test site. This includes work in support of the 2022 EEMP and the RAP program.

All reports, including quarterly monitoring summaries, are available online at www.fundyforce.ca/document-collection.

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Appendix II Viehman et al. 2022. The ups and downs of using active acoustic technologies to study fish at tidal energy sites. Frontiers in Marine Science 9: 851400. Doi: 10.3389/fmars.2022.851400

Introduction

This report outlines monitoring activities occurring at the Fundy Ocean Research Centre for Energy test site in the Minas Passage, Bay of Fundy during April-June 2022. Specifically, this report highlights results of environmental monitoring activities conducted by FORCE and other research and development activities conducted at the FORCE site. This report also provides a summary of international research activities around tidal stream energy devices.

About FORCE

FORCE was created in 2009 to lead research, demonstration, and testing for high flow, industrial-scale tidal stream energy devices. FORCE is a not-for-profit entity that has received funding support from the Government of Canada, the Province of Nova Scotia, Encana Corporation, and participating developers.

FORCE has two central roles in relation to the demonstration of tidal stream energy converters in the Minas Passage:

1. Host: providing the technical infrastructure to allow demonstration devices to connect to the transmission grid; and
2. Steward: research and monitoring to better understand the interaction between devices and the environment.

The FORCE project currently consists of five undersea berths for subsea tidal energy device generators, four subsea power cables to connect the devices to land-based infrastructure, an onshore substation and power lines connected to the Nova Scotia Power transmission system, and a Visitor Centre that is free and open to the public from May to November annually. These onshore facilities are located approximately 10 km west of Parrsboro, Nova Scotia.

The marine portion of the project is located in a 1.6 km x 1.0 km tidal demonstration area in the Minas Passage. It is also identified as a Marine Renewable-electricity Area under the Province's Marine Renewable-energy Act. This area consists of five subsea berths that are leased to tidal energy companies[1] selected by the Nova Scotia Department of Natural Resources and Renewables. Current berth holders at FORCE are:

Berth A: Minas Tidal Limited Partnership
Berth B: Rio Fundo Operations Canada Limited[2]
Berth C: Sustainable Marine Energy (Canada)[3]
Berth D: Big Moon Power Canada
Berth E: Halagonia Tidal Energy Limited[4]

Research, monitoring, and associated reporting is central to FORCE's steward role, to assess whether tidal stream energy devices can operate in the Minas Passage without causing significant adverse effects on the environment, electricity rates, and other users of the Bay.

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[1] Further information about each company may be found at: fundyforce.ca/partners

[2] On April 30, 2019 the Department of Energy and Mines approved the transfer of the Project Agreement and FIT approvals from Atlantis Operations (Canada) Ltd. to Rio Fundo Operations Canada Ltd.

[3] On May 15, 2019 the Department of Energy and Mines issued an approval for Black Rock Tidal Power to change its name to Sustainable Marine Energy (Canada) Ltd. with the transfer of assets from SCHOTTEL to Sustainable Marine Energy.

[4] Berth E does not have a subsea electrical cable provided to it.

As part of this mandate FORCE has a role to play in supporting informed, evidence-based decisions by regulators, industry, rightsholders, the scientific community, and the public. As deployments of different technologies are expected to be phased in over the next several years, FORCE and regulators will have the opportunity to learn and adapt environmental monitoring approaches as lessons are learned.

Background

The FORCE demonstration project received its environmental assessment (EA) approval on September 15, 2009 from the Nova Scotia Minister of Environment. The conditions of its EA approval[5] provide for comprehensive, ongoing, and adaptive environmental management. The EA approval has been amended since it was issued to accommodate changes in technologies and inclusion of more berths to facilitate provincial demonstration goals.

In accordance with this EA approval, FORCE has been conducting an Environmental Effects Monitoring Program (EEMP) to better understand the natural environment of the Minas Passage and the potential effects of tidal stream energy devices as related to fish, seabirds, marine mammals, lobster, marine sound, benthic habitat, and other environmental variables. All reports on site monitoring are available online at: www.fundyforce.ca/document-collection.

Since 2009, more than 100 related research studies have been completed or are underway with funding from FORCE, Net Zero Atlantic (formally the Offshore Energy Research Association (OERA)) and others. These studies have considered socioeconomics, biological, and other research areas.[6]

Monitoring at the FORCE site is currently focused on lobster, fish, marine mammals, seabirds, and marine sound and is divided into developer (≤ 100 m from a device) and FORCE led (> 100 m from a device) monitoring. As approved by regulators, individual berth holders complete monitoring in direct vicinity of their device(s), in recognition of the unique design and operational requirements of different technologies. FORCE completes site level monitoring activities as well as supporting integration of data analysis between these monitoring zones, where applicable.

All developer and FORCE monitoring programs are reviewed by FORCE's Environmental Monitoring Advisory Committee (EMAC), which includes representatives from scientific, First Nations, and local fishing communities.[7] These programs are also reviewed by federal and provincial regulators prior to device installation. In addition, FORCE and berth holders also submit an Environmental Management Plan (EMP) to regulators for review prior to device installation. EMP's include environmental management roles and responsibilities and commitments, environmental protection plans, maintenance and inspection requirements, training and education requirements, reporting protocols, and more.

Tidal Stream Energy Device Deployments

Since FORCE's establishment in 2009, tidal stream energy devices have been installed at the FORCE site three times: once in 2009/2010, November 2016 – June 2017, and July 2018 –

[5] FORCE's Environmental Assessment Registration Document and conditions of approval are found online at: www.fundyforce.ca/document-collection.

[6] Net Zero Atlantic Research Portal (https://netzeroatlantic.ca/research) includes studies pertaining to infrastructure, marine life, seabed characteristics, socio-economics and traditional use, technology, and site characterization.

[7] Information about EMAC may be found online at: www.fundyforce.ca/about-us

present. Given the limited timescales in which a device has been present and operating at the FORCE site, environmental studies to-date have largely focused on the collection of baseline data and developing an understanding of the capabilities of monitoring devices in high flow tidal environments.

On July 22, 2018, CSTV installed a two-megawatt OpenHydro turbine at Berth D of the FORCE site and successfully connected the subsea cable to the turbine. CSTV confirmed establishment of communication with the turbine systems on July 24. On July 26, 2018, Naval Energies unexpectedly filed a petition with the High Court of Ireland for the liquidation of OpenHydro Group Limited and OpenHydro Technologies Limited.[8] For safety purposes, the turbine was isolated from the power grid that same day. On September 4, 2018, work began to re-energize the turbine, but soon afterwards it was confirmed that the turbine's rotor was not turning. It is believed that an internal component failure in the generator caused sufficient damage to the rotor to prevent its operation. Environmental sensors located on the turbine and subsea base continued to function at that time except for one hydrophone.

As a result of the status of the turbine, the monitoring requirements and reporting timelines set out in CSTV's environmental effects monitoring program were subsequently modified under CSTV's Authorization from Fisheries and Oceans Canada. The modification requires that CSTV provide written confirmation to regulators monthly that the turbine is not spinning by monitoring its status during the peak tidal flow of each month. This began October 1, 2018 and was expected to continue until the removal of the turbine; however, as a result of the insolvency of OpenHydro Technology Ltd., all developer reporting activities by CSTV ceased as of March 1, 2019. FORCE subsequently provided monthly reports to regulators confirming the continued non-operational status of the CSTV turbine from March 2019 – May 2020 and received authorization from the Nova Scotia Department of Environment on June 2, 2020, to conclude these monthly reports.

In September 2020, Big Moon Canada Corporation (Big Moon) was announced as the successful applicant to fill berth D at the FORCE test site following a procurement procedure administered by Power Advisory LLC. As part of the agreement, Big Moon has provided a $4.5 million security deposit to remove the non-operational CSTV turbine currently deployed at berth D, and has until December 31, 2024 to raise the turbine. The project start date for BigMoon is largely dependent on the economic recovery from the COVID-19 pandemic and the potential impact to Big Moon's supply chain. As such, the project start date is not known at this time.

Additional devices are expected to be deployed at the FORCE site in the coming years. In 2018, Sustainable Marine Energy (formerly Black Rock Tidal Power) installed a PLAT-I system in Grand Passage, Nova Scotia under a Demonstration Permit.[9] This permit allows for a demonstration of the 280 kW system to help SME and its partners learn about how the device operates in the marine environment of the Bay of Fundy. On May 11, 2022, SME announced it has successfully delivered the first floating tidal stream energy to Nova Scotia's power grid.[10] Also in 2018, Natural Resources Canada announced a $29.8 million contribution to Halagonia Tidal Energy's project at the FORCE site through its Emerging Renewable Power Program.[11] The project consists of

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[8] See original news report: https://www.irishexaminer.com/breakingnews/business/renewable-energy-firms-with-more-than-100-employees-to-be-wound-up-857995.html.

[9] To learn more about this project, see: https://novascotia.ca/news/release/?id=20180919002.

[10] To learn more about this project, see: https://www.sustainablemarine.com/press-releases/sustainable-marine-delivers-first-floating-tidal-power-to-nova-scotia-grid.

[11] To learn more about this announcement, see: https://www.canada.ca/en/natural-resources-canada/news/2018/09/minister-sohi-announces-major-investment-in-renewable-tidal-energy-that-will-power-2500-homes-in-nova-scotia.html.

submerged turbines for a total of nine megawatts – enough capacity to provide electricity to an estimated 2,500 homes.

Each berth holder project will be required to develop a device-specific monitoring program, which will be reviewed by FORCE's EMAC and federal and provincial regulators including Fisheries and Oceans Canada, the Nova Scotia Department of Environment, and the Nova Scotia Department of Energy and Mines prior to device installation.

Overall, the risks associated with single device or small array projects are anticipated to be low given the relative size/scale of devices (Copping 2018). For example, at the FORCE site a single two-megawatt OpenHydro turbine occupies ~ 1/1,000th of the cross-sectional area in the Minas Passage (Figure 1). A full evaluation of the risks of tidal stream energy devices, however, will not be possible until more are tested over a longer-term period with monitoring that documents local impacts, considers far-field and cumulative effects, and adds to the growing global knowledge base.

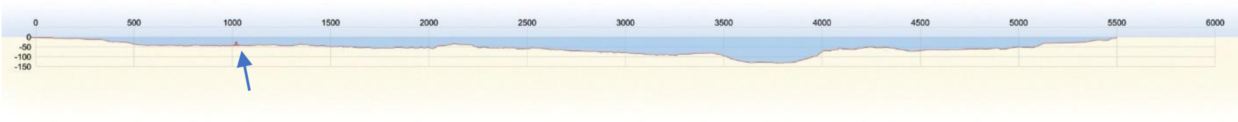

Figure 1: The scale of a single turbine (based on the dimensions of the OpenHydro turbine deployed by CSTV, indicated by the red dot and above the blue arrow) in relation to the cross-sectional area of the Minas Passage. The Passage reaches a width of ~ 5.4 km and a depth of 130 m.

International Experience & Cooperation

The research and monitoring being conducted at the FORCE test site is part of an international effort to evaluate the risks tidal energy poses to marine life (Copping 2018; Copping and Hemery 2020). Presently, countries such as China, France, Italy, the Netherlands, South Korea, the United Kingdom, and the United States (Marine Renewables Canada 2018) are exploring tidal energy, supporting environmental monitoring and innovative R&D projects. Tidal energy and other marine renewable energy (MRE) technologies such as tidal range, tidal current, wave, and ocean thermal energy offer significant opportunities to replace carbon fuel sources in a meaningful and permanent manner. Some estimates place MRE's potential as exceeding current human energy needs (Lewis et al. 2011; Gattuso et al. 2018). Recent research includes assessments of operational sounds on marine fauna (Schramm et al. 2017; Lossent et al. 2018; Robertson et al. 2018; Pine et al. 2019), the utility of PAM sensors for monitoring marine mammal interactions with turbines (Malinka et al. 2018) and collision risk (Joy et al. 2018b), demonstrated avoidance behavior by harbour porpoise around tidal turbines (Gillespie et al. 2021), a synthesis of known effects of marine renewable energy devices on fish (Copping et al. 2021), and the influence of tidal turbines on fish behavior (Fraser et al. 2018).

Through connections to groups supporting tidal energy demonstration and R&D, FORCE is working to inform the global body of knowledge pertaining to environmental effects associated with tidal power projects. This includes participation in the Fundy Energy Research Network[12], the

[12] FERN is a research network designed to" coordinate and foster research collaborations, capacity building and information exchange" (Source: fern.acadiau.ca/about.html). FORCE participates in the Natural Sciences, Engineering, and Socio-Economic Subcommittees of FERN.

Bay of Fundy Ecosystem Partnership[13], TC114[14], the Atlantic Canadian-based Ocean Supercluster[15], and OES-Environmental[16].

FORCE will continue to work closely with OES-Environmental and its members to document and improve the state of knowledge about the interactions of MRE devices interactions with the marine environment. To that end, Dr. Hasselman is currently serving as a guest editor alongside Dr. Huidong Li (Pacific Northwest National Laboratory), Dr. Emma Cotter (Woods Hole Oceanographic Institute) and Dr. James Joslin (University of Washington) for a special issue of Frontiers in Marine Science entitled 'Novel Technologies for Assessing the Environmental and Ecological Impacts of Marine Renewable Energy Systems'. The editorial team advertised the special issue on the Tethys website and received nine abstracts from researchers developing cutting-edge technologies for monitoring around marine renewable energy devices. Full manuscript submissions were due by January 9, 2022 and the editorial team is aiming for publication of the special issue in mid-late 2022.

Additionally, OES-Environmental is pursuing the development of new research topics for the 2024 State of the Science Report related to i) knowledge of environmental effects as the tidal energy industry scales up from single devices to arrays, ii) understanding the cumulative impacts of marine renewable energy with other anthropogenic effects, and iii) an ecosystem approach for understanding environmental effects, including interactions between trophic levels, between ecosystems and between ecosystem services. Dr. Hasselman is involved in the development of all three of these topics, but is leading the effort to understand the environmental effects of 'scaling up'.

On April 7th, FORCE hosted a half-day workshop in Halifax focused on advancing understanding of the precautionary principle as it applies to the regulation of the marine renewable energy sector. The purpose of this workshop was to bring together stakeholders, rights holders and regulators to better understand the precautionary principle and the benefits and challenges it brings to regulating and advancing tidal development. The workshop consisted of three speakers who shared their knowledge on the precautionary principle which had 39 participants (29 in person and 10 virtual). Presentations were followed by breakout group discussions. A report on key takeaways is currently in development and will be available later this year.

Dr. Hasselman chaired a session at the Pan American Marine Energy Conference in Ensenada, Mexico on June 17th entitled 'The role of MRE test centers in facilitating MRE development'. The afternoon session included 5 presentations which provided an overview of the role of marine renewable energy (MRE) test centers in device testing and their capacity to demonstrate the utility of monitoring technologies and approaches for understanding environmental effects of MRE devices. The presentations and round table discussions built on the first workshop held at PAMEC 2020 in Costa Rica and fostered dialogue around the value of test centers like FORCE and their

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[13] BoFEP is a 'virtual institute' interested in the well-being of the Bay of Fundy. To learn more, see www.bofep.org.
[14] TC114 is the Canadian Subcommittee created by the International Electrotechnical Commission (IEC) to prepare international standards for marine energy conversion systems. Learn more: tc114.oreg.ca.
[15] The OSC was established with a mandate to "better leverage science and technology in Canada's ocean sectors and to build a digitally-powered, knowledge-based ocean economy." Learn more: www.oceansupercluster.ca.
[16] OES Environmental was established by the International Energy Agency (IEA) Ocean Energy Systems (OES) in January 2010 to examine environmental effects of marine renewable energy development. Member nations include: Australia, China, Canada, Denmark, France, India, Ireland, Japan, Norway, Portugal, South Africa, Spain, Sweden, United Kingdom, and United States. Further information is available at https://tethys.pnnl.gov.

role in building social license and addressing questions relevant to the establishment of MRE technologies regionally.

FORCE Monitoring Activities

FORCE has been leading site-level monitoring for several years, focusing on a variety of environmental variables. FORCE's previous environmental effects monitoring program (2016-2020) was developed in consultation with SLR Consulting (Canada)[17] and was strengthened by review and contributions by national and international experts and scientists, DFO, NSE, and FORCE's EMAC. The most recent version of the EEMP (2021-2023) was developed in consultation with Atlantis Watershed Consultants Ltd. with input from national and international experts, including FORCE's EMAC, and has been submitted to regulators for approval. The 2021-2023 EEMP has been modified from the 2016-2020 EEMP based on results of previous monitoring activities, experience and lessons learned. This is consistent with the adaptive management approach inherent to the FORCE EEMP – the process of monitoring, evaluating and learning, and adapting (AECOM 2009) that has been used at the FORCE site since its establishment in 2009.[18]

FORCE's EEMP currently focuses on the impacts of operational tidal stream energy devices on lobster, fish, marine mammals, and seabirds as well as the impact of device-produced sound. Overall, these research and monitoring efforts, detailed below, were designed to test the predictions made in the FORCE EA. As mentioned in the Executive Summary, since the beginning of the 2016-2020 EEMP, FORCE has completed approximately:

- 564 hours of hydroacoustic fish surveys;
- more than 5,083'C-POD' (marine mammal monitoring) days;
- bi-weekly shoreline observations;
- 49 observational seabird surveys;
- four drifting marine sound surveys and additional bottom-mounted instrument sound data collection; and
- 11 days of lobster surveys.

Since the beginning of the 2021-2023 EEMP, FORCE has completed:

- 8 days of lobster surveys; and
- bi-weekly shoreline observations

The following pages provide a summary of the site-level monitoring activities conducted at the FORCE site up to the end of June 2022 including data collection, data analyses performed, initial results, and lessons learned, that builds on activities and analyses from previous years. Where applicable, this report also presents analyses that have integrated data collected through developer and FORCE monitoring programs to provide a more complete understanding of device-marine life interactions.

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[17] This document is available online at: www.fundyforce.ca/document-collection.

[18] The adaptive management approach is necessary due to the unknowns and difficulties inherent with gathering data in tidal environments such as the Minas Passage and allows for adjustments and constant improvements to be made as knowledge about the system and environmental interactions become known. This approach has been accepted by scientists and regulators.

Monitoring Objectives

The overarching purpose of environmental monitoring is to test the accuracy of the environmental effect predictions made in the original EA. These predictions were generated through an evaluation of existing physical, biological, and socioeconomic conditions of the study area, and an assessment of the risks the tidal energy demonstration project poses to components of the ecosystem.

A comprehensive understanding of device-marine life interactions will not be possible until device-specific and site-level monitoring efforts are integrated, and additional data is collected in relation to operating tidal stream energy devices. Further, multi-year data collection will be required to consider seasonal variability at the FORCE test site and appropriate statistical analyses of this data will help to obtain a more complete understanding of device-marine life interactions.

Table 1 outlines the objectives of the site-level monitoring activities conducted at the FORCE demonstration site. FORCE led site-level monitoring summaries will be updated as devices are scheduled for deployment at FORCE. At this time, and considering the scale of device deployments in the near-term at FORCE, it is unlikely that significant effects in the far-field will be measurable (SLR Consulting 2015). Far-field studies such as sediment dynamics will be deferred until such time they are required. However, recent discussions with scientists serving on FORCE's EMAC suggests that the natural variability inherent to the upper Bay of Fundy ecosystem far exceeds what could be measured by far-field monitoring efforts. Moreover, the scale of tidal power development would need to surpass what is possible at the FORCE tidal demonstration site to extract sufficient energy from the system to have any measurable effects. In short, far-field monitoring would be futile unless tidal power development transitions from demonstration scale to commercial arrays. As more devices are scheduled for deployment at the FORCE site and as monitoring techniques are improved, monitoring protocols will be revised in keeping with the adaptive management approach. These studies will be developed in consultation with FORCE's EMAC, regulators, and key stakeholders.

Table 1: The objectives of each of the environmental effects monitoring activities, which consider various Valued Ecosystem Components (VECs), led by FORCE.

FORCE Environmental Effects Monitoring VEC	***Objectives***
Lobster	● to determine if the presence of a tidal stream energy device affects commercial lobster catches
Fish	● to test for indirect effects of tidal stream energy devices on water column fish density and fish vertical distribution ● to estimate probability of fish encountering a device based on fish density proportions in the water column relative to device depth in the water column
Marine Mammals	● to determine if there is permanent avoidance of the study area during device operations ● to determine if there is a change in the distribution of a portion of the population across the study area
Marine Sound (Acoustics)	● to conduct ambient sound measurements to characterize the soundscape prior to and following deployment of the tidal stream energy device
Seabirds	● to understand the occurrence and movement of bird species in the vicinity of tidal stream energy devices

	• to confirm FORCE's Environmental Assessment predictions relating to the avoidance and/or attraction of birds to tidal stream energy devices

Lobster

FORCE conducted a baseline lobster catchability survey in fall 2017 (NEXUS Coastal Resource Management Ltd. 2017). This catch-and-release survey design was conducted over 11 days and consisted of commercial traps deployed at varying distances around the future location of the CSTV turbine deployment planned for 2018. Captured lobsters were measured (carapace length), had their sex and reproductive stage determined (male, female, and berried female), and shell condition evaluated. This baseline survey captured 351 lobsters and reported a high catchability rate (> 2.7 kg/trap).[19] Preliminary qualitative analyses indicated that catch rates declined during the survey and were associated with increasing tidal velocities; a statistically significant negative relationship was detected between catch rates and maximum tidal range. No significant difference in catch rates was detected across separate locations from the proposed turbine deployment site. Cumulatively, these results suggested that the impact of turbines may be higher on lobster catchability than anticipated in the EA (AECOM 2009), but a repeat of the study in the presence of an operational device is required to verify this prediction.

Indeed, a repeat of this catchability survey was planned for fall 2018 in the presence of an operational turbine to test the EA prediction (with pre-installation and operating turbine collection periods) that tidal stream energy devices will have minimal have impacts on lobster populations within the FORCE test site (AECOM 2009). However, given the non-operational status of the CSTV turbine, the objectives of the 2018 survey effort could not be achieved, and the survey has been postponed until an operational device is present at the site.

In 2019, FORCE commissioned TriNav Fisheries Consultants Ltd. to redesign FORCE's lobster monitoring program based on feedback from regulators to include a more statistically robust study design for monitoring lobster at the FORCE test site. TriNav Fisheries Consultants evaluated the efficacy of using a variety of methods including divers and hydroacoustic tags to track lobster movements. However, given the strong tidal flows and brief window available during periods of slack tide, divers are not a viable option due to safety concerns. Ultimately, TriNav Fisheries Consultants identified the combination of a modified catchability survey design and a mark-recapture study using conventional tags as the best approach for monitoring lobster at the FORCE site. This study design was implemented in fall 2021 in partnership with the Fishermen and Scientists Research Society (FSRS; Figure 1) and with the assistance of a local lobster fisher. There were two phases to the study – each centered around the two neap tide phases in September to ensure trap recovery. During each phase, nine experimental lobster traps were deployed in and around the FORCE tidal demonstration site. Traps were hauled after 24 hours and lobsters were measured, assessed, and tagged prior to being released back to the water. The first phase of the study occurred during August 29-September 2, and the second phase took place during September 27-October 1. The study captured 582 lobster and tagged and released 477 of them – some of which were recaptured during the commercial lobster season in LFA 35, and their tag numbers and capture coordinates reported to FORCE. Preliminary results suggest a high catchability rate during the fall survey which is comparable to available commercial data from DFO. The final report from this monitoring program is currently undergoing edits and will be

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[19] This is classified as 'high' according to DFO's Catch Per Unit Effort (CPUE) index (Serdynska and Coffen-Smout, 2017).

available in summer 2022. Shaun Allain, FORCE Environmental Program Manager, presented the initial results of this survey at the FSRS annual conference and AGM on March 24th.

Figure 1: Lobster scientist from the Fishermen and Scientist Research Society showing a tagged lobster prior to release.

Fish

FORCE has been conducting mobile fish surveys since May 2016 to test the EA prediction that tidal stream energy devices are unlikely to cause substantial impacts to fishes at the test site (AECOM 2009). To that end, the surveys are designed to:

- test for indirect effects of tidal stream energy devices on water column fish density and fish vertical distribution; and
- estimate the probability of fish encountering a device based on any 'co-occurrence' relative to device depth in the water column.

Moreover, these surveys follow a 'BACI' (Before/After, Control/Impact) design to permit a comparison of data collected before a device is installed with data collected while a device is operational at the FORCE site, and in relation to a reference site along the south side of the Minas Passage. These 24-hour mobile surveys encompass two tidal cycles and day/night periods using a scientific echosounder, the Simrad EK80, mounted on a vessel, the Nova Endeavor (Huntley's Sub-Aqua Construction, Wolfville, NS). This instrument is an active acoustic monitoring device and uses sonar technology to detect fish by recording reflections of a fish's swim bladder.

Analyses of hydroacoustic fish surveys completed during baseline studies in 2011 and 2012 (Melvin and Cochrane 2014) and surveys during May 2016 – August 2017 (Daroux and Zydlewski 2017) evaluated changes in fish densities in association with diel stage (day/night), tidal stage (ebb/flood), and device presence or absence (an OpenHydro turbine was present November 2016

– June 2017). Results support the EA prediction that tidal stream devices have minimal impact on marine fishes. However, additional surveys in relation to an operating device are required to fully test this prediction.

In 2019, the University of Maine conducted a thorough analysis for 15 fish surveys conducted by FORCE from 2011-2017. The hydroacoustic data set included six ‘historical’ surveys conducted between August 2011 and May 2012, and nine ‘contemporary’ surveys conducted between May 2016 and August 2017. The analyses included comparisons of fish presence/absence and relative fish density with respect to a series of temporal (historical vs. contemporary, or by survey), spatial (CLA vs. reference study area, or by transect) and environmental (tide phase, diel state, or with/against predicted tidal flow) explanatory variables. The report identified a statistically significant difference in fish presence/absence and relative fish density between the historical and contemporary data sets that may be attributable to differences in the survey design/execution between the time periods, or could reflect changes in fish usage of the site. As such, remaining analyses were restricted to the contemporary data sets. The results revealed that: i) data collection during the ebb tide and at night are important for understanding fish presence in the CLA, ii) various explanatory variables and their additive effects should be explored further, and iii) increasing the frequency of surveys during migratory periods (consecutive days in spring/fall) may be required to understand patterns and variability of fish presence and density in Minas Passage. Importantly, the report suggested a statistically significant difference in fish presence/absence and relative density between the CL and reference site, suggesting that the reference site may not be sufficiently representative to serve as a control for the CLA, and for testing the effects of an operational device on fish density and distribution in Minas Passage. Additional work is underway using data from eight additional contemporary fish surveys (2017-2018) to determine whether this finding is biologically meaningful, or whether it is simply a statistical artefact of how the data was aggregated in the original analysis.

Because complex hydrodynamic features of the Minas Passage introduce turbulence and bubbles into the water column that interfere with the use of hydroacoustics, FORCE’s mobile fish surveys have been optimized for collecting data during the best neap tidal cycle per month when turbulence is greatly reduced. However, this approach limits the number of surveys that can be conducted, and regulators have suggested that the scope of the program be expanded so that survey results are more representative of how fish use the Minas Passage. To that end, FORCE conducted multiple fish surveys during each of three neap tidal cycles in fall 2020 (i.e., September 25, 27, 29; October 7, 9, 13; and October 24, 26, 29) to determine whether variation in fish density and distribution for any given survey within a neap cycle was representative of the other surveys conducted during that same time frame. Previous work comparing stationary and mobile hydroacoustic surveys in Minas Passage found that the temporal representative range of a 24-hr mobile was approximately three days (Viehman et al. 2019). Post-processing and analyses of the data will commence in 2022 and will provide additional information about the temporal representativeness of FORCE’s mobile fish surveys and will help determine how frequently these surveys are required to understand fish usage of the Minas Passage.

A recent study (Viehman et al. 2022, Appendix II) examined entrained air contamination in echosounder data collected at the FORCE test site. It found that fish abundance estimates in the lower 70% of the water column and current speeds less than 3 m/s were well represented in that there was little contamination of the data set from entrained air. However, undersampling of the upper water column and faster speeds strongly affected fish abundance estimates especially during strong spring tides. This means that data collected during neap tides are more likely to yield a more accurate picture of fish abundance and distribution than those collected during spring tides. The study also highlighted how estimates of fish abundance may be affected differently depending on where fish are in the water column. For example, (hypothetical) fish located at mid-depths were omitted from the data more often as current speeds increased. These findings indicate a complex and dynamic ecosystem where the interactions of water movement and fish distribution affect our ability to infer how fish populations may interact with tidal power devices in the Minas Passage. The use of acoustic telemetry being studied under the RAP program could be used concurrently with echosounders to fill gaps in datasets and optimize what can be learned about fish abundance and distribution at tidal energy sites.

FORCE is currently working towards a development of a comprehensive fish synthesis that will bring together existing knowledge of fish distribution, abundance, and use of the Minas Passage using existing literature from stock assessments, prior hydroacoustic surveys, acoustic telemetry-based surveys, as well as other relevant sources of information. This synthesis will focus on species of conservations concern, cultural relevance, and commercial and recreational value. The results of this synthesis project will be available later this year and will help to determine to what extent questions regarding fish and tidal energy project permitting have been answered and what the remaining knowledge gaps are. Graham Daborn at Acadia University is leading this work.

Marine Mammals

Since 2016, FORCE has been conducting two main activities to test the EA prediction that project activities are not likely to cause significant adverse residual effects on marine mammals within the FORCE test site (AECOM 2009):

- passive acoustic monitoring (PAM) using ‘click recorders’ known as C-PODs; and
- an observation program that includes shoreline, stationary, and vessel-based observations.

Passive Acoustic Monitoring

The first component of FORCE’s marine mammal monitoring program involves the use of PAM mammal detectors known as C-PODs, which record the vocalizations of toothed whales, porpoises, and dolphins.[20] The program focuses mainly on harbour porpoise – the key marine mammal species in the Minas Passage that is known to have a small population that inhabits the inner Bay of Fundy (Gaskin 1992). The goal of this program is to understand if there is a change in marine mammal presence in proximity to a deployed tidal stream energy device and builds upon baseline C-POD data collection within the Minas Passage since 2011.

From 2011 to early 2018, more than 4,845 ‘C-POD days’[21] of data were collected in the Minas Passage. Over the study period, it was found that harbour porpoise use and movement varies over long (i.e., seasonal peaks and lunar cycles) and short (i.e., nocturnal preference and tide stage) timescales. This analysis, completed by Sea Mammal Research Unit (Canada) (Vancouver, BC), showed some evidence to suggest marine mammal exclusion within the vicinity of CSTV turbine when it was operational (November 2016 – June 2017) (Joy et al. 2018a). This analysis revealed that the C-PODs in closest proximity to the turbine (230 m and 210 m distance) had reduced frequency of detections, but no evidence of site avoidance with a device present and operating. These findings also revealed a decrease in detections during turbine installation

[20] The C-PODs, purchased from Chelonia Limited, are designed to passively detect marine mammal ‘clicks’ from toothed whales, dolphins, and porpoises.

[21] A ‘C-POD day’ refers to the number of total days each C-POD was deployed times the number of C-PODs deployed.

activities, consistent with previous findings (Joy et al. 2017), but requiring additional data during an operational device to permit a full assessment of the EA predictions.

This monitoring program demonstrates the prevalence of harbour porpoise at FORCE, with the species being detected on 98.8% of the 1,888 calendar days since monitoring with C-PODs commenced in 2011. Harbour porpoise detections at FORCE varies seasonally, with peak activity occurring during May – August, and lowest detections during December – March. Harbour porpoise detections also vary spatially, with C-PODs deployed at locations W2 and S2 recording the greatest detection rates, and D1 values typically low. Mean lost time across C-PODs, due to ambient flow noise saturating the detection buffer on the C-POD, averaged 22.6%. Interestingly, an analysis against past datasets that controlled for time of year, indicated that the effects of the non-operational CSTV turbine structure had no detectable effect on the rate of harbour porpoise detection.

SMRU provided their 4th year final report of harbour porpoise monitoring using C-PODs at the FORCE test site (Palmer et al. 2021). The report describes the results of C-POD deployments #11-12 (i.e., 1,043 days of monitoring from August 2019 – September 2020), and places the results in the broader context of the overall marine mammal monitoring program at FORCE. The final report includes summary data that revealed that harbour porpoise was detected on a least one C-POD every day, with a median value of 11 and 17 minutes of porpoise detections per day during deployments 11 and 12, respectively. The mean percent lost time due to ambient flow and sediment noise was 19.5% and 23.8%, respectively, comparable to previous deployments. Overall, the final report supports previous findings of monitoring activities that harbour porpoise are prevalent at the FORCE test site.

The final report also reiterates that sufficient baseline data has been collected to meet the goals of the EEMP. As such, FORCE has recommended in its 2021-2023 EEMP proposal that the collection of additional baseline harbour porpoise data using C-PODs be suspended until an operational device is deployed at the FORCE site. Upon receiving confirmation that a device will be deployed at the tidal demonstration area, FORCE will deploy C-PODs prior to the construction phase to begin collecting data and assessing any changes to harbour porpoise detections in the presence of an operational device.

Harbor porpoise (Phocoena phocoena) monitoring at the FORCE Test Site, Canada featured on Tethys (by FORCE and SMRU): https://tethys.pnnl.gov/stories/harbor-porpoise-phocoena-phocoena-monitoring-force-test-site-canada

Observation Program

FORCE's marine mammal observation program in 2022 includes observations made during bi-weekly shoreline surveys, stationary observations at the FORCE Visitor Centre, and marine-based observations during marine operations. All observations and sightings are recorded, along with weather data, tide state, and other environmental data. Any marine mammal observations will be shared with SMRU Consulting to support validation efforts of PAM activities when C-PODs are deployed.

FORCE uses an Unmanned Aerial Vehicle (UAV) for collecting observational data along the shoreline and over the FORCE site using transects by programming GPS waypoints in the UAV to standardize flight paths. FORCE staff received training to operate FORCE's UAV and have acquired UAV pilot certification by successfully passing the 2019 Canadian Drone Pilot Basic Operations Examination, administered by Transport Canada. These staff are now licensed to safely operate the UAV at the FORCE site. FORCE also hosts a public reporting tool that allows members of the public to report observations of marine life: mmo.fundyforce.ca

Marine Sound (Acoustics)

Marine sound – often referred to as 'acoustics' or 'noise' – monitoring efforts are designed to characterize the soundscape of the FORCE test site. Data collected from these monitoring efforts will be used to test the EA predictions that operational sounds produced from functioning tidal stream energy devices are unlikely to cause mortality, physical injury or hearing impairment to marine animals (AECOM 2009).

Results from previous acoustic analyses completed at the FORCE site indicate that the CSTV turbine was audible to marine life at varying distances from the turbine, but only exceeded the threshold for behavioural disturbance at very short ranges and during particular tide conditions (Martin et al. 2018). This is consistent with findings at the Paimpol-Bréhat site in France where an OpenHydro turbine was also deployed – data suggests that physiological trauma associated with a device is improbable, but that behavioural disturbance may occur within 400 m of a device for marine mammals and at closer distances for some fish species (Lossent et al. 2018).

In previous years, regulators have encouraged FORCE to pursue integration of results from multiple PAM instruments deployed in and around the FORCE test site. To that end, FORCE, and its partner JASCO Applied Sciences (Canada) Ltd. pursued a comparative integrated analysis of sound data collected by various hydrophones (i.e., underwater sound recorders) deployed autonomously and mounted on the CSTV turbine. That work revealed that flow noise increased with the height of the hydrophone off the seabed but had little effect on hydrophones deployed closer to the sea floor. The comparative integrated analysis provided valuable information about future marine sound monitoring technologies and protocols while building on previous acoustics analyses at the FORCE site.

In its 2021-2023 EEMP proposal, FORCE has recommended conducting a test survey in the presence of an operational device using an internationally recognized standard methodology for monitoring sound (International Electrotechnical Commission 2019). This would permit the feasibility of the approach to be tested in the Minas Passage to ensure the method can be implemented as described. This work is pending an operational device being deployed at the FORCE tidal demonstration area.

Seabirds

FORCE's seabird monitoring program is designed to test the EA prediction that project activities are not likely to cause adverse residual effects on marine birds within the FORCE test area (AECOM 2009). However, there has been limited opportunity to determine potential effects of an operational device on seabirds at the FORCE test site and to test the EA predictions.

Since 2011, FORCE and Envirosphere Consultants Ltd. (Windsor, NS) have collected observational data from the deck of the FORCE Visitor Centre, documenting seabird species presence, distribution, behaviour, and seasonality throughout the FORCE site (Envirosphere Consultants Ltd. 2017). Envirosphere Consultants Ltd. recently published the results of their monitoring from 2010-2012 and demonstrated that the species and seasonal cycles of seabirds in Minas Passage reflect patterns that are typical of the inner Bay of Fundy and the northeast Atlantic coast of North American. The report also highlights the importance of the Minas Passage as a migratory pathway for black scoter (*Melanitta americana*) and Red-throated loon (*Gavia stellata*).

In 2019, FORCE commissioned Envirosphere Consultants Ltd. and Dr. Phil Taylor (Acadia University) to synthesize the results of its observational seabird surveys (2011-2018) at the FORCE test site, and to evaluate advanced statistical techniques for analysing seabird count data in relation to environmental predictor variables. The seabird count data were examined using Generalized Additive Models (GAMs) to characterize seabird abundance and to better understand the potential impacts of tidal stream energy devices on seabirds at the FORCE test site. The results of the analyses revealed that overall model fit is suitable to characterize count data for some species, and that there are clear patterns of effects of time of year, wind speed and direction, tide height and time of day on the number of seabirds observed. However, the analyses also revealed that not all species reported at FORCE have been observed frequently enough to be modelled effectively using the GAM approach. This is due in part to the variability in count data that is particularly relevant for modelling abundance of migratory species that are only present at the FORCE site for brief periods during annual migrations. This is consistent with observational data collected over the course of these surveys that have demonstrated that the FORCE site has a lower abundance of seabirds in relation to other areas of the Bay of Fundy, and even other regions of Atlantic Canada. Given these results, the report recommends that future monitoring and analyses focus on locally resident species (i.e., great black-backed gull, herring gull, black guillemot, and common eider) so that the EA predictions can be tested most effectively. This work contributes to the development of appropriate analytical methods for assessing the impacts of tidal power development in the Minas Passage on relevant seabird populations and supports the continued responsible development of tidal energy at FORCE.

In 2022 FORCE has begun work with Strum Consulting to test radar-based seabird monitoring capabilities and to adapt existing data processing algorithms and statistical analysis tools for quantifying seabird use of the FORCE site. This feasibility study is nearing completion and results are expected later this summer.

Developer Monitoring Activities

While FORCE completes site-level monitoring activities at the FORCE site, device specific monitoring is led by individual berth holders. Like the FORCE monitoring programs, the developer monitoring plans and reports undergo review by FORCE’s EMAC and regulators.

In September 2018, it was confirmed that that CSTV turbine rotor was not spinning. Since that time, CSTV had been providing written confirmation to regulators monthly that the turbine is not operational by monitoring its status during the peak tidal flow of each month. However, because of the insolvency of OpenHydro Technology Ltd., all reporting activities by CSTV ceased as of March 1, 2019. Data collection from the turbine-mounted ADCPs to confirm the turbine is no longer spinning was managed and reported by FORCE to regulators monthly from March 2019 – May 2020 but was discontinued following an amendment to this requirement.

As additional developer, device-specific environmental effects monitoring programs are required and implemented for deployed tidal stream devices, berth holder updates will be included as appendices to future reports.

Other FORCE Research Activities

Risk Assessment Program

The Risk Assessment Program (RAP) for tidal stream energy is a collaborative effort between FORCE, academic partners, First Nations, and industry to advance our understanding of the environmental risks of tidal stream development in Minas Passage. The greatest potential risk of tidal stream energy device operations continues to be perceived by regulators and stakeholders as collisions between marine animals and turbine blades (Copping and Hemery 2020). However, these types of interactions are difficult to observe directly due to the environmental conditions under which they would occur (i.e., fast flowing, turbid waters) and using the suite of environmental monitoring instrumentation currently available (i.e., standard oceanographic and remote sensing instruments intended for use in more benign marine conditions) (Hasselman et al. 2020), but can be modeled using appropriate baseline data. The objective of the RAP program is to develop statistically robust encounter rate models for migratory and resident fishes with tidal stream energy devices in the Bay of Fundy using a combination of physical oceanographic data related to flow and turbulence in the Minas Passage and hydroacoustic tagging data for various fish species curated by the Ocean Tracking Network (OTN) at Dalhousie University.

Recent research has revealed how hydrodynamics (flow and turbulence-related features) in tidal stream environments can influence the distribution of marine animals, including fish (Lieber et al. 2018, 2019; McInturf et al. 2019). The Minas Passage is characterized by a series of turbulent hydrodynamics features (i.e., vortices, eddies, whirlpools, wakes, and shear currents) that could impact the spatiotemporal distribution of various fishes. The RAP will use a series of ADCP data collection efforts combined with a high-resolution radar network to create the first spatiotemporal flow atlas of the Minas Passage to understand these hydrodynamic features. Two Nortek Signature 500 autonomous ADCP's (Figure 2) were deployed in the tidal demonstration area on January 27th. One of the ADCP's was successfully recovered on May 4th however, the second unit could not be recovered due to an unforeseen issue with the acoustic release recovery mechanism. Further attempts to recover the unit will be made this summer. Concurrently, hydroacoustic data for various migratory and resident fish species in the Bay of Fundy that is curated by OTN will be compiled and analysed to understand their spatiotemporal distributions. The hydrodynamic and hydroacoustic data will then be combined with information about device specific parameters (e.g., turbine blade length, swept area, turbine height off the seabed) to develop encounter rate models for various fish species. These models will then be refined and validated through a series of hydroacoustic tagging efforts, ultimately leading to the development of a user-friendly Graphical User Interface (GUI) similar to what is available for the offshore wind energy industry in the United Kingdom (McGregor et al. 2018). Ultimately, the RAP will contribute towards improving our understanding of the risks of tidal stream energy development for fishes of commercial, cultural, and conservation importance in the Bay of Fundy, and will assist in the development of future environmental effects monitoring programs.

Figure 2: Two Nortek Signature 500 autonomous ADCP’s fitted in aluminum frames during deployment at the FORCE tidal demonstration area.

Since the program commenced in April 2020, OTN has acquired acoustic tag data from 22 contributors, covering nine species of fish in the Bay of Fundy (i.e., alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), American eel (*Anguilla rostrata*), Atlantic salmon (*Salmo salar*), Atlantic sturgeon (*Acipenser oxyrhinchus oxyrhinchus*), Atlantic tomcod (*Microgadus tomcod*), spiny dogfish (*Squalus acanthias*), striped bass (*Morone saxatilis*), and white shark (*Carcharodon carcharias*)). FORCE has also established a high-resolution radar network in Minas Passage and has begun quantifying hydrodynamic features (turbulence, flow etc.) of Minas passage (Figure 3). The integration of physical habitat variables with acoustic tag data commenced in 2021, including the development of species distribution models for each species and species distribution maps. This work continues in 2022 with additional tagging currently underway to further validate model predictions. In collaboration with the Mi’kmaw Conservation Group (MCG) (Figure 4) fish tagging has been completed on 25 Atlantic salmon, 24 American shad and 50 alewives. The Atlantic Salmon were tagged by DFO Science as their contribution to the project. Shad and alewife tags were purchased by FORCE berth holder Sustainable Marine as part of their contribution to RAP. Later this summer tagging will be completed with 4 Atlantic sturgeon and 15 spiny dogfish in the Minas Basin.

The acoustic receiver array (Figure 5) for detecting tagged fish was deployed in 2021 between early June and late August and again from September to early December. Due to the dynamic nature of the Minas Passage the equipment required extensive repairs which has delayed redeployment of the array. This time was used to reassess the positioning of acoustic receivers on the mooring/SUBs packages and develop a more streamlined design to alleviate extensive drag and reduce damage (Figure 6). The array was redeployed in May 2022 with the new design configuration and will be recovered late summer.

Figure 3: One of two high-resolution radars constructed near the FORCE site to be used for the Risk Assessment Program.

Figure 4: Acoustic tagging of alewife from the Avon River by RAP partner organization Mi’kmaw Conservation Group in 2021.

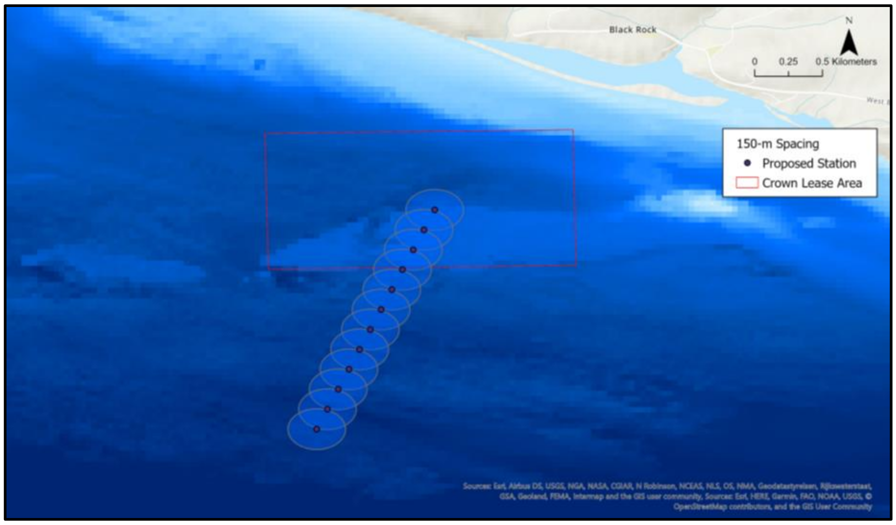

Figure 5: Acoustic receiver array deployment configuration in Minas Passage.

Figure 6: New positioning of acoustic receivers and release mechanism on a SUB package.

Fundy Advanced Sensor Technology (FAST) Activities

FORCE's Fundy Advanced Sensor Technology Program is designed to advance capabilities to monitor and characterize the FORCE site. Specifically, the FAST Program was designed to achieve the following objectives:

1) To advance capabilities of site characterization;
2) To develop and refine environmental monitoring standards and technologies; and
3) To enhance marine operating methodologies.

FAST combines both onshore and offshore monitoring assets. Onshore assets include a meteorological station, video cameras, an X-band radar system, and tide gauge. Offshore assets include modular subsea platforms for both autonomous and cabled data collection and a suite of instrumentation for a variety of research purposes. Real-time data collected through FAST assets will be broadcasted through the Canadian Integrated Ocean Observing System (CIOOS) later this year. Static ADCP data is currently available on the CIOOS website.[22]

Platform Projects

The first and largest of the FAST platforms houses an instrument called the Vectron. Developed in partnership with Nortek Scientific (Halifax, NS), Memorial University (St. John's, NL), and Dalhousie University (Halifax, NS), the Vectron is the world's first stand-alone instrument to remotely measure, in high resolution, turbulence in the mid-water column. Measurements and analysis from the Vectron will help tidal energy companies to better design devices, plan marine operations, and characterize the tidal energy resource.

A smaller platform called FAST-3 was equipped with an upward looking echosounder and deployed during 2017-2018 to monitor fish densities at the FORCE site. FORCE and its partners, including Echoview Software completed data processing and analysis in 2019. This data was integrated with the mobile hydroacoustic surveys that FORCE conducts as part of its EEMP to evaluate the temporal and spatial representativeness of each method and to determine the degree to which results were corroborative (Figure 7). Although the spatial representative range of the stationary results could not be determined from the mobile data, it did reveal strong tidal and diel periods in fish density estimates at the site, with greater variation over shorter time frames than over the course of a year. These findings reinforce the importance of 24-hr data collection periods in ongoing monitoring efforts. The report reveals that collecting 24 hours of data allows the tidal and diel variability to be quantified and isolated from the longer-term trends in fish density and distribution that need to be monitored for testing the EA predictions. This project was funded by Natural Resources Canada (NRCan), the NSDEM, and Net Zero Atlantic (formally OERA).

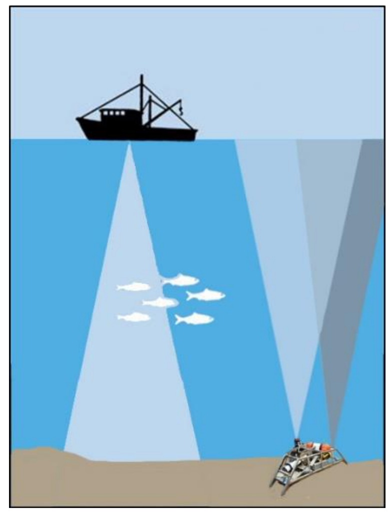

Figure 7: A representation of the data collection methods of the FORCE site-level fish EEMP and the FAST-3 platform.

Vitality Project

FORCE is actively participating in a new research and development program called the VITALITY Innovation Ecosystem Activity Project that is focused on integrating tidal stream data from the FORCE test site into CIOOS. CIOOS is a national online digital platform for sharing, discovering, and accessing ocean data in Canada, and data that is integrated into CIOOS is visible regionally and nationally. FORCE's component of the VITALITY project has three primary objectives:

1. Integration of FORCE's resource characterization and relevant environmental monitoring data (real time and static) into CIOOS to support better data accessibility and preservation,
2. Incorporation of industry and other stakeholder's data into CIOOS (i.e., industry use case), and
3. Installation and commissioning of a cabled subsea node at the FORCE site with applied R&D sensors whose real-time data will be integrated into CIOOS.

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[22] This is available online at: https://catalogue.cioosatlantic.ca/dataset/ca-cioos_db15458d-df2c-4efb-b5a0-791e7561a0cb

To that end, FORCE and its project partner Dalhousie University have recently developed a cabled subsea platform that includes an ADCP for measuring tidal current flow, waves and water temperature, a video camera for providing live stream video, and an array of hydrophones for testing the real-time detection of harbour porpoise. The platform underwent a deployment in the intertidal zone near the FORCE test site for initial testing this spring which was deemed a success. (Figure 8). Once the intertidal testing was completed, the platform was recovered from the intertidal zone and re-deployed in closer proximity to the FORCE site to test capabilities in the dynamic tidal conditions of the Minas Passage. This deployment took place on May 25th and the platform is now successfully streaming live data back to the FORCE visitor centre. Work is currently underway to make those data sets accessible to CIOOS.

Figure 8: The cabled subsea platform developed for the VITALITY project just prior to deployment at the FORCE test site.

Video of the VITALITY platform being deployed at the FORCE Test Site: https://vimeo.com/718028837

Fish Tracking

To enhance fish monitoring and to expand its data collection capacity, FORCE partnered with the Ocean Tracking Network (OTN)[23] and attached one VEMCO[24] fish tag receiver (a VR2W receiver) to each C-POD mooring/SUBS (Streamlined Underwater Buoyancy System) package (see above). These receivers are used to supplement OTN's ongoing data collection program within the Minas Passage and are referred to as 'Buoys of Opportunity.' Upon retrieval of the C-PODs and receivers, instruments are shared with OTN where data is offloaded prior to redeployment. This effort will support increased knowledge of fish movement within the Minas Passage, which

[23] Ocean Tracking Network's website: www.oceantrackingnetwork.org.

[24] VEMCO is "the world leader in the design and manufacture of acoustic telemetry equipment used by researchers worldwide to study behaviour and migration patterns of a wide variety of aquatic animals." Learn more: www.vemco.com.

has applicability beyond tidal energy demonstration, as well as complement FORCE's hydroacoustic data collection efforts that do not allow for species identification. No C-POD mooring/SUBS have been deployed since 2020, however ongoing data collection for fish monitoring is occurring through the RAP acoustic receiver line.

OTN data managers are in the process of acquiring information, including species identification, and sharing this with FORCE. Initial results show that the OTN receivers deployed by FORCE have detected tags from the following projects:

- Maritimes Region Atlantic salmon marine survival and migration (Hardie, D.C., 2017);
- Quebec MDDEFP Atlantic Sturgeon Tagging (Verreault, G., Dussureault, J., 2013);
- Gulf of Maine Sturgeon (Zydlewski, G., Wippelhauser, G. Sulikowski, J., Kieffer, M., Kinnison, M., 2006);
- OTN Canada Atlantic Sturgeon Tracking (Dadswell, M., Litvak, M., Stokesbury, M., Bradford, R., Karsten, R., Redden, A., Sheng, J., Smith, P.C., 2010);
- Darren Porter Bay of Fundy Weir Fishing (Porter, D., Whoriskey, F., 2017);
- Movement patterns of American lobsters in the Minas Basin, Minas Passage, and Bay of Fundy Canada (2017);
- Shubenacadie River Monitoring Project: Tomcod (Marshall, J., Fleming, C., Hunt, A., and Beland, J., 2017);
- MA Marine Fisheries Shark Research Program (Skomal, G.B., Chisholm, J., 2009);
- UNB Atlantic Sturgeon and Striped Bass tracking (Curry, A., Linnansaari, T., Gautreau, M., 2010);
- Inner Bay of Fundy Striped Bass (Bradford, R., LeBlanc, P., 2012);
- Minas Basin Salmon Kelt (McLean, M., Hardie, D., Reader, J., Stokesbury, M.J.W., 2019);
- New York Juvenile White Shark Study (Tobey Curtis); and
- Massachusetts White Shark Research Program (Greg Skomal)

Further information about these Buoys of Opportunity, and the projects listed above, can be found on OTN's website: https://members.oceantrack.org/project?ccode=BOOFORCE

Starting in 2018, FORCE has worked in collaboration with Dr. Mike Stokesbury at Acadia University to install additional VEMCO receivers of a new design on FORCE's C-POD moorings/SUBS packages. These new receivers are expected to be even more effective in picking up acoustic detections in high flow environments, where tag signals can be obscured by noise. This partnership will contribute additional information regarding movement patterns of Atlantic salmon, sturgeon, striped bass, and alewife in Minas Passage and Basin. This work is sponsored by the OERA, NRCan, NSDEM, the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Canadian Foundation for Innovation (CFI).[25]

[25] Information about this project, and others funded through this program, is available online at: https://netzeroatlantic.ca/sites/default/files/2020-04/2020-04-09%20NRCan%20Public%20Report%20Final%20-%20Resize.pdf

Discussion

The year 2022 represents a strategic opportunity for FORCE and its partners to learn from previous experiences, incorporate regulatory advice, and to re-evaluate approaches to research and monitoring in the high flows of the Minas Passage. The 2021-2023 EEMP is designed to prepare for effects testing with the deployment of operational devices, and adheres to the principles of adaptive management by evaluating existing datasets to ensure appropriate monitoring approaches are being implemented. Moreover, the plan adopts internationally accepted standards for monitoring where possible, including feasibility assessments for new monitoring approaches that are planned to be implemented.

FORCE has also invested in the development of its internal scientific capacity by hiring a PhD level hydroacoustician (Dr. Louise McGarry). This will assist FORCE with tackling the high volume of monitoring data that requires processing, analyses, and integration with other data sets. Dr. McGarry will also assist with the development of study designs to help advance our understanding of how fish utilize the Minas Passage.

While the 2020 COVID19 outbreak initially impacted our ability to gather data at our site and conduct marine operations – all of which require multiple people working in close proximity – our operations and monitoring data collection activities have resumed. As such, FORCE and its partners have resumed conducting monitoring, engaging in meaningful assessments of monitoring technology capabilities, and providing data analyses and interpretation that advance our ability to effectively monitor the effects of tidal stream energy devices in high flow environments, and specifically at the FORCE test site. Reports from FORCE's partners and updates are routinely subjected to review by FORCE's EMAC and regulators, along with continued results from FORCE's ongoing monitoring efforts.

FORCE continues to implement lessons learned from the experiences of local and international partners, build local capacity, and enhance skills development, test new sensor capabilities, and integrate results from various instruments. Cumulatively, these efforts provide an opportunity for adaptive management and the advancement and refinement of scientific approaches, tools, and techniques required for effectively monitoring the device and site-level areas of tidal stream energy devices in dynamic, high-flow marine environments.

Ongoing monitoring efforts will continue to build on the present body of knowledge of marine life-device interactions. While it is still early to draw conclusions, initial findings internationally and at the FORCE test site have documented some disturbance of marine mammals primarily during marine operations associated with device installation/removal activities, but otherwise have not observed significant effects.

FORCE will continue to conduct environmental research and monitoring to increase our understanding of the natural conditions within the Minas Passage and, when the next device(s) are deployed and operating, test the EA prediction that tidal energy is unlikely to cause significant harm to marine life. In the longer-term, monitoring will need to be conducted over the full seasonal cycle and in association with multiple different device technologies to understand if tidal energy can be a safe and responsibly produced energy source. FORCE will continue to report on progress and release results and lessons learned in keeping with its mandate to inform decisions regarding future tidal energy projects.

References

AECOM. 2009. Environmental Assessment Registration Document - Fundy Tidal Energy Demonstration Project Volume I: Environmental Assessment. Available from Available at www.fundyforce.ca.

Copping, A.E. 2018. The State of knowledge for environmental effects - driving consenting/permitting for the marine renewable energy industry. Available from https://tethys.pnnl.gov/sites/default/files/publications/The State of Knowledge Driving Consenting Permiting for the MRE.pdf.

Copping, A.E., and Hemery, L.G. 2020. OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). *In* State Sci. Rep. doi:10.2172/1632878.

Copping, A.E., Hemery, L.G., Viehman, H., Seitz, A.C., Staines, G.J., and Hasselman, D.J. 2021. Are fish in danger ? A review of environmental effects of marine renewable energy on fishes. Biol. Conserv. **262**: 109297. Elsevier Ltd. doi:10.1016/j.biocon.2021.109297.

Daroux, A., and Zydlewski, G. 2017. Marine fish monitoring program tidal energy demonstration site – Minas Passage. : 34. Orono, ME.

Envirosphere Consultants Ltd. 2017. Marine seabirds monitoring program – tidal energy demonstration site – Minas Passage, 2016-2017.

Fraser, S., Williamson, B.J., Nikora, V., and Scott, B.E. 2018. Fish distributions in a tidal channel indicate the behavioural impact of a marine renewable energy installation. Energy Reports **4**: 65–69. Elsevier Ltd. doi:10.1016/j.egyr.2018.01.008.

Gaskin, D.E. 1992. Status of the harbour porpoise, Phocoena phocoena, in Canada. Can. F. Nat. **106**(1): 36–54.

Gattuso, J.P., Magnan, A.K., Bopp, L., Cheung, W.W.L., Duarte, C.M., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, V.I., Gates, R.D., Irisson, J.O., Middelburg, J.J., Pörtner, H.O., and Rau, G.H. 2018. Ocean solutions to address climate change and its effects on marine ecosystems. Front. Mar. Sci. **5**(OCT). doi:10.3389/fmars.2018.00337.

Gillespie, D., Hastie, G., Palmer, L., Macaulay, J., and Sparling, C. 2021. Harbour porpoises exhibit localized evasion of a tidal turbine. Aquat. Conserv. Freshw. Ecosyst.: 1–10. doi:10.1002/aqc.3660.

Hasselman, D.J., Barclay, D.R., Cavagnaro, R., Chandler, C., Cotter, E., Gillespie, D.M., Hastie, G.D., Horne, J.K., Joslin, J., Long, C., McGarry, L.P., Mueller, R.P., Sparling, C.E., Williamson, B.J., and Staines, G.J. 2020. Environmental monitoring technologies and techniques for detecting interactions of marine animals with turbines. *In* Report for Ocean Energy Systems (OES).

International Electrotechnical Commission. 2019. Marine Energy - Wave, tidal and other water current converters - Part 40: Acoustic characterization of marine energy converter.

Joy, R., Robertson, F., and Tollit, D. 2017. FORCE Marine Mammal Environmental Effects Monitoing Program - 1st Year (2017) Monitoring Report.

Joy, R., Wood, J., and Tollit, D. 2018a. FORCE echolocating marine mammal environmental effects monitoring program - 2nd year (2018) monitoring report.

Joy, R., Wood, J.D., Sparling, C.E., Tollit, D.J., Copping, A.E., and McConnell, B.J. 2018b. Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine. Mar. Pollut. Bull. **136**: 92–106. Elsevier. doi:10.1016/j.marpolbul.2018.08.052.

Lewis, A., Estefen, S., Huckerby, J., Musial, W., Pontes, T., and Torres-Martinez, J. 2011. Ocean Energy. *In* Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. *Edited by* O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, and S. Kadner. Cambridge

University Press, Cambridge, Massachusetts. pp. 497–534.
Lieber, L., Nimmo-Smith, W.A.M., Waggitt, J.J., and Kregting, L. 2018. Fine-scale hydrodynamic metrics underlying predator occupancy patterns in tidal stream environments. Ecol. Indic. **94**: 397–408. Elsevier. doi:10.1016/j.ecolind.2018.06.071.
Lieber, L., Nimmo-Smith, W.A.M., Waggitt, J.J., and Kregting, L. 2019. Localised anthropogenic wake generates a predictable foraging hotspot for top predators. Commun. Biol. **2**(1): 1–8. Springer US. doi:10.1038/s42003-019-0364-z.
Lossent, J., Lejart, M., Folegot, T., Clorennec, D., Di Iorio, L., and Gervaise, C. 2018. Underwater operational noise level emitted by a tidal current turbine and its potential impact on marine fauna. Mar. Pollut. Bull. **131**(May 2017): 323–334. Elsevier. doi:10.1016/j.marpolbul.2018.03.024.
Malinka, C.E., Gillespie, D.M., Macaulay, J.D.J., Joy, R., and Sparling, C.E. 2018. First in situ passive acoustic monitoring for marine mammals during operation of a tidal turbine in Ramsey Sound, Wales. Mar. Ecol. Prog. Ser. **590**: 247–266. doi:10.3354/meps12467.
Marine Renewables Canada. 2018. State of the Sector Report: Marine Renewable Energy in Canada.
Martin, B., Whitt, C., and Horwich, L. 2018. Acoustic data analysis of the OpenHydro opencentre turbine at FORCE: final report.
McGregor, R.M., King, S., Donovan, C.R., Caneco, B., and Webb, A. 2018. A Stochastic Collision Risk Model for Seabirds in Flight. Available from https://www2.gov.scot/Resource/0053/00536606.pdf.
McInturf, A.G., Steel, A.E., Buckhorn, M., Sandstrom, P., Slager, C.J., Fangue, N.A., Klimley, A.P., and Caillaud, D. 2019. Use of a hydrodynamic model to examine behavioral response of broadnose sevengill sharks (Notorynchus cepedianus) to estuarine tidal flow. Environ. Biol. Fishes **102**(9): 1149–1159. Environmental Biology of Fishes. doi:10.1007/s10641-019-00894-3.
Melvin, G.D., and Cochrane, N.A. 2014. Investigation of the vertical distribution, movement and abundance of fish in the vicinity of proposed tidal power energy conversion devices. Final Report for the Offshore Energy Research Association. Research Project 300-170-09-12.
NEXUS Coastal Resource Management Ltd. 2017. Lobster Catchability Study Report.
Palmer, K.J., Wood, J., and Tollit, D.J. 2021. FORCE Marine Mammal EEMP - Yer 4 Final Report.
Pine, M.K., Schmitt, P., Culloch, R.M., Lieber, L., and Kregting, L.T. 2019. Providing ecological context to anthropogenic subsea noise: Assessing listening space reductions of marine mammals from tidal energy devices. Renew. Sustain. Energy Rev. **103**(July 2018): 49–57. Elsevier Ltd. doi:10.1016/j.rser.2018.12.024.
Robertson, F., Wood, J., Joslin, J., Joy, R., and Polagye, B. 2018. Marine Mammal Behavioral Response to Tidal Turbine Sound. (206). doi:10.2172/1458457.
Schramm, M.P., Bevelhimer, M., and Scherelis, C. 2017. Effects of hydrokinetic turbine sound on the behavior of four species of fish within an experimental mesocosm. Fish. Res. **190**: 1–14. Elsevier B.V. doi:10.1016/j.fishres.2017.01.012.
SLR Consulting. 2015. Proposed Environmental Effects Monitoring Programs 2015-2020 for Fundy Ocean Research Center for Energy (FORCE).
Viehman, H., Hasselman, D., Boucher, T., Douglas, J., and Bennett, L. 2019. Integrating hydroacoustic approaches to predict fish interactions with in-stream tidal turbines. Available from https://netzeroatlantic.ca/sites/default/files/2020-04/FISH FINDER Final Report 31-03-2020_0.pdf.
Viehman, H.A., Hasselman, D.J., Douglas, J., and Boucher, T. 2022. The ups and downs of using active acoustic technologies to study fish at tidal energy sites. Front. Mar. Sci. **9**: 851400. doi:10.3389/fmars.2022.851400.

Appendix I

Acronyms

AAM	Active Acoustic Monitoring
ADCP	Acoustic Doppler Current Profiler
AMAR	Autonomous Multichannel Acoustic Recorder
BACI	Before/After, Control/Impact
BC	British Columbia
BoFEP	Bay of Fundy Ecosystem Partnership
CFI	Canadian Foundation for Innovation
CIOOS	Canadian Integrated Ocean Observing System
CLA	Crown Lease Area
cm	Centimetre(s)
CPUE	Catch Per Unit Effort
CSTV	Cape Sharp Tidal Venture
DFO	Department of Fisheries and Oceans (Canada)
DEM	Department of Energy and Mines (Nova Scotia)
EA	Environmental Assessment
EEMP	Environmental Effects Monitoring Program
EMAC	Environmental Monitoring Advisory Committee
EMP	Environmental Management Plan
FAD	Fish Aggregation Device
FAST	Fundy Advanced Sensor Technology
FAST-EMS	Fundy Advanced Sensor Technology – Environmental Monitoring System
FERN	Fundy Energy Research Network
FORCE	Fundy Ocean Research Center for Energy
GPS	Global Positioning System
hr	Hour(s)
IEA	International Energy Agency
kg	Kilogram(s)
km	Kilometre(s)
kW	Kilowatt(s)
m	Metre(s)
MET	Meteorological
MRE	Marine Renewable Energy
MREA	Marine Renewable-electricity Area
NL	Newfoundland and Labrador
NRCan	Natural Resources Canada
NS	Nova Scotia
NSDEM	Nova Scotia Department of Energy and Mines
NSE	Nova Scotia Department of Environment
NSERC	Natural Sciences and Engineering Research Council
NSPI	Nova Scotia Power Inc.
OERA	Offshore Energy Research Association of Nova Scotia
OES	Ocean Energy Systems
ONC	Ocean Networks Canada
ORJIP	Offshore Renewables Joint Industry Programme
OSC	Ocean Supercluster
OTN	Ocean Tracking Network
PAM	Passive Acoustic Monitoring

Q1/2/3	Quarter (1, 2, 3), based on a quarterly reporting schedule
R&D	Research and Development
TC114	Technical Committee 114
SUBS	Streamlined Underwater Buoyancy System
SME	Sustainable Marine Energy (Canada)
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
VEC(s)	Valuable Ecosystem Component(s)

Appendix II

frontiers in Marine Science

ORIGINAL RESEARCH
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The Ups and Downs of Using Active Acoustic Technologies to Study Fish at Tidal Energy Sites

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Active acoustic instruments (echosounders) are well-suited for collecting high-resolution information on fish abundance and distribution in the areas targeted for tidal energy development, which is necessary for understanding the potential risks tidal energy devices pose to fish. However, a large proportion of echosounder data must often be omitted due to high levels of backscatter from air entrained into the water column. To effectively use these instruments at tidal energy sites, we need a better understanding of this data loss and how it may affect estimates of fish abundance and vertical distribution. We examined entrained air contamination in echosounder data from the Fundy Ocean Research Center for Energy (FORCE) tidal energy test site in Minas Passage, Nova Scotia, where current speeds can exceed 5 $m \cdot s^{-1}$. Entrained air depth was highly variable and increased with current speed, and contamination was lowest during neap tides. The lower 70% of the water column and current speeds <3 $m \cdot s^{-1}$ were generally well-represented in the dataset. However, under-sampling of the upper water column and faster speeds strongly affected simulated fish abundance estimates, with error highly dependent on the underlying vertical distribution of fish. Complementary sensing technologies, such as acoustic telemetry and optical instruments, could be used concurrently with echosounders to fill gaps in active acoustic datasets and to maximize what can be learned about fish abundance and distribution at tidal energy sites.

Keywords: active acoustics, hydroacoustics, fish, entrained air, data quality, marine renewable energy, tidal energy, MHK

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1 INTRODUCTION

The tidal energy sector is a nascent industry, and the potential environmental effects of marine hydrokinetic (MHK) devices on fish continues to be an area of concern for regulators and stakeholders of the marine environment (Copping et al., 2021). Predicting fish interactions with MHK devices, and therefore potential device effects, requires information on fish presence, abundance, and distribution at a resolution and scale that is rarely required elsewhere. Spatial resolution must be on the order of meters for data to be related to an individual MHK device, and collected throughout the water column and/or across tidal channels that can be kilometers wide. Similarly, fine temporal resolution (seconds to minutes) may be required to capture shifts in fish distribution that affect MHK device encounter rates but years of observations may be needed to characterize seasonal patterns and longer-term population shifts. Active acoustic instruments are excellent tools for collecting this high-resolution information across large spaces and periods of time. This technology includes single beam, split beam, and multibeam echosounders utilizing single or multiple frequencies in narrow- or broad-band modes (Demer et al., 2015). Active acoustics is a vital component of fisheries stock assessments worldwide, given these instruments' unequaled capacity to rapidly and non-invasively sample large volumes of water (Horne, 2000; Simmonds and MacLennan, 2005). Echosounders have been employed in studies of fish at tidal energy sites around the world, as well (e.g. Viehman et al., 2015; Fraser et al., 2017; Viehman et al., 2018; Gonzalez et al., 2019; Williamson et al., 2019; Scherelis et al., 2020; Whitton et al., 2020).

Tidal channels are characterized by fast currents and complex hydrodynamics that pose unique challenges to active acoustics technology, which can hamper the translation of raw data to information that can be used by scientists, developers, and regulators of the tidal energy industry. The primary challenge is the high prevalence of air bubbles entrained into the water column, which scatter the sound transmitted by echosounders. Air entrainment is a common occurrence in the open ocean, with the primary source of entrainment being breaking waves (Woolf, 2001; Baschek et al., 2006). Air plumes in the open ocean commonly extend to depths of 10-15 m, but the extreme hydrodynamic conditions in areas with strong tidal currents can draw bubbles to depths well over 100 m (Baschek et al., 2006). Though bubbles entrained in the water column tend to be very small (e.g. < 1 mm diameter; Woolf, 2001; Baschek et al., 2006), they are strong scatterers of sound. The sound scattered by clouds of bubbles observed at tidal energy sites is similar to, or stronger than, that scattered by fish (for example, in the 120 kHz data assessed here, volume backscatter of the entrained air layer averaged -46 dB re 1 m^2m^{-3}), and the two scatterer types cannot be separated in active acoustics data if they inhabit the same volume of water. Measurements containing backscatter from entrained air must therefore be removed from acoustic datasets prior to analyzing backscatter from fish.

Studies at tidal energy sites have utilized different methods to remove backscatter from entrained air. The majority of methods exploit the distinct temporal and/or morphological characteristics of the bubble plumes to differentiate them from fish backscatter, including occurrence and duration in time and surface connectivity (Fraser et al., 2017; Scherelis et al., 2020). Features with the designated characteristics are then removed from the dataset, either manually or with some mix of automated and manual steps. Removal has included omitting just the contaminated data points (Fraser et al., 2017; Whitton et al., 2020), or a fixed depth range plus the entire water column when air extends further (Viehman et al., 2018). Other studies have kept only the lowermost portion of the water column as the depths of primary interest, ignoring the upper layers (Viehman et al., 2015; Gonzalez et al., 2019). Regardless of the method, the result is omitting a large amount of water that could contain fish but is unable to be effectively sampled by active acoustics instruments.

Omitting the entrained air layer is likely to affect acoustically derived estimates of fish abundance and vertical distribution, and therefore our ability to estimate encounters with MHK devices. Moreover, it is possible that different fish species' or life stages' contributions to acoustic measurements will be unequally affected by removing different portions of the water column, given depth preferences that are often species- or life-stage-specific. For example, in the northwest Atlantic, Atlantic salmon post-smolts and adults (*Salmo salar*) tend to be found within the upper 10 m of the water column (Dutil and Coutu, 1988; Sheehan et al., 2012). Other species utilize the entire water column more generally (e.g. Atlantic herring, *Clupea harengus*, Huse et al., 2012; Viehman et al., 2018; Atlantic mackerel, *Scombur scombrus*, Castonguay and Gilbert 1995), while others are typically associated with the bottom (e.g. Atlantic cod, *Gadus morhua*, Hobson et al., 2007). American eel (*Anguila rostrata*) have exhibited distinct vertical migrations to take advantage of favorable tidal currents, a behavior known as selective tidal stream transport (STST; Parker and McCleave, 1997). At present, it is unclear whether depth preferences observed in lower-energy environments will persist within highly energetic tidal channels, and there is some evidence that they may differ (Stokesbury et al., 2016; Lilly et al., 2021).

Though data contamination by entrained air is an issue at all tidal energy sites, we have yet to examine the resulting data loss in detail (e.g. its magnitude and spatiotemporal distribution), or how this loss could affect our acoustically derived estimates of fish abundance and vertical distribution. This information would be particularly helpful in the planning stages of a study or environmental monitoring plan, when steps can be taken to address any expected limitations of the active acoustic dataset. These steps may include, for example, the simultaneous use of complementary technologies and sampling techniques.

In this paper, we examined the entrained air layer in active acoustic data collected at the FORCE tidal energy test site. We developed a method for identifying and removing the data points contaminated by entrained air, quantified entrained air depth and resulting data loss, and demonstrated the effects of this data loss on estimates of fish abundance and vertical distribution obtained from simulated vertical distributions of fish. The active acoustic data assessed in this paper are from a fixed-location split beam, narrowband, scientific-grade echosounder, which is the type most used for assessing the abundance and vertical distribution of fishes over long periods of time or space. Our goal was to provide researchers, developers, and regulators of the tidal energy industry with the information they need to utilize active acoustics technology to its fullest potential, and to mitigate the limitations imposed on it by this exceptionally challenging environment.

2 MATERIALS AND METHODS

2.1 Data Collection

Data were collected at the Fundy Ocean Research Center for Energy (FORCE) tidal energy test site, in the Bay of Fundy, Nova Scotia, Canada (**Figure 1**). Instruments were installed on the Fundy Advanced Sensor Technology subsea platform, FAST-3 (**Figure 2**). This stationary platform was deployed on the seafloor

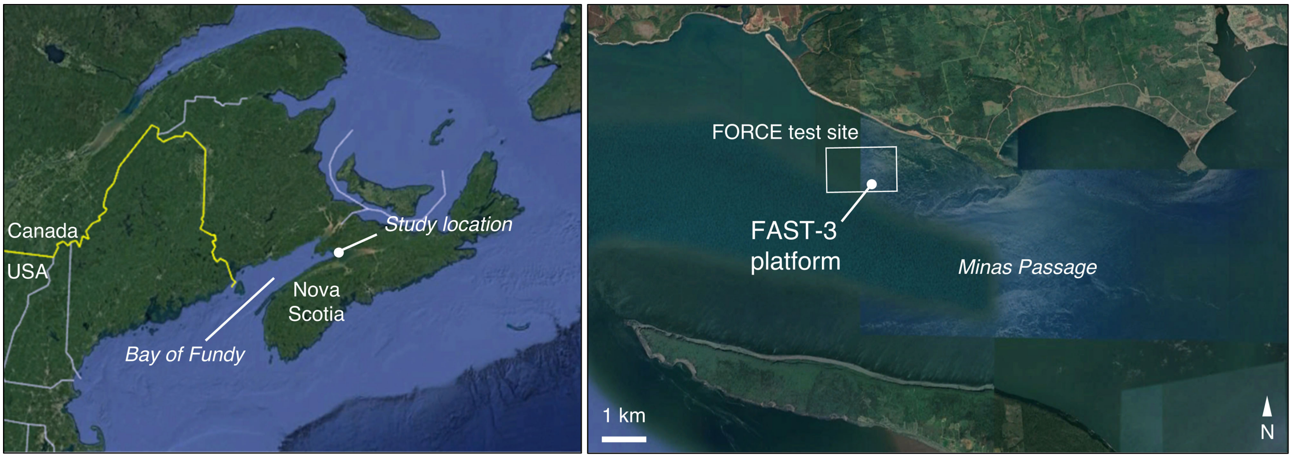

FIGURE 1 | Study location in the Minas Passage of the Bay of Fundy, Canada. The location of Minas Passage is indicated by the filled circle in the left-hand panel, and the study site is shown on the right.

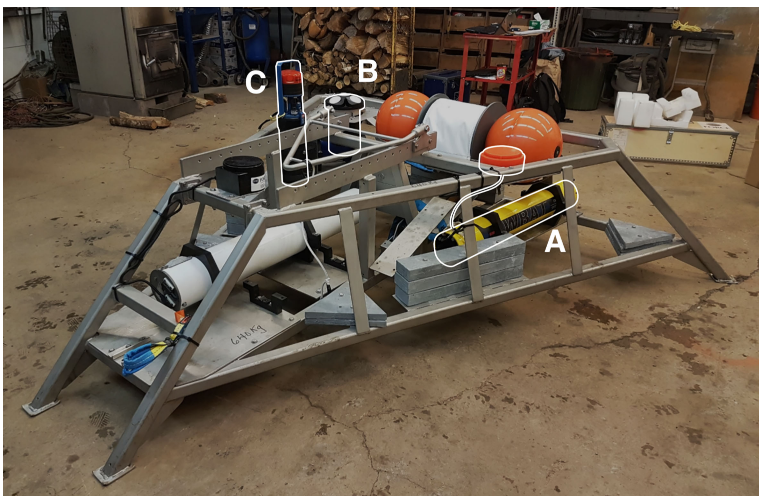

FIGURE 2 | FAST-3 platform deployed at the FORCE Tidal energy test site from 30 Mar to 23 May 2018. Equipment included **(A)** Simrad WBAT EK80 echosounder, **(B)** Nortek Signature 500 ADCP, **(C)** Aanderaa SeaGuard RCM.

at 45°21'47.34" N, 64°25'38.88" W, and was in place for 53 days from 30 March to 23 May 2018. At this location, water column depth averaged 33 m at low tide and 43 m at high tide.

Active acoustic data were collected by a Simrad EK80 WBAT echosounder with a 120 kHz split beam transducer (7° half-power beam angle), located 0.7 m above the seafloor and facing upward. Data were collected in 5-min recording periods every half hour, with a ping rate of 1 Hz, pulse duration of 0.128 ms, transmit power of 125 W, and maximum recording range of 60 m. Collection settings were chosen based on pilot data collected near this site in February 2017.

Measurements of current velocity throughout the water column were collected by a Nortek Signature 500 acoustic doppler current profiler (ADCP). The ADCP's face was located at 0.7 m above the seafloor. Data were collected in 5-min bursts every 15 min, alternating with echosounder measurements to avoid acoustic interference between the two instruments. The sample rate during each burst was 2 Hz, the blanking distance was 1 m, and the cell size was 1 m.

Water temperature and salinity at the platform were measured by an Aanderaa SeaGuard RCM every half hour.

2.2 Data Processing

2.2.1 Active Acoustic Data

Active acoustic data processing was carried out using Echoview® software (12.1, Myriax, Hobart, Australia). We developed a data processing routine in Echoview that detected the surface and entrained air layer, minimizing the need for manual correction as much as possible. The template developed for this process is provided in supplementary materials with a detailed explanation of all steps.

Briefly, the surface was detected with a line, and the boundary of the surface dead zone was delineated below this (0.16 m below on average; Ona and Mitson, 1996). A line was also defined at 2x the acoustic nearfield distance from the transducer face (Simmonds and MacLennan, 2005), and acted as the lower analysis limit in all following steps. Entrained air was defined morphometrically as clusters of backscatter which extended downward from the surface, similar to Fraser et al. (2017). Detection of these clusters required a series of separate processing steps, including smoothing the raw volume backscatter (S_V) data, applying a minimum data threshold, and using Echoview's schools detection algorithm to detect contiguous clusters of backscatter that surpassed this threshold. Clusters which were connected to the surface were isolated and expanded in depth and time, and a line was drawn below the resulting backscatter to establish the lower extent of the entrained air layer. The maximum depth of this layer was limited by the acoustic nearfield, 2.4 m above the seafloor.

All processing steps and settings were chosen by iteratively reviewing the performance of the processing routine on a subset of data files that represented a wide range of entrained air contamination, until the level of necessary manual corrections to the surface and entrained air lines was deemed acceptably low. All data files were then batch-processed in Echoview using the finalized routine. The resulting Echoview files were reviewed manually to make any necessary corrections to the surface and entrained air lines.

Once all necessary corrections were made, the surface and entrained air line depths were exported, and we calculated the average water column depth and entrained air depth for each 5-min data recording period. For each recording period, we also calculated the number of samples (individual datapoints) omitted due to the entrained air layer. We converted this number to a percent of analyzable samples, which was more comparable over time as water level changed. We defined analyzable samples as all samples between the nearfield and surface dead zone because samples outside of these boundaries would always be excluded from acoustic analysis.

Echosounder data were calibrated using calibration sphere measurements obtained at a calm location off-site, before and after the deployment. As environmental conditions changed significantly over the course of the deployment (temperature and salinity shifts caused the speed of sound to increase from 1452 $m \cdot s^{-1}$ to 1477 $m \cdot s^{-1}$), acoustic data were split into sections to which different calibration parameters were applied. Details of data calibration are supplied in supplementary materials.

2.2.2 ADCP Data

ADCP measurements were first corrected for platform tilt and compass declination using Ocean Contour (version 2.1.5, Ocean Illumination Ltd., Canada). We obtained average horizontal speed and direction for each 1-m cell of every ADCP burst. The first measurement cell was centered 2 m from the transducer face. Measurements from the uppermost 10% of the water column could not be used due to interference from side lobes, so we removed these upper cells prior to calculating water column average speed and direction. We then interpolated these speed and direction values in time to obtain water column averages at the midpoint of each echosounder recording period. All future references to current speed or direction measurements refer to these interpolated water column averages.

Slack tide was defined as current speed < 0.5 $m \cdot s^{-1}$, which captured the period of time when current direction was shifting between ebb and flood. In this dataset, slack tide defined in this way (by current speed and direction) occurred approximately 15-30 min after the time of lowest or highest water. Spring and neap tides were identified in the current velocity time series as maxima and minima in peak flow speed.

2.2.3 SeaGuard RCM Data

Conductivity and temperature readings from the SeaGuard RCM were used in the calculation of sound speed, for calibrating echosounder data (see supplementary material).

2.3 Data Analysis

There was no way to predict how many fish were omitted from the acoustic dataset by removing the entrained air layer. We therefore demonstrated how entrained air contamination affects estimates of fish abundance and distribution by constructing five hypothetical fish distribution scenarios that we then subjected to different levels of contamination and data removal. Analysis was carried out in R software version 4.1.2 (R Core Team, 2021).

The five vertical distribution scenarios each spanned one tidal cycle, which was split into 24 equally spaced time segments (tide bins; approximately 30 min each). All recording periods from the acoustic dataset were partitioned into these tide bins, and for each tide bin we calculated mean water column depth and the 5th, 50th (median), and 95th percentiles of entrained air depth. The mean water column depth from each tide bin defined the hypothetical water column in each fish distribution scenario. The water column was then split into 1 m depth bins to be populated with some number of fish. For simplicity, total fish abundance was held constant over time (1000 fish per tide bin, 24000 fish total). The fish distribution scenarios we generated were:

1. Fish utilizing the entire water column: for each tide bin, 1000 fish were distributed randomly into all water column bins, from the seafloor to the surface.
2. Surface-oriented fish: for each tide bin, 1000 fish were distributed into the upper 10 bins of the water column. To simulate a gradual increase in fish abundance towards the surface (as observed previously; e.g. Viehman et al., 2018), fish were assigned to depth bins following a beta distribution which peaked in the 2-3 m depth bins.
3. Bottom-oriented fish: for each tide bin, 1000 fish were assigned to the lowermost 10 m of the water column, using the same method as for Scenario 2 but with fish abundance increasing towards the sea floor and peaking in the lowermost bin.

4. Selective tidal stream transport (STST): fish were bottom-oriented during the flood tide (as in Scenario 3) and surface-oriented during ebb tide (as in Scenario 2), transitioning through the mid-water-column during slack tides. This scenario represented STST for a species migrating outward toward the open ocean, utilizing the current during ebb tide.
5. Mixed fish assemblage: Scenarios 1-4 were combined to represent a mix of species exhibiting different depth preferences and vertical movements. 50% of fish were randomly distributed, 20% were surface-oriented, 20% were bottom-oriented, and 10% exhibited STST. The proportions of fish exhibiting each vertical distribution were chosen arbitrarily for illustration purposes, as these proportions are not yet known for fishes utilizing Minas Passage.

To simulate the effects of entrained air contamination on acoustically-derived estimates of fish abundance, we removed counts from any depth bins within the entrained air layer. The 5th, 50th, and 95th percentile air layer depths represented "best", "middle", and "worst" contamination conditions, respectively. We also omitted fish below the nearfield range, as that portion of active acoustic data would not be useable either. We calculated "observed" fish abundances as the water column sums for each tide bin in these reduced datasets (making the assumption that all fish would be equally detectable by the echosounder). We then compared observed abundances to the known water column sums ("actual" fish abundance), which was 1000 fish per tide bin.

For scenario 5, we also compared actual and observed fish vertical distribution for each stage of the tide: low (tide bins 1 and 24), high (tide bin 13), flood (tide bins 2 to 12), and ebb (tide bins 14 to 23). The vertical distribution for each tidal stage was constructed by breaking the water column into depth bins which spanned 5% of the total water column height (to account for changing water level), then summing the numbers of fish contained within each percentage bin.

3 RESULTS

The entrained air detection method worked well, with only a small number of files requiring manual adjustments to the automatically detected surface and entrained air lines (approximately 6% and 3%, respectively). Most entrained air was easily identifiable as backscatter extending downward from the surface, whereas most backscatter likely to be from fish did not overlap with the surface (**Figure 3**).

Despite the entrained air layer detection algorithm generally working well (**Figure 4A**), there were still instances where it was difficult to differentiate backscatter from bubbles or fish based on appearance alone. Some backscatter could have been either aggregated fish or partial, detached bubble plumes (**Figure 4C**). This ambiguous backscatter needed to be

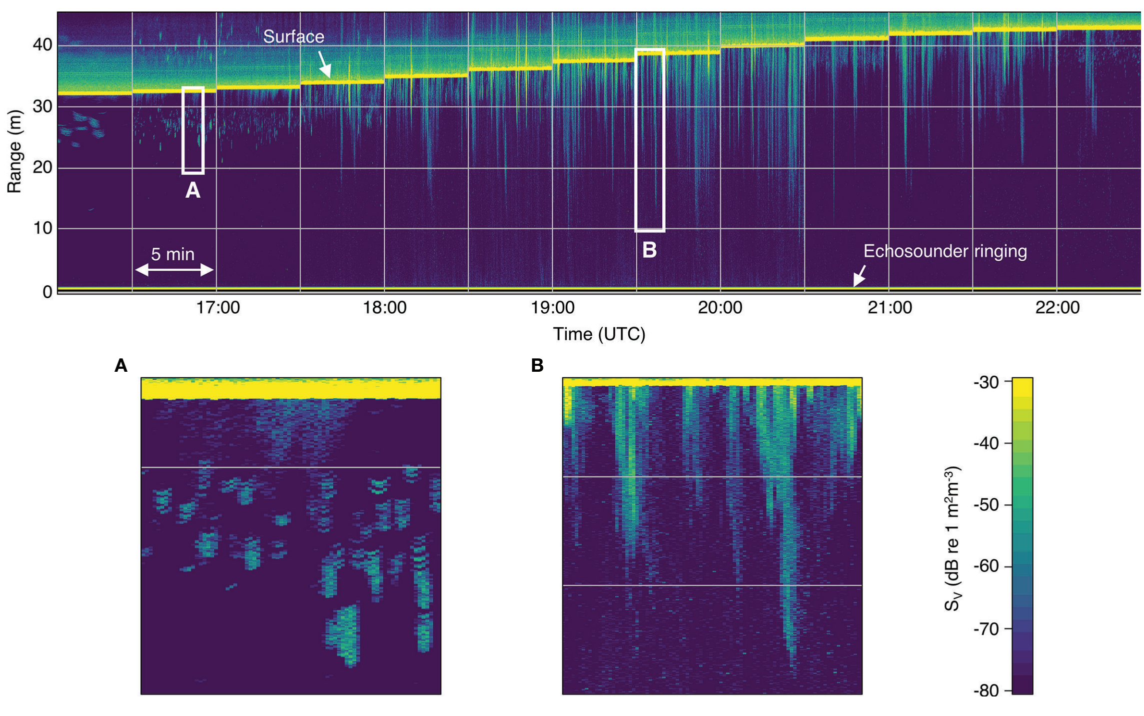

FIGURE 3 | Volume backscatter (S_V) echogram from a typical flood tide (on 22 May 2018). Low tide is on the left and high tide is on the right. Vertical gridlines separate the 5-min echosounder recording periods, which began every half hour (times shown in UTC). Horizontal gridlines indicate 10-m range bins (measured upwards from the transducer face). All following echograms use the same grid and color scale shown here. **(A)** Backscatter from small aggregations of fish visible near the surface near low tide. **(B)** Bubble plumes extending far into the water column during the peak flow.

classified manually based on the appearance of the surrounding water column and neighboring recording periods. There were also many periods where fish were evident within bubble plumes but inseparable from plume backscatter, and therefore omitted (**Figure 4B**).

Backscatter from entrained air was not always confined to dense plumes of bubbles. At peak current speeds, when the plumes were most obvious, it was clear that the remaining water column was also subject to additional backscatter that often surpassed the same minimum threshold applied to the plumes (**Figure 5**). This more dispersed backscatter was likely also related to bubbles, given its strong association with deep bubble plumes, and it was therefore considered to be part of the entrained air layer. This situation is the cause of all recording periods that were missing 100% of their analyzable samples.

The final dataset consisted of 2583 5-min recording periods. Across all recording periods, 29% of all analyzable samples were removed due to contamination from entrained air. Entrained air depth varied greatly over time, from the surface to the nearfield-exclusion line (**Figure 6B**). Consequently, the percentage of analyzable samples that would be omitted from any given recording period also varied from near 0% up to 100% (**Figure 6C**). Overall, 4% of recording periods were missing all of their analyzable samples, 16% were missing at least half of their samples, and 41% were missing at least a quarter. Almost all recording periods missing 100% of their samples occurred during peak flow near spring tides, when current speeds were highest (**Figures 6A, C**, orange bars). During neap tides, data loss in a given recording period did not often exceed 50% (**Figure 6C**, purple bars).

Due to entrained air extending downward from the surface, the lower water column was sampled more consistently than the upper water column. Across all recording periods, the uppermost 5% of the water column was only sampled 15% of the time, whereas the

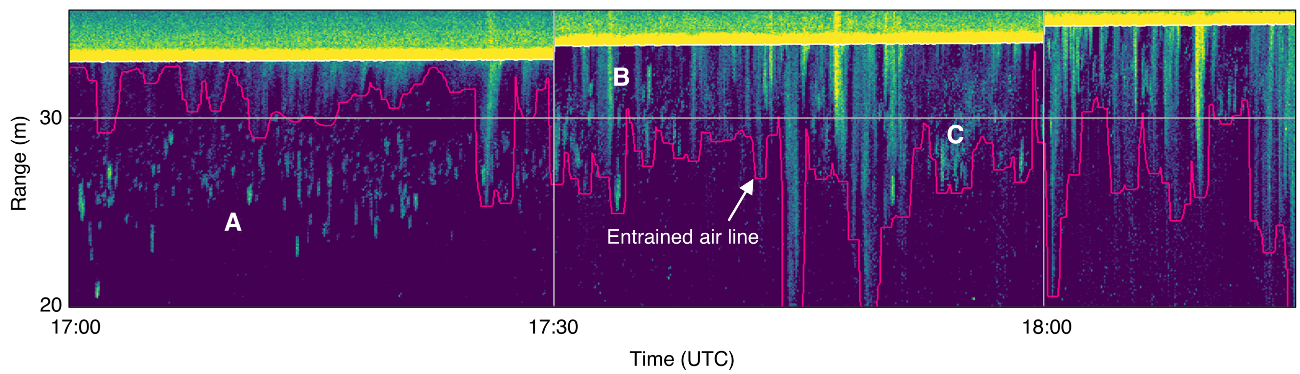

FIGURE 4 | Subset of echogram shown in **(Figure 3)**, showing backscatter from fish and entrained air (delineated by pink line). **(A)** Small fish aggregations clearly visible in upper water column, separate from entrained air layer. **(B)** Aggregations appear to shift upward into entrained air layer, where they can still be seen. **(C)** Unclear whether backscatter is from fish aggregations or detached/dispersed bubble plumes.

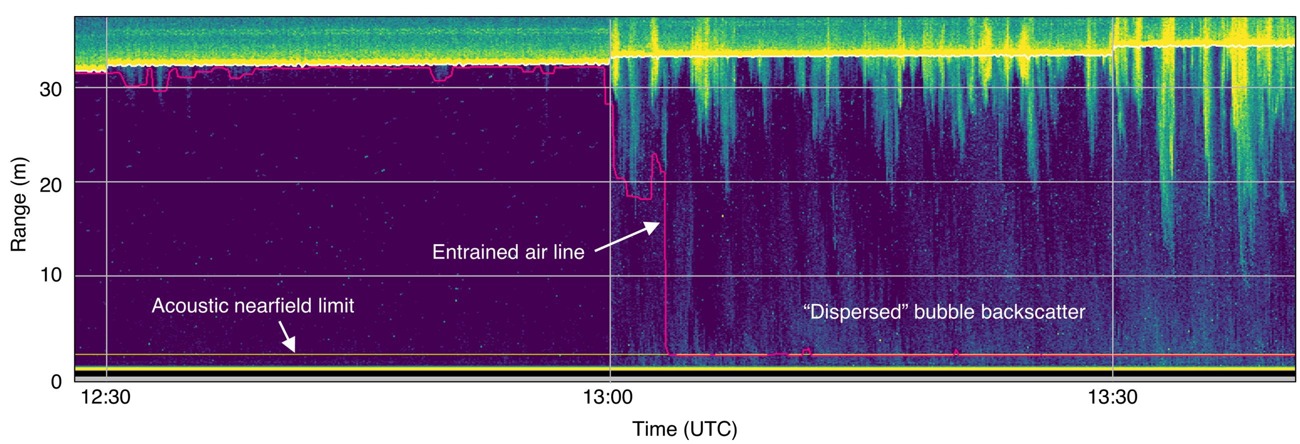

FIGURE 5 | Example of backscatter from bubbles entrained throughout the water column. The detected entrained air line (pink) extends to the acoustic nearfield (horizontal yellow line), resulting in omission of most or all of the water column.

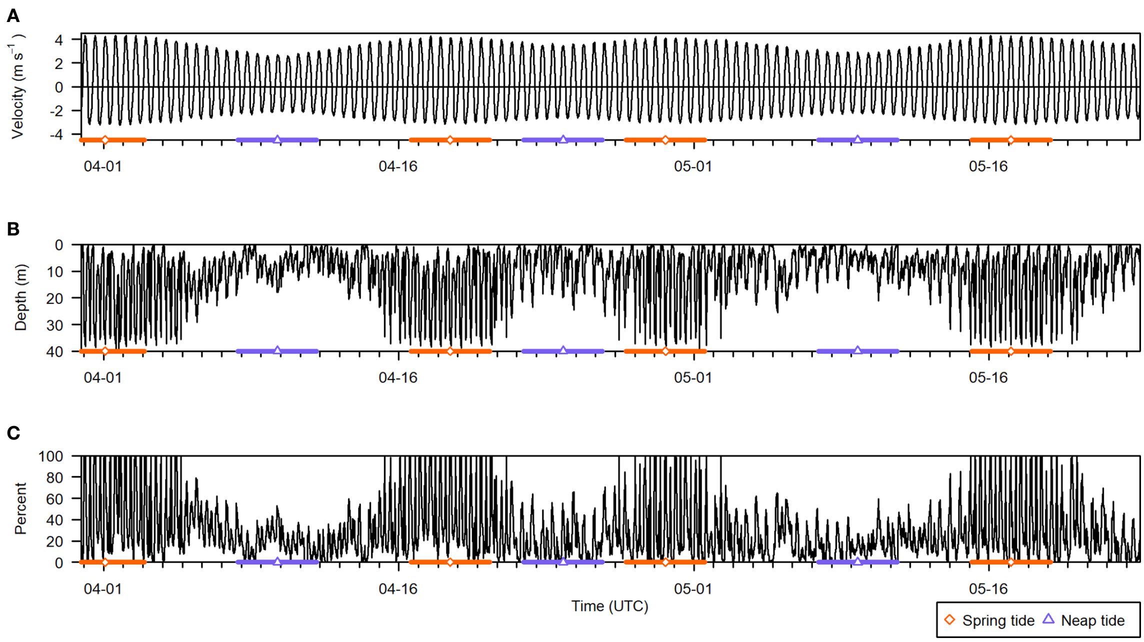

FIGURE 6 | Summary of all active acoustic recording periods from the deployment, spanning 30 March to 23 May 2018. **(A)** Current velocity (negative is ebb direction, positive is flood), **(B)** entrained air depth, and **(C)** percent of analyzable samples that were contaminated by entrained air in each recording period. The times of spring and neap tides are indicated by the orange diamond and purple triangle symbols, respectively, and the colored bars span 2 days on either side. Note that the entrained air layer depth stops at the acoustic nearfield, located 2.4 m above the seafloor.

5% above the nearfield was sampled 93% of the time (**Figure 7A**). The uppermost water column was almost exclusively sampled at current speeds less than 2 m·s^{-1}, and current speeds over 3 m·s^{-1} were only well sampled in the lower half of the water column (i.e. in proportions similar to total recording periods, **Figure 7A**, upper panel). The fastest current speeds, greater than 4 m·s^{-1}, were very rarely sampled without contamination from entrained air, and only in the lower 45% of the water column.

There was a noticeable difference between depths and current speeds sampled during spring and neap tides (**Figures 7B, C**). Most current speeds greater than 3 m·s^{-1} occurred during spring tides (**Figure 7B**, upper panel), but were not well sampled anywhere in the water column (**Figure 7B**, lower panel). During spring tide, contamination by entrained air at these faster speeds resulted in omitting at least 20% of recording periods throughout the water column, and more closer to the surface.

Conversely, during neap tides, the current speeds sampled in the lowermost 75% of the water column largely reflected the current speeds measured across all neap tide periods. Moreover, bins in the lower 70% of the water column were contaminated less than 10% of the time. Though surface depth bins were still under-sampled relative to lower bins, data collected during neap tides spanned the most representative range of current speeds for the largest portion of the water column.

The unequal representation of current speeds across depths was due to the correlation of entrained air depth with current speed (**Figure 8A**). Higher current speeds resulted in greater air contamination and data loss. The highest current speeds recorded during either flood or ebb tide (occurring near spring tides) were often correlated with 100% contaminated samples (**Figure 8B**), though peak speeds were lower during ebb than flood (**Figure 9C**). The recording periods missing all or nearly all samples were mainly due to the "dispersed" bubble backscatter shown in **Figure 5**.

The correlation of entrained air depth with current speed meant the uncontaminated portion of the water column grew and shrank in an approximately 6-hour cycle, aligned with the tidal currents. This was very clear when data were summarized by tide bin (**Figure 9**).

The 5 hypothetical fish distribution scenarios are shown in **Figures 10A–E**, along with samples removed according to the 5th, 50th, and 95th percentile entrained air depth for each tide bin (hatchlines), and acoustic nearfield (crosshatched area along the bottom). Different levels of entrained air contamination had clear effects on fish abundances obtained from each of the 5 distribution scenarios (**Figure 11**). The magnitude of the impact on "observed" fish abundance over the course of the tidal cycle varied according to the underlying vertical distribution of fish. Generally, error in abundance estimates was greatest whenever fish were most concentrated in the upper water column (**Figures 11B, D**). For scenarios with fish in the upper- and mid-water-column, omission of data in the entrained air layer generated a distinct tidal pattern in observed fish abundance, as fewer fish were detected at higher current speeds (**Figures 11A, B, D, E**). This was true for all three entrained air levels applied to the simulated scenarios. Observed abundance of fish inhabiting the lowermost water column was primarily affected by the exclusion of data in the acoustic nearfield

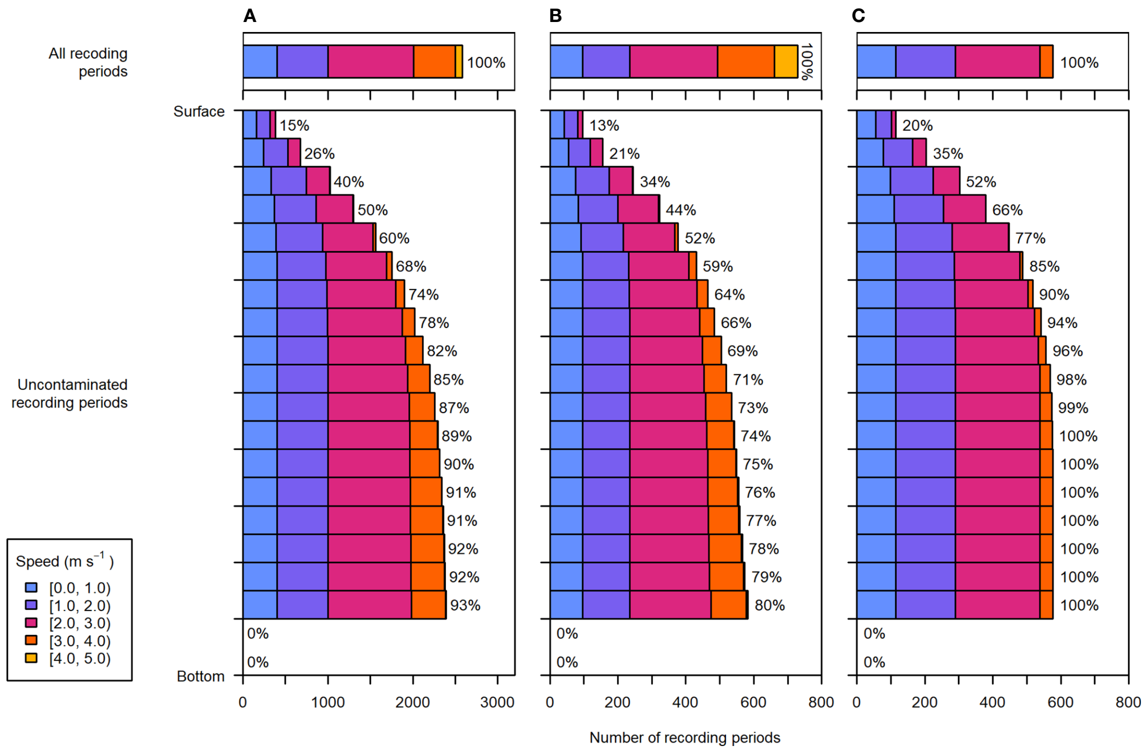

FIGURE 7 | Distribution of depths and current speeds sampled during **(A)** the entire dataset, **(B)** recording periods within 2 days of spring tides, and **(C)** recording periods within 2 days of neap tides. Upper panels: the current speeds recorded during all periods of the respective data subset, representing speeds that would be sampled throughout the water column if there were no contamination from entrained air. Lower panels: the depth and current speed distribution of uncontaminated recording periods. Each depth bin spans 5% of the water column (the lowermost two depth bins were not sampled in any recording periods due to the height of the nearfield exclusion above the sea floor). To the right of each bar is the percentage of total recording periods within the respective data subset (e.g., entire dataset, spring tide, or neap tide).

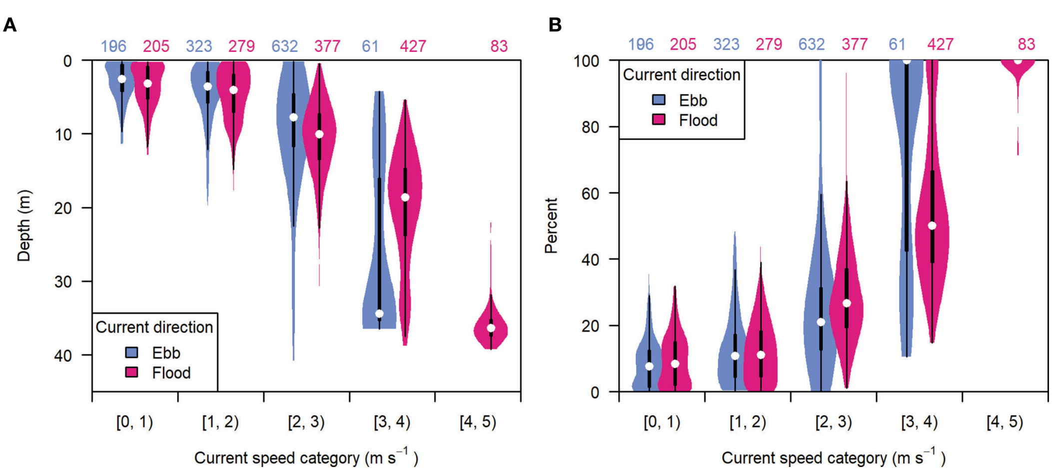

FIGURE 8 | The distribution of **(A)** entrained air depth and **(B)** percent of analyzable samples missing from each recording period, grouped by current speed category and tidal current direction (ebb or flood). Light blue indicates ebb tide, dark pink indicates flood tide. White points are the median value, boxes span the interquartile range (IQR), whiskers extend to 1.5*IQR, and violins span the minimum and maximum values in each group. Numbers at the top indicate the number of recording periods in each group.

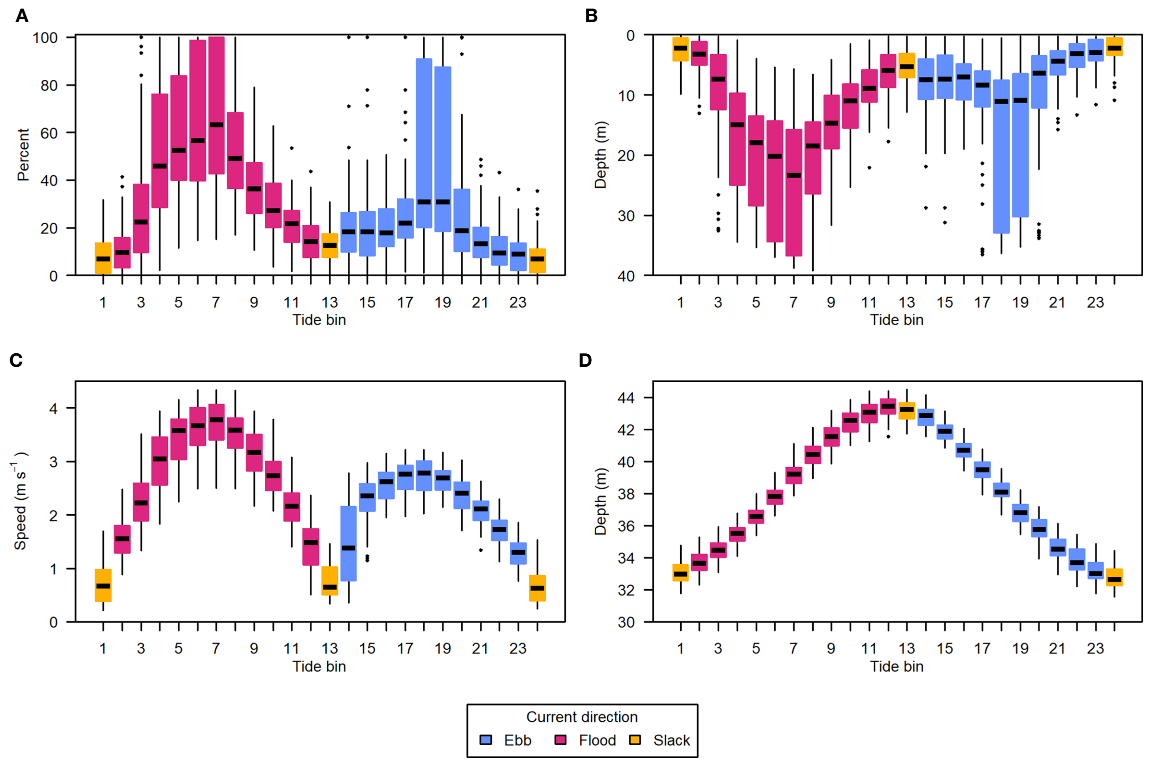

FIGURE 9 | Data from all recording periods summarized by position in the tidal cycle. **(A)** Percent of analyzable samples missing due to entrained air contamination, **(B)** depth of entrained air layer relative to the surface, **(C)** water column mean current speed, and **(D)** water column total depth. The tidal cycle was divided into 24 equal bins, each spanning approximately half an hour. Light blue indicates ebb tide, dark pink indicates flood tide, and yellow indicates the tide bins containing slack tides. Horizontal black lines are the median of each group, boxes span the interquartile range (IQR), whiskers extend to 1.5*IQR, and points are outlying values.

(a constant negative bias; **Figure 11C**, solid red line); however, lower-water-column observed abundances were also affected by the more extreme level of entrained air contamination (**Figure 11C**, dashed red line).

The observed vertical distribution of fish was also heavily affected by the differing levels of entrained air contamination, as demonstrated with scenario 5 (**Figure 12**). Estimates of fish abundance in the uppermost portion of the water column were most affected, particularly during the running tides (ebb and flood) when entrained air extended the farthest. Even the best case situation, using the 5th percentile of entrained air depths, resulted in excluding the majority of fish in the upper 10% (3.2-4.5 m depth) of the water column in all tidal stages, and the upper 20% (6.3-8.9 m depth) during flood tide. Due to the height of the acoustic nearfield above the sea floor, fish in the lowermost layers of the water column were also noticeably under-sampled.

4 DISCUSSION

Active acoustics technologies provide more detail and breadth of information on fish throughout the water column than any other sampling method currently available. However, entrained air poses a significant problem for active acoustics data collected at tidal energy sites, and this must be considered when developing a study or environmental monitoring plan. The magnitude of entrained air contamination varies by site, and will be heavily dependent on local conditions (e.g. hydrodynamics, bathymetry, and weather; Baschek et al., 2006; Jech et al., 2021). The FORCE tidal energy test site has some of the fastest tidal currents on the planet (> 5 $m \cdot s^{-1}$, Karsten et al., 2013), and its complex bathymetry and resulting dynamic current regime makes it one of the more challenging locations to use active acoustics instruments. Though the FORCE site is heavily affected by entrained air, the considerations discussed below will likely apply to echosounder users at other tidal energy test sites, as well.

Backscatter from entrained air contaminated 30% of all samples in our active acoustic dataset, and most of these were in the upper water column. However, contamination by entrained air varied greatly over time. The entrained air layer regularly spanned the entire water column during spring tides, though it rarely surpassed the middle water column during neap tides. So, while there were multiple days in a row with high levels of entrained air contamination, there were also periods of time with "best case" contamination levels, which would yield lower error rates in acoustically derived estimates of fish abundance. Peak current speeds were lower during neap tides than spring tides, but were well represented in the data throughout much of

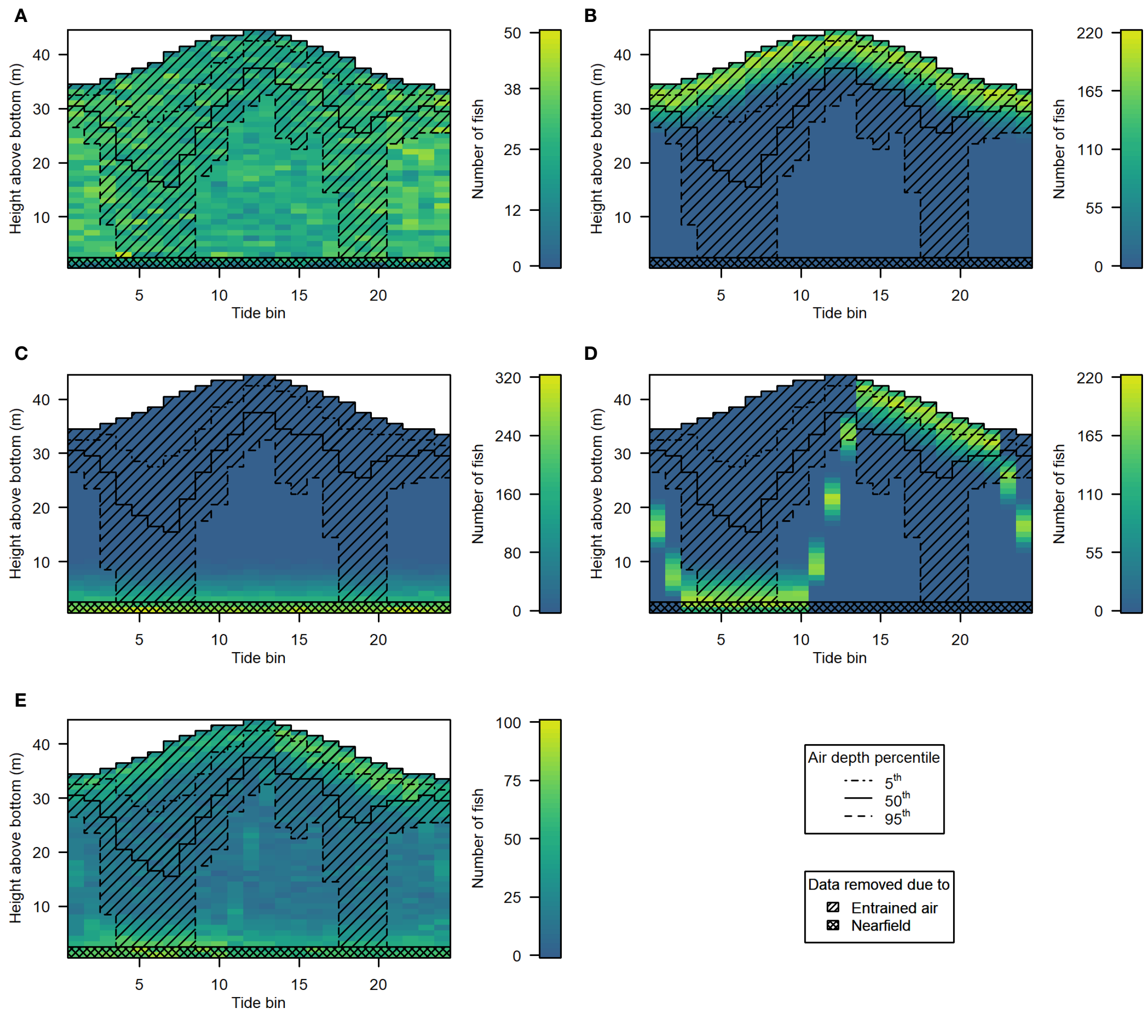

FIGURE 10 | Hypothetical fish distributions generated for scenarios 1 to 5 **[(A-E)**, respectively]. Color indicates the number of fish in each depth bin. Datapoints excluded by the 5th (dot-dash line), 50th (solid line), and 95th (dashed line) percentile depth of the entrained air layer are indicated by the hatched area. The crosshatched rectangle covering the lowermost 2 m of the water column indicates the data that would be omitted due to the height of the acoustic nearfield above the sea floor.

the water column. Active acoustics data collected near neap tides are therefore likely to consistently yield more complete information on fish abundance and vertical distribution than data collected closer to spring tides.

That being said, we found that the distribution of entrained air backscatter over the shorter time scales (e.g. during a tidal cycle) could magnify the error introduced to estimates of fish abundance and vertical distribution. In our simulations, the tidally fluctuating extent of the entrained air layer generated false tidal patterns in observed fish abundance, depending on the underlying vertical distribution of fish. The largest errors occurred when fish were mainly present in the uppermost layers of the water column, as this generated the strongest tidal pattern in estimated abundance (**Figures 11B, D**). Fish in the mid-water-column were increasingly omitted as current speed increased (**Figures 11A, E**). Abundance estimates of fish in the lowermost layers were mainly affected by the omission of data due to the height of the instrument above the sea floor and the extent of the acoustic nearfield, which introduced a constant negative bias (**Figure 11C**). Given the many species- and life-stage-specific depth preferences of fish, the prevalence of entrained air will therefore influence the extent to which different species are likely to be sampled by active acoustic instruments (for now ignoring other species-specific factors that affect detectability, such as their acoustic scattering properties; Horne, 2000).

The spatiotemporal fish distributions that we simulated were generalized examples of some commonly exhibited depth preferences among fish, and these may apply to many of the species likely to be in Minas Passage. For example, Scenario 1 may represent pelagic fish species that use most of the water column over the course of a day, including Atlantic herring,

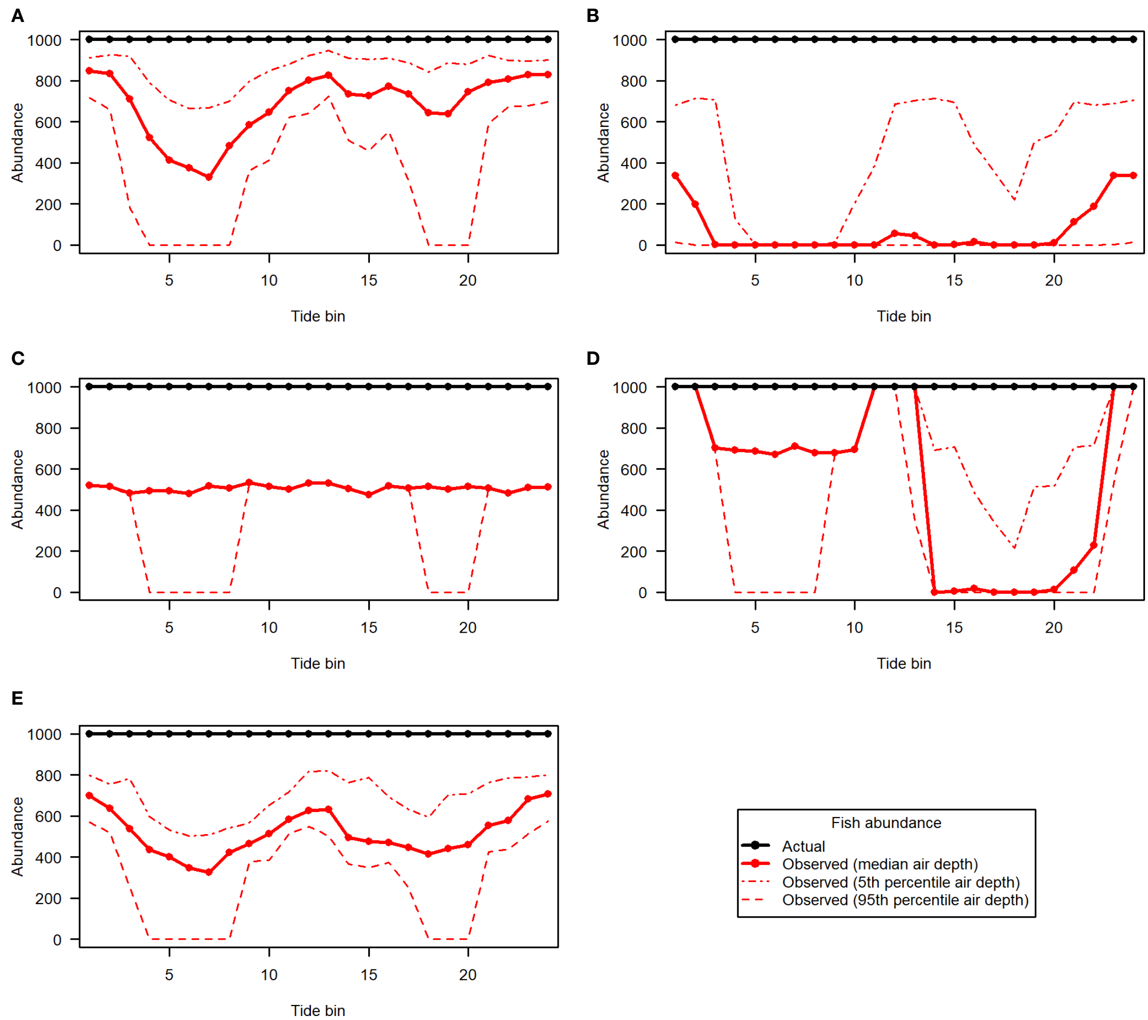

FIGURE 11 | Fish abundance over the course of the tidal cycle for simulated fish distribution scenarios 1 to 5 [**(A–E)**, respectively]. Actual abundance (black) is shown in contrast to abundance that would be observed under different levels of entrained air contamination (red lines).

Atlantic mackerel, and striped bass (Castonguay and Gilbert 1995, Redden et al., 2014; Keyser et al., 2016; Viehman et al., 2018). Atlantic salmon, typically found in the uppermost 10 m in the northwest Atlantic, may be well-represented by Scenario 2 (Dutil and Coutu, 1988; Sheehan et al., 2012). The Minas Basin is inhabited by a large number of demersal species, such as Atlantic cod, Atlantic sturgeon (*Acipenser oxyrhynchus*), winter flounder (*Pseudopleuronectes americanus*), white hake (*Urophycis tenuis*), and dogfish (*Squalus acanthius*), among many others (Parker et al., 2007). Such species are likely to be on the seafloor or in the lowermost meters of the water column (e.g. Hobson et al., 2007), and therefore represented best by Scenario 3. Silver- and yellow-phase American eels have exhibited STST (Scenario 4) when migrating or moving around their home range, though with more frequent vertical movements during a tide and not always traversing the whole water column (Parker and McCleave, 1997). Other species have also exhibited STST, such as Atlantic cod (though with smaller vertical movements above the seafloor; Arnold et al., 1994; Hobson et al., 2009), and possibly Atlantic mackerel (Castonguay and Gilbert 1995). The cyclic changes represented by Scenario 4 could also be extended to diel differences in vertical distribution, which would bring fish into and out of the under-sampled layers of the water column on a 24-hour cycle (rather than 12-hour). Many species and life stages of fish exhibit some level of diel vertical migration; e.g. Atlantic herring (Huse et al., 2012; Viehman et al., 2018) and alosids (American shad, *Alosa sapidissima*; Alewife, *A. pseduoharengus*; and river/Blueback herring, *A. aestivalis;* Stone and Jessop, 1992). Scenario 5 may represent a mixed species assemblage, which is more realistic for this location; however, the proportions of fish exhibiting each type of distribution were chosen somewhat arbitrarily, as there is little information to base these on.

It is unknown whether species-specific depth preferences will persist in high-speed tidal channels. Apart from STST, most

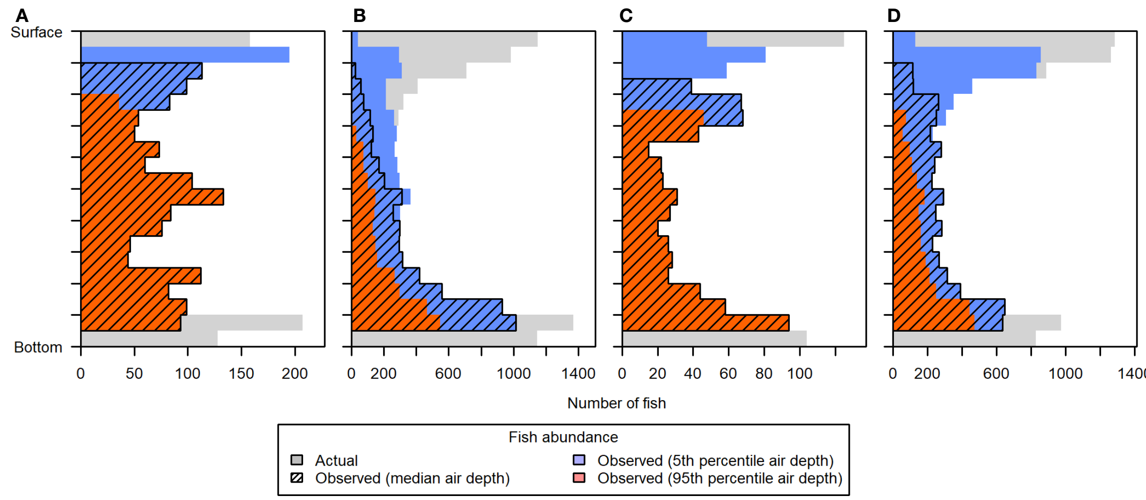

FIGURE 12 | Vertical distribution of fish in simulated distribution Scenario 5, during **(A)** low, **(B)** flood, **(C)** high, and **(D)** ebb tide. The "actual" vertical distribution (light gray) is overlaid by the vertical distributions that would be observed under different levels of contamination by entrained air: 5th percentile air depth (blue), 50th percentile air depth (hatched), and 95th percentile air depth (dark orange). Each depth bin spans 5% of the total water column depth, to facilitate comparison across tidal changes in water level. Fish counts in the lowermost two depth bins were primarily reduced due to the height of the acoustic nearfield above the sea floor.

knowledge of different species' depth distributions and vertical movements comes from measurements obtained in less energetic environments. Some information exists for tidal channels. Atlantic sturgeon, for example, are normally a demersal species, but acoustically-tagged sub-adults were found to transit Minas Passage pelagically (Stokesbury et al., 2016), slightly deeper during ebb tide than flood tide (Lilly et al., 2021). This could increase their detectability by active acoustics instruments (deployed as presented here), as individuals would be more likely to be in the middle-water-column rather than in the omitted layers near the sea floor. Eight acoustically tagged silver-stage American eels have been detected in the FORCE test site, and though they were mainly detected during ebb tide, they did not appear to exhibit the vertical motions associated with STST which this species has displayed elsewhere, instead utilizing most of the water column (Redden et al., 2014). Striped bass have been detected at the FORCE test site from summer through winter, carrying out diel vertical migrations from 20-40 m depth during the day to the upper 30 m at night, except at temperatures below 1˚C (Redden et al., 2014; Keyser et al., 2016). If Atlantic sturgeon, American eel, and striped bass all move pelagically at the FORCE site, then their availability to sampling by active acoustics may be best represented here by Scenario 1 (e.g., greater error in estimated abundance at peak flow). A better understanding of how different species utilize the water column in high-flow areas is necessary to assess their likelihood of sampling by active acoustic instruments.

Tidal and diel shifts in fish depth appear to be common across tidal energy sites, and these shifts could additionally influence the effects of entrained air on acoustically derived estimates of fish abundance and distribution. In Minas Passage, active acoustic measurements of fish (expected to be mainly overwintering Atlantic herring) found them to be more evenly spread out in the water column at night than during the day (Viehman et al., 2018), which was also observed throughout the year for a mixed fish assemblage in Cobscook Bay, USA (Viehman et al., 2015). In a tidal channel in Tasmania, Australia, fish were more closely associated with the surface at higher current speeds (Scherelis et al., 2020). In the Holyhead Deep, UK, European sprat (*Sprattus sprattus*) carried out diel vertical migrations linked to the depth of light penetration (Whitton et al., 2020), and in Admiralty Inlet, USA, the vertical location of fish and zooplankton changed on a 24-hour cycle (Gonzalez et al., 2019). Periodic vertical movements such as these could bring fish into and out of the entrained air layer at regular intervals. The possible interaction of this periodic movement with tidal patterns in entrained air depth could mask or generate patterns in observed fish abundance over time (as seen for Scenarios 4 and 5; **Figures 11D, E**). These considerations also apply to fish shifting their depth usage in response to deployed MHK devices; for example, avoiding a device by moving higher or lower in the water column, and therefore potentially into or out of the entrained air layer. There has been some evidence that marine animals (including fish and marine mammals) may change their swimming behavior in response to device presence (Williamson et al., 2021).

While the upper water column and higher current speeds (> 3 $m \cdot s^{-1}$) were under-sampled in this dataset, the lower 70% of the water column was generally well-sampled for current speeds up to 3 $m \cdot s^{-1}$ (**Figure 7A**). This is a large amount of data that can yield information on fish use of particular depth bins and how their depth may be influenced by a range of current speeds, all of which can inform our understanding of their likelihood of encountering an operating MHK device. However, information gained from a subset of the full range of depths and current speeds experienced at a site should not be assumed representative of the remaining, under-sampled depths and speeds. This is due to the above links between species, current speed, and depth usage, but also to other potential effects of current speed on fish behavior. For example, at a tidal energy site in the Pentland Firth, UK, fish school abundance and physical size was found to change as current speed surpassed 1 $m \cdot s^{-1}$, potentially indicating an effect of physical forcing from tidal currents on schooling behavior (Fraser et al., 2018; Williamson et al., 2019). In these environments dominated by extreme physical forcing by tidal currents, it remains important to determine the extent to which information gathered at greater depths and lower speeds can be extrapolated (if at all). This could be examined at tidal energy sites that may have lower levels of entrained air contamination, or in future data collected with additional, complimentary sensors.

Additional sensing technologies will be essential for filling the gaps in active acoustics datasets that are left by entrained air, and for providing the necessary context for interpreting results. Acoustic telemetry has already provided valuable insight into when different species are likely to be present and where they are likely to be in the water column, and therefore how likely they are to be sampled with active acoustics in a deployment such as ours. Acoustically tagged individuals can be tracked over large distances, providing much-needed spatial context for the narrow volume sampled by an echosounder. Acoustic telemetry can help answer essential questions for building probability of encounter models, such as the proportion of a given fish population likely to come into the vicinity of a tidal turbine, and whether fish are actively swimming or drifting passively with the current. This adds to the information active acoustics provides for such models, which is fine-scale information on fish presence in the depths spanned by a given device, and how this changes over short and long time scales (for many more fish than can be tagged).

As with active acoustics, the efficiency of some acoustic telemetry systems can be reduced by current speed (Redden et al., 2014; Keyser et al., 2016; Tsitrin, 2019), resulting in fewer observations of fish location and depth during the time periods of greatest interest. This drop in detection probability could be related to the number of pulses that must be received from a given tag to allow a detection (Redden et al., 2014), the chance of a fish moving quickly past a receiver between acoustic tag transmissions (Keyser et al., 2016), as well as severe tilting of tethered receiver moorings in faster currents (Sanderson et al., 2017). These issues could be mitigated with appropriate choice of acoustic tags, mooring design, and receiver deployment (Sanderson et al., 2017; Sanderson et al., 2021). Recent experiments have shown drifting receivers could improve long-term tracking of individuals transiting Minas Passage, which wouldn't necessarily be possible with fixed receiver arrays (Sanderson et al., 2021). A combination of active acoustics and acoustic telemetry, using both stationary and drifting receivers, could yield a much more complete picture of fish use of a tidal energy site and their chance of encountering MHK devices.

Fish activity within the entrained air layer itself may be quantifiable using optical techniques. While bubble plumes are largely "opaque" to active acoustic instruments, cameras may be less affected unless bubble density is very high. Video has been used for studying fish interactions with tidal energy turbines (Hammar et al., 2013; Broadhurst et al., 2014; Matzner et al., 2017), and in many other underwater applications requiring fish detection (e.g. Davidsen et al., 2005; Ellis and Bell, 2008). Optical systems cannot be used at night without additional lighting, which can affect fish behavior (Marchesan et al., 2005), and turbid or debris-laden water reduces fish detectability substantially (Ellis and Bell, 2008; Matzner et al., 2017). However, during daylight and with a few meters of visibility, there is an opportunity for video to be utilized for fish detection within the entrained air layer (Pattison et al., 2020). If optical data could be collected concurrently with an active acoustic system, ensuring sampled volumes overlap (or nearly do), results could help us understand how fish presence in the entrained air layer compares to abundance lower in the water column, and to what extent acoustically derived information from greater depths might be extrapolated upward.

Additional sensing technologies can help address another gap in active acoustics data analysis, which is the species and sizes of detected fish. This information would be helpful to those assessing the risk posed by tidal energy turbines, particularly when threatened or endangered species may be present. Information on fish species and length is also required to convert acoustic backscatter values to quantities of fish (Horne, 2000), unless fish are spread out enough to be detected and counted individually (e.g. Shen et al., 2016). Active acoustics data cannot usually provide identification of the detected scatterers to the species level without additional supporting information, which is typically obtained with trawls (Horne, 2000). The highly energetic and dynamic conditions at tidal energy sites often make them very difficult to sample safely or efficiently with trawls (Vieser et al., 2018), particularly at the spatial and temporal resolution required for classifying backscatter from a mixed assemblage within a rapidly changing environment. To date, most active acoustic studies at tidal energy sites have lacked physical sampling and stopped short of converting fish backscatter to estimates of abundance or biomass (Viehman et al., 2015; Fraser et al., 2018; Viehman et al., 2018; Staines et al., 2019; Williamson et al., 2019; Scherelis et al., 2020), with only one able to carry out concurrent trawling of a distinct layer of schools (Whitton et al., 2020).

Stereo optical camera or video systems may be useful alternatives to physically sampling fish at tidal energy sites. In recent years, species and length estimates from stereo camera systems have been found suitable for converting active acoustics backscatter to biological quantities, including in "untrawlable environments" (Rasmuson et al., 2021). Stereo optical systems are additionally non-lethal to sampled fish, less cumbersome than midwater trawls, and offer greater spatial resolution than trawls can provide (Boldt et al., 2018). Integrated optical-acoustic systems have been explored for MRE site monitoring, though so far only alongside high-frequency multibeam echosounders (Cotter and Polagye, 2020). Some challenges will need to be overcome for optical sensors to inform analysis of active acoustic data collected throughout the water column. As previously mentioned, optical systems require adequate lighting and water clarity for fish detection and identification. They also sample a much smaller volume than active acoustic instruments, which can complicate comparison to the larger volume sampled acoustically and can result in low sample sizes (Boldt et al., 2018). In addition to optical systems, acoustic tag detections could provide insight on the species in the area of an echosounder; however, only the species that were tagged would be detected, and any effects of high flow on detection probability would need to be addressed.

Using multiple acoustic frequencies could also broaden the information that can be gained from an active acoustic dataset. Data from multiple frequencies could aid in identifying different groups of scatterers (e.g. air bubbles, fish with and without swim bladders, zooplankton, etc.) based upon their frequency response (Horne, 2000; Korneliussen, 2018). The frequency response alone may not always be sufficient to identify fish to the species level without supporting information on which species are likely to be present. However, it is possible that the frequency response could be used to improve identification and removal of backscatter from entrained air bubbles. The entrained air detection method we used here relied mainly on morphological characteristics of the backscatter, which, for entrained air, mainly took the form of plumes extending downward from the surface. This is similar to methods used at other tidal energy locations (Viehman et al., 2015; Fraser et al., 2018; Whitton et al., 2020). Manual scrutiny of the data showed that backscatter from entrained air did not always take this form (e.g., when the entire water column appeared to be contaminated by additional backscatter; **Figure 7**), and there were many near-surface backscatter features that were not easily classified as fish or bubbles based on morphological criteria alone (**Figure 5**). Adding a frequency response filter to the morphological one applied here could improve backscatter classification, and further ensure that remaining backscatter is likely to be from fish.

Multiple acoustic frequencies could also aid in characterizing the entrained bubbles themselves, which would be useful for assessing whether they are likely to affect the performance of surface-mounted echosounders transmitting sound through the air layer to quantify fish below (Dalen and Løvik, 1981; Vagle and Farmer, 1991; Jech et al., 2021). To our knowledge, frequency response has not yet been used for identifying or characterizing entrained bubbles at tidal energy sites. However, this approach would be worth exploring in new or existing multifrequency datasets, as it can inform data collection moving forward.

5 CONCLUSION

Active acoustic technologies are well-suited for collecting information on fish abundance and distribution throughout the water column, with the resolution and breadth required for predicting the likelihood of fish occurring at the same depths as MHK devices. This information can add to our understanding of potential encounter rates, and therefore risk devices pose to fish. However, the prevalence of entrained air at tidal energy sites often masks large portions of the upper water column from echosounders, particularly at high current speeds. In the dataset examined, the lower 70% of the water column was well-represented for current speeds under 3 $m \cdot s^{-1}$, but the upper water column and faster current speeds were under-sampled in comparison. These under-sampled depths and periods of time constitute gaps in the active acoustic dataset that limit our ability to accurately measure fish abundance and vertical distribution, and therefore their potential overlap with MHK devices. Additional technologies, such as acoustic telemetry and optical systems, could be used concurrently with active acoustics to help fill these gaps and maximize the information that can be extracted from active acoustics data. While other tidal energy sites may experience less data contamination from entrained air, patterns in data loss are likely to be similar. The possible influence of these patterns on acoustically derived measurements of fish abundance and vertical distribution must be considered when planning a study or environmental monitoring plan at a tidal energy site, and when interpreting results from active acoustic datasets.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

HV, TB, and JD carried out preparation and planning of equipment deployment, including testing equipment settings and calibrating instruments. TB and JD deployed and retrieved the instruments. HV and JD processed the data. HV and DH contributed to the design of this study. HV completed the analysis, wrote the manuscript, and produced the tables and figures. All authors contributed to manuscript revision. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.851400/full#supplementary-material

REFERENCES

Arnold, G. P., Greer Walker, M., Emerson, L. S., and Holford, B. H. (1994). Movements of Cod (*Gadus Morhua* L.) in Relation to the Tidal Streams in the Southern North Sea. *ICES J. Mar. Sci.* 51, 207–232. doi: 10.1006/jmsc.1994.1021

Baschek, B., Farmer, D. M., and Garrett, C. (2006). Tidal Fronts and Their Role in Air-Sea Gas Exchange. *J. Mar. Res.* 64, 483–515. doi: 10.1357/002224006778715766

Boldt, J. L., Williams, K., Rooper, C. N., Towler, R. H., and Gauthier, S. (2018). Development of Stereo Camera Methodologies to Improve Pelagic Fish Biomass Estimates and Inform Ecosystem Management in Marine Waters. *Fish. Res.* 198, 66–77. doi: 10.1016/j.fishres.2017.10.013

Broadhurst, M., Barr, S., and Orme, D. (2014). *In-Situ* Ecological Interactions With a Deployed Tidal Energy Device, an Observational Pilot Study. *Ocean Coast. Manage.* 99, 31–38. doi: 10.1016/j.ocecoaman.2014.06.008

Castonguay, M., and Gilbert, D. (1995). Effects of Tidal Streams on Migrating Atlantic Mackerel, *Scomber Scombrus* L. *ICES J. Mar. Sci.* 52, 941–954. doi: 10.1006/jmsc.1995.0090

Copping, A. E., Hemery, L. G., Viehman, H., Seitz, A. C., Staines, G. J., and Hasselman, D. J. (2021). Are Fish in Danger? A Review of Environmental Effects of Marine Renewable Energy on Fishes. *Biol. Cons* 262, 1–13. doi: 10.1016/j.biocon.2021.109297

Cotter, E., and Polagye, B. (2020). Automatic Classification of Biological Targets in a Tidal Channel Using Multibeam Sonar. *J. Atmos. Ocean. Technol.* 37, 1437–1455. doi: 10.1175/JTECH-D-19-0222.1

Dalen, J., and Løvik, A. (1981). The Influence of Wind-Induced Bubbles on Echo Integration Surveys. *J. Acoust. Soc. Am.* 69, 1653–1659. doi: 10.1121/1.385943

Davidsen, J., Svenning, M.-A., Orell, P., Yoccoz, N., Dempson, J. B., Niemelä, E., et al. (2005). Spatial and Temporal Migration of Wild Atlantic Salmon Smolts Determined From a Video Camera Array in the Sub-Arctic River Tana. *Fish. Res.* 74, 210–222. doi: 10.1016/j.fishres.2005.02.005

Demer, D. A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., et al. (2015). Calibration of Acoustic Instruments. *ICES Cooperative Res. Rep. No*, 326. doi: 10.17895/ices.pub.5494

Dutil, J. D., and Coutu, J. M. (1988). Early Marine Life of Atlantic Salmon, *Salmo Salar*, Postsmolts in the Northern Gulf of St. Lawrence. *Fish. Bull.* 86, 197–212.

Ellis, W. L., and Bell, S. S. (2008). Tidal Influence on a Fringing Mangrove Intertidal Fish Community as Observed by *in Situ* Video Recording: Implications for Studies of Tidally Migrating Nekton. *Mar. Ecol. Prog. Ser.* 370, 207–219. doi: 10.3354/meps07567

Fraser, S., Nikora, V., Williamson, B. J., and Scott, B. E. (2017). Automatic Active Acoustic Target Detection in Turbulent Aquatic Environments. *Limnol. Oceanogr-Meth.* 15, 184–199. doi: 10.1002/lom3.10155

Fraser, S., Williamson, B., Nikora, V., and Scott, B. (2018). Fish Distributions in a Tidal Channel Indicate the Behavioural Impact of a Marine Renewable Energy Installation. *Energy Rep.* 4, 65–69. doi: 10.1016/j.egyr.2018.01.008

Gonzalez, S., Horne, J. K., and Ward, E. J. (2019). Temporal Variability in Pelagic Biomass Distributions at Wave and Tidal Sites and Implications for Standardization of Biological Monitoring. *Int. J. Mar. Energy* 2, 15–28. doi: 10.36688/imej.2.15-28

Hammar, L., Andersson, S., Eggertsen, L., Haglund, J., Gullström, M., Ehnberg, J., et al. (2013). Hydrokinetic Turbine Effects on Fish Swimming Behaviour. *PloS One* 8, e84141. doi: 10.1371/journal.pone.0084141

Hobson, V. J., Righton, D., Metcalfe, J. D., and Hays, G. C. (2007). Vertical Movements of North Sea Cod. *Mar. Ecol. Prog. Ser.* 347, 101–110. doi: 10.3354/meps07047

Hobson, V. J., Righton, D., Metcalfe, J. D., and Hays, G. C. (2009). Link Between Vertical and Horizontal Movement Patterns of Cod in the North Sea. *Aquat. Biol.* 5, 133–142. doi: 10.3354/ab00144

Horne, J. K. (2000). Acoustic Approaches to Remote Species Identification: A Review. *Fish Oceanogr* 9, 356–371. doi: 10.1046/j.1365-2419.2000.00143.x

Huse, G., Utne, K. R., and Fernö, A. (2012). Vertical Distribution of Herring and Blue Whiting in the Norwegian Sea. *Mar. Biol. Res.* 8, 488–501. doi: 10.1080/17451000.2011.639779. 5-6.

Jech, J. M., Schaber, M., Cox, M., Escobar-Flores, P., Gastauer, S., Haris, K., et al. (2021). Collecting Quality Echosounder Data in Inclement Weather. *ICES Cooperative Res. Rep.*, 352. doi: 10.17895/ices.pub.7539

Karsten, R., Swan, A., and Culina, J. (2013). Assessment of Arrays of in-Stream Tidal Turbines in the Bay of Fundy. *Phil. Trans. R. Soc A.* 371, 1985. doi: 10.1098/rsta.2012.0189

Keyser, F. M., Broome, J. E., Bradford, R. G., Sanderson, B., and Redden, A. M. (2016). Winter Presence and Temperature-Related Diel Vertical Migration of Striped Bass (*Morone Saxatilis*) in an Extreme High-Flow Passage in the Inner Bay of Fundy. *Can. J. Fish. Aquat. Sci.* 73, 1777–1786. doi: 10.1139/cjfas-2016-0002. 12.

Korneliussen, R. J. (2018). Acoustic Target Classification. *ICES Cooperative Res. Rep. No*, 344. doi: 10.17895/ices.pub.4567

Lilly, J., Dadswell, M. J., McLean, M. F., Avery, T. S., Comolli, P. D., and Stokesbury, M. J. W. (2021). Atlantic Sturgeon Presence in a Designated Marine Hydrokinetic Test Site Prior to Turbine Deployment: A Baseline Study. *J. Appl. Ichthyol.* 37, 826–834. doi: 10.1111/jai.14274. 6.

Marchesan, M., Spoto, M., Verginella, L., and Ferrero, E. A. (2005). Behavioural Effects of Artificial Light on Fish Species of Commercial Interest. *Fish. Res.* 73, 171–185. doi: 10.1016/j.fishres.2004.12.009. 1-2.

Matzner, S., Trostle, C., Staines, G., Hull, R., Avila, A., and Harker-Klimeš, G. (2017). *Triton: Igiugig Fish Video Analysis (PNNL-26576). Report to the U.S. Department of Energy* (Richland, Washington: Pacific Northwest National Laboratory).

Ona, E., and Mitson, R. B. (1996). Acoustic Sampling and Signal Processing Near the Seabed: The Deadzone Revisited. *ICES J. Mar. Sci.* 53, 677–690. doi: 10.1006/jmsc.1996.0087

Parker, S. J., and McCleave, J. D. (1997). Selective Tidal Stream Transport by American Eels During Homing Movements and Estuarine Migration. *J. Mar. Biol. Ass. U.K.* 77, 871–889. doi: 10.1017/S0025315400036237

Parker, M., Westhead, M., and Service, A. (2007). *Ecosystem Overview Report for the Minas Basin, Nova Scotia* (Fisheries and Oceans Canada, Dartmouth, NS: Oceans and Habitat Report 2007-05).

Pattison, L., Serrick, A., and Brown, C. (2020). *Testing 360 Degree Imaging Technologies for Improved Animal Detection Around Tidal Energy Installations. Final Report to the Offshore Energy Research Association of Nova Scotia (OERA)* (Dartmouth, NS: Applied Oceans Research Group, Nova Scotia Community College).

Rasmuson, L. K., Fields, S. A., Blume, M. T. O., Lawrence, K. A., and Rankin, P. S. (2021). Combined Video-Hydroacoustic Survey of Nearshore Semi-Pelagic Rockfish in Untrawlable Habitats. *ICES J. Mar. Sci.* 0, 1–17. doi: 10.1093/icesjms/fsab245

R Core Team. (2021). *R: A Language and Environment for Statistical Computing* (Vienna, Austria: R Foundation for Statistical Computing). Available at: https://www.R-project.org/.

Redden, A. M., Stokesbury, M. J. W., Broome, J. E., Keyser, F. M., Gibson, A. J. F., Halfyard, E. A., et al. (2014). Acoustic Tracking of Fish Movements in the Minas Passage and FORCE Demonstration Area: Pre-Turbine Baseline Studies (2011-2013). *Final Report to the Offshore Energy Research Association of Nova Scotia and Fundy Ocean Research Centre for Energy* (Acadia University, Wolfville, NS: Acadia Centre for Estuarine Research Technical Report No. 118).

Sanderson, B., Buhariwalla, C., Adams, M., Broome, J., Stokesbury, M., and Redden, A. (2017). Quantifying Detection Range of Acoustic Tags for Probability of Fish Encountering MHK Devices, In: *EWTEC 2017: Proceedings of the 12th European Wave and Tidal Energy Conference*; 2017 Aug 27 – Sep 1 (Cork, Ireland).

Sanderson, B., Stokesbury, M. J. W., and Redden, A. M. (2021). Using Trajectories Through a Tidal Energy Development Site in the Bay of Fundy to Study Interaction of Renewable Energy With Local Fish. *J. Ocean Technol.* 16, 51–70. 1.

Scherelis, C., Penesis, I., Hemer, M. A., Cossu, R., Write, J. T., and Guihen, D. (2020). Investigating Biophysical Linkages at Tidal Energy Candidate Sites: A Case Study for Combining Environmental Assessment and Resource Characterization. *Renew. Energy.* 159, 399–413. doi: 10.1016/j.renene.2020.05.109

Sheehan, T. F., Reddin, D. G., Chaput, G., and Renkawitz, M. D. (2012). SALSEA North America: A Pelagic Ecosystem Survey Targeting Atlantic Salmon in the Northwest Atlantic. *ICES J. Mar. Sci.* 69, 1580–1588. doi: 10.1093/icesjms/fss052. 9.

Shen, H., Zydlewski, G. B., Viehman, H. A., and Staines, G. (2016). Estimating the Probability of Fish Encountering a Marine Hydrokinetic Device. *Renew. Energy.* 97, 746–756. doi: 10.1016/j.renene.2016.06.026

Simmonds, J., and MacLennan, D. N. (2005). *Fisheries Acoustics: Theory and Practice* (Oxford: Blackwell Science) 437 p.

Staines, G., Zydlewski, G., and Viehman, H. (2019). Changes in Relative Fish Density Around a Deployed Tidal Turbine During on-Water Activities. *Sustainability.* 11, 2. doi: 10.3390/su11226262

Stokesbury, M. J. W., Logan-Chesney, L. M., McLean, M. F., Buhariwalla, C. F., Redden, A. M., Beardsall, J. W., et al. (2016). Atlantic Sturgeon Spatial and Temporal Distribution in Minas Passage, Nova Scotia, Canada, a Region of Future Tidal Energy Extraction. *PloS One* 117, e0158387. doi: 10.1371/journal.pone.0158387

Stone, H. H., and Jessop, B. M. (1992). Seasonal Distribution of River Herring *Alosa Pseudoharengus* and A. Aestivalis Off the Atlantic Coast of Nova Scotia. *Fish. Bull.* 90, 376–389.

Tsitrin, E. (2019). Sofishticated Tracking: Improved Protocol for Acoustic Tagging of Sensitive Clupeid Fishes, and Applications in Investigating Postspawning Migration of Alewife (Alosa pseudoharengus) in Minas Basin, Bay of Fundy. [Master's thesis]. Wolfville (NS): Acadia University.

Vagle, S., and Farmer, D. M. (1991). The Measurement of Bubble-Size Distributions by Acoustical Backscatter. *J. Atmos. Ocean. Technol.* 9, 630–644. doi: 10.1175/1520-0426(1992)009<0630:TMOBSD>2.0.CO;2

Viehman, H., Boucher, T., and Redden, A. (2018). Winter and Summer Differences in Probability of Fish Encounter (Spatial Overlap) With MHK Devices. *Int. J. Mar. Energy* 1, 9–18. doi: 10.36688/imej.1.9-18. 1.

Viehman, H., Zydlewski, G., McCleave, J., and Staines, G. (2015). Using Hydroacoustics to Understand Fish Presence and Vertical Distribution in a Tidally Dynamic Region Targeted for Energy Extraction. *Estuaries Coast* 38, 215–226. doi: 10.1007/s12237-014-9776-7. 1.

Vieser, J. D., Zydlewski, G. B., and McCleave, J. D. (2018). Finfish Diversity and Distribution in a Boreal, Macrotidal Bay. *Northeastern Nat.* 25, 545–570. doi: 10.1656/045.025.0403. 4.

Whitton, T. A., Jackson, S. E., Hiddink, J. G., Scoulding, B., Bowers, D., Powell, B., et al. (2020). Vertical Migrations of Fish Schools Determine Overlap With a Mobile Tidal Stream Marine Renewable Energy Device. *J. Appl. Ecol.* 57, 729–741. doi: 10.1111/1365-2664.13582

Williamson, B. J., Blondel, P., Williamson, L. D., and Scott, B. E. (2021). Application of a Multibeam Echosounder to Document Changes in Animal Movement and Behaviour Around a Tidal Turbine Structure. *ICES J. Mar. Sci.* 78, 1253–1266. doi: 10.1093/icesjms/fsab017

Williamson, B., Fraser, S., Williamson, L., Nikora, V., and Scott, B. (2019). Predictable Changes in Fish School Characteristics Due to a Tidal Turbine Support Structure. *Renew. Energy* 141, 1092–1102. doi: 10.1016/j.renene.2019.04.065

Woolf, D. K. (2001). "Bubbles," in *Encyclopedia of Ocean Sciences* (Cambridge, MA: Academic Press), 352–357. doi: 10.1006/rwos.2001.0062

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